Lecture Notes in Civil Engineering

Kunwar D. Yadav
Namrata D. Jariwala
Amit Kumar
Alok Sinha *Editors*

Recent Advances in Sustainable Waste Management Practices

Proceedings of SWMP 2023

Springer

Lecture Notes in Civil Engineering

Volume 430

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Editors
Kunwar D. Yadav
Department of Civil Engineering
SVNIT
Surat, Gujarat, India

Namrata D. Jariwala
Department of Civil Engineering
Sardar Vallabhbhai National Institute of Technology
Surat, Gujarat, India

Amit Kumar
Department of Civil Engineering
NIT
Jaipur, India

Alok Sinha
Department of Environmental Science Engineering
IIT(ISM)
Dhanbad, Jharkhand, India

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-99-4185-8 ISBN 978-981-99-4186-5 (eBook)
https://doi.org/10.1007/978-981-99-4186-5

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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About the Editors

Dr. Kunwar D. Yadav is Associate Professor at Sardar Vallabhbhai National Institute of Technology, Surat. With over 15 years of experience in the field of Environmental Engineering as Academician, he was Incharge Registrar, Prof. Incharge (Administration) of SVNIT, Surat, and currently handling institute-level responsibilities such as Coordinator at Regional Coordinating Institute—UBA, and Associate Dean (R&C). He established himself in other various key positions as well such as Environmental Auditor at Gujarat Pollution Control Board; Solid Waste Management Expert at Hon National Green Tribunal; Waste Management Expert at Surat Municipal Corporation, Surat; International Ecosan Expert at Capacity Building Trainer for Ecological Sanitation; and National Compost Expert at GIZ/MoU&UA, New Delhi. He is Lifetime member of various professional bodies like Indian Water Works Association (IWWA), International Water Association (IWA), National Solid Waste Association of India (NSWAI), and International Solid Waste Association (ISWA).

He received his Ph.D. from IIT, Kanpur in 2009. His area of interest is mainly but not limited to ecological sanitation, solid waste management, composting/vermicomposting of organic waste, and reuse/recycling of graywater. He has published 5 book chapters and 81 publications in various reputed international and national journals and conferences. He has seven granted patents/IPRs. Furthermore, Dr. Yadav has served as both Principal Investigator and Co-principal Investigator on numerous sponsored research projects with a total grant amount of more than 45 lakh funded by SVNIT, Surat, and Department of Science and Technology (DST) over the period of 2009–2017.

Dr. Yadav has organized more than 40 training and workshop programs in SVNIT, Surat. He attended many conferences and workshops and also delivered expert lecture talks all over India and abroad sharing his knowledge and experience.

Dr. Namrata D. Jariwala is working as Assistant Professor in Civil Engineering Department at S. V. National Institute of Technology, Surat. She is having 23 years of teaching experience. She has obtained her bachelor's degree in Civil Engineering and master's degree in Environmental Engineering from M. S. University, Vadodara.

She was awarded gold medal for securing highest marks in bachelor's study. She has obtained Ph.D. from S. V. National Institute of Technology, Surat.

She has guided 5 Ph.D. students and 24 M.Tech. students. She has wide experience of development of laboratories in the field of Environmental Engineering. Apart from the academic career, she has handled and involved various consultancy projects of CPCB, GPCB, Surat Municipal Corporation, and of other local government bodies in the area of Environmental Engineering. She is Coordinator of Environmental audit cell for schedule I industries at SVNIT.

She has published 26 papers in national journals and international journals. She has presented many papers in national and international conferences at USA, Italy, and London. She has organized 3 interdisciplinary international conferences and various faculty development programs. She has also coordinated the training program for Environmental Auditor with GPCB Gandhinagar.

Her area of research is health and risk studies in environmental engineering, air pollution-related studies, soft computing techniques in environmental engineering, and fuzzy logic and its application.

Dr. Amit Kumar serves as Assistant Professor in the Department of Civil Engineering at Malaviya National Institute of Technology (MNIT) Jaipur. With an extensive background in both research and industry, he has contributed to projects in India and the USA. His areas of interest are environmental risk assessment, material flow analysis, solid waste engineering, landfills and waste dumps, legacy waste mining and treatment, and water reuse.

Dr. Alok Sinha is currently serving as Professor in the Department of Environmental Science and Engineering and Dean (Infrastructure) at Indian School of Mines, Dhanbad, India. Dr. Sinha did his Ph.D. from IIT Kanpur in Environmental Engineering and taught in colleges like SRMSCET Bareilly, HBTI Kanpur, and IIT(ISM) Dhanbad. He has carried research in development of ZVI technology for in-situ remediation of contaminated groundwater with pollutants like halogenated organic compounds, pesticides, chromium, etc. He has also been granted a patent on "Novel system for regenerating and reusing nZVI/ZVI particles in wastewater treatment". He has more than 60 publications in peer-reviewed journal and is Guest Editor for "Frontiers in Environmental Science". He has been awarded Best Paper Award by BITS Pilani. He has received Certificate of Excellence for Knimbus "Young Innovator Award" for the year 2013–2014. He is Fellow Member of The Institution of Engineers (India). He has guided 13 Ph.D. thesis and more than 35 M.Tech. theses and has completed many R&D and consultancy proposals. Currently, he is working in the area of water and wastewater treatment of industrial origin with special emphasis on emerging contaminants using various techniques like nanotechnology, AOPs, and electrochemical and combination of biological and physico-chemical methods.

Best Practices of Solid Waste Management and Its Application to Nashik City

Nikita Bamb, Isha Bahade, and Madhuri Jawale

Abstract Solid waste management (SWM) in urban areas is a pressing issue today. With an ever-increasing population accompanied by improvements in the standard of living in society, waste generation has rapidly increased. As per the Central Pollution Control Board (CPCB), for 2020–21, India produced around 65 million MT of waste annually. Thus, management of waste at all levels, right from the initial collection point and its transport to properly segregating, processing, and disposing of waste, is necessary. The strategic focus of waste management in the nation has rapidly changed during the last few years. As per Swachh Survekshan 2022, Indore and Navi Mumbai are respectively at number one and number three. Planned, systematic, and consistent approaches have helped the cities achieve this position. Looking up to these cities and following their best practices, the paper focuses on developing strategies for the city of Nashik (currently ranked 20), helping it ascend the ladder and become one of the cleanest cities in the country. The study focuses on adapting various strategies to tackle SWM issues from the micro to macro levels as well as citizen participation. Further, on the basis of the above study, recommendations are given, focusing primarily on waste segregation at the source, decentralization systems, transport efficiency, and strict actions by the authorities.

Keywords Citizen participation · Decentralization system · Solid waste management · Source segregation · Transport

N. Bamb (✉)
Post Graduate Diploma in Urban Planning and Development, IGNOU, Delhi, India
e-mail: bnikita2098@gmail.com

I. Bahade
Urban Planning Intern, NMSCDCL, Nashik, India
e-mail: ibahade15@gmail.com

M. Jawale
Urban Planner, NMSCDCL, Nashik, India
e-mail: madhurij13@gmail.com

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_1

1 Introduction

As per the United Nations' World Urbanization Prospects 2018, about 34% of India's population lives in urban areas [2]. And as per the projections, over half of India's population will be living in urban areas by 2050 [2]. With rapid urbanization coupled with an increase in population and growth in industrial, educational, economic, and medical infrastructure, appropriate planning of the city in all aspects is crucial. Solid waste management is now one of the most fundamental issues. Solid waste refers to junk or rubbish that has been discarded as unwanted by residential, institutional, commercial, or industrial activities. SWM is a discipline concerned with managing the production, storage, collection, transport, processing, and disposal of solid waste while taking into account economic, environmental, and public health factors.

With speedy urbanization and growth in population, improvements in standards of living, along with an expanding economy, have increased the generation of waste. It is estimated that urban India generates between 1,30,000 and 1,60,000 metric tons (MT) of municipal solid waste every day. As per the Central Pollution Control Board (CPCB), in 2020–21, India produced around 65 million MT annually. Of the total waste, 50% is treated, 18.4% is landfilled, and the remaining 31.7% remains unaccounted for. The remaining MSWM is dumped unprocessed, which can cause a variety of environmental and health problems and will rise to 125 million MT a year by 2031 [7]. It is alarming that the waste composition is also drastically changing from a high percentage of biodegradable waste to non-biodegradable waste.

Under the Ministry of Housing and Urban Affairs, policies and action plans have been prepared that lay out the path to efficient municipal solid waste management in urban areas. Various planned cities effectively trained the SWM strategies at the inception of the planning, while several cities gained momentum and set examples after the initiation of various campaigns like the Swachha Bharat Abhiyan and the Swachha Survekshan. Two of them are Navi Mumbai and Indore, respectively. Indore and Navi Mumbai have set examples by focusing intensely on the source segregation, collection, and processing aspects; Navi Mumbai has strategically followed a process over the years to achieve this stature today, while the Indore government took on the challenge of transforming their city and becoming the first 7-star garbage-free city in India in a matter of few years with sheer consistency and performance. These cities today would not be the same if their citizens did not actively participate in their evolution. Awareness campaigns, citizen involvement, and active participation have been integral.

Taking inspiration from the smart cities of Indore and Navi Mumbai, the study in this paper looks forward to implementing the learnings and adapting the processes and strategies used for solid waste segregation at the source and efficient transport of the waste to the dump yard or landfill site in the context of the city of Nashik. To achieve this, primary data about the city was collected from the officials of the Health and Sanitation Department, Nashik Municipal Corporation, and secondary data was referred to for the literature review.

Mumbai, Pune, and Nashik form an important Golden Triangle and are crucial for development. Nashik is an integral part of this development triangle, and for business purposes, the city must prepare for growth, expansion, socioeconomic development, and business development. Thus, Nashik has to work heavily on the aspect of solid waste management to attract more opportunities. The city is ranked 20th in the Swachh Survekshan 2022 survey [1]. It is an emerging smart city, and with the right approach and steps taken toward solid waste management, the city can very well attain the badge of being one of the cleanest cities in the country.

2 Literature Review

2.1 Nashik

Nashik is referred to as the "Wine Capital of India," which is the fourth largest urban area in Maharashtra. As the city is one of the major and important cities in the state of Maharashtra, it is important to have a sustainable Solid Waste Management system. The city was generating about 300 metric tons of solid waste per day in 2006, which has increased to 600 metric tons in 2022. The city has a centralized system, so all the solid waste is brought from every ward in Nashik to the Municipal Solid Waste Facility at Pathardi, where it is processed after being sorted. Nashik Municipal Corporation (NMC) has given the contract for the collection and transportation of solid waste in its six divisions to private contractors (Fig. 1).

Nashik is moving towards becoming a bin-free city. NMC provides community bins only during religious programs throughout the city. To increase awareness, penalties are implemented for regular offenders. Waste collection is carried out according to division—six divisions: East, West, Nashik Road, Panchavati, CIDCO, and Satpur. The division-wise waste distribution for September 2022 (Table 1):

Following is the flow chart of the municipal solid waste management in Nashik city (Fig. 2):

The following are the services provided by the NMC (Table 2):

2.1.1 Waste Generation and Segregation

The Nashik Municipal Corporation (NMC) waste management plant receives waste from three sources: residential, commercial, and industrial. The waste generated from them is classified as wet, dry, and hazardous waste. NMC takes charge of the collection of waste from residential and commercial complexes and domestic waste

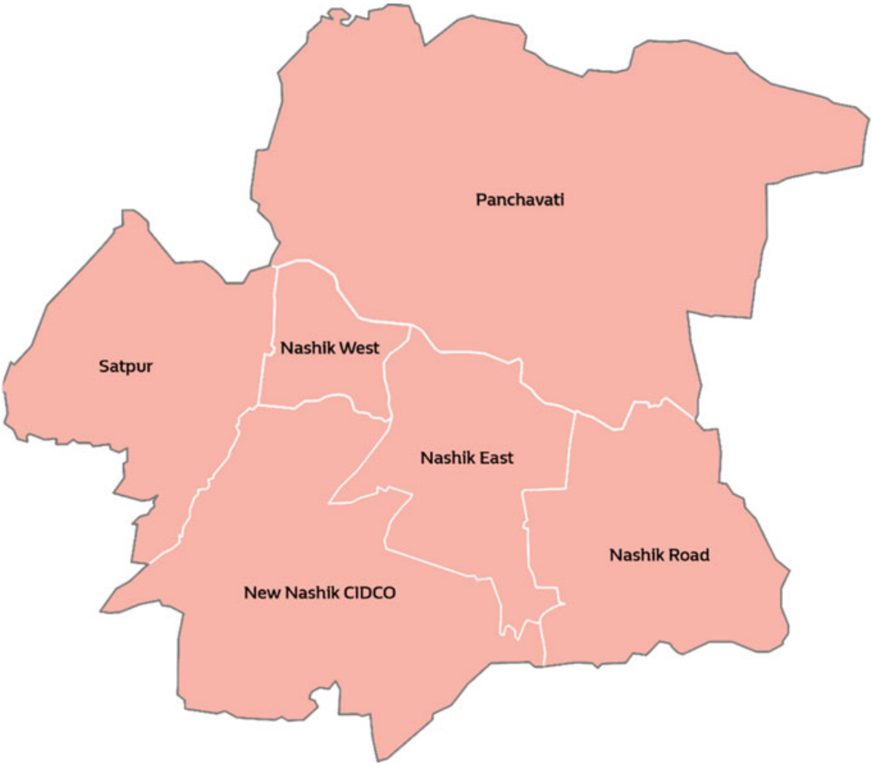

Fig. 1 Map depicting the six divisions of Nashik. *Source* (NMC, Nashik Draft Revised Development Plan 2016–2036 [19])

Table 1 Division-wise waste distribution in September 2022

Sr. no	Division	Door to door (MT)	Garden (MT)	Debris (MT)
1	East	3346	330	225
2	West	2065	313	157
3	Nashik Road	2891	265	119
4	Panchvati	3680	95	125
5	CIDCO	3886	207	170
6	Satpur	2918	183	67
Total		18,789	1396	866

Source Municipal solid waste processing plant, Nashik Municipal Corporation

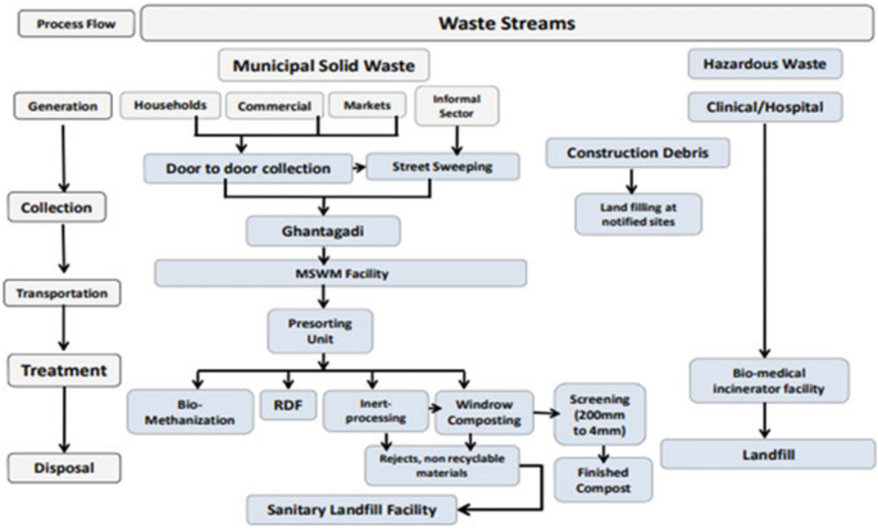

Fig. 2 Flow chart of municipal solid waste management in Nashik. *Source* (NMC, Municipal solid waste management for Nashik Municipal Corporation [18])

Table 2 Services provided by the NMC

Sr. no.	Services	Planning, procurement, design and construction	Operation and maintenance
1	Collection of MSW and transfer to MSW processing plant	Purchase of vehicles (Ghanta Gadis) by Mechanical Department	Done by private operator and monitored by Health Department Maintenance of vehicles (Ghanta Gadis) by the vehicle supplier company for the initial five years under the monitoring of Mechanical Department
2	Municipal solid waste processing plant	Mechanical department	Mechanical department
3	Related to land reservation and allocation	Town planning department	Town planning department

Source NMC, City Sanitation Plan for Nashik [16]

from industries. The industries treat the rest of the waste. The vehicles deployed primarily collect domestic waste, construction and demolition waste, and garden waste.

Table 3 Waste collected by NMC in year 2021–2022

Sr. no	Type of waste	Quantity (MT)
1	Door to Door	207,610.795
2	Garden	20,954.520
3	Debris	11,929.730
Total		240,495.045

Source Municipal solid waste processing plant, Nashik Municipal Corporation

The various types of waste collected by NMC for 2021–2022 are as follows (Table 3):

2.1.2 Waste Collection and Transportation

Waste is collected in six divisions: East, West, Nashik Road, Panchavati, CIDCO, and Satpur. As stated by an NMC official, "Nashik was the first city to introduce door-to-door collection of solid waste." NMC has improved its door-to-door collection system over the years by providing tipper trucks for forward areas and mini-lorries or trucks for construction and debris waste collection. Currently, 124 GhantaGadi is collecting solid waste from all six divisions in Nashik. Private contractors handle the city's collection and transportation divisions. The waste is collected in partitioned tippers in a 50:50 ratio. Recently, a small compartment for domestic hazardous materials has been set up in the tippers. The wet and dry waste are gathered by the vehicles in separate chambers.

All the collection vehicles are equipped with GPS. Though GPS tracking is installed, it is seldom monitored. Using a GPS tracking system, information about the vehicles, including the vehicle number, route, speed, checkpoints, and stoppages, can be tracked, or checked. The route of the Ghanta Gadis is predefined by the contractors. A minimum of six points per day on their routes should be covered, and any deviation from the route will result in penalties.

Further, all the waste is collected from the wards and unloaded together at the centralized disposal facility on the outskirts of Nashik (Figs. 3, 4, 5, and 6).

2.1.3 Weighbridge

The entrance of the processing plant has a weighbridge facility where all the vehicles are weighed while entering and exiting the plant. A receipt is produced and recorded at the office. This receipt delineates the amount of waste unloaded, the type of waste, the vehicle number, and the in-and-out time of the vehicle.

Fig. 3 Photo of Ghanta Gadi, with an internal partition

Fig. 4 Photos of Ghanta Gadi with partitions for wet and dry waste and domestic hazardous waste in a red box (right). *Source* Primary Survey

2.1.4 Solid Waste Management During the Kumbh Mela

The NMC has made plans for solid waste management during the Kumbh Mela. The solid waste was systematically collected at specified locations, from where it was transported to the waste management site through dumpers. To engage the public and encourage proper waste disposal, NMC provided a unique shape of dustbin in the shape of an earthen pot (Kumbh or Kalash). Separate crews and agencies were hired to sweep the streets, parking lots, Sadhu gram, and ghats regularly. Cleaning crews were heavily mobilized in the days after the Kumbh Mela event.

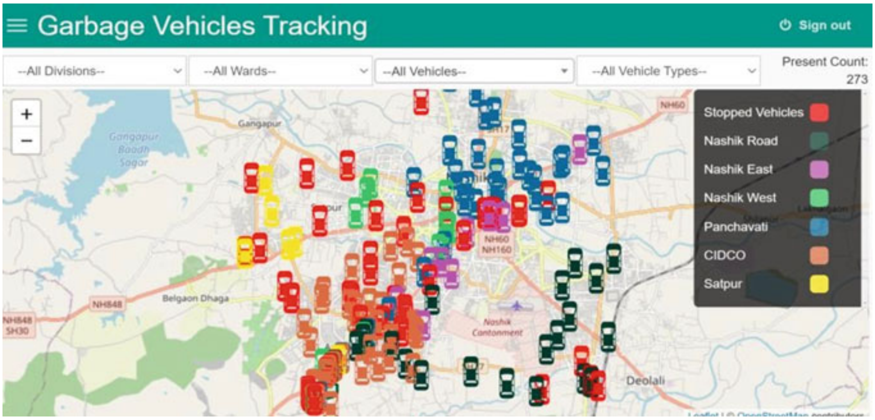

Fig. 5 Software interface depicting the movement of the collection vehicles in all the wards through the entire city. *Source* Municipal solid waste processing plant, Nashik Municipal Corporation

Fig. 6 The interface depicting a typical route of the collection vehicle and its various stoppages. *Source* Municipal solid waste processing plant, Nashik Municipal Corporation

2.1.5 Road Sweeping

The roads are cleaned according to divisions. Some divisions use private contractors, while others rely on NMC. A total of 1700 sweepers are appointed.

Each sweeper must cover 1 km of road in an 8-h shift. They must include roads, dividers, and footpaths. For efficient work, senior officials from the NMC and private contractors are appointed to monitor the workers.

2.1.6 Citizen Awareness and Capacity Building

The NMC has taken various actions to make citizens aware of source segregation. All the Ghanta Gadis play jingles while collecting waste from all the wards. Every residential, commercial, and public area is encouraged to adopt source segregation. Murals and social media are used in addition to jingles. In some areas (mostly in slum areas), educational shows are performed by municipal officials to persuade people to separate their waste. There are nearly 5000 visitors to the municipal solid waste disposal and processing center, where all the visitors are made aware of waste segregation, waste management, and steps to manage waste at their level.

Currently, 815 people are employed by private contractors, working with the NMC as waste collectors and educating citizens regarding the segregation of waste at the source. With every tipper truck, there are three workers: one driver and two collectors. Every 15 days, contractors during meetings conduct workshops or training programs for the workers and truck drivers regarding waste collection, medical facilities, and safety while collecting garbage.

2.2 Indore

The educational and commercial center of Madhya Pradesh, Indore, is located on the Malwa Plateau. From 2017 to 2022, Indore has been ranked first for six years now, moving up from position 25 in 2016. It is the first 7-star garbage-free city in India. Surat is second, followed by Navi Mumbai and Visakhapatnam [1]. It produces approximately 1029 metric tons of garbage each day (392.4 g per person per day). The city has received the first "Water Plus" certificate in the nation in addition to being free of open defecation. It has been chosen for the International Clean Air Catalyst Program, making it the only city in India to be selected.

Indore Municipal Corporation (IMC) implemented door-to-door collection as a test operation in Wards 42 and 71 in December 2015. IMC launched awareness programs in these wards to persuade homeowners to sort their waste into biodegradable and non-biodegradable components. They have demonstrated a readiness to collaborate as long as consistent, dependable waste collection services are provided. The purpose of IMC's second pilot, which was undertaken in two additional wards, was to ascertain which type of vehicle is more efficient for door-to-door collection:

tricycles or auto-tippers. Tricycle door-to-door collection was found to cost Rs. 2,886 per tonne, whereas auto-tippers were found to cost Rs. 1662 per tonne [5]. IMC rolled out the less expensive auto-tippers citywide.

2.2.1 Citywide

IMC had set up two sets of trash cans, but a third bin was added for masks and gloves during the pandemic. To increase awareness and guarantee that all waste is correctly segregated, IMC appoints one resource person to each garbage collection vehicle. The assistant health officer and ward daroga can be called in to punish the offender if a resource person is unable to persuade any households. Although this is expensive, IMC is prepared to pay for it since it recognizes how important it is to guarantee complete waste segregation.

2.2.2 Waste Generation and Segregation

The waste produced in Indore is segregated. The waste generators are named household (under 25 kg every day), semi-bulk (25–100 kg every day), and bulk generators (above 50 kg). Currently, the city has divided vehicles into six separate compartments: one for each tipper, including wet, dry, plastic, sanitary, domestic hazardous, and electronic.

2.2.3 Waste Collection and Transportation

The waste is gathered in a segregated structure for domestic generators by partitioned tippers. These tippers have been partitioned in the proportions of 50:50, 60:40, or 85:15 [13]. The wet and dry waste are gathered by these vehicles in separate chambers. These tippers transport trash from homes to the Garbage Transfer Station (GTS). All waste collection and transportation vehicles are equipped with GPS. The GPS is monitored by a dedicated cell. The tippers have predefined collection routes that have been described in their arrangement plan and are controlled by the command center. Route deviations result in penalties for drivers, and repeated deviations might lead to their dismissal. The tippers finish their routes, move to their assigned GTS, and offload their waste into the assigned compactor. The compactor packs the waste, which is then stacked on the hook loader to be moved to the central processing plant. Waste from all the locations is collected by either a tipper or dumper, depending on the type of waste generated. Generators of more than 100 kg of waste, such as community gardens and hotels, have been put in place. Only dry waste is gathered from these generators, as they treat the wet waste they create on site.

2.2.4 Weighbridge

The processing plant for the weighbridge facility is an automated facility and an important point for all vehicles to meet before approaching the plant. A receipt is produced and recorded at the office. This receipt delineates the amount of waste moved, the type of waste, the enlistment number of the vehicle, the source transfer station, and the in–out time of the vehicle.

2.2.5 Road Cleaning

800 km of streets are cleared by machines, and footpaths and road dividers are washed by a water mist. This uses 400 L of water each night, the majority of which is recycled water from the three sewage treatment plants set up by the IMC. The inside streets that make up the remainder of the 2,200 km are swept, and the waste is gathered by vans and taken to a waste processing plant.

2.2.6 Finance

IMC spends approximately Rs 879 crore annually to operate the waste management system. User fees total Rs 27 crore each year, with property taxes covering the rest of the city's expenses. Shops pay up to Rs 150 each month, while households pay up to Rs 60. Rs. 3 is paid for each kilogram of trash removed from businesses, offices, and so on [5].

2.2.7 Awareness

IMC launched many actions to raise awareness among the populace and inspire acceptance of segregation. The "Do Bin Har Din" campaign made use of garbage collection vehicles that go door to door (two bins every day). Every residential neighborhood, every business district, and every public space engaged in the campaign. Along with radio jingles, murals, nukkad nataks, and other mediums, social media was extensively adopted. Schools were asked to encourage student segregation through cleanliness-focused competitions and morning assembly oath-taking rituals. Together with the general population, municipal officials performed roadshows and joint visits to persuade people to separate their waste. Due to the significant influence that religious and communal leaders had over the community, they were persuaded to become swachha grahas and brought together on a single platform. To raise awareness about source segregation, IMC has worked with more than 8,000 women in more than 800 self-help groups. Markets and colonies that succeed at trash management are given "zero-waste" designations.

2.3 *Navi Mumbai*

2.3.1 Introduction

The twin city of Mumbai, Navi Mumbai, is the world's largest planned city. It is on the west coast of Maharashtra in the Konkan Division. The city has a growing residential development alongside large industrial and commercial areas. Apart from this, Navi Mumbai boasts a strong network of hospitals and medical facilities that generate diverse categories of waste.

According to Navi Mumbai Municipal Corporation's (NMMC) Draft Development Plan of 2018–2038 [20], Navi Mumbai Municipal Corporation initiated and developed a solid waste management strategy for the effective disposal of municipal waste. Navi Mumbai was ranked third among Indian cities in the Swachh Survekshan 2022 Awards.

For all the activities under "solid waste management," i.e., collection, transportation, and disposal of municipal solid waste (MSW), private contractors have been appointed for all 8 nodes coming under the NMMC's jurisdiction. Turbhe's scientific landfill site receives MSW daily, which gets processed and disposed of at the site. Wet and dry waste are separated and processed separately. This reduces the amount of waste disposed of in landfills. The corporation focuses on and emphasizes on-site segregation for better waste management.

2.3.2 Waste Generation

The daily average municipal solid waste (MSW) generation in the year 2018–19 was 753 metric tons (MT), of which 92%, i.e., 692 MT, of the total waste is generated from residential areas (Table 4).

Table 4 Total waste generated in Navi Mumbai

Sr. No.	Node	Ward	Average daily MSW generation (metric tons)
1	Belapur	A	113.0
2	Nerul	B	113.0
3	Vashi	C	85.0
4	Turbhe	D	134.0
5	Koparkhairane	E	124.0
6	Ghansoli	F	78.0
7	Airoli	G	82.0
8	Digha	H	24.0
Total	753		

Source Navi Mumbai Municipal Corporation [6]

The waste generated in the city comprises mainly biodegradable waste (58%). It is important to note that the share of plastic waste has gone down from 17 to 11.7% in 2017–18 after initiatives taken by NMMC to curb the problem of plastic pollution.

2.3.3 Waste Segregation

The least one can do to manage solid waste is to segregate waste at the source. It is the basic and primary step in scientific waste management. Waste segregation reduces the problem of waste by 80% as more and more materials at the disposal end can be retrieved for recycling. Segregation at source has been the topmost priority of the waste department, which is reflected in their working approach at the department and numerous initiatives taken on an annual basis.

The corporation has kept various sizes and colors of dustbins (80, 120, and 240 L) at each node citywide as part of waste segregation (green for wet waste, blue for dry waste, and red for E-waste and hazardous waste).

2.3.4 Waste Collection and Transportation

From the doorsteps of 6443 housing societies, 800 businesses, educational institutions, and industrial buildings, 100% of the garbage is collected every day. The NMMC has provided 120-L bins, green for wet garbage and blue for dry garbage, at each NMMC node and marketplace.

NMMC's Solid Waste Management Department not only aims at collecting and transporting solid waste but also undertakes daily road sweeping and cleans storm water drains before the monsoon every year. The corporation appoints private contractors to carry out these activities.

The route of the waste collection vehicles is tracked by GPS and RFID tags. The NMMC has prepared the route map, mentioned the timings for each vehicle (the vehicle number is also mentioned), and published it on the official site so that no vehicles deviate from the said information and the public is well informed.

Daily sweeping is undertaken by private contractors. The city is divided into eight administrative divisions, which are further divided into 91 sub-divisions for monitoring purposes. A total of 2,646 sweepers are employed, and sweeping is conducted daily for about 8 h in the morning.

NMMC has eight mechanical sweepers and efficient sweeping machines with suction technology, water sprinklers, and brushes that are used to collect dirt, sand, pebbles, and scattered leaves from the road and efficiently sweep the roads.

2.3.5 Decentralized Waste Composting

Navi Mumbai is a planned city. During the planning of the city, emphasis was given to the solid waste aspect as well. As a result, NMMC created a system for solid waste collection and transportation from the point of origin to the landfill. With the ever-increasing population and change in lifestyle, the amount of MSW generated increases, for which the corporation has to consider alternative strategies. The corporation has to, therefore, think of alternative solutions to work on the possible cost increase with waste transportation. NMMC has therefore started implementing the concept of decentralized waste composting, starting in the slum areas.

As a pilot project, the corporation constructed the compost pits, provided bins, and started engaging the local community in the slums. The appointed workers collected and segregated waste and operated composting units.

This initiative can be scaled up 100% using the same approach. NMMC has planned to launch the initiative in small pockets of the city. The scaling up of this initiative will not only help in solving the waste problem but also help in generating employment opportunities as well. It would also help corporations to curb the costs involved in collection and transportation. NMMC initiated this idea in two areas with more than 4000 households and plans to cover the entire city, where segregating waste at the source or composting is a major task.

2.3.6 Awareness Campaigns and Initiatives

Initiative Under Swachha Bharat Abhiyan

NMMC constructed a Swachhata Park in Nisarg Udyan of Sector 14 in Koparkhairane under the Swachha Bharat Abhiyan initiative. The project creates awareness about the garbage problem and depicts the importance of waste segregation.

Anti-plastic Drive

NMMC started the anti-plastic drives to reduce the use of plastic and consider the harmful effects plastic has on the environment. The ward officers were instructed to conduct drives in their respective wards. During 2018–2019, NMMC seized 39,210 kg of plastic from 969 shops and establishments, for which the fine collected was Rs. 46,99,650/- (Swachh Maharashtra Abhiyan Kaksha, NMMC).

Initiatives by Navi Mumbai Citizens

The citizens of Navi Mumbai are proactively participating in waste management. Several housing complexes, institutions, and hotels that generate more than 100 kg of wet waste per day have composting units installed on their premises, which convert wet waste into compost at the source.

3 Comparison Between Nashik, Indore, and Navi Mumbai

The waste management systems in the cities of Nashik, Indore, and Navi Mumbai describe the situation of waste management in the cleanest cities in India and Class 2 cities. Following an analysis of the procedures used to handle municipal solid waste in the following cities, the following data is provided (Table 5):

The following part discusses in detail the main characteristics of using SWM as a general approach, including waste collection, transportation, generation, segregation, and treatment:

3.1 Citywide

Unlike Nashik and Indore, which have none, Navi Mumbai has approximately 15,000 communal bins installed throughout the city. This has resulted in the establishment of numerous black corners in Nashik. All of the cities mentioned above have enacted harsh penalties and fines for repeat offenders, which is a step in the right direction.

Table 5 Comparison between Nashik, Indore, and Navi Mumbai

Sr. No	Particulars	Nashik	Indore	Navi Mumbai
1	Population—2022 (in million)	2.04	2.70	1.54
2	Area (in sq. km)	264.2	276	108.6
3	Density (per sq. km)	5100	3800	10,318
4	Number of wards	31	85	89
5	Number of zones	6	19	8
6	Municipal Solid waste generation excluding C&D waste (in MT per day)	600	1029	753
7	Number of road sweepers	1700	2854	2646
8	Number of Community bins	0 (only during festivals)	0	15,583
9	Waste Management vehicle fleet size	273	829	134
10	Percentage of households covered under door-to-door waste collection	100	100	100
11	Percentage of households segregating waste	70	100	100
12	Percentage of waste processed	85	100	100

Source For Nashik—NMC officials, For Indore—Waste wise cities by Niti Aayog, For Navi Mumbai—Environmental Status Report of Navi Mumbai Municipal Corporation 2018–2019 [20]

In terms of road sweeping, Indore and Navi Mumbai have two shifts per day for cleaning roads, footpaths, and public spaces. Nashik has only one safai karamchari shift. Compared to Indore and Navi Mumbai, there are very few safai karamcharis employed for the same purpose.

3.2 Waste Generation and Segregation

Door-to-door collection is available in all three cities: Indore, Navi Mumbai, and Nashik. At the source, waste is separated into six categories in Indore: dry, wet, plastic, sanitary, domestic hazardous, and e-waste, whereas waste is separated into only three categories in Navi Mumbai and Nashik: dry, wet, and domestic hazardous (or e-waste in Navi Mumbai). Household segregation is 100% in Navi Mumbai and Indore, and 70% in Nashik.

3.3 Waste Collection and Transportation

In Navi Mumbai, Indore, and Nashik, waste is gathered in a segregated structure by partitioned tippers or trucks.

As previously stated, Nashik must address the issues to improve the city's solid waste management process. This analysis will help in focusing on the shortcomings that need to be addressed.

3.4 Awareness

Indore has launched various source segregation awareness programs, such as radio jingles, murals, nukkad nataks, social media, and roadshows by municipal officials, under the influence of religious and communal leaders, and primarily in schools, where students are asked to take oaths during morning assemblies. They also dubbed the campaign "Do Bin Har Din," which was widely used during the awareness campaign. In Navi Mumbai, the NMMC has taken several steps to raise awareness about source segregation. After encouraging citizens to segregate at the source, they have now replicated the dustbin mascot in three different ways to raise public awareness.

In Nashik, citizens and visitors to the municipal solid waste management plant are only informed at the source and the municipal solid waste management plant, respectively. Besides, a few murals and jingles have been installed on Ghantagadi.

4 Conclusion

From all the studies made above, it is evident that Nashik has a well-established system of solid waste management. Nevertheless, SWM can still be improved. Following are the proposals for the city in areas where the NMC can perform well and apply the learnings to make the city a garbage-free and clean city, pointing out flaws in the system and drawing inspiration from the best practices of Indore and Navi Mumbai.

4.1 Source Segregation

Enough emphasis should be placed on the source segregation of waste. It is a fact that the disposal of waste becomes easier and faster if the waste is segregated well at the source. Similar to Indore's adoption of segregation of waste at the micro level, Nashik should start segregating waste as dry, wet, sanitary, domestic hazardous, plastic, and electronic. This will reduce the load on the treatment plant at the disposal site. The temporary partitions should be replaced with properly segregated compartments, which do not leave any room for the wastes to get mixed at any point.

4.2 Transport Efficiency and Tracking

The management of the truck routes and stoppages division-wise has been well detailed at the organization level by the NMC and communicated to the contractors and drivers. Though GPS devices and RFID tags are installed in transport vehicles, often the drivers tend to skip the stoppages, slightly deviate from the given route, or not strictly follow the time limit given to them. As implemented in Indore, to improve the efficiency of the provided transport facility, there must be a dedicated cell where the employees monitor and track the movement of the vehicles assigned to them regularly.

4.3 Decentralized Waste Processing

Approx. 600 MT of waste was generated in the annual year 2021–22, which has doubled since 2011. The severity of the rapid increase of waste in a short period conveys the fact that alternative solutions should be thought of to manage solid waste and reduce the pressure on the processing site. A huge amount of transportation cost is incurred when the total waste has to be transported to a centralized system. Thus, to reduce the transport cost and make the management system more efficient, the waste processed needs to be decentralized.

In addition to the decentralized system, wet waste from gated communities, slum areas, institutions, and industries should be treated on the campus itself. Secondly, dry waste, which includes plastic, cardboard, and e-waste, should be segregated at the source level, and the waste should be collected by private contractors and sent directly to the recycling plant. This will, however, help in managing the waste properly and lowering the pressure on the landfill sites.

4.4 Responsibility of Government Authorities and Their Strict Actions

The first step towards setting up a system for the SWM and following it consistently comes with the strong will of the government officials to work towards it. As seen in Indore, it was because of the initiative taken by the mayor that Indore could achieve this stature today. Similarly, it is important that the authoritarian officials in Nashik, with all their might, just take action and act strictly toward the implementation of the policies prepared for the city.

4.5 Sweeping

Sweeping the streets regularly is one of the most important activities to keep the city clean. If one does not see waste on the streets, likely, people will not litter around. But if the streets remain unclean, citizens will surely add to the nuisance. In Indore, sweeping takes place in three shifts for the entire day, while in Navi Mumbai it happens in two shifts from morning to late evening. Whereas, in Nashik, it is observed that this just happens once a day from morning 6 a.m. to afternoon 2 p.m. This is not enough to maintain the streets of the city well. The workforce needs to be increased and shifts added. Besides, for efficient working, mechanical sweeping machines need to be used where footfall is high and the areas are of strategic importance, such as CBD areas and public places.

4.6 Awareness Campaigns and Public Participation and Education

Educating the public is the foremost thing to do. Repetitive awareness campaigns should be conducted in societies, schools, colleges, and public places elsewhere, and the needs and benefits of proper solid waste management should be conveyed to the public. For any reform to take place, it is the equal responsibility of the people in power and the citizens to make it work. For the actions taken by the authority, the citizens should cooperate well and abide by the rules made. Strict penalties and fines should be levied on the citizens if they happen to break the rules.

4.7 Employment Opportunity

It is observed, the workforce employed in the city of Nashik is well below the required strength. For example, in the region of Panchvati, 350 swachhata karmacharis are deployed for work that needs a strength of 1000 workers. There is a high requirement for workers for management in the city. The employment openings should be considered and taken up by the officials so that a workforce is built that helps in achieving the aim of making Nashik one of the cleanest cities in India.

From this research, it is clear that Nashik city has made progress in solid waste management in the last few years. But it can remain a challenge and pose public health and environmental risks if it is neglected and these observations are not considered. But on the other hand, if necessary, actions are taken, it can also be a display of strong leadership for sustainable practices toward SWM.

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A Review of E-waste Management and Practice Scenario in India

Rohit Singh, Dharmendra, and Bharti

Abstract The largest and fastest growing manufacturing sector in the world is electronics. However, the production of electronic waste, also known as e-waste, has resulted from the rise in sales of electronic devices and their rapid obsolescence because of changes in fashion, style, and status. If it is not properly managed, e-waste can have a negative impact on human health as well as the environment because it contains numerous hazardous components. Due to the production and disposal of waste in a globalized world, the e-waste issue is of global concern. Because India generates its own e-waste and dumps e-waste from developed nations, e-waste management has greater significance in India. In addition, India lacks the necessary infrastructure and recycling procedures for this waste. The challenge is coming up with creative and affordable ways to clean up polluted environments caused by electronic waste, make them safe for people to live in and use, and keep the ecosystems that support life running smoothly. This paper discusses the various categories of e-waste, the classification of the various hazardous components that are found in e-waste, methods for treatment of e-waste, different disposal methods, and the difficulties that India faces in managing e-waste.

Keywords E-waste · Hazardous · Management · etc.

R. Singh (✉) · Dharmendra · Bharti
Department of Civil Engineering, National Institute of Technology
Hamirpur, Hamirpur 177005, India
e-mail: 21mce413@nith.ac.in

Dharmendra
e-mail: djha@nith.ac.in

Bharti
e-mail: 21mce404@nith.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*,
Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_2

1 Introduction

Electronic trash, commonly known as e-waste, contains a number of potentially dangerous chemicals including mercury, lead, and brominated flame retardants. These substances disrupt almost all of the body's major systems when they are exposed for an extended period of time during hazardous e-waste recycling activities, including the neurological and blood systems, brain development, skin conditions, lung cancer, heart, liver, and spleen damage. This is particularly important in the informal sector, since a large proportion of e-waste workers do not take any measures to safeguard or prevent their health.

According to a study by the Associated Chambers of Commerce and Business of India (ASSOCHAM), almost 80% of employees in the Indian e-waste industry have respiratory conditions like breathing problems, irritation, coughing, and choking because of inadequate safety precautions. Workers and children are frequently among those who are subjected to the highest levels of daily hazardous fume exposure since they frequently work with their hands uncovered and do not wear protective facemasks (Table 1).

1.1 E-Waste Pollutants

Circuit boards, batteries, plastics, and LCD (liquid crystal displays) screens tend to have the most pollutants or poisons in discarded electronics. The most common contaminants found in previously owned electrical and electronic equipment are shown in Table 2.

1.2 Impact of Hazardous Substances on Health and Environment

Toxic metals such as cadmium and lead can be found in electronic waste, as can lead oxide and cadmium in monitor cathode ray tubes (CRTs), mercury in switches and flat-screen monitors, cadmium in computer batteries, polychlorinated biphenyls in older capacitors and transformers, and brominated flame retardants on printed circuit boards, plastic housings, cables, and PVC cable insulation, all of which can release

Table 1 E-Waste generation in India [1]

S. no.	Financial year	Generation (Tones)
1	2017–2018	7,08,445
2	2018–2019	7,71,215
3	2019–2020	10,14,961.2

Table 2 Chemical constituents and their sources (Metals and Metalloids) [7]

Constituents	Sources
Arsenic	LEDs (light-emitting diodes), semiconductors, microwaves, diodes, and solar cells
Barium	Lubricating additives, rubber and plastic fillers, and electron tubes
Brominated flame-proofing agent	Plastic circuit boards, cables, PVC cables, and casing
Cadmium	Circuit boards, computer batteries, pigments, solder, alloys, cathode ray tubes, and batteries for batteries (CRTs)
Chrome	Switches, solar, and dyes/pigments
Cobalt	Insulators
Copper	Conducted in cables, coils, electronics, copper ribbons, and pigments
Lead	Batteries that can be recharged with lead, solar energy, transistors, lithium batteries, stabilizers for polyvinyl chloride, lasers, LEDs, thermoelectric components, and circuit boards
Liquid crystal	Displays
Lithium	Mobile phones, camera and video equipment, etc.
Mercury	Parts found in steam irons and copper machines; batteries found in clocks and pocket calculators; switches; LCDs
Nickel	Batteries, pigments, relays, semiconductors, and alloys
PCBs (polychlorinated biphenyls)	Transformers, capacitors, paint, glue, and plastic softening agents
Selenium	Pigments, photocopiers, fax machines, photoelectric cells, and more
Silver	Capacitors, switches (contacts), batteries, resistors
Zinc	Metals like steel, brass, alloys, rechargeable and throwaway batteries, and illuminating materials

highly toxic gases when burned [8]. Cancer-causing and poisonous chemicals make up a large portion of these compounds. Even in developed countries, recycling these materials is a challenge due to their complexity and difficulty. The following table details the hazardous materials found in electrical and electronic devices.

Metal	Health impact
Lead	A neurotoxic that harms the reproductive system and kidneys Large doses can be lethal. Children's mental development is impacted. Lead is released as powder and fumes during the mechanical breaking of CRTs (cathode ray tubes) and solder removal from microchips
Plastics	They contain carcinogens and are present in cables, cabinets, and circuit boards. Carcinogenic brominated dioxins and furans are released by BFRs, or brominated flame retardants. Dioxins can impair the immunological and reproductive systems. Dioxins are also created when PVC, a component of plastics, is burned. BFR may contaminate landfills. BFR is present in even the dust on computer cabinets

(continued)

(continued)

Metal	Health impact
Chromium	Used to prevent corrosion of a computer's metal housings and plates. Hexavalent chromium, also known as chromium 6, when inhaled can harm the liver and kidneys and lead to bronchial illnesses such asthmatic bronchitis and lung cancer
Mercury	impacts the kidneys, immunological system, and central nervous system. Through mother's milk, it damages babies and stunts the growth of fetuses. It is emitted during the burning and shattering of switches and circuit boards. Through microbial action, mercury present in water bodies can transform into methylated mercury. Methylated mercury can enter the human food chain through aquatic environments and is hazardous
Beryllium	On printed circuit boards and switch boards. Lung diseases are brought on by its carcinogenicity
Cadmium	A cancer-causing substance. Itai-itai disease, which is brought on by protracted exposure, produces excruciating pain in the spine and joints. It weakens bones and has an effect on the kidneys. While crushing and grinding plastics, CRTs, and circuit boards, cadmium is discharged as a powder into the atmosphere. Dust can emit cadmium, which can then get into groundwater and surface waters
Acid	Circuit boards are disassembled, and the metals are separated using sulfuric and hydrochloric acids. Chlorine and sulfur dioxide, which are found in fumes, are respiratory irritants. They are harmful to the skin and eyes

2 Objective

1. To study the effect of e-waste impacts on both human beings as well as the environment.
2. To study the methods which are available for the management of e-Waste in India and to find the hazardous effects associated with it.

3 E-Waste Management Challenges in India

As a result of the enormous amounts of e-waste that are produced, unlawful dumping, ineffective regulation, a lack of infrastructure, resistance to administrative action, and its consequences, on Indian cities and towns controlling piles of e-waste is a significant concern. A few of these are covered below [2]

1. Lack of Technical Expertise in E-waste Area: Lack of technical skills is India's E-waste Management System's biggest issue. Most of the time, residential e-waste is disposed of with other sorts of domestic waste in domestic dust-bins. Additionally, most informal gatherings are uninformed and unprofessional. E-waste consequently becomes combined with ordinary waste, which results in tragic treatment that never ends. Additionally, there is a low possibility that it

will be separated before reaching its destination, which puts the environment and human health at risk.

2. Lack of Data Inventorization on E-waste Generation in India: The rapidly expanding market brings an increasing amount of EEE manufacturing, increasing the amount of e-waste on the globe. India is having trouble generating accurate and comprehensive data on e-waste in various states due to sporadic collection and a lack of credible parameters for estimating EEE sales. Many organizations and SPCBs of the states in the nation have started the process of data inventorizing e-waste (MoEF&CC Guidelines, 2016). However, because of inconsistent data sources and compotators, these exercises have not been carried out consistently. However, the "E-waste in India by Rajya Sabha, 2011" report, which contains data on e-waste generation in various states, is still used as a reference. As a result of the always changing data, there are discrepancies between the data from the various sources that are available, making it challenging to execute management and policy.
3. Lack of Stringent Rules and Regulations: The current e-waste rules and legislation are essential in establishing guidelines and accountability among the involved public and private entities. Due to a lack of interest, information, or awareness about the present policies, stakeholders may not necessarily agree with them. Since a sizable amount of e-waste is treated in a crude and unscientific manner, the rules also make it difficult to put them into practise.
4. Lack of Environmentally Sound E-Waste Treatment: E-waste handling that is environmentally responsible is either non-existent or very limited in underdeveloped countries. Because electronic gadgets tend to have higher levels of toxic contamination than other types of garbage, managing e-waste is more difficult than managing MSW. Therefore, special techniques are needed to handle e-waste and stop the release and dispersal of poisons into the environment. Only 29% of the 3.4 Mt of e-waste produced in the US in 2012, according to the EPA, was recycled; the remainder was disposed of in landfills or burned. The current technologies for recovering metal from e-waste, such as smelting and acid leaching, have certain limits.
5. Lack of Awareness and Market Information: In India, there is a severe lack of public understanding of the health risk associated with recycling e-waste. The makers, trash dealers, and refurbishes who work on fixing outdated technology are unaware of the EPR, the cost of the e-waste, or the potential risks to their health and the environment. However, the Kabadiwalas are typically paid in exchange for the home e-waste. Additionally, the biggest gap in data collection is due to emotional links to the products, as well as a lack of knowledge and information on e-waste-related issues.

4 E-Waste Issues

Based on the results of the study done and the agreement achieved at the National Workshop on Electronic Waste Treatment held in March 2004 and June 2005 and hosted by CPCB and the Ministry of Environment and Forests, an evaluation of the existing practise in e-waste management was created. The assessment revealed the following problems [4]:

1. Increasing amount of e-Waste: Due to the quick pace of creation, the dynamism of product manufacturing, and the short lifespan of many computer devices (less than two years), product obsolescence is speeding up. Due to short product lifespans and exponential growth that averages 15% per year, the volume of e-waste will double over the next five to six years.
2. Toxic components: Because it is recognized that e-waste contains hazardous substances like lead, cadmium, mercury, polychlorinated biphenyls (PCBs), etching agents, and brominated flame retardants, it must be treated cautiously. Inadequate management of these materials led to the uncontrolled release of harmful compounds into the environment because of irregular recycling methods in the informal sectors.
3. Lack of environmentally sound recycling infrastructure: It has been established that improperly disposed electronic waste eventually finds its way to scrap merchants, who then move it up the supply chain to dismantlers. The current eco-friendly recycling infrastructure cannot handle the increasing amounts of e-waste. The majority of the risky demolition work is done in the informal/ unorganized sector. Due to the potential for increasing e-waste generation and the need for adequate recycling infrastructure, many recyclers from around the world have expressed interest in opening facilities in India.

5 Policy Level Legislation in India

Due to the detrimental effects that hazardous waste has on the environment and human health, several countries argued that a global agreement was required to address the problems and challenges that these wastes present. Though relatively primitive, India's policy-level activities against e-waste require immediate attention. Here are a few of India's e-waste policy-level initiatives:

1. Hazardous Wastes (Management and Handling) Amendment Rules, 2003: E-waste is described in Schedule 3 as "Waste Electrical and Electronic Equipment, including all components, subassemblies, and their fractions, with the exception of batteries coming under these guidelines" [6].
2. Guidelines for Environmentally Sound Management of E-waste, 2008: The Ministry of Environment and Forest and the Central Pollution Control Board gave their approval to this directive, which was an initiative of the Indian government. It categorized e-waste based on its numerous constituents and compositions

and placed a strong emphasis on e-waste management and treatment procedures. The policy included ideas like “Extended Producer Responsibility” [10].

3. E-waste Management and Handling Rules, 2011: The 2011 e-waste Management and Handling Rules were announced in May 2011 and went into effect on May 1, 2012. The manufacturer concerned in this is alerted beforehand so that they have the time to prepare and set up the necessary infrastructure for the successful application of these guidelines [5].

    1. Lead acid batteries are covered under the batteries management and handling guidelines from 2001, and micro and small businesses as well as radioactive waste as defined by the Atomic Energy Act of 1962 are included in the Enterprises Development Act from 2006.
    2. Schedule 1 regulations apply to all machinery and consumables used in the manufacture of electrical and electronic equipment (EEE). All consumables and equipment that are packaged with the product at the time of disposal are subject to the regulations.
    3. The regulations also prohibit the use of hazardous materials, or their usage in small quantities, in electrical and electronic appliances. In accordance with these regulations, each electrical and electronic manufacturer must make sure that their products are free of metals and compounds, such as certain amounts of lead, cadmium, mercury, hexavalent chromium, and polybrominated biphenyls.
    4. The MoEF/CPCB will decide with clarity by comparing any products or industrial components with significant doubt to scheduled-I components.
    5. Although it is believed that the machinery used to produce electronic equipment is exempt from the schedule-1 restrictions, the waste from these machines must still be transported to a recycling facility until it has been fully recycled.

6 E-Waste Disposal Methods

Due to landfilling and incineration, the presence of hazardous materials in e-waste has the possibility of intensifying their environmental discharge.

Following are some potential treatment and disposal options based on composition [3].

6.1 Landfilling

E-waste in landfills undergoes extremely intricate and protracted degrading processes. Due to the following factors, it is currently impossible to measure the environmental effects of e-waste at landfills: (1) Landfills contain mixtures of different waste streams; (2) the emission of pollutants from landfills can be delayed for many years; and (3) data on the concentration of substances in leachate and landfill gas from municipal waste landfill sites vary by a factor of 2–3 depending on climatic conditions and technologies applied in landfills (such as leachate collection and treatment, impermeable bottom layers, and gas collection). The conditions on a landfill site are different from a native soil, notably in terms of the leaching behavior of metals, according to one study on landfills, therefore the environmental risks from landfilling of e-waste cannot be ignored. Additionally, it is known that mercury and cadmium are released either diffusely or through a landfill gas combustion facility.

Landfilling does not seem to be an environmentally sound treatment method for substances that are volatile and not biologically degradable (Cd, Hg, CFC), persistent (PCB), or with unknown behavior in a landfill site (brominated flame retardants), even though the risks cannot be quantified and linked to e-waste. Due to the complex material composition of e-waste, even in secured landfilling, environmental (long-term) concerns cannot be eliminated.

6.2 Incineration

The advantage of incineration of e-waste is the decrease in trash volume and the exploitation of combustible materials' energy content. Some facilities take the iron out of the slag for recycling. During combustion, several organic chemicals that are harmful to the environment are changed into less dangerous molecules. The disadvantages of incineration include the high number of residues left over after gas cleaning and combustion, as well as emissions to the air from materials that escape flue gas cleaning. There are no studies or similar data available that show how e-waste emissions affect the efficiency of municipal garbage incineration facilities. The annual emissions of cadmium and mercury from waste incineration facilities are large.

Furthermore, heavy metals that are not released into the atmosphere are transferred to the residues of slag and exhaust gas and may reenter the environment upon disposal. Therefore, e-waste incineration will result in a rise in these emissions, necessitating the need for mitigation measures like heavy metal removal.

7 E-Waste Treatment Technologies

Environmentally sound e-waste treatment technologies are used at three levels as described below [9]

1. 1st level treatment
2. 2nd level treatment
3. 3rd level treatment.

7.1 1st Level Treatment

Input: e-waste items like TV, refrigerator, and Personal Computers (PC).

Unit Operations: There are three unit operations at the first level of e-waste treatment.

7.1.1 Decontamination

Decontaminating and making the e-waste non-hazardous is the initial stage in treatment. This entails recovering and storing any gases and liquids that were removed under negative pressure.

7.1.2 Dismantling

To extract the parts from the used equipment, the decontaminated e-waste or e-waste that doesn't require decontamination is disassembled. Ample safety precautions must be taken during the operations when disassembling something, whether it be manually or mechanically.

7.1.3 Segregation

After disassembly, the components of the e-waste fractions are separated into hazardous and non-hazardous parts to be transported for third-level treatment.

Output:

1. Segregated hazardous wastes like CFC, Hg Switches, batteries, and capacitors.
2. Decontaminated e-waste consisting of segregated non-hazardous e-waste like plastic, CRT, circuit board, and cables.

7.2 2nd Level Treatment

Input: Decontaminated e-waste consisting of segregated non-hazardous e-waste like plastic, CRT, circuit board, and cables.

Unit Operations: There are three unit operations at the second level of e-waste treatment:

1. Hammering
2. Shredding
3. Special treatment Processes comprising of

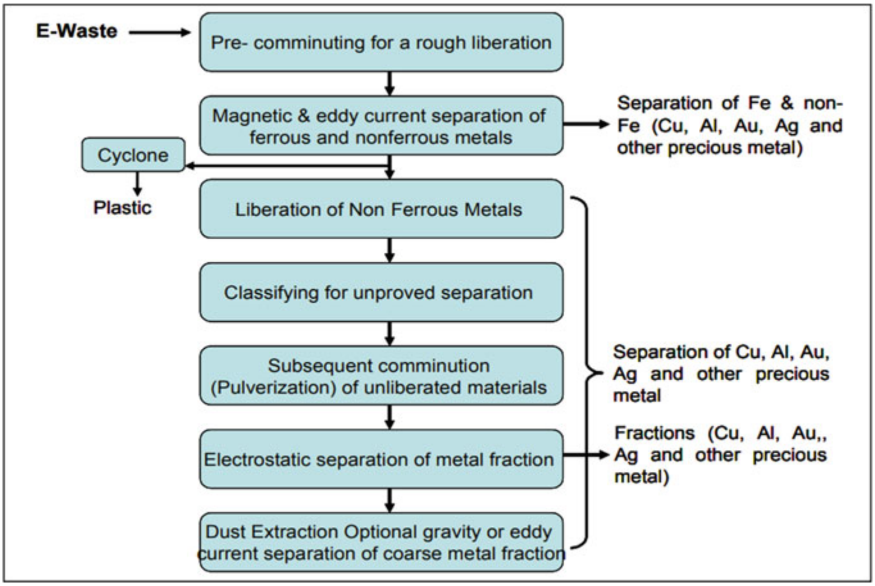

Fig. 1 Process flow of non-CRT-based e-waste treatment [9]

i. CRT treatment consisting of separation of funnels and screen glass.
ii. Electromagnetic separation.
iii. Eddy current separation.
iv. Density separation using water.

The main objective of hammering and shredding is size reduction (Fig. 1).

1. The proposed technology is entirely based on dry processes that use mechanical activities for e-waste sorting, treatment, recycling, and disposal.
2. Separation of plastic, CRT, and the remaining non-CRT-based e-waste is part of the pre-comminuting stage. At the comminuting step, tools like hammer mills and shear shredders will be utilized to chop and grind e-waste to prepare it as a feedstock for magnetic and eddy current separation.
3. A heavy-duty hammer mill grinds the material to achieve the separation of inert materials and metals.
4. Metal fractions made up of ferrous and non-ferrous metals are subjected to magnetic current separation after being separated from inert material. After separating the non-ferrous fraction from the ferrous-containing fraction, it is electrostatically separated and ground into distinct non-metal fractions.
5. Following screening and dusting of the ground material, valuable metal fractions are separated using electrostatic, gravimetric, and eddy current separation technologies to recover fractions of Copper (Cu), Aluminum (Al), and any remaining fractions containing Gold (Au), Silver (Au), and other precious metals. As a result, clean metallic concentrates are recovered and supplied to smelters

for additional refinement. Water can occasionally be utilized as a last stage of separation.

6. Different fractions of non-ferrous metals, namely, are separated from e-waste using electric conductivity-based separation, which separates materials with different electric conductivity (or resistivity). Based on electrical conductivity, the eddy current separation technology has been utilized to separate non-ferrous metals from e-waste. Permanent magnets made of rare earth are what make it work. Eddy currents will be created in a conductive particle when it is subjected to an alternating magnetic field, creating a magnetic field that opposes the magnetic field. The separation process is brought about by the electrodynamic activities that arise on conductive non-ferrous particles as a result of interactions between the magnetic field and the produced eddy currents.
7. The anticipated yields and output of the recycling system are a key factor in determining its effectiveness. The improvement of the separation parameters will determine the anticipated yields/output from the recycling systems.

7.2.1 CRT Treatment Technology

The salient features of CRT treatment technology are given below

1. CRT is manually removed from plastic/wooden casing.
2. Picture tube is split, and the funnel section is then lifted off the screen section and the internal metal mask can be lifted to facilitate internal phosphor coating.
3. Internal phosphor coating is removed by using an abrasive wire brush and a strong vacuum system to clean the inside and recover the coating. The extracted air is cleaned through an air filter system to collect the phosphor dust.

7.3 3rd Level Treatment

The recovery of ferrous and non-ferrous metals, polymers, and other things with economic value is the primary goal of the third phase of e-waste treatment. The main recovery operations are concentrated on recovering ferrous and non-ferrous metals, which are either carried out geographically at various locations or at a single location in an integrated plant (Figs. 2, 3, and 4).

8 Findings

1. E-waste sector is highly unorganized as total 5% is recycled formally. A policy should be designed for the safe recycling of e-waste.
2. The level of treatment of e-waste depends on the complexity of its constituents.

Input/ WEEE Residues	Unit Operation/ Disposal/ Recycling Technique	Output
Sorted Plastic	Recycling	Plastic Product
Plastic Mixture	Energy Recovery/ Incineration	Energy Recovery
Plastic Mixture with FR	Incineration	Energy Recovery
CRT	Breaking/ Recycling	Glass Cullet
Lead Smelting	Secondary Lead Smelter	Lead
Ferrous metal scrap	Secondary steel/ iron recycling	Iron
Non Ferrous metal Scrap	Secondary copper and aluminum smelting	Copper/ Aluminum
Precious Metals	Au/ Ag separation (refining)	Gold/ Silver/ Platinum and Palladium
Batteries (Lead Acid/ NiMH and Li ION)	Lead recovery and smelting Remelting and separation	Lead
CFC	Recovery/ Reuse and Incineration	CFC/ Energy recovery
Oil	Recovery/ Reuse and Incineration	Oil recovery/ energy
Capacitors	Incineration	Energy recovery
Mercury	Separation and Distillation	Mercury

Fig. 2 Input/output and unit operations for 3rd-level treatment of e-waste [9]

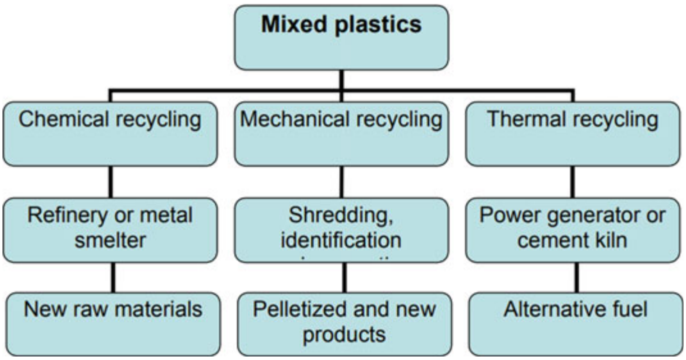

Fig. 3 Recycling options for managing plastics from end-of-life electronics [9]

3. Producers are given a vital responsibility for the disposal and treatment of the products through “Extended Producers Responsibility”.
4. Informal recycling leads to uncontrolled emission of hazardous toxics that are going into the air, water, and soil. The health hazards from fumes, ashes, and harmful chemicals affect not only the workers who met the e-waste but also the environment.

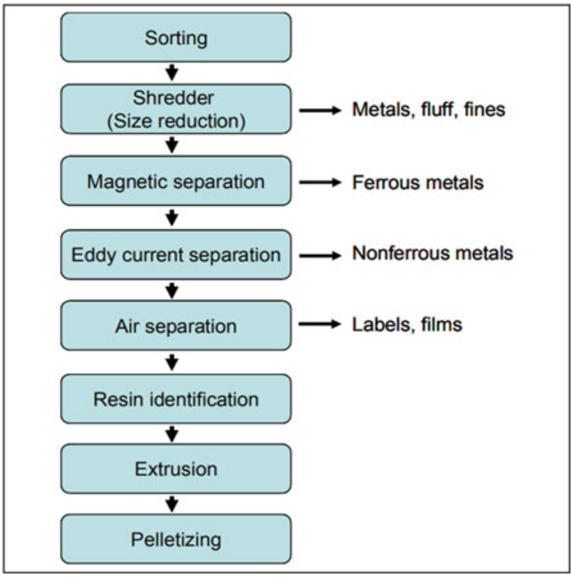

Fig. 4 Flow diagram for the mechanical recycling of post-consumer plastics [9]

9 Research Gap

1. Proper recycling infrastructure for e-waste in India is not set up.
2. For a different component of e-waste, different types of recycling treatment is required. So, recycling e-waste is a challenge due to its complexity and difficulty.
3. Proper legislation should be made so that organized recycling of e-waste will increases.

10 Conclusion

In this review paper, we studied the various aspects of e-waste from the perspective of India. At present there is an inadequate, inefficient, and unorganized way of handling e-waste in India which further worsens by the fact that we have an un-accounted import of e-waste from overseas. From analyzing previous years' data, it is clearly indicated that the rate of e-waste generation will increase in the future also. The effects of hazardous substances released from informal recycling of e-waste is a matter of concern; it not only harms the environment but also human beings majorly affecting those who work in this sector and live nearby the dumping site. There are social and economic constraints which restrict the complete stoppage of informal recycling practices. These practices could not be controlled also due to the lack of any pertaining legislation in this regard.

Based on the constituents of e-waste, there are 3 levels of treatment for the recovery of valuable metals from the e-waste and recycling. There are also 2 methods for the disposal of e-waste which are landfill and incineration. Policies that will encourage private recycling businesses need to be implemented. We should also increase EEE product manufacturers to use less toxic materials that don't contain any hazardous components. By offering tax breaks and other incentives, such practices can be encouraged. In order to reduce toxicity in EEE products, research efforts should also be expanded in order to make technology eco-friendlier and more sustainable.

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A Review on Sustainable Rice Straw Management Through Anaerobic Digestion

Sugato Panda and Mayur Shirish Jain

Abstract Even though technologically we have advanced many folds, the dreadful practices of eco-asphyxiating the sanctity of a clean air parcel are widely prevalent in our country. Among the famous agrarian economies of the world, India and China are one of the largest generators of agro-waste with a non-streamlined infrastructure for agro-waste management. Of late, reports of smog in the Northern regions of India were in trend owing to farmers' open burning of paddy straw in Haryana and Punjab. These emissions account for more than 29% of PM 2.5 emissions which, along with other sources, are one of the major contributors to bad health. This also adds to the escalating greenhouse gas emissions (GHG), which messes up the global climate balance. In light of the latest COP26, where all the developed and developing nations are hoarding toward carbon neutrality, a discussion on the existing eco-depleting activities is necessary. The paper, therefore, strives to understand the direct causes of why the farmers are adopting these practices and briefly outlines the current rice straw (RS)-based biogas plants that have been commissioned by the Indian government and explore the lab-scale interventions done on rice straw valorization, and tries to suggest a sustainable solution for agro-waste management and climate change mitigation.

Keywords Eco-asphyxiating · Agro-waste · Open burning · Biogas · Global climate balance

1 Introduction

The agrarian Indian economy has a mammoth potential to tap into the escalating requirements for a cleaner energy source. With power shortages as well as rising electricity prices, governments all around the globe are seeking to explore alternative routes of energy production. Lignocellulosic wastes have a demonstrated history of

S. Panda (✉) · M. S. Jain
Department of Civil Engineering, Indian Institute of Technology Indore, Madhya Pradesh, Simrol 453552, India
e-mail: sugatopanda@gmail.com

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_3

recalcitrance and are challenging to digest. Wastes like rice straw (RS) that result from post-harvesting of rice are one of the major culprits for smog engulfment in the Delhi-NCR region. Yearly, farmers of Punjab and Haryana are found to be burning off the straws as a result of significant mismanagement on their part [19]. Burning and tilling back are two commonly applied techniques for residue management, which significantly add to greenhouse gas emissions and climate crisis [12, 20]. Additionally, Jha [11] mentions the recent power shortages that Haryana is facing and the government's plans to buy 3000 MW of power from alternative sources. In such situations, anaerobic digestion (AD)-based technologies could be helpful. AD is a 4-step utilization of biodegradable organic matter by potent microbes in the absence of an electron acceptor (Oxygen, Nitrogen, Sulfides), followed by bio-methanation and pollutant deletion [26]. Hydrolysis that kick-starts the reaction is considered the rate-limiting of AD as the initial degradation starts from there, though [16] argue that the conversion of volatile fatty acids (VFA) by methanogens is considered the rate-limiting step. Lignocellulosic recalcitrance hinders the reducing sugars' accessibility by the microbes and reduces the enzymatic access, thereby reducing the rate of anaerobic digestion [35]. Pretreatment and co-digestion are two alternatives that AD-based researchers at large have widely explored. Pretreatment reduces recalcitrance and increases soluble organic concentration within the system [25]. On the other hand, a depleted N, in the case of a high C/N ratio system, retards the AD process, as the microbes find it difficult to flourish. In such cases, co-digestion is chosen, where the process progresses synergistically toward a considerable methane generation [7]. But, as a standardized conversion technique is not available, straw is not yet an industrially adopted option for bioenergy generation [32]. Hence, it is imperative to develop standardized solutions that can be significantly impactful and industrially adopted. Therefore, this study aims to describe the existing practices that have been done on this and suggest possible solutions and behavioral changes for the sustainable management of RS (Fig. 1).

2 Background

2.1 Exploring the Indian Scenario: RS Generation and Problems

2.1.1 RS Generation

Among the Asian countries, India produces around 122.27 million metric tons (MMT) of rice, making it the second largest producer. Still, it has approximately 112 million metric tons (MMT) of rice straw, thereby holding the position of the leading RS waste generator [31]. Mothe and Polisetty [18] write that RS is 29% of the total paddy after harvesting, which can generate 100 kWh worth of power with a calorific value of 2400 kcal/kg. After harvesting, the RS is collected using a baler

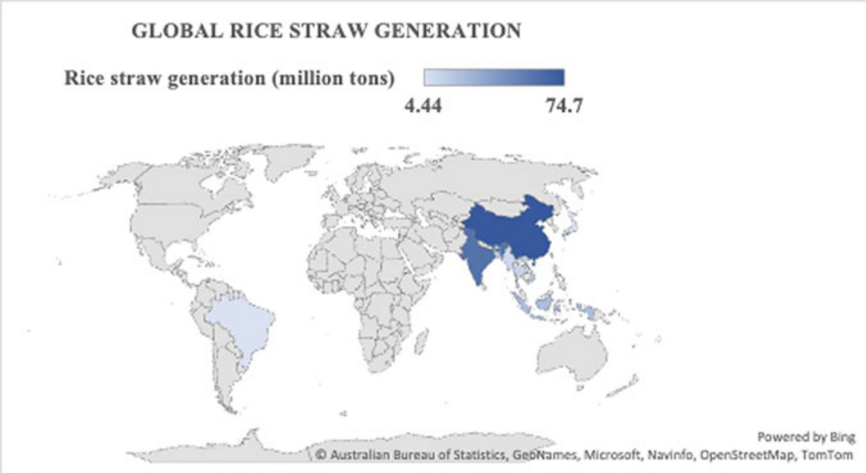

Fig. 1 Global rice straw generation (Retrieved from Singh et al. [31])

machine, and the moisture content remains around 50–60%. It is then ensured that the moisture content goes below 25%, and fermentation is arrested before proceeding to the bio-ethanol fermentation plant [31]. By 2070, India targets to achieve net zero emissions, hence the potential of the biomass sector is highly demanding [19] (Fig. 2).

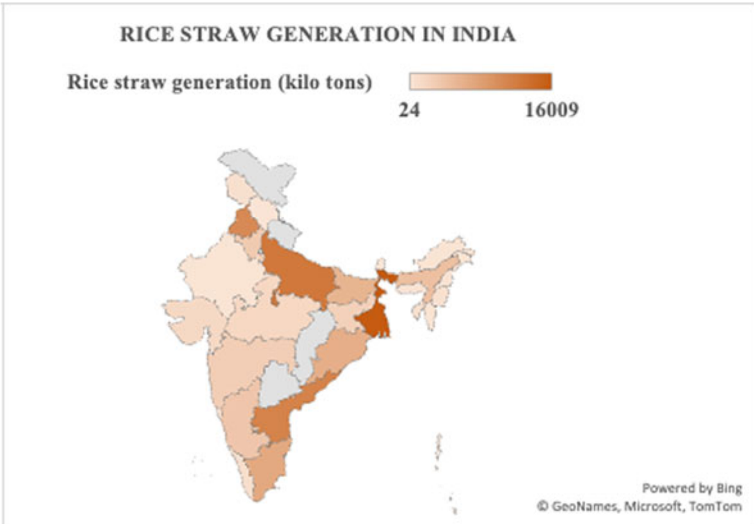

Fig. 2 State-wise rice straw generation (Retrieved from Singh et al. [31])

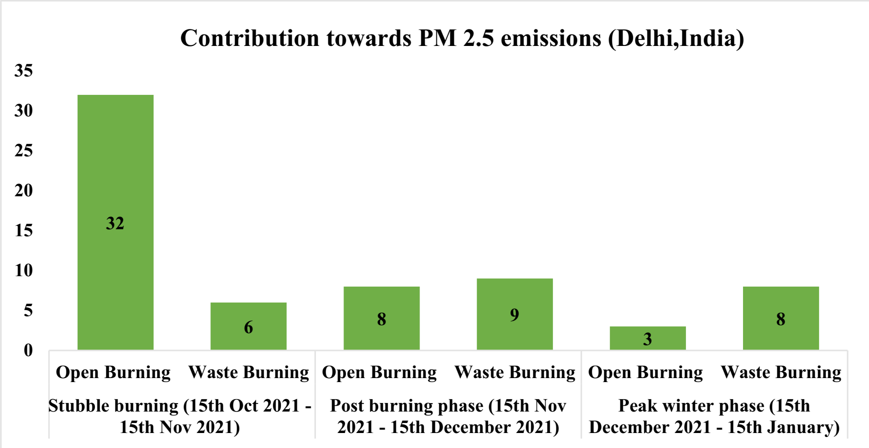

Fig. 3 Stake of open burning and open emissions from waste burning in Delhi's net PM 2.5 emissions

2.1.2 Problems of Rice Straw Management: A Nightmare for Farmers?

The paddy straw burning issue contributed to 6–48% of the PM 2.5 concentration in Delhi's air quality in 2021, as per the reports of the Indian Institute of Tropical Metrology (IITM). The Indian apex court has criticized the union government for blaming the farmers and not catering to their needs. To understand this topic in detail, [4] surveyed a group of farmers hailing from the Punjab and Haryana regions. The average education period of the group was 14 years; mainly, everyone held a marginal share of farms. The state governments promised them subsidized electricity for irrigation and agricultural use, provided the rice–wheat system of the plantation was followed. Machinery essential for gathering and compressing the straw into bales was also unavailable, which compromised transportation [19]. Bhattacharyya et al. [4] commented on their survey about a very narrow time window between two seasons for plantations and labor costs that motivated the farmers to opt for open burning. The study further suggested the high direct price in the short run, with open burning becoming the best alternative. Roy and Kaur [28] also surveyed a farmer group based in West Bengal and mentioned significant problems faced during the domestic use of rice straw (Fig. 3).

2.1.3 Issues with Biomass-Based Power Plants

The significant issues biomass-based power plants face are non-linear feed procurement patterns and high labor charges. Until now, there exists no regulation on paddy straw waste management, plus this sector faces tough competition with solar and wind industries, which are relatively cheaper [19]. Among others, sugarcane has a significant share as bagasse is a by-product of the sugarcane-making process. Very soon, the news of sugarcane-based waste to energy plants can also be expected. With a generation rate of around 20 million tons (MT) of paddy straw, Punjab tops the chart among the potential leaders of bioenergy producers (estimated—at 3172 MW). Characterization of RS reveals the high silica, low bulk density, and higher ash content which is not entirely combustible and damages the machinery. Dr. Ram Chandra, Assistant Professor at CRDT IIT Delhi, also commented in one of the interviews regarding the boiler's emissions, the ash's creation, and the underutilization of all the nutrients that should have gone into the soil. Prasad and Raturi [27] mention the unavailability of biomass inventory in the public domain, which shrouds the availability of biomass-based resources. Due to this, investors are not sure about investing in this area. Many a time, some established biomass power plants misuse the permissible coal limit provided to them to keep the plant operational during shortages in biomass availability. This problem maps directly to marginal land holdings, increased equipment costs, and unrevised government tariffs [10].

2.1.4 RS Characterization as Well as Possible Mitigation Options

The lignocellulosic framework of rice straw contains cellulose, hemicellulose, lignin, and some appreciable amounts of silica. Goodman [9] mentions that rice straw contains around 32–38.6% of cellulose, 19.7%–35.7% of hemicellulose, 13.5–22.7% of lignin, and 10–17% of ash [17]. Several pretreatments have been carried out to ward off the lignocellulosic recalcitrance, a summary of which is given in Table 1. Until now, a cost-effective pretreatment method has not been found, and all the pretreatment methods have shown varying effects on the composition of lignocellulose and sugar yields [3]. Moreover, the inhibitors generated during pretreatments are again a cause of concern with the progressing process flows. Pretreatments like thermal, electro-kinetic, and hydrothermal are energy-intensive processes and have not been seen to get recommended for industrial scaled-up applications. Kainthola [12] mentions the generation of 5-hydroxymethylfurfural (HMF) phenols during the pretreatment processes that hinder cellulose hydrolysis. Biological pretreatment is a cheap environment-friendly technique that does not release inhibitors during degradation processes [3].

Anaerobic co-digestion studies help deal with two wastes simultaneously, and the synergistic valorization minimizes time and increases productivity. The compiled Table 2 shows some of the significant studies published on the co-digestion of rice straw. Sewage sludge management is also a huge issue in India, as most houses with septic tanks face this periodically. The C/N ratio (6–9) and low volatile solids content make it suitable for being a co-substrate [23]. Such studies should be encouraged more in light of waste management in rural areas to motivate farmers to adopt newer interventions.

Table 1 Some major pretreatment methods used during AD-mediated RS management

S./No.	Method	Operating conditions/mode	Raw materials	Results	References
1	Physical	Hydro-thermal: T = 200 °C, t = 10 min, vapor pressure = 1.55 MPa	Rice straw	Increment in biogas production by 225.6%	[5]
2	Chemical	Acid: 0.075, 0.15, 0.3, 0.75 mol/L acetic and propionic acid in 1: 1 ratio	Rice straw	34.19% of lignin was eliminated, and methane was reduced by 35.85%	[37]
3	Chemical	Alkali: NaOH	Rice straw	A 132% increase in biogas	[5]
4	Biological	Peptone and cellulose solubilization	Rice straw	The methane production rate increases by 62.4%	[29]
5	Biological	Fungal: *T. reesei*, *P. ostreatus*	Rice straw	Lignin removal averaged 23.6%, with methane yield reaching 92% and 120%, respectively	[21]

Table 2 Major co-digestion studies to manage RS through AD-based techniques

S./No.	Feedstock	Operating conditions	Results	Factors	References
1	Rice straw + cow dung	T = 37 ± 10 °C V = 2.5L (batch), 40L (continuous)	Improved bio-methanation by 5.8%	High buffering capacity	[13]
2	Rice straw + municipal solid waste	At 37 °C, 150 mL working volume, and 100 revolutions per minute	Bio-methanation and biogas output were boosted by 57% and 60%, respectively	C/N ratio	[22]
3	Rice straw + sewage sludge	Mesophilic temperature	sixfold biogas yield enhancement	C/N ratio	[1]
4	Rice straw + pig urine	Different S/I ratios in batch thermophilic conditions	Lower S/I ratios are preferred, as are greater biogas yields	Minimal VFA production with NH_3 and pH concentration in the range	[15]

3 Materials and Methods

The methodology involves identifying and understanding problem statements through various newspaper articles and a comprehensive literature survey using *Google Scholar*. Some of the important keywords to narrow the study were "Rice straw biogas", "Rice straw anaerobic digestion", "Anaerobic digestion of paddy straw", and "Review on anaerobic digestion of paddy straw". Further, the field experience from reviewing some of the biogas plants and lab-scale experience with paddy straw has also formed the basis of several arguments made in the manuscript.

4 Results and Discussion

4.1 Global Scenario

Singh and Brar [30] commented that since the South East Asian countries are the primary rice producers, the RS management issues are clustered around this region. China globally produces 200 tons of RS yearly yet struggles with its management. Similar to the Indian perspectives discussed previously, open burning is also considered a favorable alternative there. Anaergia, one of the companies pioneering clean energy, has signed a deal with European energy to supply biogenic carbon dioxide to e-methanol plants in Denmark. According to *biofuels international*, Anaergia will provide liquified CO_2 from the anaerobic digesters built in TØnder, Denmark. Another e-magazine, *bioenergy global*, 2019, also mentions a rice straw-based biogas facility set up in the Philippines, which aims to transform straw into clean fuel by targeting rural prosperity. RS waste mitigation through anaerobic digestion should be promoted rigorously, as it can potentially contribute to the global energy demand. California, in particular, uses rice as a mono-crop, and farmers generally target on-field recycling. But again, counting on the biomass-based electricity sources, at least ten medium-sized plants exist to handle biomass wastes, which is not RS, because of higher ash and chlorine association with the firing of fuels. Individual initiatives like those taken by Craig Jamieson for promoting RS-based bioenergy should be encouraged.

4.2 Latest Indian Interventions

Researchers at VNIT Nagpur, India, in association with Merino Industries, have developed a novel bio-culture that can mineralize recalcitrant biomass (C/N > 50) and produce a nutrient-rich compost within two weeks of application. The bio-culture Fig. 4 [14] is now utilized for biogas, enzyme extraction, etc. Economic interventions like this are an optimistic gesture toward on-field utilization of RS and aid the farmers to be more self-reliant and resilient in their approach. Indraprastha Gas Ltd., one of India's largest CNG distribution companies, has also been directed to set up an RS-based biogas plant in Karnal, Haryana. This plant is estimated to convert stubble generated from 20,000 acres of land into biogas [33]. The Punjab government has also been permitted to set up two biomass-based power plants utilizing RS as a feedstock. Currently, a 1 MW biogas power plant is operational in the Fazilka district (Punjab) and is feeding energy to the power grids [19]. Indian Oil Corporation Limited (IOCL) has also received clearance from the Punjab government to set up a 3000 TPD (ton/day) RS in Patiala [8]. The Punjab energy development agency's (PEDA) website lists the multiple projects dedicated to paddy straw waste to energy initiatives [24]. Only time can tell how successful these initiatives will be in the long run. Projects like those at VNIT should be motivated to develop a framework that would promote newer ways of sustainable mitigation of these organic wastes. A team of researchers led by Dr. Chandra from IIT Delhi has also stated the efficacy of RS mitigation through anaerobic digestion as the best environmentally and economical alternative [6]. Recently, Punjab has also commissioned a 33.23 TPD biogas plant in Bhuttal Kalan Village that commercially supplies gas to an IOCL outlet. Asia's biggest CBG plant has also been set up in Sangrur, which aims to employ around 8000 individuals [34]. In Uttar Pradesh, Adani Total Gas has entered into a public welfare partnership to treat 150 TPD of RS as substrate [33]. All these initiatives highlight the significance of this substrate, keeping in view the national view of clean energy; hence, more research must be encouraged to optimize the processes further.

Fig. 4 Bajrang Ban—a bio-culture capable of creating compost out of rice straw in just 14 days (Courtesy: VNIT Nagpur, SWAHA Lab)

4.3 Footprint Estimation

Researchers are constantly re-evaluating the metrics through which they can assess the environmental impact due to industrial and field-scale processes like energy analysis, LCA, water footprint, and carbon footprint [36]. Ecological footprint is a measure of anthropogenic activities exerted on the environment. Various software utilize nation-specific data from large databases from agencies like eco-invent, ECLD, and USDA and transform the data into midpoint and endpoint indicators. For measuring ecological footprint using net primary production of the region, the critical load of acid deposition of sand, and wetland nitrogen retention, the LCA-energy and ecological footprint technique (LEEF) uses midpoint indicators such as GWP (100 years), AP (acidification potential), and EP (Eutrophication potential). A comparative impact assessment of 100 kg straw when subjected to open burning and biomethane-potential (BMP) test has been presented. The analysis shows that open burning holds 13 times more GWP than a conventional lab-scale BMP. Additionally, AP and EP hold a 99.97% stake in the processes. Though previously, the manuscript discusses the suitability of adopting and optimizing anaerobic digestion techniques for bioenergy, a detailed discussion on the footprint of the existing biogas reactors in the country is yet a bottleneck that needs addressing for further optimization of process flows (Fig. 5).

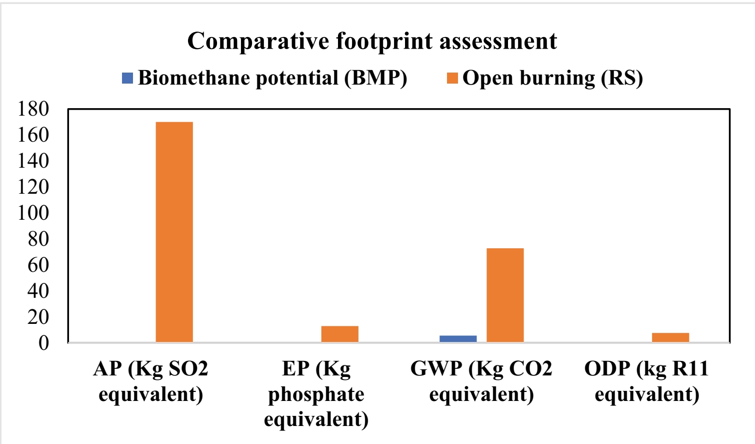

Fig. 5 Comparative impact assessment of BMP test and open emissions from stubble burning

4.4 Current Operational Challenges and Future Scopes for Research

RS possesses a higher bulk density and porosity that hinders the flowability within the reactor. Barua and Kalamdhad [2] also mention the need for an axial flow agitator for maintaining a uniform concentration gradient for lignocellulosic feedstocks. But industrially, voluminous water usage is discouraged as it adds to the water footprint, and continuous agitation also significantly contributes to the energy footprint (1kwh electricity = 1.06 kg CO_2 equivalent). With the Deenbandhu models and the UASBR mainly dominating the AD sectors on a household and industrial scale, CSTRs have also had their fair share in handling municipal solid wastes. Owing to the unavailability of specialized compact reactor designs widely operational at industrial levels, research should develop novel strategies to standardize a pre-digestion step for lignocellulosic AD.

5 Conclusion

The government should develop a robust framework to monitor the biogas plants and impose harsher restrictions on industries that exploit conventional energy sources. A decentralized energy architecture within any organization is a significant step toward sustainability. To curb transportation and logistics costs, decentralization of biogas units could be implemented cluster-wise in villages. Farmers mainly involved in harvesting RS should be trained and educated about the negative implications of open-field burning. It is a typical attitude among farmers to burn any sort of crop residue but seldom do they "think" of alternatives. The Krishi Vigyan Kendra (KVK) should also take up this cause and set up workshops to instruct the farmers regarding unsustainable behavior potentially lethal to the ecosystems. It has been a common observation that farmers generally do not want to adopt the "biogas way" of electrification owing to a lack of understanding of the systems. Generally, the reliance on cow dung also discourages the farmers, as many complain about the tedious operation of conventional digesters. Hence, the technical and research institutions should be pushed and supported to design a compact and economical digester that would be both ergonomically and economically viable.

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An Assessment of Qualitative and Quantitative Municipal Solid Waste City Compost by Indexing Method

Srishti Khare, Anupam Singhal, Anant Mishra, and Brajeswar Das

Abstract Globally, the disposal of municipal solid waste (MSW) is a significant environmental challenge. The production of MSW is continuous in megacities, small cities, and large villages, and if wastes are not managed properly, they can have a detrimental effect on both the environment and human health. Processes such as incineration, anaerobic digestion, and composting are widely adopted. The MSW city compost (MSWCC) generated poses significant challenges due to the presence of a high amount of residual metal toxicity. Therefore, the researcher examined the material's physical and chemical properties, as well as its heavy metal content and spectral characteristics were investigated to assess the applicability of its use for different purposes generated from MSW dump yards. For this purpose, spectral characterization including mineralogical analysis with X-ray diffraction (XRD) was used to determine the presence of heavy metals; topographical imaging and elemental mapping with a scanning electron microscope and energy dispersive X-ray analysis were carried out (FESEM-EDX). Current investigation shows that (i) XRD, SEM–EDX confirms the evidence of HMs in MSWC; (ii) In terms of Zn, Cu, Cd, Pb, and Ni, MSW compost did not meet the quality control guidelines of 'The Fertilizer (Control) Order 1985.' (iii) Using the Indexing method, the Fertilizing Index (FI) of compost was found to be 4.4, which means it has a high potential to fertilize. The Clean Index (CI) of compost, on the other hand, was found to be 1.7, which means it has a high potential to pollute with heavy metals; (iv) The compost sample belongs to RU-3 (Restricted Use category 3) class and, hence, has been found unsuitable for any kind of use.

Keywords Municipal solid waste · Compost · Fertilizing index · Clean index · Heavy metal

S. Khare (✉) · A. Singhal · A. Mishra · B. Das
Department of Civil Engineering, Birla Institute of Technology and Science Pilani, Pilani 333031, India
e-mail: srishtikhare1808@gmail.com

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_4

1 Introduction

Municipal governments have major challenges in waste, water, and energy management. Indeed, municipal solid waste (MSW) is becoming a substantial source of worry around the world as the human population grows, resulting in higher levels of consumption and a greater need for waste disposal [14]. MSW production in the world is approximately 1.3 billion tonnes annually, expected to rise to 2.2 billion tonnes annually by 2025 [13]. In India, about 1,52,076 thousand tons of MSW is generated in 2018–19. Nationally, we produce approximately 300 and 700 g of municipal solid waste per person, which is growing at an alarming pace [7].

In terms of global solid waste, organic materials contribute 46%, paper 17%, plastic 10%, glass 5%, metal 4%, and other wastes 18% [23]. When looking at the global economy, paper, plastic, and other inorganic materials make up the bulk of MSW in wealthy countries, whereas organic waste predominates in underdeveloped ones [27].

Leachate percolation from MSW possesses the potential to impair groundwater quality, while greenhouse gas emissions from different treatment procedures having the potential to pollute the health and ecology are both negatively impacted by the illegally dumped materials [2, 5]. Waste generation reduction, recycling maximization, and resource recovery are three of the most promising approaches to enhancing the MSW management system. Applying compost to farmland instead of dumping it in a landfill or burning it saves money. The composting process not only results in a stable soil conditioner but also supplies crops with much-needed nutrients. Because of this, employing organic compost is a sustainable method of managing soil fertility [21]. Compost comprises organic matter, plant micronutrients (Zn, Cu, Cd, Pb, Ni, and Cr), and primary plant nutrients (TN, TP, and TK), all of which enhance soil characteristics by enhancing oxygenation and water retention capacity [11]. For India to achieve its goals of sustainable agriculture and resource management, the preparation of MSW city compost (MSWCC) must be mitigated. Most MSWCC also did not comply with the FCO, Government of India's required criterion. The reason for this is that the composition of feedstocks varies (mixed MSW). So, more than 2.86105 t [dry weight (DW)] of HMs are found in animal dung [33]. Meanwhile, there is a broad range of items created from residential trash that contain significant amounts of HMs. These include household dust, batteries, disposable tools, plastics, paints and inks, body care products, medications, and household insecticides. In comparison to smaller cities, those with populations over a million had composts that usually have a higher concentration of zinc (86%) and copper (155%), cadmium (194%), lead (105%), nickel (43%), and chromium (132%) [31], analyzed MSW waste from Delhi, Malad, Gwalior, Bangalore, Ahmedabad, and Nasik and found the concentration of all HMs exceeded the limits). In addition, [15] looked into Delhi and discovered that 66.7% of the population had levels of Cr, Cu, and Pb that were too high (FCO standard). Heavy metal levels are too high for direct utilization in agricultural applications and are one of the requirements of the SWM: as found by [28] exploration of Okhla and Bhalswa in Delhi, Hyderabad, and Kadapa. Due to its indestructibility, HM pollution has developed into a worldwide environmental threat [24]. Humans, animals, and plants may all be put at risk by this pollution. A considerable amount of HMs may accumulate in agricultural soils as a result of the persistent use of raw animal manure, posing harm as it relates to the health of the public—the ingestion of harvested food [28].

World's most populous city, Mumbai, with a population of 20 million in 2018 in India (UN, Sustainable transport, sustainable development, 2021), produces an estimated 10,817 tonnes of municipal solid waste (MSW) per day [7]. Wet weight analysis reveals that 54.42% of the waste is biodegradable, 15.52% is recyclable, and 30.0 6% is inert [18]. When municipal solid waste (MSW) is not properly disposed of, it can clog drains, leading to mosquito breeding grounds and flooding during wet periods.

This investigation tested the hypothesis that MSWCC made from unsorted MSW would be of lower quality. We consequently analyzed the fertilizing and quality indicators of the MSWCC being produced at Mumbai's compost plants. The long-term viability of MSWCC depends on operators of compost facilities understanding and improving the product's quality and marketability, ensuring a uniform grade, and providing users with information about its use.

2 Analytical Characterization Methods

The MSWCC were subjected to a series of experiments designed to adequately characterize them, with multiple techniques being utilized whenever possible. Experiment composts were air-dried at room temperature (about 25 °C), pulverized (quartered), homogenized (mixed), and sieved (2 mm).

2.1 MSWCC Sampling and Characterization

Ten MSWCC (M1 to M10) were collected from Mumbai, the most populated city in India. The samples were collected once by following methods of schedule-ii, part-A of FCO [1] (grab samples). Uniform and oven-dried at 70 degrees Celsius, the MSWCC samples were then analyzed using a screen with 2 mm size perforations, as shown in Table 1. Analyses followed: moisture content, pH, electrical conductivity, TOC, TN, TP, TK, and heavy metals. The method of analysis is mentioned in Table 1.

2.2 MSWCC Microscopic Morphology

After 48 h of oven drying at 70 °C, all ten samples were mixed and were sieved below 75 µm for analysis.

Table 1 Characteristics of MSWCC and method of analysis

Characteristics	Method	Method of test
Bulk density	Bulk density	Schedule-IV, Part D,9, FCO 1985 [1]
Moisture content	Oven method (thermogravimetric method)	IS16556:2016, Annex B [6]
pH	pH Meter	IS16556:2016, Annex C [6]
Electrical conductivity (EC)	Conductivity cell	IS16556:2016, Annex D [6]
Total organic carbon (TOC)	Dry combustion (muffle furnace)	Schedule-IV, Part D,5, FCO 1985 [1]
Total nitrogen (TN)	Kjeldahl method	Schedule-II, Part B,3, FCO 1985 [1]
Total phosphorus (TP)	Vanadomolybdate yellow colour	Schedule-II, Part B,4, FCO 1985 [1]
Total potassium (TK)	Flame photometric method	Schedule-IV, Part D,9, FCO 1985 [1]
Heavy metal: zinc (Zn), copper (Cu), lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr)	Diacid digestion: Pb Triacid digestion; Cd, Cu, Ni, Zn, Cr Analysis: AVIO200 ICP-OES	IS16556:2016, Annex P [6]

2.2.1 X-Ray Diffraction (XRD)

The X-ray diffraction (XRD) system is used to analyze a sample in order to determine the minerals it contains (Model: Rigaku Miniflex). In order to ensure that the samples were uniform in consistency, materials were manually crushed and sieved using a 75 prefilter. After placing the prepared sample in a rectangular holder and pressing it down to create a homogeneous layer, the holder was affixed to the instrument. The generator was set at 45 kV for the tube voltage and 40 mA for the current. The acquisition was recorded at angles ranging from 10 to 80 degrees, and the scan rates were 0.02 degree steps with a 1 s step duration (Cu KA = 0.154061). The specimen is scanned with the X-ray beam from a variety of angles. The crystalline nature of the sample is revealed by the diffracted X-ray beam, which revealed the presence of distinct minerals. Match is the corresponding app for determining the minerals present.

2.2.2 Field Emission Scanning Electron Microscopy-Energy-Dispersive X-Ray Spectrometer (FE-SEM-EDX)

FE-SEM was used to analyze the manufactured nanoparticles and establish their surface morphology and size distribution. The process was achieved using an Apreo LoVac type FE-SEM. Furthermore, the distribution of heavy metals was studied using a multipoint energy-dispersive X-ray spectrometer (EDX) (Aztec Standard

EDS equipment, resolution 127 eV on Mn-k). To prepare dried MSWC samples for examination, we used a Leica Ultra Microtome EM UC7 sputter coater to apply a thin layer of gold. The samples were accelerated for 30 s at 20 kV on a copper stub.

2.3 Grading the Quality of MSWCC

MSWCC needs to be graded to determine and categorize the compost. Earlier, a Quality Control guideline prohibited the distribution of MSWCC that met or exceeded a selection of Quality Control characteristics that attested to their benign impact on the environment. Users can get a better sense of the overall quality of MSWCC with the assistance of this indexing system. Urban compost is categorized based on its Fertilizing index and Clean index scores. These parameters are used for quality control in MSWCC quality control indices.

2.3.1 Fertilizing Index

Improved crop yield or quality is mostly attributable to fertilizer's effect on soil. Factors that most strongly affect fertilizing value are total organic carbon, nitrogen, phosphate, potash, and the C:N ratio. Table 2 displays the 'score' values assigned to various components according to their concentration [22]. The parameters that promote soil productivity are also assigned a 'weighing factor' based on scientific research. By reducing emissions of greenhouse gases and increasing a wide spectrum of soil productivity indices, organic carbon contributes to mitigating climate change. Therefore, total organic carbon (TOC) in compost is the most important element, therefore maximum weighting factor of 5 was given. Also, high C:N ratios carry a high weight factor because they prevent nitrogen and other nutrients from being leached out of the soil. Despite their significance in growing crop yield, nitrogen, phosphorus, and potassium each received a different weighting score from 1 to 5 based on how often they are lacking in soils and how useful they are.

Table 2 Criteria for assigning 'weighing factor' to fertility considerations and 'score value' to MSWCC

Macronutrient parameters	Score value (s_i)					Weighing factor (ω i)
	5	4	3	2	1	
Total organic C (% dm)	>20.0	15.1–20.0	12.1–15.0	9.1–12.0	<9.1	5
Total N (% dm)	>1.25	1.01–1.25	0.81–1.00	0.51–0.80	<0.51	3
Total P (% dm)	>0.60	0.41–0.60	0.21–0.40	0.11–0.20	<0.11	3
Total K (% dm)	>1.00	0.76–1.00	0.51–0.75	0.26–0.50	<0.26	1
C:N	<10.1	10.1–15	15.1–20	20.1–25	>25	3

To calculate compost's FI values, use the following formula:

$$FI = \frac{\sum_{n}^{i=1} s(i)\omega(i)}{\sum_{n}^{i=1} \omega(i)}$$

where '$S(i)$' is the score value and '$W(i)$' is the weighing factor of the ith fertility parameter of analytical data.

2.3.2 Clean Index

Government agencies can utilize the Clean Index value to restrict the amount of heavy metals that can enter nearby water supplies, farmland, and the environment. Various heavy metals received scores and weighted criteria from researchers for their analytical value [22]. The score values were based on the toxicity level of the respective heavy metal. A 'weighing factor' of 5 is set for cadmium because of its potential medium to high phytotoxicity and high toxicity to mammals. However, zinc and nickel have low phytotoxicity potential, medium mammalian toxicity, and an important physiological purpose; thus they are assigned only a 'weighing factor' of 1. A 'weighting factor' between 1 and 5 is assigned to the remaining heavy metals. The following formula is used to compute the CI values of compost (Table 3):

$$CI = \frac{\sum_{n}^{j=1} s(j)\omega(j)}{\sum_{n}^{j=1} \omega(j)}$$

where '$S(j)$' is the score value and '$W(j)$' is weighing factor of the jth fertility parameter of analytical data.

Table 3 Criteria for assigning 'weighing factor' for heavy metal parameters and 'score value' to MSWCC

Micronutrient parameters (Heavy metal)	Score value (s_j)						Weighing factor (ωj)
	5	4	3	2	1	0	
Zn (mg/kg dm)	<151	151–300	301–500	501–700	701–900	>900	1
Cu (mg/kg dm)	<51	51–100	101–200	201–400	401–600	>600	2
Cd (mg/kg dm)	<0.3	0.3–0.6	0.7–1.0	1.1–2.0	2.0–4.0	>4.0	5
Pb (mg/kg dm)	<51	51–100	101–150	151–250	251–400	>400	3
Ni (mg/kg dm)	<21	21–40	41–80	81–120	121–160	>160	1
Cr (mg/kg dm)	<51	51–100	101–150	151–250	251–350	>350	3

2.3.3 Classification of Composts on the Basis of 'Fertilizing Index' and 'Clean Index'

Compost is the source of plant nutrients and is also used to condition soil, hence its fertilizing index is of utmost importance to farmers. However, the Clean index score is highly valued by public health and environmental organizations and government agencies since it provides a comprehensive analysis of MSWCC. When it comes to reducing the amount of waste deposited and emissions from disposal sites, municipal authorities have a responsibility to recycle as much garbage as feasible through the composting process. Contrarily, many who make compost see their work as a profession and believe that better pricing will increase sales.

Grading of compost is based on quality characteristics like its clean index (CI) and fertility index (FI) which in turn determines its selling price. Using the FI and CI determinations, compost quality can be broken down into seven distinct categories: A, B, C, D, RU-1, RU-2, and RU-3. Each of the four categories A–D represented high-quality compost that has a high market value and could be utilized for organic farming and high-value crops. The remaining categories are of limited utility and are not suitable for organic farming. Table 4 displays the various types of MSWCC based on their marketability and potential applications. In addition, the results have been double-checked using a compost quality analyzer program [22].

3 Results and Discussion

In Table 5, we can see the physical and chemical parameters of the MSWCC, as well as the range and median values.

3.1 Physical and Chemical Characteristics

The compost samples ranged in moisture content from 15.21% to 33.62% wet matter (wm) for a sample with 22.84% serving as the median (Table 5). An item's moisture content can shed light regarding how it will perform in processing or storage, in addition to how feasible it will be to carry in terms of bulk. The optimal moisture content for the final product is 15–25%. Less-humid composts may not have been stabilized properly or may have been stored for too long, both of which can cause moisture loss. Compost with too high of a moisture content becomes too clumpy and increases the cost of transportation, while compost that is too dry is sometimes dusty and unpleasant to handle [22]. The moisture levels in sample were satisfactory.

Table 5 shows that there is a wide range of pH values among the samples, 7.10 to 7.60 with a median value of 7.4 (Table 5). Samples of MSWCC were found to have a pH level that was slightly alkaline and well within the normal range [20], whereas the median for EC is 2.35 and samples ranged from 0.29 to 6.89 EC values

Table 4 Classification of MSWCC for their marketability and use in different areas

Class	Fertilizing index	Clean index	Quality control compliance	Overall quality and area of application	
Marketable classes	A	>3.5	>4.0	Complying with all heavy metal parameters	Best quality. High manurial value and low heavy metal content. Can be used for high-value crops and in organic farming
	B	3.1–3.5	>4.0		Very good quality. Medium fertilizing potential and low heavy metal content
	C	>3.5	3.1–4.0		Good quality. High fertilizing potential and medium heavy metal content
	D	3.1–3.5	3.1–4.0		Medium quality. Medium fertilizing potential and medium heavy metal content
Restricted use classes	RU-1	<3.1	–	Not complying with all heavy metal parameters	Low fertilizing potential but safe for environment. Can be used as soil conditioner
	RU-2	>3.1	>4.0		Can be used for growing non-food crops. Requires periodic monitoring of soil quality if used repeatedly
	RU-3	>3.1	<4.0		Can be used only for developing lawns/gardens, tree plantation in forestry (with one-time application)

(Table 5), significantly correlated with soluble Cl at the 1% probability level ($r = +0.91$), suggesting that contamination with chloride salts may have contributed to the electrical conductivity of the compost samples 42.

The Bulk Density values for the sample ranged 17.92–24.38 with a median value of 24.46, respectively (Table 5). Bulk density of samples decreased as organic matter content. As a result of sifting (mandatory by Indian law), the organic matter content of the composts in this study was reduced, resulting in a higher bulk density. The presence of organic material and inert material/ash can be inferred from the bulk density calculated on a dry weight basis. When applied consistently over a long period of time, composts with a lower bulk density boost the soil's ability to retain water [26].

Table 5 Physical and chemical properties of the MSWCC for M-samples

Properties	FCO and IS16556:2016	M-samples	Median
Bulk density, g/cm^3, Max	1	17.92–24.38	24.46
Moisture (% wm), Max	25	15.21–33.62	22.84
pH	6.5-7.5	7.10–7.6	7.4
Electrical conductivity, dsm^{-1}, Max	4	0.29–6.89	2.35
Total Organic Carbon (TOC), Min	14	19.12–73.34	36.82
Total Nitrogen (as N), Min	0.8	0.41–2.39	2.03
Total Phosphate (as P_2O_5), Min	0.4	0.21–0.74	0.51
Total Potash (as K_2O), Min	0.4	0.17–0.93	0.46
C:N ratio, Max	20:01	14.3–36.42	18.13
Cadmium (as Cd), mg/kg dm, Max	5	17.11–25.73	26.24
Chromium (as Cr), mg/kg dm, Max	50	30.46–34.74	33.58
Copper (as Cu), mg/kg dm, Max	300	244.81–251.68	249.63
Lead (as Pb), mg/kg dm, Max	100	327.46–372.18	368.66
Nickel (as Ni), mg/kg dm, Max	50	30.67–32.83	32.13
Zinc (as Zn), mg/kg dm, Max	1000	4537.11–5247.28	4927.06

3.2 Fertilizing Potential of MSWC

3.2.1 Organic Matter Content

Oxidizable organic C and total organic C (TOC) are indicators of organic matter content in the MSWCC samples. Median values were 36.82% dm for the samples, respectively and ranges were 19.12% to 73.34% dm (Table 5).

3.2.2 Major Plant Nutrients Contents

Since these are three of the main nutrients that plants get from the soil, nitrogen, phosphorus, and potassium are crucial compost quality characteristics [20]. Median values for total N, P, and K in the sample were 0.41% to 2.39% dm, 0.21% to 0.74% dm, and 0.17% to 0.93% dm, for the sample, respectively (Table 5). Many authors said that the concentration of N in municipal solid waste (MSW) has been seen to rise over time as microorganisms use up C [32]. One sample's unusually high P content may be traced back to fortification with pulverized rock phosphate before composting in the respective region [22].

3.2.3 Carbon to Nitrogen Ratio

The carbon to nitrogen ratio (C:N) is used as a chemical indication of compost maturation with regard to organic matter and N cycling. Field-grown plants supplemented with composts containing a high carbon-to-nitrogen (C:N) ratio sometimes exhibit symptoms of N shortage, such as yellowing or stunting [22]. The median for C:N ratio sample in the research was 18.13. The range for the C:N ratio was from 14.3 to 36.42, respectively (Table 5). It was found that the C:N ratio in samples was well above 30:1, indicating that some of the composts produced were not stabilized, even though the feedstock's C and N levels were known [10]. According to some authors [30], the ideal C:N ratio for compost feedstock combinations is 30:1, although it should drop to less than 20:1 during the composting process.

3.2.4 Heavy metal Contamination in MSWCC

Another valuable aim is to keep heavy metals out of the ground and out of the water supply. This makes the amount of heavy metals a key quality metric. Figure 1 shows the heavy metal concentration in the sample. Table 5 shows that the heavy metal concentrations in the sample varied in the range 4537.11–5247 mg/kg dm for Zn, with a median of 4927.06, 244.81–251.68 mg/kg dm for Cu with a median of 249.63 mg/kg, 17.11 to 25.73 mg/kg dm for Cd with a median of 26.24 mg/kg, 327.46 to 372.18 mg/kg dm for Pb with median of 368.66 mg/Kg, 30.67–32.83 mg/kg dm for Ni with median of 32.13 mg/Kg, and 30.46 to 34.74 mg/kg dm for Cr 33.58 mg/kg, /kg. The average levels of these heavy metals in compost samples were considerably higher as compared to the contents found in the samples [4, 8, 15, 25]. The solid waste from bigger cities was found to have a high concentration of heavy metals than the waste from smaller cities [15]. Therefore, heavy metals limit the use of compost on agricultural land. The effects of heavy metal-contaminated compost on the environment depend on the soil type, plant species, and compost quality [20].

3.3 MSWCC Microscopic Morphology

3.3.1 X-Ray Diffraction (XRD)

The presence of heavy metals in the composts was further investigated using XRD analyses, Fig. 2. XRD is used for both qualitative and quantitative phase investigations of multiphase mixtures to determine their raw material component's mineralogical composition. The crystallinity of the material was revealed by analyzing the XRD patterns spanning the range of 10° to 70°, where 2 is the intensity of the diffracted beam as a function of Bragg's law. Crystallography Open Database (COD) was utilized to identify minerals that matched the spectra, and the results are reported in Fig. 2 along with the respective Miller Index (hkl). The study's XRD findings also

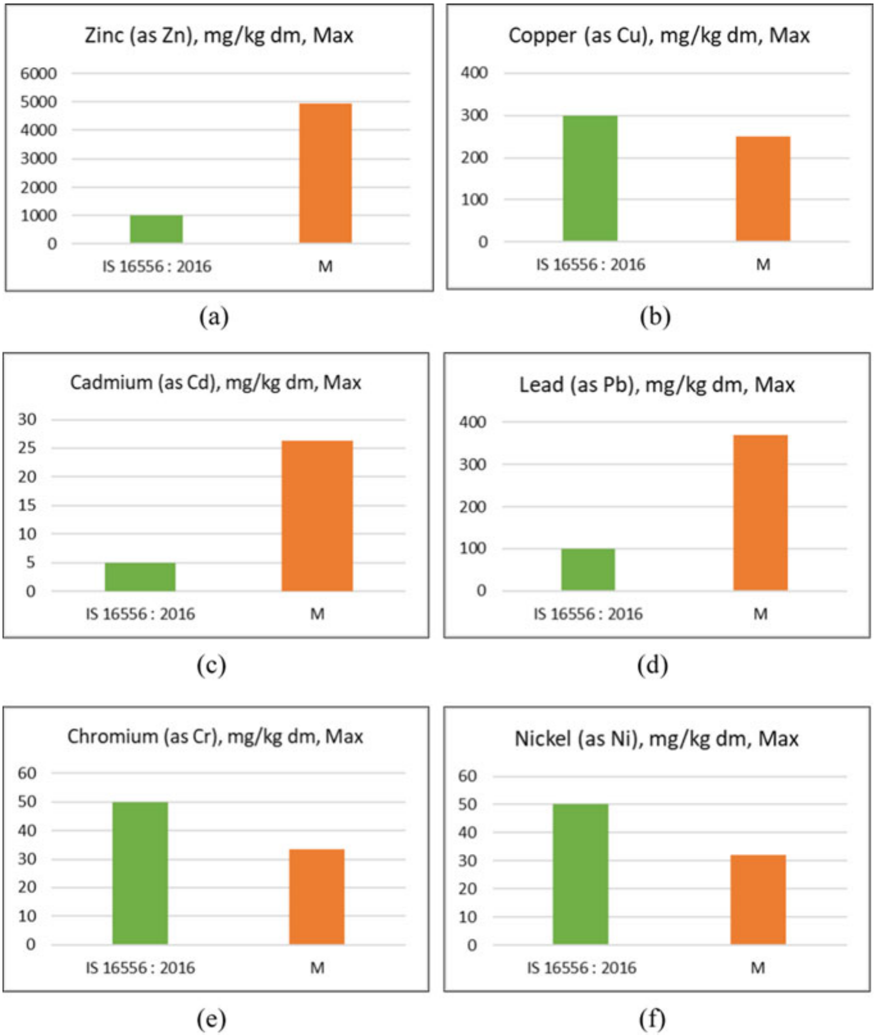

Fig. 1 Heavy metal concentration in MSWCC

reveal that ZnO, CuO, $CdSO_4$, Cr_2O_3, Li–$NiFeO_4$, and $PbSO_4$ are also present as part of the mineral make-up of heavy metals in the sample.

3.3.2 Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM) is a type of microscope that can be utilized to examine and analyze nanoparticles and microparticles at extremely high magnifications [29]. Figure 3 shows that the surface morphology of the sample corroborates

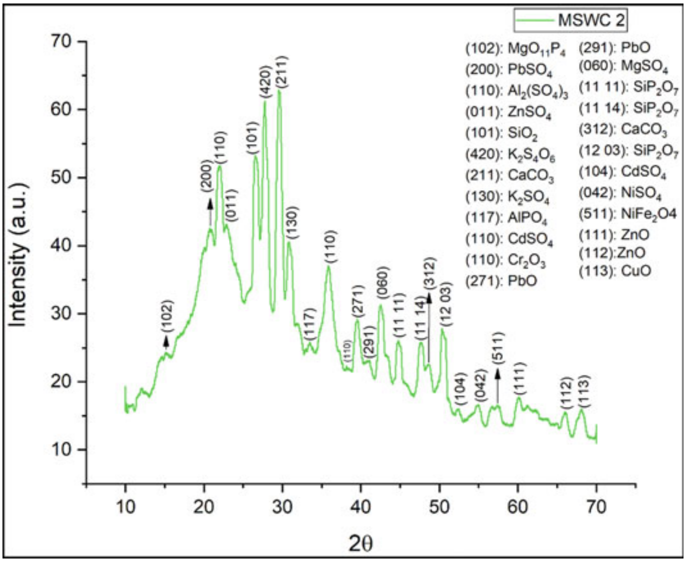

Fig. 2 XRD peaks of MSWCC

the results of the XRD analysis. Nanoparticles of pure chromium oxide are present, and they exhibit the appearance of brilliant white crystals, while pure ZnO has a morphology characterized by globular clusters of microscopic particles [12]. The shape of CuO nanoparticles, meanwhile, has evolved into a floral-like structure. The self-organizing nanofibrous monomers [9] are used to construct these floral hierarchical structures. $CdSO_4$ morphology revealed a disorganized structure due to the non-uniform distribution of globules and microscopic, almost spherical particles that make them up [17]. X-ray diffraction investigation reveals that the crystal structures of $PbSO_4$ (anglesite) and $CaCO_3$ (calcite), respectively, have orthorhombic and trigonal crystal forms with rhombohedral axes, while the particle morphologies of these two substances are respectively cluster and cubic. Thus, the sample generated cerussite ($PbCO_3$) crystals with the stick-like form seen in Fig. 3 [3]. A large number of open pores in the Li–$NiFe_2O_4$ nanoparticles shown in Fig. 3 make them well-suited for adsorption and humidity detection [16]. When compared to the XRD study, the SEM results are better in accordance with expectations. SEM image processing of samples confirmed the presence of minerals with this composition.

3.3.3 Energy Dispersive X-Ray (EDX)

Energy dispersive X-ray (EDX) and scanning electron microscopy (SEM) are used together to find out certain crystals or features. Figure 4 shows the distribution of elements in the sample based on EDX elemental mappings that were taken at a higher magnification to learn more about a sample. In EDX Spectra, oxygen (O), carbon

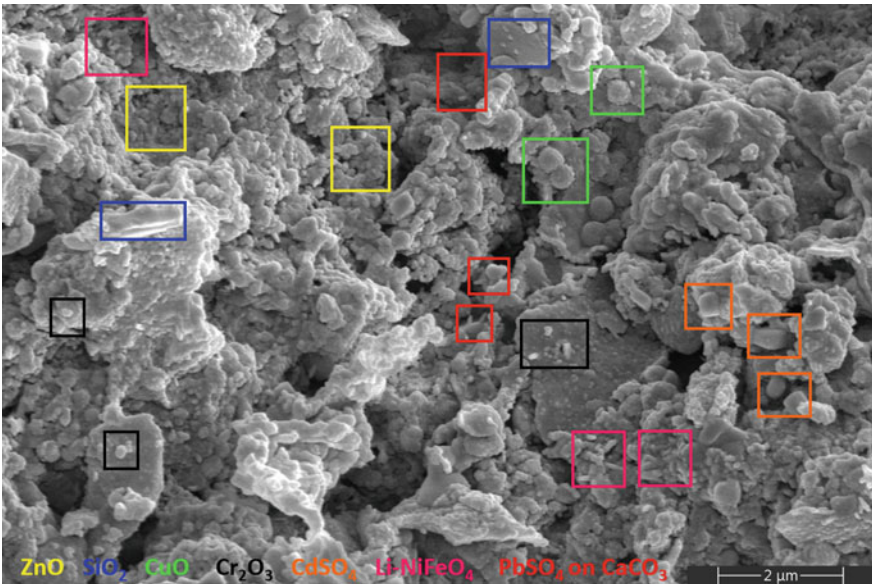

Fig. 3 SEM morphological view of MSWCC

Table 6 Weight and atomic percentages of EDX

Element	C	N	O	P	K	Cr	Ni	Cu	Zn	Cd	Pb	Total
Weight%	20.97	0	37.99	1.38	15.75	0.67	1.28	0	15.11	0.81	6.04	100
Atomic %	32.83	0	43.16	0.96	10.27	0.73	0.75	0	9.95	0.45	0.9	100

(C), and silica (Si), which have the highest peak of all the elements, are all clearly reflected. After EDX analysis, the heavy metals (Zn, Cu, Cd, Pb, Ni, and Cr) are easy to see in the X-ray spot profile. Table 6 shows how much each element weighs and how many atoms it is made up of. Figure 4 shows an EDX-based SEM image scaled to 5 m, an EDS-layered image, and an elemental mapping. These results show that the XRD and SEM tests mentioned above have been done on the sample surface.

3.4 Compliance of MSWCC to India's Quality Control Standards

Quality control (QC) procedure (Table 5) for regulation of the production and distribution of high-quality municipal waste composts in India has been established by FCO 1985 [1] and IS16556:2016. As per Table 5, analysis indicates that compliance differed considerably throughout QC parameters. The bulk density, pH, EC, TOC, TN, TP, TK, and C:N ratio of the samples were all within the allowable

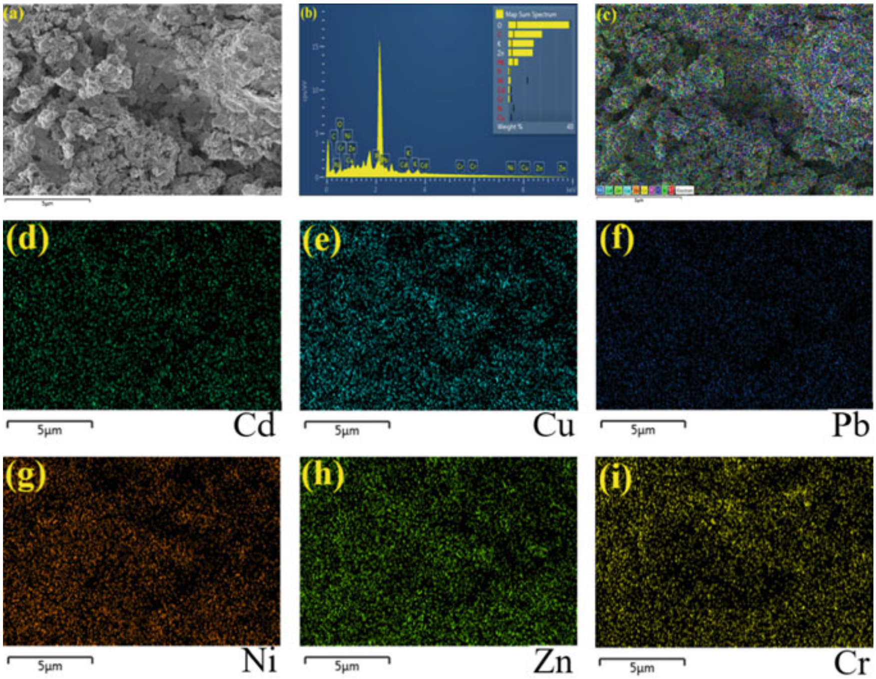

Fig. 4 Elemental Mapping of MSWC 1: **a** EDX-based SEM image; **b** EDX spectrum as per percentage composition; **c** EDX layered image; **d** Cd; **e** Cu; **f** Pb; **g** Ni; **h** Zn; **i** Cr mapping

levels. However, compliance standards have varied considerably with regard to certain heavy metals. Heavy metals like Zn, Cu, Cd, Pb, and Ni all exceeded the allowable limit; nevertheless, the degree of compliance was relatively high for Cr levels. One of the primary causes of such poor compliance with respect to these critical parameters, and requirements is the failure to properly separate biodegradable wastes before composting. Although all Indian municipal authorities were urged to collect biodegradable and non-biodegradable wastes from households' doorsteps on a daily basis in an effort to comply with the MSW (Management and Handling) rules 2000, this goal has only been partially achieved [19]. This necessitates revising the quality control (QC) standard for MSW composts so that composts manufactured using MSW can be accepted. In terms of metal density, this is definitely significant. materials that have decomposed (and have a 'Clean index' greater than 4.0) called composts, unusable in certain situations due to the presence of heavy metals; for example, they cannot be used to cultivate non-food crops such as ornamental plants, fiber crop, agro-forestry plantation, and garden establishments. However, if the compost has a good fertilizing and clean index value, it will contribute to greater recycling of city wastes and reduced landfill pressure [22].

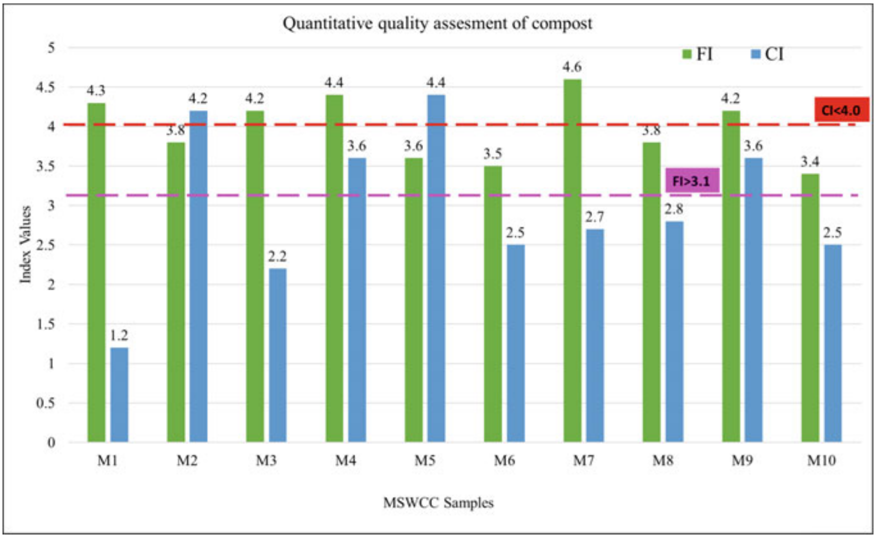

Fig. 5 FI and CI values of M1 to M10 samples

3.5 Grading the Quality of MSWCC

Prevailing Quality control guidelines safeguard environmental safety by prohibiting the sale of MSW organic manure that exceeds predetermined limits for multiple quality control measures. However, it doesn't indicate their total quality as a result of specific types of input material and a specific composting process. The user can be guided in their assessment of the MSWCC overall quality by using the following indexing approach [22].

3.5.1 Fertilizing Index (FI)

The analyzed sample had 'Fertilizing index' values (5.0-point scale) ranging from 3.4 to 4.6, with a mean value of 4.4. The FI values for M1 to M10 samples are shown in Fig. 5. It was observed that there was no noticeable variation in the FI of composts. This states that the samples have good fertilizing potential.

3.5.2 Clean Index (CI)

The estimated 'Clean index' varied between 1.2 and 2.8, with a mean value of 1.7, for the sample (5.0-point scale) (Fig. 5). Composts with such a high concentration of heavy metals are not allowed to be used in specially designated agricultural land.

3.5.3 Grade of Compost

With the help of both the FI and CI values, MSWCC is put into groups based on its marketability and ability to be used in different places (Table 4). Figure 5 shows the FI and CI measurements that were taken for all 10 samples (M1 to M10). Organic compost made from municipal waste has high fertilizing and heavy metal pollution potentials in the sample (CI value is the desired value). So, the current research suggested that MSWCC production at the selected site falls into the RU-3 category of limited use. We ended up finding the samples to be entirely useless and not satisfactory for marketing.

4 Conclusion

The increasing rate of MSW production in urban areas (0.3–0.7 kg/person/day) is directly correlated with the increasing rate of urbanization. The organic component of solid waste can be used as fertilizer by Indian farmers, which will help them increase crop yields. As a result of its high nutrient content, compost prepared from MSWCC is widely used to enhance the bioavailability of nutrients in soils. Constraints in utilizing this vast resource of plant nutrients to boost agricultural yields are mostly caused by improper solid waste management and the generation of low-quality composts. Using a wide variety of wastes as compost feedstock, this study found that most MSWCC samples of Mumbai fell short of the required specification with respect to heavy metal characteristics of the QC standard. The QC values of various heavy metals (especially Zn, Cu, Cd, Pb, and Ni) are placed at fairly greater levels in the FCO and IS16556:2016; yet, several compost sample generated MSW did not fulfill such standards. Therefore, in order to optimize composting of municipal solid wastes for recycling while preserving land resources from contamination, the current QC standard specification of India [1] and IS16556:2016 [6] in regard to heavy metals must be amended. Since applying composts with a high fertilizing index value and high clean index value degrades soil resources, composts made from municipal solid wastes can be evaluated quantitatively in terms of their quality with the help of a classification based on their fertilizing capacity and polluting potential. The grade of composts derived from MSW in Mumbai needs to be improved, hence a closer look at the complete composting process is required to address this problem. This will aid in the coordination of urban waste management with rural and peri-urban crop nutrient management.

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Waste Materials as Rejuvenator—A Review

Ritika and Praveen Aggarwal

Abstract Asphalt binder is used to build approximately 80% of roads worldwide in the form of flexible pavement. Many flexible pavements collapse due to surface distress such as potholes, rutting, alligator cracking, raveling, and so on, and a significant amount of maintenance work is required to address these pavement stresses. To reduce building costs, it is required to recycle asphalt pavement. The best method to preserve natural resources and minimize maintenance costs in the building industry is to use recycled asphalt pavement (RAP). However, from the literature review, it has been found that RAP is too stiff when compared to virgin binders, so different oils as a rejuvenator can be added to reduce the stiffness. Consequently, WCO (waste cooking oil) and WEO (waste engine oil) are used to improve the quality of old asphalt. This review paper included an overview of numerous studies on the WEO- and WCO-based rejuvenation of aged asphalt. It has been discovered that using WEO and WCO to rejuvenate asphalt has both positive and negative effects and the WCO produces superior results than the WEO.

Keywords Recycled asphalt pavement (RAP) · Waste engine oil (WEO) · Waste cooking oil (WCO)

1 Introduction

1.1 Background

The pavements are divided into two groups, such as flexible and rigid pavements, based on their structural behavior. Flexible pavement is that which generally has low or negligible flexural strength, and these layers reflect the bottom layer's deformation onto the layer's interface, stiff pavement is that which has notable flexural strength or flexural rigidity, and these layers have slab action that can transmit the load stresses

Ritika (✉) · P. Aggarwal
Department of Civil Engineering, National Institute of Technology, Kurukshetra 136118, India
e-mail: kambojritika.43@gmail.com

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_5

through a wider area below. Flexible pavement is preferred to rigid pavement for several reasons, such as its adaptability to be strengthened and enhanced as traffic volume increases and its lower initial and ongoing maintenance costs. The flexible pavement is made up of base and sub-base courses beneath the surface course of bituminous material. The bituminous substance is usually asphalt, whose viscous nature allows for significant plastic deformation. Depending on the temperature at which it is poured, asphalt can be categorized as hot mix asphalt (HMA), warm mix asphalt, or cold mix asphalt and it is used to construct about 80% of the world's highways. Due to numerous inherent issues such as potholes, depression, edge cracks, and raveling, many asphalt pavements deteriorate before reaching the desired life. Asphalt waste has been produced due to pavement material degradation, making land filling more challenging. By consuming less virgin asphalt binder, aggregates, and fuels; lowering carbon emissions, and using recycled asphalt material reduce the consumption of non-renewable resources. Reclaimed asphalt pavement, or RAP, is a term used by the Federal Highway Administration to describe asphalt that has been previously used but has been cracked, fractured, or aged. After being fully crushed and screened, RAP is formed of premium, well-graded aggregates that have been coated in the asphalt mix. It is used to create flexible pavement to promote sustainable growth with positive economic and environmental effects.

Recent technological advancements have resulted in the depletion of natural resources, and numerous strategies for the exploitation of solid waste have been adopted. Recent price rises for asphalt surface materials have paved the path for finding cheaper alternatives, such as using recycled asphalt, which also reduces solid waste. Utilizing recycled materials can also cut down on carbon emissions during road building and adding recycled asphalt as an ingredient to hot mix asphalt (HMA) has both financial and environmental advantages.

The different chemical elements that makeup bitumen are divided into four groups: resins, aromatics, saturates, and asphaltenes. The first three groups are frequently referred to as maltenes. Aging causes the polar resins to oxidize, which causes the asphaltenes fraction to rise while the maltenes fraction falls. As asphalt ages, the asphaltenes component increases while the maltenes component decreases, making asphalt binder harder. The quantity of asphaltenes in aged asphalt is reduced using a variety of methods, such as recycling agents, also referred to as rejuvenators. These are frequently added to the RAP to equalize the ratio of maltene to asphaltene in old asphalt, making it more elastic and capable of spreading oil while increasing adhesion.

The two categories of recycling agents are rejuvenators and softeners. The rejuvenators are further divided into oil- and petroleum-based rejuvenators. Recycling agents that are dependent on RAP content are used to minimize fatigue and intermediate temperature cracking. Waste and commercial recycling agents are the two main types of recycling agents. Waste cooking oil (WCO), waste engine oil (WEO), and other types of waste recycling agents are available commercially, along with various commercial rejuvenators such as Pongamia oil and tall oil. In this review paper, we discuss the waste recycling agent which is waste engine oil and waste cooking oil.

When choosing a rejuvenator, price is the main factor to consider. Upcoming sections briefly discuss these recycling agents.

1.2 WEO (Waste Engine Oil)

Engine oil also referred to as vehicle oil keeps internal combustion engines cool while they are running and lubricates their moving parts. The recycling of WEO into new engine oil is challenging when an engine is running continuously because the oil's performance deteriorates over time. Burning WEO will result in contaminants that can damage people's health and enter their lungs. Numerous studies suggest that using WEO from automobiles could enhance the effectiveness of asphalt [4]. Compared to fresh oil, WEO has different chemical and physical characteristics. In terms of fresh EO, it mostly consists of additives, gasoline, and high levels of heavy metals such as Cd, Fe, Pb, and Cr as well as Zn and Mg. These metals pollute the soil and groundwater when they are discharged onto land. WEO is composed of several chemical compounds having molecular mass under 200 g/mol. Paraffin oil, polyolefin oil, and aromatic solvents, which are like asphalt aromatics, represent the majority of WEO's chemical components [7] (Table 1).

1.3 WCO (Waste Cooking Oil)

It is gathered from eateries, food producers, and stores that sell disposable items, and recycling facilities. It is also referred to as used cooking oil (UCO), non-edible oil, or waste oil (WEO). A small amount of waste cooking oil is appropriately collected and

Table 1 The chemical compound in WEO [7]

S. no.	Formula	Molecular mass
1	C_9H_{12}	120.192
2	C_9H_{12}	120.192
3	$C_{10}H_{16}O$ $C_{10}H_{14}$	152.233 134.218
4	$C_{10}H_{16}O$ $C_{10}H_{14}$	152.233 134.218
5	$C_{10}H_{14}$	134.218
6	$C_{10}H_{12}$	132.202
7	$C_{12}H_{12}O_2$ $C_{12}H_{11}NO$	182.222 185.222
8	$C_{11}H_{14}$	146.229
9	$C_{11}H_{10}$	142.197

Table 2 Chemical composition of WEO [2]

Fatty acid	WCO
Lauric acid	0.34
Myristic acid	1.03
Palmitic acid	38.35
Stearic acid	4.33
Oleic acid	43.67
Linoleic acid	11.39
c-Linolenic acid	0.37
Linolenic acid	0.29
Cis-11-eicosenoicacid	0.16
Heneicosanoic acid	0.08
Total	100

recycled. A large amount of waste cooking oil is deliberately thrown into dumping sites and waterways, resulting in pollution. Controlling waste cooking oil is a major problem. WCO has lighter oil that is like asphalt, employing it as a rejuvenator is an environmentally beneficial alternative. Research also shows that WCO has greater potential for usage as a rejuvenator [1]. The chemical properties of filtered waste cooking oil are the basic ingredients that determine the behavior of regenerated bitumen. Gas chromatography-mass spectrometry (GCMS) was therefore utilized by the Combinatorial and Catalysis Research Centre (COMBICAT) to assess the chemical composition of spent cooking oil. Consequently, the chemical test results, a common occurrence of chemical constituents in this waste cooking oil were palmitic acid, oleic, and linoleic acid [2] (Table 2).

1.4 Objective

This study intends to evaluate prior research on adding WEO and WCO as a recycling agent to used asphalt in order to ascertain which one is more efficient. In order to lessen WCO environmental issues and WEO harm to human health, respectively, this article examines the feasibility of recycling WEO and the possibilities for employing WCO as a recycling agent for aged bitumen binders. The study summarizes the effects of WEO and WCO on the physical, rheological, and micro-structural characteristics of aged asphalt. The summary was expanded in order to identify which of the two rejuvenators is more efficient.

2 Assessment of Rejuvenated Asphalt Properties

2.1 Fundamental Properties of Aging Asphalt Rejuvenated by WEO and WCO

The penetration test (ASTM D5), softening point test (ASTM D36), and ductility test (ASTM D113), as well as other physical characteristics of asphalt binder, are being investigated in this portion.

Consistency is determined by the penetration test, i.e., lower penetration indicates stiffer consistency. Penetration value is the vertical distance traveled or penetrated by the point of a standard needle into the bituminous material in one-tenth of a millimeter under a particular load of 100 g for five seconds at 25 °C. The amount of viscosity in a bituminous substance determines the distance that a needle may move. As a result, viscous bitumen substance has a lower penetration value.

The softening point is used to indicate a material's ability to flow at high temperatures. The softening point of bitumen is the temperature at which the material softens to a specific degree. According to IS1205-1978, it is the temperature at °C at which a standard ball passes through a bitumen sample in a mold and falls through a height of 2.5 cm when heated under water or glycerin at defined test conditions. The temperature of the bath is raised by 5 °C every minute. Before being used on roads, the binder needs to be sufficiently fluid. By using a ring and ball apparatus, the softening point may be calculated.

Bitumen's ductility is its ability to extend under traffic pressure without cracking during road building. When a standard briquette sample of the material is split at a specific speed and temperature, the length in cm that it elongates before breaking is used to determine the ductility of the material. A solution of dextrin and glycerin is applied in equal parts to the surface of the brass plate and the internal sides of the briquette mold to prevent the bituminous material from adhering to the surface. The water bath is used to keep the temperature at 27 °C. The sample is pulled until it ruptures at 50 mm per minute. The ductility value is the distance in centimeters to the breaking point. It is generally known that these properties decrease during the life of an asphalt binder.

The effectiveness of using WCO and WEO as rejuvenators with optimal percentages of 3–4% and 5–6% results in a gain in penetration value because the asphaltenes-to-maltenes ratio reduces and the softening value is reduced when compared to virgin binders [3].

As the WCO content increases, penetration increased linearly, resulting in a decrease in aromatic components and an increase in maltene components, while the softening point decreases as the amount of WCO increases, generating a low-temperature susceptibility by adding different Aged Bitumen (AB) such as AB30/40, AB40/50, and AB50/60 [2].

With increases in the proportion of WEO (0–8%), ductility and penetration values rise but the softening point values fall. Asphalt binder with WEO has superior thermal deformation ability because of increased ductility and decreased resistance due to increased penetration value. However, WEO has a better softening effect due to a decrease in softening point. It demonstrates that the asphalt binder containing WEO has a superior capacity for deformation at low temperatures by comparing with Bitumen having penetration grade (PG) of 60/70 and styrene–butadiene–styrene copolymer-modified asphalt (PMB-A) [7].

The penetration value of 5 h aged asphalt with 1% WEO and 1% WCO recovered up to 96.8 and 102.9% as compared to virgin asphalt. It resulted in WCO having more efficiency which must be compared to WEO since it made aged asphalt softer than WEO. The recovery of the 5 h aged asphalt's softening point value with 1% WEO and 1% WCO was up to 93.8% and 90.7%, respectively. It demonstrated that the WCO has a lower softening effect than WEO. The ductility value at 10 °C of 5 h aged asphalt with 1% WCO and 3% WEO was found to be comparable to that of fresh asphalt as shown in Fig. 1. The optimum amount of WEO and WCO results in enhancing the low-temperature performance [5].

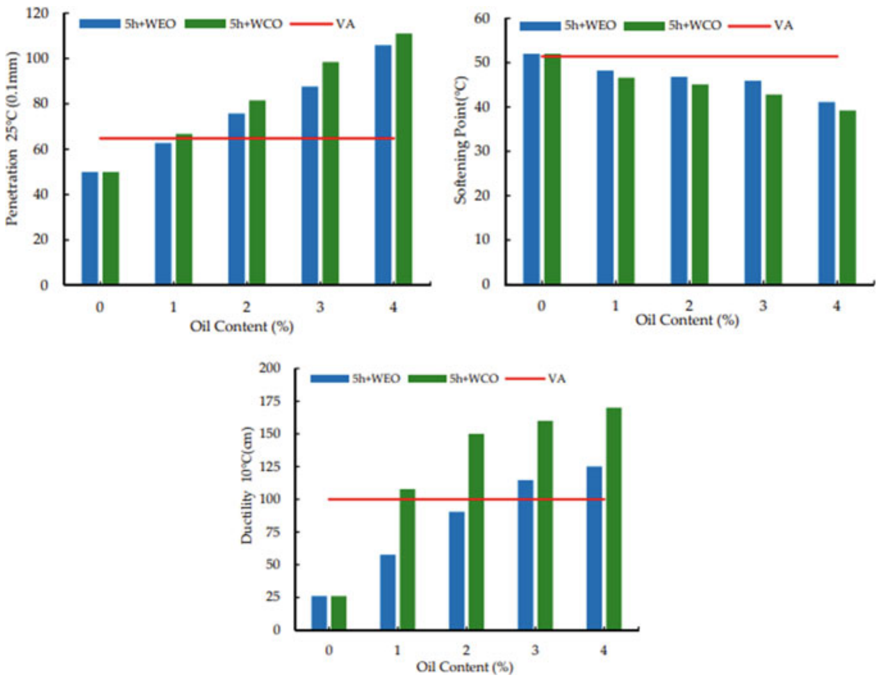


Fig. 1 Asphalt with WEO and WCO at 5 h aging time [5]

2.2 Rheological Characteristics of Rejuvenated Asphalt

This section discusses the viscosity and the effectiveness of the bitumen binder at different test temperatures for WEO- and WCO-rejuvenated asphalt. The bending beam rheometer (BBR) test is used to determine the cracking resistance at low temperatures (ASTM D6648), the dynamic shear rheometer (DSR) test (ASTM D7175) is used to measure the fatigue at intermediate temperatures and rutting resistance at high temperatures, and the bending beam rheometer (BBR) test is used to determine the cracking resistance at low temperatures (ASTM D6648). The parameters G*·Sinδ and G*/Sinδ, respectively, control the fatigue and rutting resistance. In general, asphalt performs poorly in terms of elastic recovery when its phase angle is greater. As a result of having a larger complex modulus and a smaller phase angle, asphalt with a higher G*/sin value has superior rutting resistance [7].

When the quantity of WEO increases, the G*/Sinδ and G*·Sinδ decrease, and the temperature rises. It has been observed that 4% WEO reduced the resistance to rutting by 30–40% and 8% WEO reduced the resistance to rutting by 60–70% for all the asphalt binder samples as shown in Fig. 2. Although the addition of WEO significantly affects asphalt rutting resistance, it may improve asphalt fatigue cracking resistance [7].

With the addition of 4% WCO to the aged bitumen, the viscosity is brought to a level with the original bitumen. The phase angle rises as the temperature falls, as shown in Fig. 2. Therefore, it can be stated that the rejuvenated bitumen has the same viscosity as the original binder and that the binder should only have a viscous character because of the 90° phase angle that was reached at 65°. When 3% WCO is added, the complex modulus remains the same as that of the original binder as shown in Fig. 3 [2].

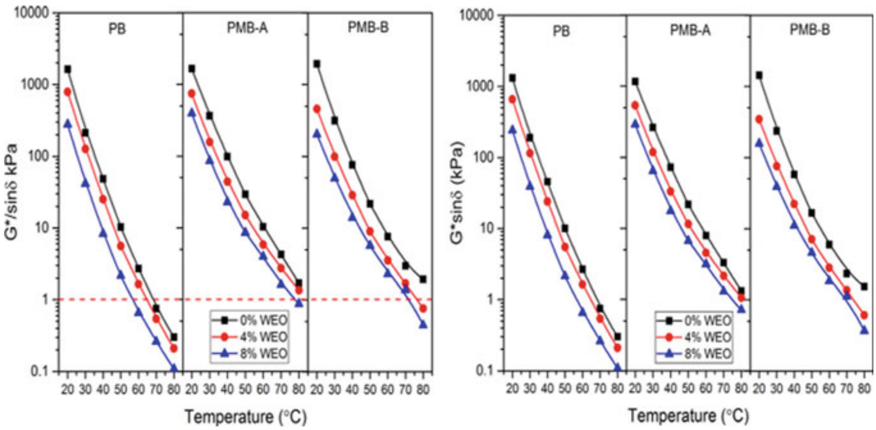


Fig. 2 Rutting and fatigue resistance of asphalt binders [7]

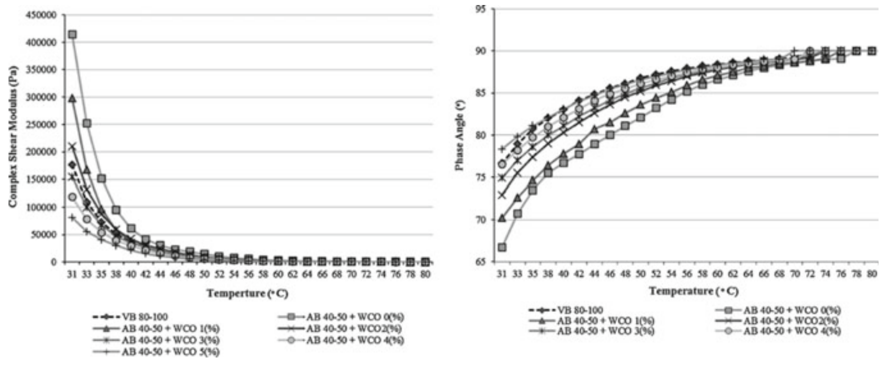


Fig. 3 A plot between complex shear modulus and phase angle with temperature for different rejuvenated WCO [2]

With the addition of 3–4% WCO, the value of the rutting parameter (G*/Sinδ) would be the same as the original bitumen, and it also showed a lower value of the fatigue parameter (G*·Sinδ), which meant having greater fatigue cracking resistance as shown in Fig. 4. However, adding 5.5% WEO reduced the rutting parameter's value below that of the original binder, making it more susceptible to rutting and only suitable for low traffic volumes. It had been determined that WEO was less resistant to rutting and fatigue than WCO [3].

The amount of WEO and WCO (i.e., 0–4%) increases while the viscosity of aged bitumen falls. It proved that the frictional resistance would be enhanced by the WCO and WEO as represented in Fig. 5. However, if the viscosity of old asphalt is too high, it causes segregation, which negatively affects the performance of the asphalt, and if the viscosity is extremely low, it causes the asphalt to be liable to permanent deformation, so the viscosity is appropriate for which the quantity of oil should be sufficient. With an increase in temperature, adding enough WEO and WCO (i.e., 1–4%) caused the rutting parameter to drop as shown in Fig. 6. However, it also showed that WEO and WCO both recovered the performance of asphalt, though the WCO produced the same results with less content [5].

2.3 *Micro-structural Properties of Rejuvenated Asphalt*

The micro-structural characteristics of asphalt binder are determined using a Fourier transform infrared spectrometer (FTIR). FTIR is the only analytical approach that directly monitors the vibrations of the functional groups that characterize molecule structure at the same time [1]. It is commonly used for qualitative and quantitative investigations of organic materials. The FTIR analyzes the organic group of virgin binder, aged binder, and rejuvenated asphalt binder in order to evaluate the micro-structural characteristics of rejuvenated asphalt [6].

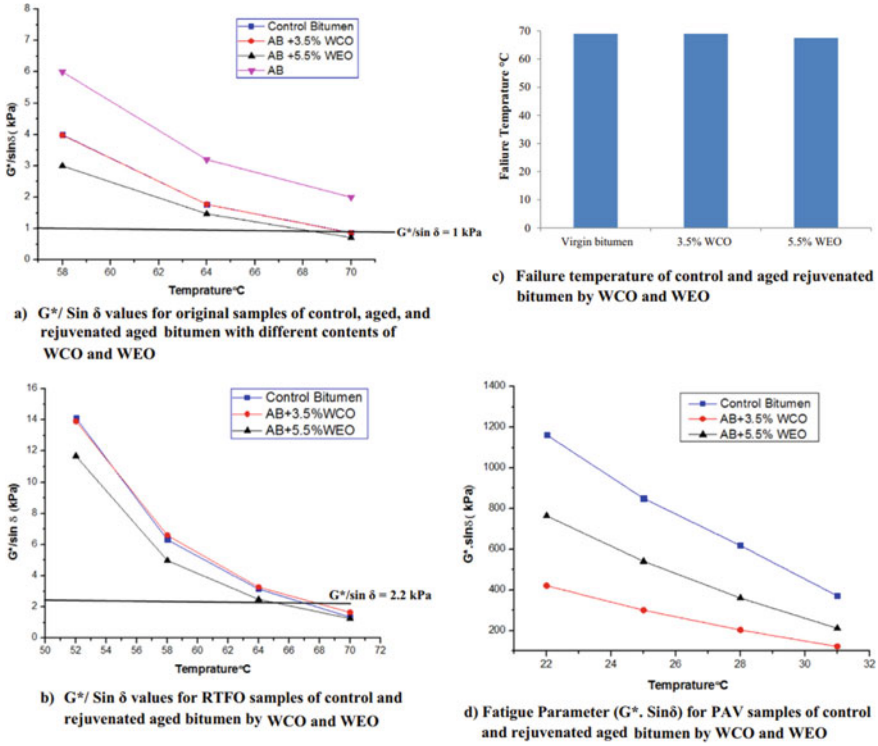
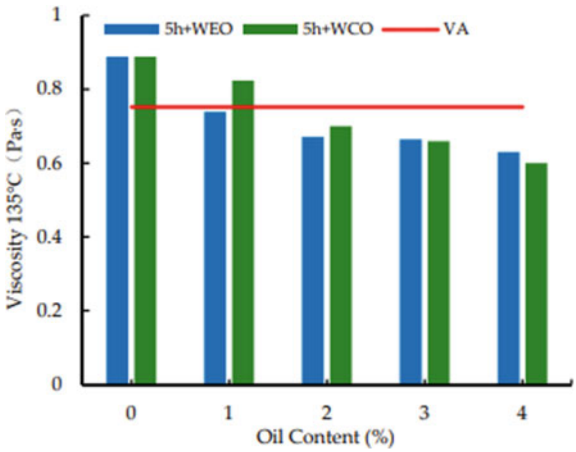


Fig. 4 DSR results of WCO and WEO [3]

Fig. 5 Rejuvenated asphalt after 5 h aging time of VA [5]



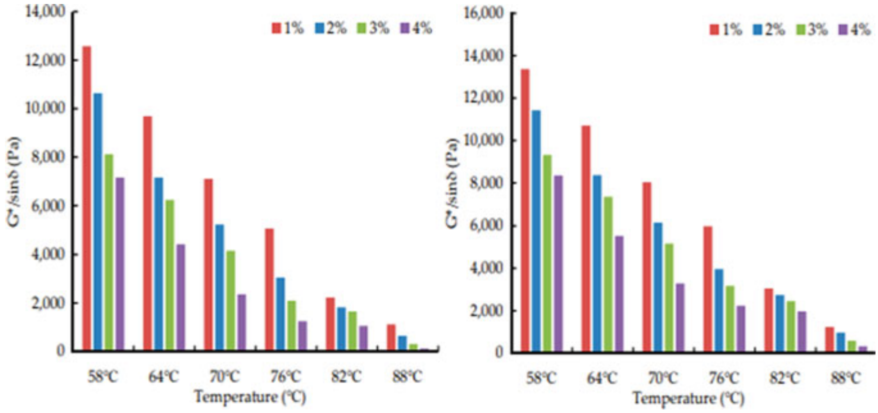


Fig. 6 Influences of WCO and WEO on rutting resistance factor of rejuvenated asphalt (5 h aging time of VA) [5]

FTIR analysis of the control and aged bitumen as well as the FTIR results of the rejuvenated aged bitumen by both WCO and WEO as shown in Fig. 7. After WEO and WCO were added, the C=C bond in the aged asphalt decreased, potentially lowering the amount of asphaltenes. However, the naphthene aromatic content and carbonyl or ester were increased by both the recycled bitumen, resulting in an increase in maltenes content as shown in Table 3. As a result, the ratio of maltenes to asphaltenes decreases in recycled asphalt but does not regain its original value [3].

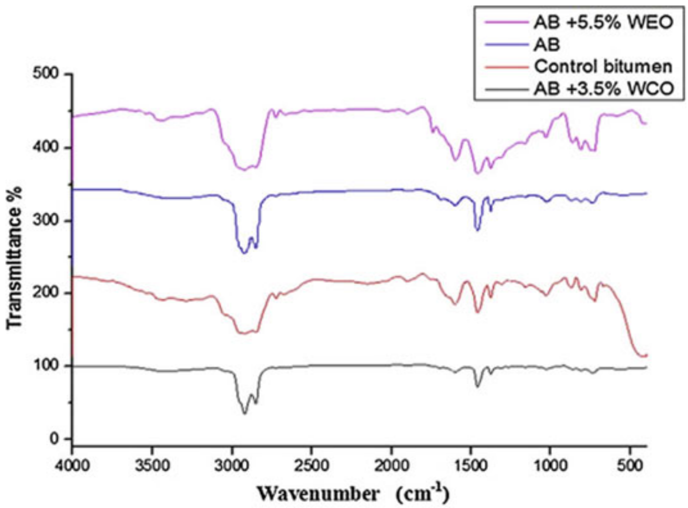


Fig. 7 FTIR analysis of control, aged bitumen, and rejuvenated aged bitumen by WEO and WCO [3]

Table 3 FTIR compounds and functional groups [3]

Control bitumen		Aged bitumen (AB)		AB + 3.5% WCO		AB + 5.5% WCO	
Wave length (cm^{-1})	Functional group	Wave length (cm^{-1})	Functional group	Wave length (cm^{-1})	Functional group	Wave length (cm^{-1})	Functional group
3291 broad	–OH	3384	–OH	3432 broad	–OH	3349	–OH stretching
2923	CH–alkane stretching	2924	CH–alkane stretching	2923	CH–alkane stretching	2924	CH–alkane stretching
1732	C=O	2852	CH–alkane stretching	2852	CH–alkane stretching	1744	C=O
1663	C=O	1688	C=O	1705	C=O	1600	C=C
1604	C=C	1603	C=C	1600	C=C	1460	C=H Bending
1459	C–H bending	1456	C–H bending	1459	C–H bending	1376	–OH blending
1376	OH blending	1376	–OH blending	1376	–OH blending	1301	C–O
1030	C–O	1027	C–O	1029	C–O	–	–

The determination of the FTIR spectra for the matrix asphalt and aged asphalt binder using 4 and 8% WEO as rejuvenators. There is no change in the qualitative analysis of the matrix asphalt and the rejuvenated asphalt. Consequently, the matrix asphalt and the rejuvenated asphalt have the same functional group. This demonstrates that the WEO's functional group and micro-structural characteristics are comparable to those of an original binder [7].

3 Conclusion

According to the above-reviewed literature, it can be inferred that adding enough WEO and WCO causes the ductility and penetration value to increase, and the softening point value to drop, and in addition, it demonstrates that when the temperature rises, the fatigue ($G^*\cdot Sin\delta$) and rutting parameter ($G^*/Sin\delta$) decrease. It also demonstrated that lesser WCO quantity is needed than WEO to get comparable results. Additionally, it demonstrates that WEOs have lower fatigue and rutting resistance than WCOs because WEOs are more susceptible to rutting. The amount of oil and the proportion of old asphalt in the mix affect the characteristics of WEO and WCO. In general, WCO or WEO was a suitable rejuvenating agent to enhance the performance of aged asphalt. In the field of recycling asphalt pavement, it offered a unique application technique for WEO or WCO that accomplished waste recycling and environmental protection.

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Treatment of Water Using Natural Fibres

Ankita and Dharmendra

Abstract The environment's top priority is wastewater treatment. Wastewater is treated using a variety of techniques. Membrane separation, chemical precipitation, disinfection, coagulation, ion exchange, adsorption, solvent extraction, electrolysis and chemical oxidation are the techniques we can use to obtain water that is free of contaminants [1]. In addition to the prices and hard currency, there are other factors that affect how much it will cost to receive the desired level of therapy. Numerous chemicals are also linked to issues with human health and the environment. If they are readily available locally, natural materials can greatly lower the cost of treatment while minimising or avoiding the issues. Utilising natural materials lessens the demand for new resources for their processing. Pine needles, pine cones, straw, reed, *M. oleifera*, *Strychnos potatorum* and Moringa seeds [2] are examples of natural fibres that can be utilised for the treatment. Utilising natural resources will contribute to lessening chemical usage as well as sustainable growth.

Keywords Water treatment · Natural fibre · Sustainability

1 Introduction

Water is the second most important thing to support life on the planet. Around 1.3 billion people are still deprived of safe drinking water. Increasing population and unplanned urbanisation have sharply led us to the pollution and poor human health. Water coming from rivers, ponds and lakes and even water from groundwater requires treatment before human consumption. Various metals and toxic substances are present in water which is unfit for drinking. Safe drinking water is the human right

Ankita (✉) · Dharmendra
Department of Civil Engineering, National Institute of Technology Hamirpur, Hamirpur 177005, India
e-mail: 21mce403@nith.ac.in

Dharmendra
e-mail: djha@nith.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_6

but the metals which are found in drinking water are becoming the major environmental problem. The conventional method of treatment depends on the type of pollution and the extent of pollution. These treatments should be economically friendly. Conventional methods of purification require chemicals which is not meeting the environmental standards. In the disinfection process of water treatment where chlorine is used, the presence of free chlorine found to react with natural organic matter (NOM). This very particular reaction produces Disinfection By-products (DBP) trihalomethanes, haloacetics and other halogens causes cancer and miscarriages. Moreover, usages of chemical will never lead to a sustainable future, so there is huge need of natural materials soon for treatment of water and leading a sustainable life.

Natural raw materials will not only reduce the treatment cost but also save the country's money for importing chemicals. The coal-based activated carbon will soon be exhausted from the earth, so we need an alternative of that. Various natural substances are there which are capable of producing activated carbon by following standard procedures of its preparation. Coconut shells which acidly activated can act as adsorbents for organic matter. Pine cone extract is used as coagulant for removal of turbid water. Activated carbon produced from pine cones is capable of removal of nitrates, copper and zinc. Activated carbon prepared from pine needles are also capable of removal of nickel and cadmium. Pine needles can also be used as check dams in the rivers during floods. *Moringa oleifera*, Cactus Mucilage and Chitosan can be used for the treatment of turbid water. *Moringa oleifera* and *Strychnos potatorum* contain natural polyelectrolytes which can be used as coagulant to clarify turbid water. Natural raw material studied and which can be used for the treatment of wastewater are as follows.

2 Pine Needles

Pine needles are found in abundance in Himalayan region especially in the states of Himachal Pradesh and Uttarakhand. The Botanical name of Pine Needles is Pinus roxburghii Sarg and is commonly known as Chir Pine [1, 3]. Usage of pine needles in treatment of water will reduce forest fire which happens every summer. Trees are mostly composed of cellulose which burns readily, Pine trees have elongated leaves which have large surface area to their mass which allows them to burn easily. Pine trees have flammable resins which allows them to burn even more easily. Since pine needles are often found in Himalayan Region, when they start burning on the hilly areas fire catches naturally and sometimes spectacularly spreads upwards. The needles which usually accumulate over soil cause the pathway slippery and reduce the soil moisture capacity of it [4]. Collection of pine needles for treatment of water will provide employment in these regions. Pine needles have great adsorption capacity for the various chemicals coming from the industries and domestic wastes. Crushed pine needles of various mesh sizes have the capability of absorbing calcium up to 65% [5]. Reduction in calcium can reduce the incidence of kidney stones, a serious

Fig. 1 Check dams of pine needles [5]

health concern among the Himalayan Villages. Check Dams of Pine Needles across polluted stream during low flow, high flow and during storms (Fig. 1).

The check dams will reduce organic matter which will subsequently decrease the microbial loading and biochemical oxygen demand in the downstream. The chemical oxygen demand will also get reduced due to the adsorption of calcium, boron and sodium. The activated carbon prepared from the pine needles can reduce the biochemical oxygen demand, chemical oxygen demand and total dissolved solids. These check dams when placed in seasonal streams conserved soil and moisture by decreasing the speed of runoff [6]. The increased moisture regime around the check dam area helped in preventing occurrence and spread of forest fires [5]. Activated carbon prepared from crushed pine needles is to be used to evaluate its potential to eliminate some toxic metals such as cadmium and nickel. The activated carbon was prepared after washing, drying and crushing the pine needles. The crushed pine needles had gone through the carbonisation process and followed by activation. For the chemical activation, biomass was impregnated with different compounds like KOH, $ZnCl_2$, etc. The activated carbon prepared from the crushed pine needles has great adsorbent capacity used for the treatment and removal of heavy metals from the industrial wastes. The purpose of the study is to find characterisation of activated carbon produced from crushed pine needles to evaluate the removal of Cd and Ni. The choosing of pH to be adopted in the study was based on the metal hydroxide solubility in solution. Cadmium and nickel both become insoluble in water at the pH above 8. Thus, the testing was limited to the pH 8. The array of tests was performed at different pH listing 5, 6, 7 and 8 and concentrations of cadmium were

1 and 5 mg/L. The nickel concentrations were 2 and 6 mg/L. The capacity of a newly prepared activated carbon to adsorb Cd and Ni was tested under various operating conditions. pH of solution proved to have a major impact on the adsorption capacity of the AC. In general, it was observed that an increase in solution pH led to an improvement in the removal capacity of the AC. The initial concentration of heavy metals had a clear effect on the adsorption capacity of the AC for metals. In batch experiments, higher concentrations always resulted in higher removal and higher adsorption capacity. In column testing, high concentrations (40–50 mg/L) overwhelmed the capacity of the AC for removal and resulted in lower adsorption capacities. In fixed columns, Cd was better removed at the lower concentrations (5 mg/L), while Ni removal was almost stable in the lower and middle ranges, and dropped significantly when the initial concentration was at the maximum value of 40 mg/L. For Cd, the highest capacity in column testing reached 17.54 mg/g, and a much higher removal capacity was obtained in batch experiments, reaching 43.47 mg/g. The highest Ni capacity in column testing was 20.85 mg/g, while a much higher removal capacity of 87.03 mg/g was reached in batch experiments [7].

3 Pinecones

Activated carbon prepared from pine cones will reduce its littering in the forest and will help in removal of zinc oxides coming out of the industries. Here, pine cones of Turkey named as Pine Cones Turkish Pines are used for the study. Different contact times like 20, 40, 60, 80, 100, 120, 140, 160 and 180 min were considered with the 3 g of adsorbent dosages at different pHs. 50 mL of wastewater in conical flask was closed and rotated at 250 rpm in rotary shaker. The percentage of zinc removal drastically decreased from 96 to 57% with the increase in the zinc concentration from 5 to 35 mg/L. The best efficiency of zinc removal was at pH 7 with 96% [6].

Powdered form of pine cones can be used to remove copper (II) from the industrial wastes. Pine cones in powdered form cannot be used directly for the usage, so there is a modification required to enhance the properties. Because usage of raw agricultural waste directly has some limitations such as it will increase the chemical oxygen demand, biochemical oxygen demand and total organic carbon. This happens because plant materials releases soluble organic compounds. Dilute NaOH is capable of solubilising a small portion of the soluble organics and lignin present in plant materials. After performing batch study on the biosorption of copper (II) from aqueous solution with several parameters such as pH, dosage of biosorbent and lastly temperature, we can conclude that the optimum pH was 5 and the biosorbent dosage was 8 mg/L for all samples. Increasing temperature will increase the biosorption [8].

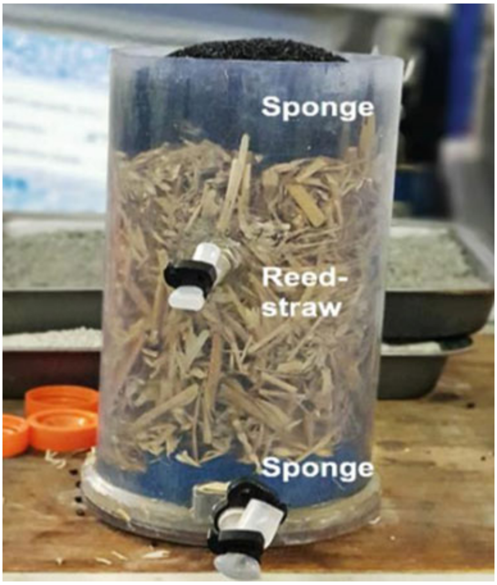

Fig. 2 Straw and reed filtration system [9]

4 Straw and Reed

Presence of iron in potable water is also a critical issue. Removal of iron from water is an expensive process which can be achieved through chemical precipitation and reverse osmosis. Agricultural waste like straw and reed can be used for the removal of iron to some extent. Straw and reed are used in the ratio of 1:1 of mass. A filtration system is established for this purpose (Fig. 2).

An artificial iron solution is produced of 10 mg/L by dissolving suitable amount of iron sulphates in deionised water. This artificial solution was treated with natural filtration system for the different retention times and different pHs of solution. The time ranging was 10–90 min and pH ranges from 4 to 9. After the entire test has been performed, it was calculated that 33.1% of iron was removed from the solution at the pH of 7 and the retention time was 80 min. So, there is positive result through the application of natural filtration which is most importantly sustainable. There is one drawback in this method is that it imparts colour after the filtration which can be removed further with suitable techniques [9].

5 Strychnos Potatorum and Moringa Oleifera

The seeds of Strychnos potatorum and Moringa oleifera contain certain elements which act as polyelectrolytes which can be used to treat turbid water [10]. Natural polyelectrolytes originated from the plants are used for many centuries to treat water in developing countries. These natural fibres can be used as homemade water filtration system [11]. Strychnos potatorum is often found in central and southern India. Moringa Oleifera is a widely found plant. In some of the villages of Maharashtra and Tamil Nadu, Strychnos potatorum is used to treat turbid water. Women of Sudan uses Moringa Oleifera for the homemade water treatment system. Seeds of Strychnos potatorum were dried and made in powdered form and were sieved through 150 mm sieve and a suspension of 2% was prepared with distilled water. Kernels of Moringa Oleifera were also dried and converted into powdered form and thoroughly pounded in a mortar to produce a pasty powder and 2% of suspension was produced. During the lab tests the direct filtration of raw water with characteristics are 15–25 NTU, heterotrophic bacteria 280–500 CFU/mL and faecal coliforms 280–500 MPN 100/mL was conducted. The seeds of Strychnos potatorum and Moringa oleifera were used as coagulant which subsequently produce an improved quality of water with new characteristics such as 0.3–1.5 NTU, heterotrophic bacteria 5–20 CFU/mL and faecal coliforms 5–10 MPN 100/mL. These natural coagulants certainly do not remove the entire coliform bacteria but reduce a low risk level. Additional boiling and other disinfection processes can be adopted to have safe drinking water [12].

6 Conclusion

Natural fibres are cheap and easily available around the world. Moreover, it will lead to a sustainable world. Pine needles and pine cones are found in abundance around the Himalayan Regions. They will help to treat the waste water as well as industrial wastes. They can be used as adsorbents and activated carbon produced from them has great adsorbent capacity. Straw and reed can be used as filtration system in which content of iron can be reduced. This usage will also help in reducing agricultural wastes. Strychnos potatorum and Moringa oleifera can be used as natural coagulants. Therefore, more study in this field will reduce chemical loading in treatment of water and subsequently leading to a sustainable future.

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Utilization of Waste Transformer Oil for the Synthesis of Biodiesel and Glyptal

Richa Tiwari, Pratibha S. Agrawal, Pramod N. Belkhode, Deepika Brijpuriya, Amit Devase, and Prajwal Samarth

Abstract Transformers are the important electrical devices which are used for the transmission of electrical energy in power systems. Transformer oil which is also known as insulating oil provides insulation and cooling to power transformers. During operation it undergoes electrical and mechanical stresses which cause deterioration of the properties of the transformer oil and it is discarded as waste in large amounts. Waste transformer oil (WTO) containing toxic pollutants is hazardous to the environment and other living beings. To overcome this problem, it can be converted into a value-added product. The current study involves chemical treatment of WTO by a well-known alkaline transesterification process. In this process, methanol/butanol is used as an alcohol with KOH and the reaction temperature is maintained at 65 °C for 1 h. After the process biodiesel and glycerol are formed. Further the esterification of WTO is also conducted using sulfuric acid with methanol/butanol and the properties such as specific gravity, kinematic viscosity, and flash point are measured for the comparative study of fuel characteristics of the obtained biodiesel and it was found that the biodiesel TW2B7 has reduced viscosity, Biodiesel TW1B4 shows much improved flash point. The obtained crude glycerol is utilized to produce valuable product glyptal (cross-linked polyester) which is a binding material and also insulating enamel which is used for making paints. The esterification reaction between obtained glycerol and phthalic anhydride in the presence of a catalyst is carried out in a lab-scale batch reactor followed by a sand bath at high temperature. Different proportions of glycerol and phthalic anhydride are used in the preparation of glyptal and the percentage yield was calculated. Thus this paper aims to obtain a biodiesel from WTO and utilize the produced by-product crude glycerol into an alkyd resin.

R. Tiwari (✉)
Department of Chemistry, R. T. M. Nagpur University, Nagpur 440033, India
e-mail: rinz1413@gmail.com

P. S. Agrawal · D. Brijpuriya · A. Devase · P. Samarth
Department of Applied Chemistry, Laxminarayan Institute of Technology, R. T. M. Nagpur University, Nagpur 440033, India

P. N. Belkhode
Department of General Engineering, Laxminarayan Institute of Technology, R. T. M. Nagpur University, Nagpur 440033, India

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_7

Keywords Waste transformer oil · Biodiesel · Transesterification · Alkyd resin

1 Introduction

Nowadays many researchers are devoted to finding an alternative fuel for diesel engines which can replace dependence on conventional fuels as the world largely depends upon conventional fuel for transportation, generating power, etc. Hike in price every day and pollution in greater extent forced researchers to find an alternative, not only to find an alternative but to be efficient in work, economical to buy, and have less polluting factors. India is spending billions of dollars of foreign currency in buying petroleum fuel; this made India to be dependent on fuel on foreign countries like Saudi Arabia, Russia, etc. Middle East countries have more amounts of petroleum fuel and make huge amounts of money by selling it. To overcome the fuel crisis biofuels are the attractive choices as these can be generated from the waste raw materials which can also solve the environmental issues caused by the disposal of waste [14]. Biofuels like biodiesel, biogas, and bioethanol are produced by the biological and chemical conversion of waste raw material which is frequently available. The generation of biofuels is increasing worldwide and in the forthcoming years it will grow due to the fuel crisis. Among the biofuels, biodiesel gains much importance as it is non-toxic, safe, biodegradable in nature, and renewable as compared to conventional fuel [15]. Generally, it is fatty acid methyl esters which are produced by the reaction between oil and alcohol in the presence of a catalyst from the feedstocks such as kitchen wastes, microalgae, energy crops, insects, and animal fats. However, utilizing waste oils in the production of biodiesel is feasible as it decreases the cost of feedstock and makes it economical [9]. Many scientists convert waste oils like waste vegetable oil, waste cooking oil, waste engine oil, waste motor oil, etc. into biodiesel by adopting different methods. Among them waste transformer oil is the waste oil that is generated after the degradation of properties of transformer oil. Transformer oil is one of the insulating oils which is used in power transformers for cooling and insulation [18].

When transformers are in operation, the oil undergoes mechanical and electrical stresses due to which its physical and chemical properties are degraded with time and then it is discarded as waste and termed as waste transformer oil. Transformer oil is generally made up of mineral oil with additives to enhance its properties and hence it has poor biodegradability. It contains many toxic pollutants like polychlorinated biphenyls which contaminate the oil through transformers since in old transformers polychlorinated biphenyls are used due to their high-temperature-resistant properties but due to its hazardous nature its use is banned by the government [6]. Waste transformer oil also contains polycyclic aromatic hydrocarbons, heavy metals, etc. Heavy metals contaminate the transformer oil when the oil comes into contact with different parts of the transformer. When WTO disposed of these toxic pollutants contaminate the waterways and soil and cause negative effects on the environment, humans, and other living beings. Thus, by recycling and reusing them, we may decrease the environmental issues caused by their open land disposal. Therefore, waste transformer oil can be converted into a more useful product after treatment and it is also found from previous literature that WTO has properties similar to diesel fuel [19].

Nabi et al. [12] in their experiments suggested that after degradation of the properties of the transformer oil the waste transformer oil contains some acidic character and therefore it can be converted into biodiesel by transesterification of waste transformer oil with methanol as an alcohol and in the presence of a catalyst NaOH. He then characterizes the biodiesel obtained and formed different blends of biodiesel with diesel fuel with quantities of WTO 20, 15, and 10% and tested in a four-stroke DI diesel engine and concluded that the properties of biodiesel are similar to those of diesel fuel and it can be used as an alternative fuel for DI diesel engine. In his experiment, he concluded that the viscosity of WTO is approximately 9.9 (cSt) which is higher than diesel fuel and after treatment the viscosity decreases. Flash point and fire point of WTO were also higher which after treatment reduced to some extent.

Nasrat et al. [13] conducted an experiment on waste transformer oil using activated bentonite as a catalyst to improve its properties that increases its life. After treatment, the refined WTO has decreased water content, reduced acidity, and improved flash point and breakdown voltage, however it was not tested as a fuel in any engine. Qasim et al. [17] transesterified waste transformer oil and waste canola oil and then took the mixture of both the transesterified oils with petroleum diesel. The transesterification process for both the waste oils is carried out in the presence of NaOH with methanol and after the reaction is completed it is separated out using a separating funnel. The biodiesel obtained is then washed with deionized water which is then dried by using Na_2SO_4 and then blended with diesel fuel. The properties of these blends were checked and it was found that the properties of the blends such as kinematic viscosity, flash point, density, water content, and acid value were improved and can be tested in single-cylinder four-stroke DI diesel engine. Ajay et al. [1] transesterified waste transformer oil using alcohol approximately at 99.8 °C and blended with diesel fuel and tested the properties of blended fuel in IC (internal combustion) engine and did a comparative study and concluded that the blend B30 generates less CO (carbon monoxide), HC (hydrocarbon) emission, showed less smoke opacity, and produced maximum of CO_2 (carbon dioxide) at all loads. However, it showed constant NOx emission at all loads.

Further transesterification which is also known as alcoholysis process is the process by which oils and fats are converted into fatty acid methyl esters and glycerol in the presence of an alcohol and catalyst at a given temperature [20]. It is the equilibrium reaction in which the products are formed by the mixing of the reactants in the presence of strong catalyst either basic or acidic which accelerates the reaction. For the high yield alcohol should be used in excess amounts. Therefore by this process waste oils can be converted into biodiesel which are the methyl esters of oils and fats. The reaction is as shown in Fig. 1.

However, there are many studies in which the glycerol obtained during the transesterification process was used as a raw material for the production of alkyd resin. Due to the availability of feedstocks, durability, excellent adhesion, economical,

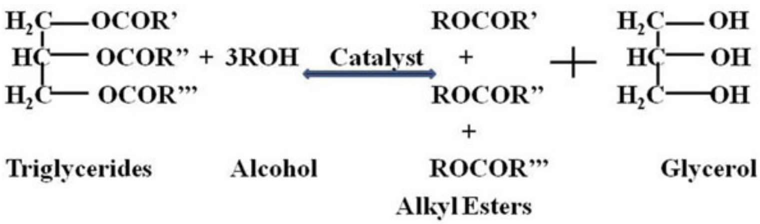

Fig. 1 Transesterification reaction of oils [2]

biodegradability, ease of application, and flexibility of alkyd resins receive more importance. These are special class of polyesters which are synthesized by the polycondensation reaction between acid anhydrides or dibasic acids, fatty oils or acids and polyols [4].

Miran et al. [11] in their experiment transesterified sunflower oil to obtain glycerol. The reactants used for the preparation of alkyd resin were phthalic anhydride, residual glycerol, sunflower oil, and lithium hydroxide (as a catalyst). The experiment was carried out in a four neck 1000 mL RB flask which is equipped with a stirrer (500–800 rpm), nitrogen gas inlet, and thermometer and dean stark trap equipped with a water condenser. The produced alkyd resin then characterized by FTIR which indicates the presence of aromatic C=C and ester links, hence polymerization reaction occurs and suggests that 0.4:1 molar ratio of phthalic anhydride to oil gave highest yield of 84.1% alkyd resin. Similarly, other scientists have also prepared glyptal using glycerol [3]. Further another scientist [5] utilizes neem seeds to extract oil from it by Soxhlet method and then applied alcoholysis-polyesterification method using phthalic and maleic anhydride for the preparation of alkyd resin and after the analysis found that the resin synthesized using maleic anhydride showed better properties.

From the literature survey, it is estimated that there is not much work done making biodiesel from WTO and utilize its glycerol, and therefore the current study involves the treatment of waste transformer oils by transesterification method, analyzing the physical properties of different biodiesels obtained and utilizing the crude glycerol in the formation of alkyd resin (glyptal).

2 Experimental Setup and Procedure of Biodiesel Preparation

2.1 Materials and Method

The required raw material, i.e., waste transformer oil was collected from the local electricity department. Two types of waste transformer oil were collected: one is 10 years old which is designated as W1TO and the other one is 3 years old and designated as W2TO. Methanol and butanol of purity (99.9%) were used for the transesterification reaction of WTO. Sodium hydroxide, potassium hydroxide, sulfuric acid, phthalic anhydride, phthalic acid, etc. of analytical-grade quality are purchased from Merck India.

2.2 Treatment of WTO

For the production of biodiesel, both the waste transformer oils are first filtered using Whatman filter paper so that the dust particles and other impurities are filtered out and then the acid value of both the waste transformer oils was found and after that the transesterification of both the waste transformer oils, i.e., W1TO and W2TO is carried out using two different types of alcohol, viz., methanol and butanol along with base catalyst KOH. Similarly, the esterification of W1TO and W2TO is also carried out using methanol and butanol as an alcohol along with sulfuric acid H_2SO_4 as an acid catalyst.

The measured amount of oil W1TO, methanol, and the base catalyst KOH were taken in a 500 mL RB flask which is attached with an electric stirrer for mixing the mixture properly. The temperature of the system was adjusted to 60–65 °C and the reaction started with continuous stirring of mixture for 1 h. After that the mixture was transferred in a separating funnel where the two layers are separated out. The upper layer is of TW1 biodiesel and the lower layer is of crude glycerol. The same procedure is repeated with W2TO. Similarly, the transesterification of W1TO and W2TO is carried out using butanol as an alcohol with the base catalyst KOH with continuous stirring at temperature 70–75 °C.

The esterification of W1TO and W2TO is carried out using methanol as an alcohol with H_2SO_4 as an acid catalyst. The measured amount of W1TO, methanol, and H_2SO_4 was taken in a 500 mL RB flask which is attached with an electric stirrer and the esterification reaction is carried out at temperature 60–65 °C with continuous stirring for 1 h. After that the reaction mixture was transferred in a separating funnel where the two layers were separated and the biodiesel and crude glycerol were taken out from the funnel for further testing. The same procedure was repeated with W2TO. Further esterification of both the oils was carried out using butanol and H_2SO_4 at temperature 70–75 °C with continuous stirring of 1 h then the two layers are separated and taken for testing. In this way, there are eight samples prepared which were tested for fuel properties. The flow sheet of the transesterification as well as esterification method is as shown in Fig. 2.

In Fig. 3, the waste transformer oil and the biodiesel produced with by-product glycerol are shown. From Fig. 3, it is evident that by seeing the color of the oil one can determine the degradation of oil because the fresh transformer oil is pale yellow in color and as the property of the oil deteriorated it becomes dark in color.

The physical properties of diesel fuel and waste transformer oils are determined and it is shown in Table 1. It is found that the kinematic viscosity, flash point, and fire point of WTO are much higher than the diesel fuel.

Also the biodiesel obtained by the transesterification of WTO is tested for its physical properties and these are summarized in Table 2.

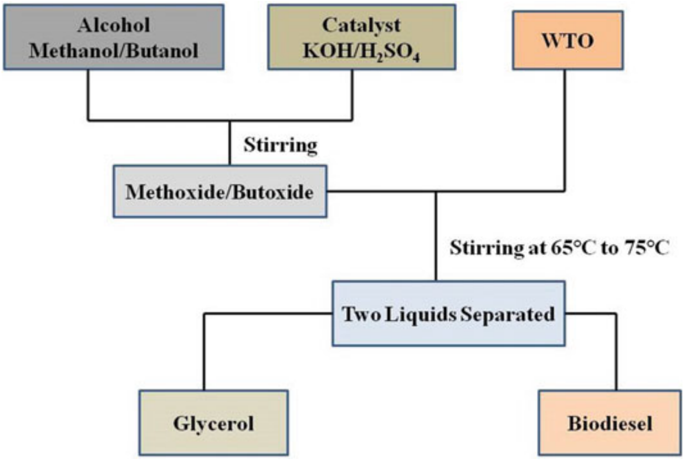

Fig. 2 Flow diagram of biodiesel preparation

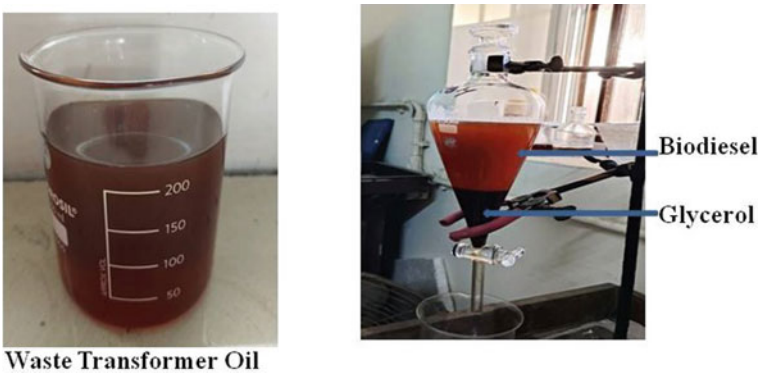

Fig. 3 Waste transformer oil and biodiesel

Table 1 Properties of diesel fuel and waste transformer oil

Properties	Diesel fuel	W1TO	W2TO
Kinematic viscosity at 40 °C (cSt)	2.37	9.568	7.82
Specific gravity at 15 °C	0.815	0.869	0.861
Flash point (°C)	50	174	170
Fire point (°C)	56	188	184
Gross calorific value (kJ/kg)	45,700	40,512	41,723
Cetane index	52	43	45

Table 2 Properties of different biodiesels produced during the reaction

Properties	TW1B1	TW1B2	TW1B3	TW1B4	TW2B5	TW2B6	TW2B7	TW2B8
Kinematic viscosity at 40 °C in cSt	6.650	5.932	5.119	4.622	4.715	5.012	4.089	4.36
Specific gravity at 15 °C	0.857	1.00	0.855	0.863	0.845	0.830	0.836	0.842
Flash point (°C)	160	158	88	60	150	156	62	76
Fire point (°C)	182	178	114	72	168	164	70	98
Gross calorific value (kJ/kg)	42,160	42,835	43,172	44,713	42,538	42,253	44,315	43,865
Cetane index	47.1	47.6	48.9	51	48.2	47.8	50.4	49.7
Yield %	82.5	95	92.5	97.5	87.5	90	93.5	98

2.3 Utilization of By-product Crude Glycerol

The Waste Transformer Oil (WTO) on transesterification gives biodiesel and crude glycerol as by-products. The abundance of crude glycerol as the by-product of biodiesel has motivated researchers on glycerol utilization as a feedstock for more profitable products. Esterification reaction between crude glycerol and 1,4-disubstituted benzene was carried out to produce glyptal. The addition of the hydroxyl group of glycerol allows for extensive branching during polymerization of glyptal. The crude glycerol was first heated to 180–200 °C in order to remove the other components like alcohol, oil, then different types of 1,4-disubstituted benzene were added, taking care to always maintain the temperature during the course of reaction. The reaction mixture was frequently stirred and the heating continued for exactly one and half hours. The stoichiometric ratio was optimized by varying the composition

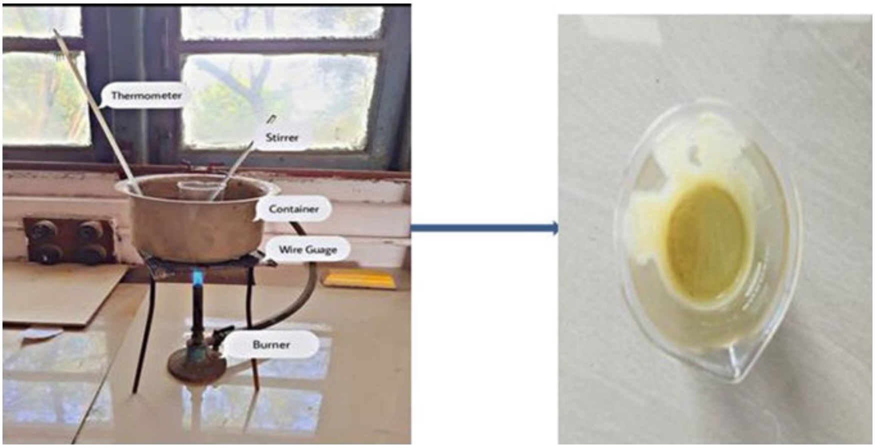

Fig. 4 Conversion of crude glycerol into glyptal

of 1,4-disubstituted benzene and crude glycerol as shown in Table 3 and it was found to be 1:1.5 (Fig. 4).

The glyptal is an alkylated resin and a cross-linked thermosetting polymer synthesized by step growth polycondensation reaction of 1,4-disubstituted benzene and disubstituted glycol monomers. If more than two active functional groups (hydroxyl groups) are present on one monomer the chain can be linked to form large and strong three-dimensional structures called thermosets [10]. During polymerization reaction of glyptal, the monomers (glycerol and 1,4-disubstituted benzene) are joined together to form macromolecules and due to increase in attractive forces between both the molecules, the mixture becomes viscous. The formula of glyptal polymer is $–(–OC–C_6H_5–CO–OCH_2CH_2O–)_n–$. The different types of 1,4-disubstituted benzene like phthalic acid, terephthaloyl chloride, phthalic anhydride, and 1,4-benzyl diamide were reacted with crude glycerol at optimized stoichiometric ratio to synthesize glyptal resin as shown in Fig. 5.

The synthesis of glyptal was cost-effective and feasible. The major application of glyptal so formed is as a surface coating agent. Moreover, it is also used as binding

Table 3 Variation in stoichiometric ratio of the reaction of 1,4-disubstituted benzene and crude glycerol reaction

Serial no.	Reaction initial moles			By-products
	–COOH, COCl, $CONH_2$, –COOOC–	–OH	–COO–	
1	1	1	Formed	Anhydride crystal + $H_2O\uparrow$
2	1	1.25	Formed	Anhydride crystal + $H_2O\uparrow$
3	1	1.5	Formed	$H_2O\uparrow$

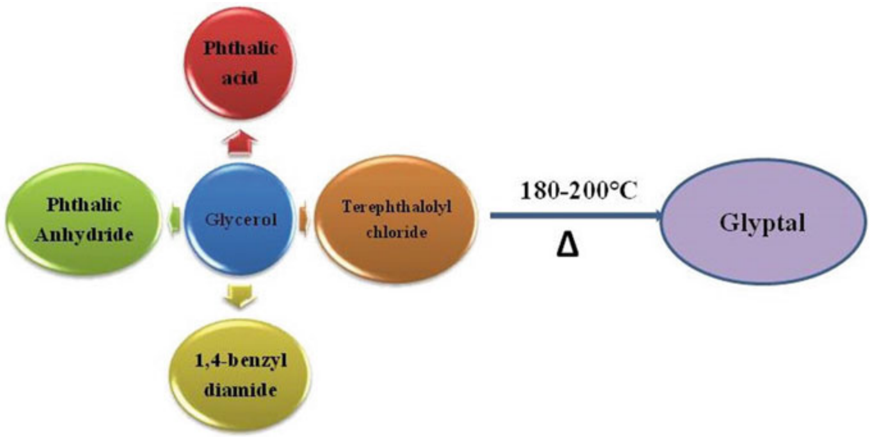

Fig. 5 Flow diagram of reaction of crude glycerol with 1,4-disubstituted benzene

material. It shows good heat aging properties and oil resistance. Film of the glyptal has excellent humidity and salt water resistance as well as dielectric strength [7].

3 Result and Discussion

3.1 Kinematic Viscosity

From the properties of diesel fuel and waste transformer oils as shown in Table 1, it is estimated that the kinematic viscosity of both the waste transformer oils is greater than diesel fuel which is due to the thermal and electrical stresses they have undergone through and it can be decreased by the treatment of both the waste oils as shown in Table 2. Therefore, the biodiesel obtained by the transesterification of both the oils shows improvement in the viscosity. Kumar et al. [8] treated the used transformer oil and found the similar reduction in the viscosity of the transesterified WTO.

As it is shown in Fig. 6 that the biodiesel TW2B7 has lower viscosity which is about 4.089 as compared to 7.82 which is the viscosity of W2TO and hence there is a considerable reduction in the viscosity of W2TO when the reaction of W2TO is carried out with butanol in the presence of base catalyst KOH. However, in the presence of H_2SO_4 with both the solvents (methanol and butanol) the viscosity of the waste transformer oil is considerably decreased.

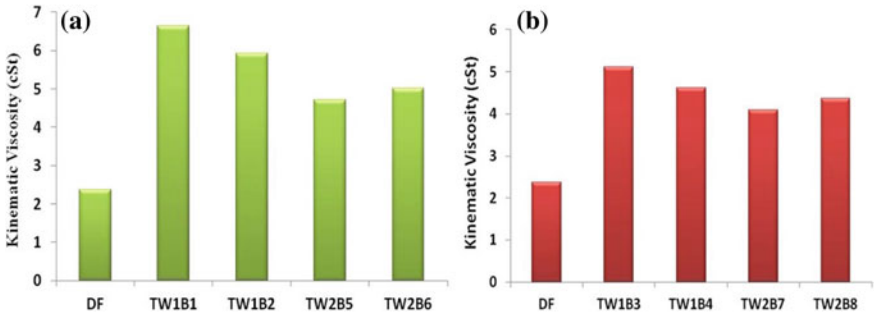

Fig. 6 **a** Biodiesel using methanol and WTO, **b** biodiesel using butanol and WTO

3.2 Flash Point and Fire Point

Flash point is the lowest temperature at which the fuel gives off vapor in enough concentration to the vessel so that it can form a mixture with air which is ignitable. Generally, lower flash point is required for the fuels so that it is easily ignited. However, the insulating liquids have high flash points and it is possible to decrease the flash point of the liquid by different methods. Sivakumar et al. [21] in their studies showed that the biodiesel produced after the transesterification of WTO has improved flash point, specific gravity, viscosity, etc. and it can be used as a fuel by blending it with diesel in diesel engines. As can be seen from Fig. 7, the flash points of both the waste transformer oils are very high. After the transesterification process, the biodiesels TW1B1, TW1B2, TW2B5, and TW2B6 have flash points, viz., 160, 158, 150, and 156 °C which shows that there is not much reduction in the flash point as compared to waste transformer oil and hence it is concluded that when methanol is used as an alcohol there is no significant difference can be seen in the flash point as well as in the fire point as can be seen from Table 2. However, when butanol is used as an alcohol the biodiesels TW1B3, TW1B4, TW2B7, and TW2B8 show considerable improvement in flash point and in all of them the biodiesel TW1B4 shows flash point of 60 °C and fire point of 72 °C which is very close to flash and fire point of diesel fuel.

3.3 Effect of the Catalyst

Catalyst plays an important role in the transesterification process of waste transformer oil to convert it into biodiesel. When potassium hydroxide (KOH) is used as a catalyst with methanol as well as with butanol the yield of the biodiesel is low as compared to sulfuric acid (H_2SO_4) which is used as catalyst with methanol and butanol in esterification of WTO. Yadav et al. [16] also found that since WTO contains long hydrocarbon chain and sulfuric acid is effective in breaking the chain and therefore

Fig. 7 Flash point of diesel fuel, WTO, and obtained biodiesels

increases the yield of the hydrocarbon fuel. Thus, from the experimentation it is concluded that the biodiesels TW2B8 and TW1B4 show highest yields of 98 and 97.5%, respectively.

4 Conclusion

As the fuel crisis is growing day by day, there are many ways by which an alternative fuel can be obtained to overcome the problem associated with decrease in fossil fuel reserves and pollution. Biofuels are a good alternative for fossil fuels as these are biodegradable, less pollutant, and frequently generated. Therefore, to generate them waste oils play an important role as feedstocks because these are easily available and by reusing them many environmental issues will also be solved. In the current study, waste transformer oils from different sources are collected and utilized to convert it into biodiesel and glycerol by transesterification method since the improper disposal of WTO causes water, land pollution, and increases greenhouse gases in the atmosphere as it contains many toxic pollutants. In this paper, two types of catalyst, viz., KOH and H_2SO_4 were used with two different alcohols, viz., methanol and butanol to transesterify both WTO and approximately 1 wt% (to oil) H_2SO_4, and 1:3 oil-to-butanol mole ratio is required to generate 1 L of WTO biodiesel and it is concluded that the biodiesel TW2B7 has low viscosity and the biodiesel TW1B4 shows improved flash point which is near to the flash point of diesel fuel and also TW1B4 and TW2B8 show high yield of biodiesel about 98 and 97.5%, respectively. Further the by-product, i.e., crude glycerol obtained during the reaction is utilized to form more value-added product glyptal which is an alkyd resin. From the experimentation, it was concluded that yield of glyptal is high with phthalic anhydride as compared to other substituted benzenes. Thus, this paper aims to treat waste transformer oil to convert it into an alternative fuel as well as to utilize the by-product crude glycerol.

5 Future Scope

This paper gives an insight about converting waste transformer oil into biodiesel by using different catalysts as well as alcohol and the conversion of by-product glycerol into more useful product glyptal. Using this paper one can find more properties of biodiesel obtained and enhance its properties and make it suitable for the future use. Further one can characterize the glyptal form and find its more applications.

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A Review of the Indian Scenario of E-waste Management: Generation, Effect, and Material Recovery Method

Ujjaval P. Sarvaiya, Anuj D. Bhatt, and Kunwar D. Yadav

Abstract E-waste is the fastest growing type of waste on a global scale. E-waste refers to trash electrical and electronic equipment rejected or discarded in whole or in part during production, refurbishing, or repair processes. In 2019, 53.6 Mt (Million tonnes) of e-waste was generated globally and is expected to rise to 74.7 Mt by 2030, with a growing rate of 3–5% annually. An estimated amount of e-waste generated by India from 0.77 to 3.2 Mt and 1,64,663 tonnes have been dismantled and recycled, in 2019. Compared to many developed countries, the overall volume produced is higher while e-waste generation is 0.6–2.4 kg/capita in India due to its population and market size. This paper reviews the research on the current state of e-waste management, the quantification and qualification of e-waste, the potential for a circular economy, the impact of e-waste, and disposal. In India, there is still a widespread practice of landfilling and incinerating of e-waste, which is also ragged, unorganized, and crude. This paper reviews research on informal and poor handling of e-waste in India and discusses the negative impact of e-waste's effects due to its complex mixture of toxic compounds. According to the available research, sustainable e-waste management in India remains a major challenge due to more informal recycling practices, a lack of rules and regulations, e-waste importation from developed countries, and a lack of awareness and information. This paper also discusses the material recovery from e-waste with available methods (such as mechanical separation, pyro-metallurgy, and hydrometallurgy), along with the possibility for the circular economy to expand. As a result, the study covers the recovery options that are available, as well as the challenges and possibilities.

U. P. Sarvaiya (✉) · A. D. Bhatt · K. D. Yadav
Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat 395007, India
e-mail: p21en020@ced.svnit.ac.in

A. D. Bhatt
e-mail: p21en023@ced.svnit.ac.in

K. D. Yadav
e-mail: kdy@ced.svnit.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_8

Keywords E-waste · E-waste management · Indian scenario · Recycling · Formal, and informal sector

Abbreviations

EEE	Electronic and electrical equipment
WEEE	Waste electrical and electronic equipment
E-waste	Electronic waste
Mt	Million metric tonnes
Kt	Kilometric ton
USD	United States dollar
PRO	Producer responsibility organization
EPR	Extended producer responsibility
CPCB	Central pollution control board
PCBs	Printed circuit boards

1 Introduction

The management of solid wastes, which are increasing in both amount and complexity, is still a serious environmental challenge on a global scale; this issue has been made worse by e-waste, which is frequently regarded as one of the most problematic types of solid waste [1]. E-waste is one of the fastest growing waste streams in the world because of rapid efficiency innovations, advancement in design, extensive rising demand, technological developments, upgradation, and rapid increase in obsolescence (either due to the reduced life span of the product or change in customers' requirement) of electrical and electronic equipment [2–4].

E-waste is generally defined as the waste generated by all parts and items of electronic and electrical equipment (EEE), or when EEE reaches the end of its lifecycle, or when EEE or its components are discarded without the intention of being reused, and is known as waste electrical and electronic equipment (WEEE), electronic waste (e-waste), or e-scrap (in a different part of the world). In this study, it is referred to by the term "E-waste" inclusively [5–7].

E-waste piles have raised concerns about their proper disposal. E-waste is disposed of through incineration, landfilling, blazing, and junking outdoors in many countries and that should be considered as the least preferred option for final disposal. To encourage the reuse of the entire product and remanufacturing, and then recycling, numerous academics have indicated that this alternative should be viewed as the least desirable one for the final disposal of e-waste [8, 9].

According to estimates by Islam et al. and Kaya [10, 11], e-waste probably accounts for between 5 and 8% of municipal solid waste globally. Sahin et al. [12]

mentioned that three times more e-waste was produced globally in 2019 than there were people on the planet [12]. As per the Global E-waste Monitor 2020 report, in 2019, 53.6 Mt of e-waste was generated globally (an average of 7.3 kg per capita). On average, the total weight of global EEE consumption increases annually by 0.4–2.5 Mt, at a rate of 3–5% per year. It is projected to grow E-waste generation to 74.7 Mt by 2030 and 110 Mt by 2050 [13].

A 9.3 Mt (17.4% of the e-waste generated) was formally collected and recycled in 2019, which is only marginally better than the rate anticipated in 2014 (17%) [7, 13]. Recycling helps keep non-biodegradable materials like glass, metals, and plastics out of landfills and reduces environmental pollution [14]. The destiny of 82.6% (44.3 Mt) of the e-waste produced in 2019 is unknown because it can be burned outdoors or discarded illegally, and its impact on the environment and human health. In 2019, 5.1 Mt of e-waste crossed international borders, of which 1.8 Mt was transported in a controlled manner. The remaining 3.3 Mt, however, was shipped in an uncontrolled manner as used-EEE or e-waste under the Basel Convention regime [13, 15]. It is recycled in informal contexts in developing nations, including Nigeria, Ghana, Brazil, Mexico, China, India, Vietnam, and the Philippines. For instance, between 25 and 75% of the used computers brought into Nigeria in 2005 were either non-operational or beyond repair, and were subsequently recycled discretely [16].

The collection, handling, recycling, and management of e-waste is a key challenge as for monitoring strategies it is quite unorganized and unofficial, which leads to the reuse and recycling of the whole product and remanufacturing, to conserve valuable materials and are designed to safeguard both the environment and public health [3, 17].

A major challenge faced today is the safe management of e-waste. To mitigate the global e-waste tsunami, current literature provides reviews on the existing state of e-waste management practice, the quantification and qualification of e-waste, the potential for a circular economy, the impact of e-waste disposal, and also discuss the e-waste generation in India, its challenges and opportunities, disposal of e-waste, and the impact on the environment.

2 Composition of E-waste

E-waste can be categorized as follows:

1. Large household equipment: Washing machines, televisions, air conditioners, refrigerator/freezer, and dishwashing machines.
2. Small household equipment: Vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, irons, coffee machines, electric shavers, calculators, radio sets, video cameras, small monitoring, stereo, and DVD/VCR player.
3. IT and Telecommunication equipment: Mobile phones, tablets, personal computers, laptops, printers, fax machines, routers, and telephones.

4. Lamp: Fluorescent lamps, high-intensity discharge lamps, and LED lamps.
5. Other electric and electronic equipment: Electrical and electronic toys, electrical and electronic tools, and medical devices.

Figure 1 illustrates the composition of e-waste, with analysis in Table 1.

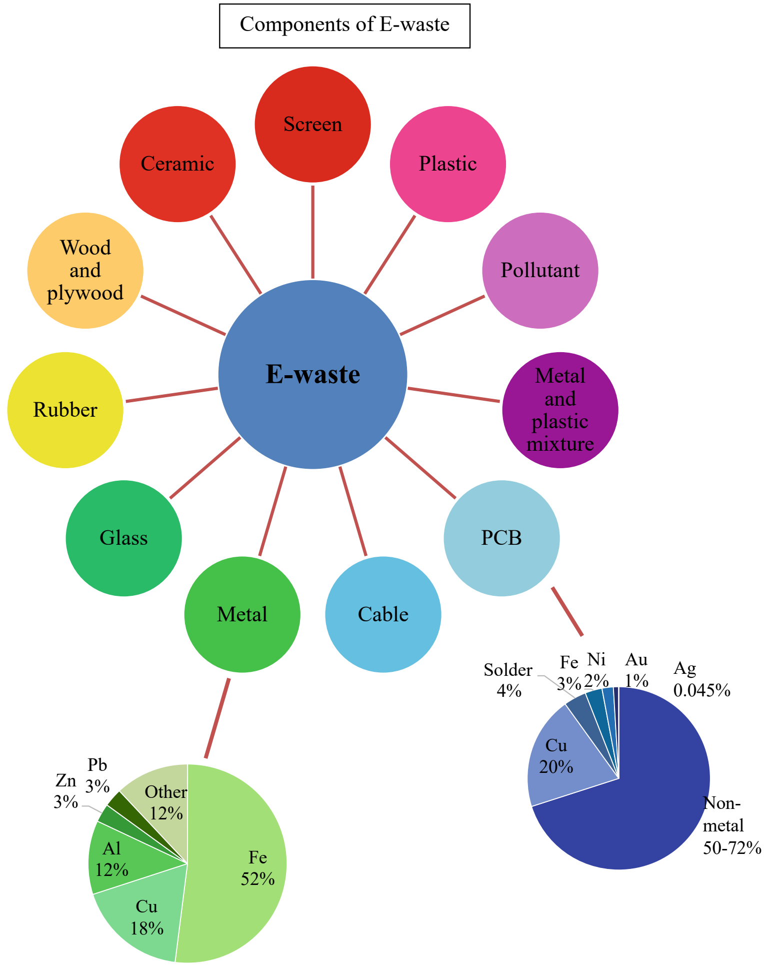

Fig. 1 E-waste composition Ref. [18–21]

Table 1 Composition of e-waste [18–20]

No.	Equipment	Weight percentage (%)
1	Metal	33–60.6
2	Plastic	15.21–30
3	CRT, LCD	11.87
4	Metal plastic mixture	4.97
5	Pollutant	2.70
6	Cables	1.97
7	PCB	1.71–3.1
8	Other	1.38–16
9	Glass	5.4–37
10	Rubber	0.9
11	Wood and plywood	2.6
12	Ceramic	2.0

3 Indian Scenario of E-waste Management

Around the globe, India is one of the top five e-waste-generating countries. Compared to many developed countries, the overall volume produced is higher while e-waste generation is 0.6–2.4 kg/capita in India due to its population and market size. In India 7,71,215 to 32,30,000 tonnes of e-waste were generated in 2019. With a growth rate of 10% per annum, it is expected to achieve 8 Mt by 2025 [13, 22, 23].

Ten states in India make up roughly 60–70% of the nation's total production of e-waste, as shown in Fig. 3. Mumbai ranked first among the top 10 cities that produce e-waste. Delhi, Bangalore, Chennai, Calcutta, Ahmedabad, Hyderabad, Pune, Surat, and Nagpur are the following cities [24]. According to Parthasarathy et al. [25], an average middle-class family produces 18 kg of e-waste annually. Additionally, Mumbai, Delhi, Madras, Hyderabad, and Ahmedabad receive most of the e-waste as a charity [2]. According to Priya and Hait [23], India's imports of electronic goods for 2018–19 were about 55,475.52 million USD.

Domestic households, the public, and the private sectors, including business, mechanical, institutional, construction and demolition, foreign embassies, EEE manufacturers and retailers, emergency clinics, multinational corporations, other city administrations, and the secondary market for used gadgets, are potential sources for generating e-waste in India [5]. In India, desktops, smartphones, laptops, and televisions are the major electronic items that are contributing to an increase in e-waste. In terms of sales, use, and Internet usage, India is one of the top countries for smartphone users worldwide [23]. Figure 2 depicts the source of e-waste. E-waste management in India divided into formal and informal sectors is discussed further.

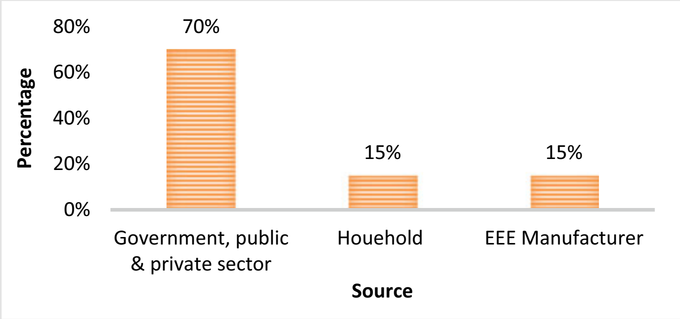

Fig. 2 Source of e-waste, Ref. [5]

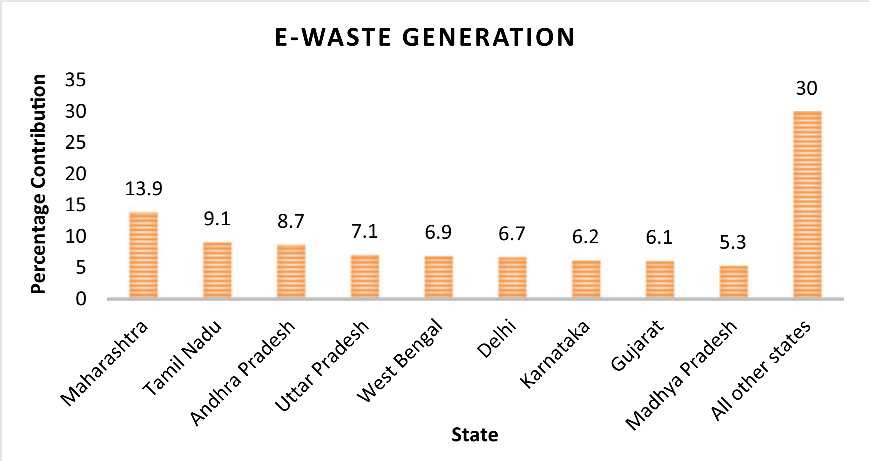

Fig. 3 State-wise generation of e-waste, Ref. [24]

3.1 Formal Sector

Formal e-waste treatment is a critical component of the sustainable management of solid waste in developing nations because it is closely related to environmental issues caused by a substantial informal industry. In Southern Asia, India is the only country with e-waste legislation. Since 2011, India has had e-waste management laws in place that require only authorized dismantlers and recyclers to collect e-waste. E-waste Management and Handling rules, 2011 strengthened the global best practice of EPR to take-back of end-of-life products. The E-Waste (Management) Rules 2016 included a manufacturer, dealer, refurbisher, and Producer Responsibility Organization (PRO) [3, 13].

The E-Waste Management Rules 2016 required producers to establish a Producer Responsibility Organization (PRO) to support EPR and conduct their obligations;

currently, India has 51 PROs. The PROs are responsible for establishing a collection and recycling mechanism and running awareness campaigns. However, many government agencies do not consider a PRO to be an authorized entity eligible to bid on their e-waste [2, 22].

India has total 2,759 E-Waste collection centers of EPR-authorized producers for e-waste collection by Central Pollution Control Board (CPCB). There are 400 authorized dismantlers/recyclers with a total processing capacity of 10,68,542.72 tonnes. 1,64,663 tonnes of e-waste were dismantled and recycled in 2019 and 2,22,436 tonnes in 2020 [13, 22]. Formal sectors use metal recovery technologies such as bioleaching, bio-recovery, hydrometallurgy, pyro-metallurgy, and other sustainable technology [3].

3.2 Informal Sector

In India, environmental authorities are concentrating their efforts on developing a strategy for controlling the informal sector. However, the informal sector remains a problem. Due to the large informal sector's use of low-cost labor employees with useful skills, it is more cost-effective than the formal sector. The informal recycling sector handles 85–95% of e-waste, which is unacceptable despite the fact that it provides income to millions of people. Delhi has been identified as one of the largest informal recycling hotspots in India, with over 5000 informal recycling hotspots engaging over 50,000 people [5, 23]. Over 3000 units are involved in informal recycling activities throughout the country. However, informal recycling/backyard recycling has negative environmental and health consequences [3, 26].

According to the E-waste Management Rule 2016, a minimum of 300 m^2 area is required for dismantling 1 tonne of e-waste per day, but the informal sector only uses 20–40 m^2. According to government guidelines, the recycling facility should install a wastewater treatment plant, but the informal units lack such treatment plants. As a result, the informal sector creates a major impact on human health and the environment [23]. When compared to formal recyclers, informal recyclers offer higher prices when purchasing e-waste because the costs of legal, environmental, and social compliance are avoided in the informal economy [2].

Informal recycling includes different key players like kabadiwallas, rag-pickers, kabaddi shops, scape dealers, waste traders, dismantlers, refurbishers, and recyclers. The informal sector has a very well-connected structure, with a sizable base of last-mile collectors known as "kabadiwallas;" they offer convenient door-to-door service at a localized level. They purchase e-waste along with other recyclable waste like old newspapers, cardboard, books, plastics, glass, bottles, etc. from consumers and sell it to waste traders and then it goes to the wholesaler. After that, the wholesaler separates and sorts various waste materials with a considerable amount of specialization [2, 4].

These wholesalers provide materials for reprocessing to recyclers, dismantlers, and disposers. In India, e-waste is handled similar to other common recyclable trash like plastics, glass, cables, etc. and is typically disposed of informally. Once precious metals like copper, aluminum, gold, silver, etc. have been extracted from the leftover e-waste, it is either burned in an incinerator, disposed of in a landfill, or dumped outside [2, 4].

3.3 Material Recovery from E-waste

The conventional e-waste recycling process includes manual segregation, mechanical separation, plastic recycling, and transportation of nonferrous materials to metallurgical treatment plants for constituent metal separation [26].

The mechanical separation is the initial step in recovering material by employing hammers, screwdrivers, pincers, and other equipment to disassemble, dismantle, de-soldering, and crush e-waste. Manual dismantling often separates reusable e-waste components, directs material recovery, and separates hazardous material and valuable materials like PCBs, casing, monitors, and batteries [6, 26, 27].

Magnetic separation, eddy current separation, and electrostatic separation all separate metallic and non-metal components, as well as ferrous and nonferrous material, from crushed e-waste and PCBs. Other separation techniques that are often used include gravity separation, air separation, jigging, and froth floatation [7, 28, 29].

Valuable metals can be recovered from e-waste as it is important for environmental and resource protection, specifically from PCBs via pyro-metallurgy, hydrometallurgy, and bio-metallurgy. Figure 4 shows a flow chart for material recovery from E-waste.

Pyro-metallurgy is a metal purification and extraction technology that uses high temperatures. The refining, smelting, combustion, roasting, sintering, combustion, and incineration are all examples of pyro-metallurgy. At higher temperatures, organic parts such as paper, wood, and rubber decompose; the volatile compounds generated can be used as chemical products. Poor operations can release hazardous substances into the environment, such as dioxin production from low-temperature incineration of brominated flame retardants [6, 26, 30].

Hydrometallurgy is the extraction of metals from concentrated mixtures or mixtures of PCBs using aqueous solutions such as inorganic acid, organic acid, cyanide, thiourea, thiosulfate, chelating agents, chlorinating agents, and so on. This is the method used by the vast majority of formal recycling operations in India. It is advantageous because there is a reduced risk of harmful and dust emissions, good metal separation, and minimal residue left over [26, 28, 31].

Another technology that has gained attention these days, is plasma technology, bio-metallurgical technology, supercritical fluid extraction technology, and vacuum metallurgical technology. These are environmentally friendly technologies shows promise, but much work is still required before they can be practical [29, 32, 33].

In India, the most common e-waste disposal methods are open dumping, landfilling, and burning. There is also some research available on emerging technology for converting waste to energy. For example, pyrolysis for energy generation, plasma

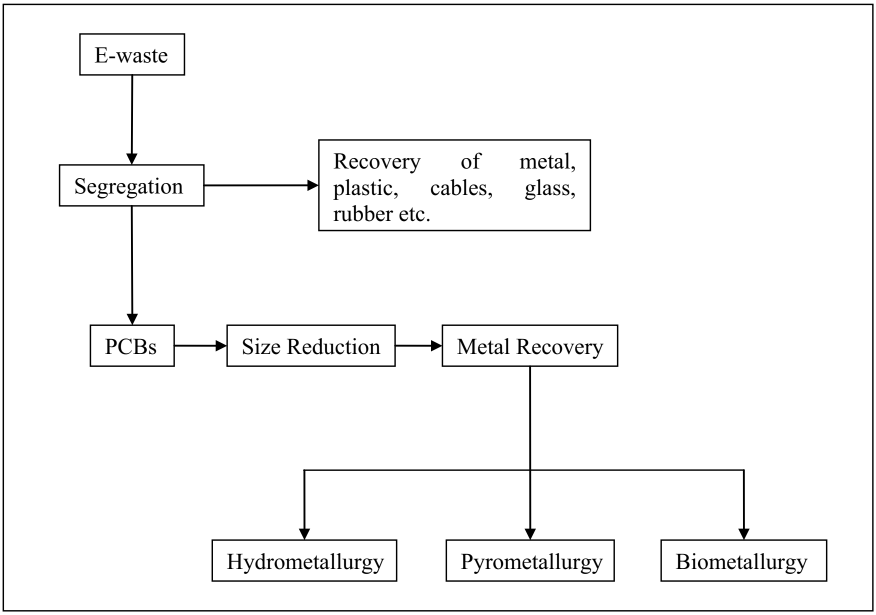

Fig. 4 Material recovery from e-waste

treatment for material recovery, hydrothermal treatment for the conversion of e-waste residual plastics into organic products, and so on [11, 28].

3.4 Challenges in India

- Informal hubs engagement and the collection and resale of e-waste informally.
- Mixing of e-waste with other solid waste at the household level.
- Dumping, landfilling, and incineration are the main methods for waste disposal.
- Lack of environmentally sound e-waste treatment (poor recycling and recovery process).
- Infrastructure for collection, transportation, treatment, recycling, and disposal is lacking, as well as formal treatment facilities.
- Unsafe treatment practices of e-waste.
- High cost for extraction of metals.
- There is a lack of coordination among various relevant authorities, stakeholders, formal channels, collectors, dismantlers, and recyclers.
- Lack of reliable parameters, non-identification of bulk consumers, unreliable data on e-waste, and inefficient audit procedures.

- Absence of strict government regulations and centralized administration with no integrated or coordinated efforts from municipal corporations and related departments.
- Lack of awareness and market information.
- Allowing import or export of hazardous waste for the purpose of recycling, recovery, and reuse process.
- Biased opinion toward selected and attractive item acceptance by recyclers.
- Poor reporting system and absence of financing for monitoring and control.

4 Potential for a Circular Economy

The circular economy is a concept that promotes the circulation of functional elements or components along with financial circuits to reduce the consumption of finite resources, optimization of resource usage, recover materials from products at the end of use, and provide closed-loop resource management by providing alternative resource raw materials in supply chains. It also enables cleaner production management, smaller material footprints, lessen the environmental burdens utilizing the 3R (reuse, recycle, and recover) concept, depending on the hierarchy level of the material in terms of economic value, thereby facilitating the circular economy [3, 34, 35].

Because of the high concentration of precious metals embedded within, printed circuit boards (PCBs) are the most valuable component of e-waste with more than 10 times the purity of mineral ores. They generate approximately 40% of the revenue generated by recycling metals in e-waste. That's why metal recovery from waste PCB is considered as "Urban Mining" [33, 35].

One tonne of e-waste has an economic potential of 500 USD to 92.9 thousand USD. The 44.7 Mt of e-waste generated in 2016 had a potential worth of 60 billion USD [35, 36]. As per the Global E-waste Monitor 2020 report, approximately $57 billion USD is the estimated value of raw materials in the global e-waste generated in 2019. With the current recycling rate of 17.4%, a raw material value of $10 billion USD is recovered in an environmentally sound way from e-waste globally, and 4 Mt of raw material could be made available for recycling [13].

The production of EEE requires various metals, including gold, silver, copper, iron, etc. For instance, it seems unclear that the mining of currently virgin minerals will be able to meet the 275–300% growth in copper demand predicted for 2050 [37]. There were 300 tonnes of gold in the global e-waste, in 2014 with a worth of 10.4 billion euro. As in the case of a million mobile phones, 9000 kg copper, 24 kg gold, 250 kg silver, and 9 kg palladium would be produced [36].

The recycling sector employs more than 1.5 million people, processes more than 500 Mt of waste annually, and generated 160 billion USD in revenue in 2019 [1]. Waste plastics are an unexploited resource for recovering valuable polymers, including polycarbonates (cost between 2.50 and 5.00 USD/kg) among many others.

In 2010, there was about 3.4 Mt of demand for waste plastics, with a 6% annual increasing rate [14].

The resale price of processed e-waste at the facility is 0.013–0.26 USD/kg for Cathode Ray Tube (CRT) glass, 0.18–0.29 USD/kg for metallic scrap components, 0.91–1.04 USD/kg for aluminum parts, and 0.100–0.13 USD/kg for shredded plastics. However, the business reports about 25–30% of the marginal profit [38].

5 Health Impact of E-waste

Although e-waste comprises over 60% useful resources; it also contains over 1000 different toxic and hazardous compounds [9]. These mixes of various substances, which include chemicals found in EEE components and chemicals produced during e-waste treatment and disposal, may constitute a substantial hazard to the environment. For example, in the United States, landfills were found to contain roughly 70% Hg and Cd and 40% Pb from consumer electronics [39]. Furthermore, because these compounds persist in the environment and have a high potential for accumulation in human and animal tissue, there may be damaging effects on human safety [16]. Table 2 shows the impact on human health and environmental damage caused by various components of e-waste.

5.1 Impact Due to Hazardous Components Generated from E-waste

5.2 Source of Toxins

These substances reach the environment through a variety of pathways. Uncontrolled e-waste disposal results in excessive metal concentrations being released into the surrounding air, dust, soils, sediments, and plants [41]. The source of these components is shown below in Table 3.

6 Conclusion

The purpose of this article was to alert people to the problem and raise their awareness about e-waste. Every year, thousands of tonnes of e-waste are dumped, and the problem worsens. E-waste is a relatively new and rapidly growing waste segment worldwide. In India, this growing problem is largely ignored or misunderstood. Since it covers all kinds of electrical and electronic devices, from smartphones to big-screen

Table 2 Impact of E-waste on the environment and human health, Ref. [11, 24, 36, 39, 40]

No.	Component	Human health impacts	Environment damage
1	Lead	Can damage children's brain development, neurobehavioral development and cause intellectual impairment, can damage the central and peripheral nervous systems, kidney, blood, and reproductive systems, chronic neurotoxicity, appetite loss, abdominal pain, constipation, fatigue, sleeplessness, irritability, and headache, leads to death	Cause air and water pollution with the release crushing of powder and fumes and toxic leachates
2	Mercury	Can damage the brain, central nervous system, neurobehavioral development of children (methylmercury), anemia, kidney damage, cause muscle tumors, mental retardation, and skin diseases	Cause air and water pollution
3	Cadmium	Highly toxic, neurotoxin, carcinogenic, and affecting the kidneys, respiratory systems, possibly reproductive damage and lung emphysema, itai-itai syndrome and severe pain in joints and spine, can be DNA damage	Cause surface and ground water, bioaccumulation in the environment, air pollution
4	Chromium or hexavalent chromium compounds	Damage to DNA, Carcinogenic, impacts neonates, reproductive and endocrine functions, liver, kidney, including asthma, bronchitis, and lung cancer, leads to death, irritating to eyes, skin, and mucous membranes	Cause groundwater pollution and higher levels of concentration deteriorate the soil quality
5	Nickel	Increased risk of lung cancer, nose cancer, cardiovascular disease, neurological deficits, developmental deficits in childhood, and high blood pressure	–
6	PVC	Incineration of PVC produces chlorinated dioxins and furans, which are highly persistent in the environment and toxic even in very low concentrations. It is carcinogenic and can damage the immune system, hormone system, and reproductive system, cause pulmonary dysfunction	Leach into landfills cause water and land pollution, pollute water bodies form methylated mercury and lead to bio-magnification
7	POPs including brominated flame retardants (penta-, octa-, deca-BDE)	Neurotoxicity, long-term exposure can lead to impaired learning and memory functions, interfere with thyroid and estrogen hormone systems, exposure in the womb has been linked to behavioral problems	Bioaccumulation in the environment (very resistant to breakdown)

(continued)

Table 2 (continued)

No.	Component	Human health impacts	Environment damage
8	Beryllium	Affect organs such as the liver, kidneys, heart, nervous system, and lymphatic system, may develop beryllium sensitization or chronic beryllium disease and skin disease, allergic reactions	–
9	Zinc	Increased risk of copper deficiency (anemia, neurological abnormalities)	–
10	Lithium	Can cause nausea, diarrhea, dizziness, muscle weakness, fatigue, and a dazed feeling	–
11	Antimony	Carcinogenic potential, irritation of eye, skin and lungs, stomach pain, diarrhea	Cause air and water pollution with the release crushing of powder and fumes and toxic leachates
12	Arsenic	Affects digestive tract, lung cancer, skin cancer, suppressed immune system, liver, nervous and reproductive system damage, allergic reaction	Toxic chemical exposures lead to air pollution and hazards from fire
13	Barium	Can cause liver, cardiac, or spleen damage, low or elevated blood potassium, cardiac arrhythmias, respiratory failure, gastrointestinal dysfunction, paralysis, muscle twitching and weakness, stomach irritation	Cause potential damage to aquatic animals and plants also high levels cause soil pollution
14	Gallium	Throat irritation, breathing problems, pain on chest	Clear evidence of carcinogenesis in experimental animals
15	Flame retardant	Retarded mental growth in children, anemia, renal toxicity and insomnia, chronic brain damage, respiratory and skin diseases	Cause air and water pollution with the release crushing of powder and fumes and toxic leachates
16	Chlorofluoro carbon (CFC)	Increased incidence of skin cancer and/or genetic damages	Deleterious effect on the ozone layer
17	Polychlorinated biphenyls	Cancer, effects on the immune systems, reproductive system, nervous system, endocrine system, and other health effect	–

Table 3 Source of hazardous component from e-waste [17, 24, 36, 40]

No.	Component	Source
1	Lead	CRTs (4–22% of Pb), television sets, batteries, PCBs, lamps, computer monitors, PCBs, batteries
2	Mercury	Lighting devices for flat screen displays (LCD), PCBs, thermostats, sensors, cathode fluorescent lamps (1–2 g per device), relays, alkaline batteries
3	Cadmium	Rechargeable and Ni–Cd batteries, switches, older CRTs, PCBs, infrared detectors, semi-conductor chips, ink or toner of photocopying machines, mobile phones, toys, and plastics
4	Chromium or hexavalent chromium compounds	Production of metal housings as corrosion-resistant coatings used for coating electro-galvanized steels and individual components (screws, rivets, switches, plugs, antenna, and other accessories), data tapes, floppy disks
5	Nickel	Ni–Cd batteries, electron guns in CRTs
6	PVC	For insulation on wires and cables, computer housings, switches, relays, older transformers, capacitors, fluorescent lighting fixtures, electrical devices
7	POPs include brominated flame retardants (penta-, octa-, deca-BDE)	Used in circuit boards (fire retardants for electronic equipment), plastic casings of computers, cables, as dielectric fluids in capacitors and transformers, lubricants and coolants in generators, fluorescent lighting, ceiling fans, dishwashers, electric motors, components such as connectors and mobile phones
8	Beryllium	Used with copper and nickel to produce electrical contacts, gyroscopes, spot-welding electrodes, springs, non-sparking tools, gears and cogs in aviation industry, power supply boxes, computers, X-ray machines, ceramic components of electronics, PCBs
9	Zinc	CRTs, metal coatings, batteries
10	Lithium	Li-batteries
11	Antimony	Batteries, semiconductors, PCB's and CRT, flame retardants in plastics
12	Arsenic	Integrated circuit, semi-conductors, gallium arsenide in light emitting diodes (LED), microwaves, solar cells, doping agent in transistors, PCBs
13	Barium	CRTs (2–9% Ba), fluorescent lamps, ceramics, automobile, electronic tubes and glass, plastics fillers, lubricant additives
14	Gallium	Semiconductors, PCBs
15	Flame retardant	Fluorescent lamp, PCBs, and CRT LCDs
16	Chlorofluoro carbon (CFC)	Cooling units, insulation foams
17	Polychlorinated biphenyls	Condensers, transformers

televisions, the rapid growth of e-waste is having a negative impact on both the environment and humanity. The formal sector in India faces several challenges when it comes to managing e-waste. Most states currently lack regular mechanisms for monitoring e-waste generation and subsequent activities because it varies due to its availability in various forms, making it difficult to plan and implement management strategies. Electronic and electrical equipment are made up of over 1000 different components. If heavy metals from e-waste are exposed, they can cause significant harm to the environment and human health. Antimony, arsenic, barium, cadmium, chromium, lead, mercury, nickel, and other heavy metals cause significant and life-threatening diseases in humans and pollute water and air. Only 17% of global e-waste is formally collected and recycled, indicating insufficient e-waste management, rules, and regulations. In India, the informal sector is particularly powerful in terms of e-waste collection and recycling. Because informal recycling does not include any health or environmental precautions, it is less expensive than formal recycling. Additionally, the informal sector promises more labor and skilled jobs for poor and middle-class families. Based on the critical review in various aspects, future suggestions for India are that without disrupting the powerful informal cycle, new regulations and policies should be enacted in India, with various schemes providing opportunities to safeguard the environment and human health, improve the formal sector of e-waste disposal, and raise awareness among consumers of electronic appliances about e-waste disposal. The concept of "urban mining" is gaining popularity since e-waste contains precious and valuable materials worth millions of dollars. However, there is no research on the entire circular economic chain of formal recycling and the recovery of precious and valuable materials. Today, eco-friendly and sustainable material recovery technologies must be implemented.

7 Research Gap

Traditional methods for recycling e-waste, like pyro-metallurgical and hydrometallurgical processes, have undergone significant advancements; nevertheless, more work needs to be done to make it practical to use these processes on an industrial scale while minimizing environmental impact. A deeper understanding is required to understand the mechanism of e-waste metal recovery and the viability of engineering applications within the context of the circular economy. Focus should be placed on electrochemical, bio-metallurgical, and supercritical fluid extraction techniques due to their superior environmental performances compared to the current industrial recycling approaches.

The majority of research on a greener and more sustainable metal recovery technique is done in laboratories. In addition, studies are needed to develop a full, closed-loop, scientific metal recovery system that should be used to increase the yield and rate of metal recovery from mixed metal solutions that contain even low concentrations. To investigate the potential for industrial implementation of these techniques, particularly in developing countries, more research is needed.

Economic concerns are the main reason that the extraction of precious metals from particular and individual electronic components like capacitors, integrated circuits, and central processing units is becoming more and more important. However, it is necessary to determine the project's overall economic viability. Therefore, researching the cost-effective sequential recycling of all components on an industrial scale is crucial, aiming to minimize the environmental impact.

The utilization of non-metallic fractions as a reinforcement in composites eliminates the need for coke, a potential fuel source or chemical feedstock. However, more research on characterization of non-metal values for determining toxic content is required in order to selectively and directly convert PCB resources into value-added products in metals, composites, carbon-based products, and catalysts.

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Evaluating Efficiency of Sewage Treatment Plant at Hamirpur: A Case Study

Bharti and Dharmendra

Abstract Wastewater typically encloses liquid and solid for agricultural, domestic, and commercial purposes. More than 3/4th of the supplied water comes back as wastewater possessing potential health hazards. To encounter this issue various wastewater treatment plants have been constructed. The efficient operation of wastewater treatment plants (WWTP) is the key to ensuring an eco-friendly and sustainable environment. The effectiveness of wastewater treatment plants is a crucial component of any region's effort to create a sustainable and environmentally friendly environment. A case study was conducted in Hamirpur with different zone categories such as zone 1, zone 2, zone 3, and NITH to determine the efficiency of wastewater treatment plants. The present case study aims to determine the effectiveness of wastewater treatment plants by comparing the samples collected at the inlet and outlet of several treatment plants. In addition, a model test will be conducted to examine the parameters of a wastewater sample in the lab and compare them to the actual parameters taken at the wastewater treatment plant. This will give us an understanding of the variation in results. The variables for the laboratory model test will be PH, DO, TSS, BOD, and COD. Finally, a cost analysis will be conducted for each treatment plant based on the area treated.

Keywords Wastewater · Parameters · Efficiencies

Bharti (✉)
Environment Engineering, Department of Civil Engineering, National Institute of Technology Hamirpur, Hamirpur 177005, India
e-mail: 21mce404@nith.ac.in

Dharmendra
Department of Civil Engineering, National Institute of Technology Hamirpur, Hamirpur 177005, India
e-mail: djha@nith.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_9

1 Introduction

Sewage comprises home wastewater, industrial wastewater that has undergone treatment or not, rainwater, and urban runoff, is the wastewater generated by a population. It is not known that sand and other coarse particles constitute sewage components (paper, bottles, etc.). They are brought to a treatment plant by water and treated like solid waste their Sewage flow rate and composition vary greatly from location to location depending on several factors, including water use, climate, social activity, the type and number of local companies, and sewer system characteristics. Waste is made up of human waste and water; the main pollutants include suspended particles, soluble organic compounds, and fecal pathogenic bacteria. Among the various contaminants discovered in sewage include pesticides, heavy metals, trace elements, detergents, solvents, and other strange chemicals. Examples include drugs, antibiotics, and hormones. Water, food, and energy security issues are becoming a major problem for both India and the rest of the world. Most river basins in India and around the world are dry or closed, resulting in moderate to severe water shortages brought on simultaneously by the consequences of expanding agriculture, industry, and urbanization. Demand management and increased water use efficiency could help to meet the demand for fresh water. Water that is of poor quality and wastewater are having an increasing impact. Sewage, sometimes called home wastewater or municipal wastewater, is one sort of wastewater created by a population. It can be described by its flow velocity or volume, physical condition, harmful chemical components, and bacterial status (which species and quantities are present). Most of it comprises the grey and black toilet flushing water and the human waste it flushes [1]. Prerna et al. [2] Using different technologies, conducted a comparison study of Chandigarh's three current sewage treatment facilities. According to the author, Chandigarh has a well-designed and constructed sewage network for the transportation of home wastewater produced by the treatment facilities. The systems being compared include the Up Flow Anaerobic Sludge Blanket (UASB), Activated Sludge Process, and Moving Bed Biofilm Reactor (MBBR). The findings showed that the effluent parameters of the STP with MBBR technology were within acceptable ranges and that the effluent water was utilized for irrigation in Chandigarh's numerous sector gardens [2].

Prachi and Sameer [3] An investigation on the Sequential Batch Reactor (SBR) technology at the Kalyan, Thane, led to a 25 MLD home wastewater treatment facility. While effluent is being discharged into the Ulhas River, the effluent parameters are being monitored. The STP was investigated over a three-month period. To learn more about the STP, a questionnaire was distributed on-site. A total of 36 samples were evaluated. The entrance, circulation chamber, and outflow all provided test sample collections. According to the results, BOD removal efficiency is 96%, TSS removal efficiency is 92.74%, total nitrogen removal efficiency is 75.67%, and phosphate removal efficiency is 71.79%. The author concluded that the regular maintenance of the aeration equipment was the cause of the better elimination efficiency [4].

Marcucci and Tognotti showed that using an activated carbon filter to reduce COD is more successful when using ozonation. Using UF makes the process of eliminating microorganisms more efficient. However, yellowish-coloured effluent removed by ozonation may be removed by UF.

Kumar et al. [5] Two treatment facilities in Bangalore City employing activated sludge techniques were identified. Wastewater treatment facilities are designed to remove from wastewater the organic and inorganic components that are harmful to the environment and human health. According to the findings, in relation to BOD, COD, and TSS, Total dissolved solids could not be handled by any treatment plants. The TDSS gave the order to shut down both plants [5].

2 Methodology

- Visit at different treatment plants Zone-I, Zone-II, Zone-III & NITH.
- Wastewater sample collection.
- Analysis of parameters:
- At inlet
- At outlet
- Monthly testing of wastewater samples such as pH, TSS, BOD, and DO of different units of sewage treatment plants.
- For analysis purposes, the wastewater treatment plant facility outside the NIT Hamirpur campus' latitude is 31.708 and longitude coordinates 76.5273 (Figs. 1 and 2).

3 Material

To carry out the experiment, composite samples from the treatment plant unit were required, including effluent from secondary clarifiers as well as influent to the treatment plant and effluent from an aeration tank (which was referred to as influent of the treatment plant). The samples were examined using the APHA, AWWA, and WCF 1998 Standard Methods. The physical, chemical, and biological characteristics of the effluent were all covered by the secondary parameters MLSS and SVI. The main variables were pH, temperature, total suspended solids (TSS), dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD5), and chemical oxygen demand (COD). The pH was determined using a pH meter.

3.1 pH

The pH of the solution describes the hydrogen ion's actions where it is the reciprocal logarithmic of concentration of the ions in hydrogen. A digital pH meter is used to calculate the pH of the sample at STP. Using pH paper or a colour comparison with

Fig. 1 Location of the study area

Fig. 2 NIT Hamirpur WWTP site

different indicators like methyl orange, phenol red, methyl violet, methyl red, etc., the course of action is assessed.

3.2 Techniques for Identifying Solids in a Wastewater Sample

The sample is evaporated and dried in an oven at a specified temperature (103–105 °C), leaving behind the solid. The phrase includes non-volatile (inorganic), volatile (organic), no filterable, and filterable substances. Overall for Solids Before evaporation, the provided sample is filtered to extract the dissolved solids [6]. Residue in suspension is filtered out and collected. The remaining portion of the evaporated sample is represented by the fixed residue following hourly combustion (total solids). This can be achieved by evaporating dishes made of glass, silica, and porcelain, as well as drying them in the oven.

4 Explanation of the Research Area

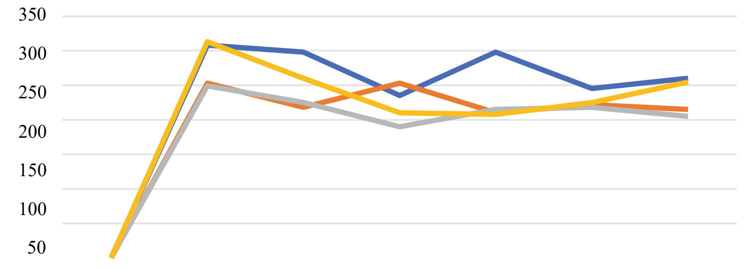
The study's selected area for the domestic sewage treatment plant is NH3 Hamirpur, which is outside of the NIT Hamirpur campus. The sewage treatment plant can handle 0.27 MLD, 3.13 MLD, 1.35 MLD, and 0.67 MLD at NITH, Zone-I, Zone-II and Zone-III respectively. The treatment plant's inlet and outlet are where the sample is taken. Testing was conducted for about six months on a weekly basis (Jan-June).

4.1 Month-Wise Data Analysis of WWTP

Weekly wastewater samples from the treatment facility were taken, analysed, and compared. As seen in the table below, trends reveal declining pH, TSS, BOD, COD, and rising DO levels [7].

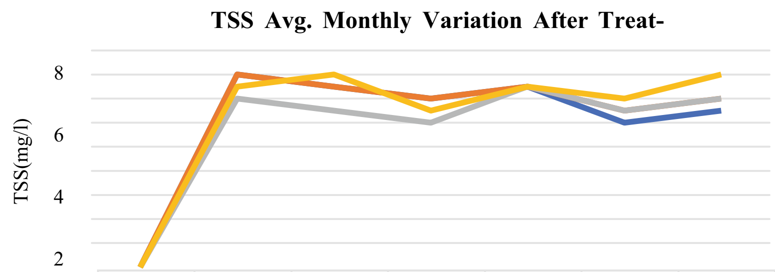
4.2 Displaying the Average Value of Different Parameters Before and After Treatment

See the Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13.



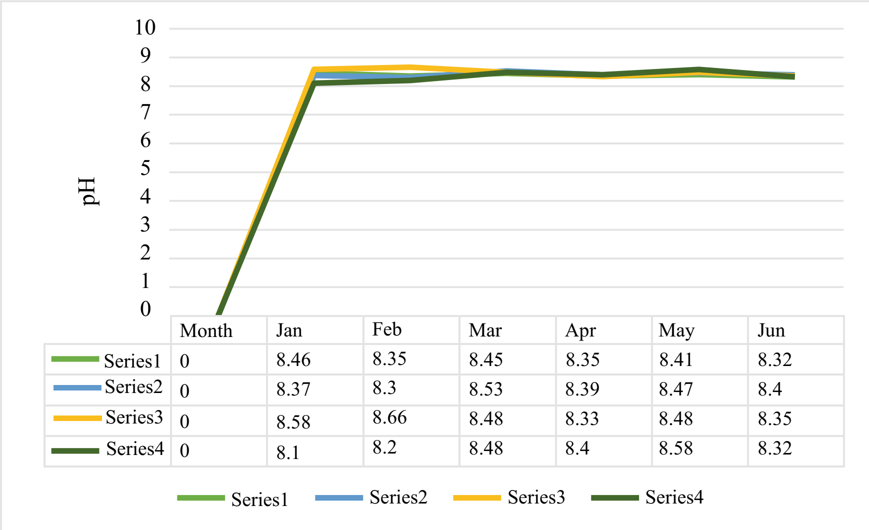
	Month		Jan	Feb	Mar	Apr	May	Jun
Series1	0		308	298	235	298	245	260
Series2	0		253	218	253	210	222	215
Series3	0		249	225	190	215	218	205
Series4	0		313	260	210	208	225	255

Fig. 3 TSS Avg. monthly variation before treatment (Series 1, Series 2, Series 3, Series 4 representing here Zone-I, Zone-II, Zone-III, NITH)



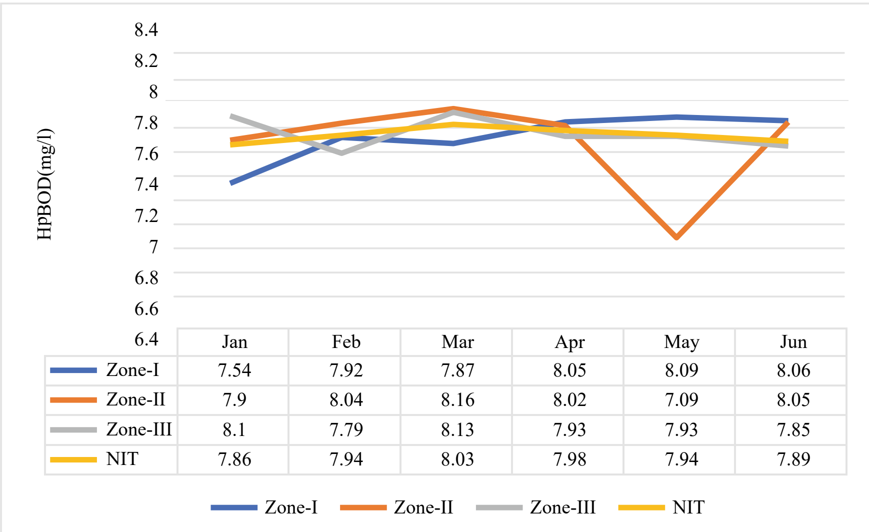
	Month	Jan	Feb	Mar	Apr	May	Jun
Series1	0	16	15	14	15	12	13
Series2	0	16	15	14	15	13	14
Series3	0	14	13	12	15	13	14
Series4	0	15	16	13	15	14	16

Fig. 4 TSS Avg. monthly variation after treatment (Series 1, Series 2, Series 3, Series 4 representing here Zone-I, Zone-II, Zone-III, NITH)



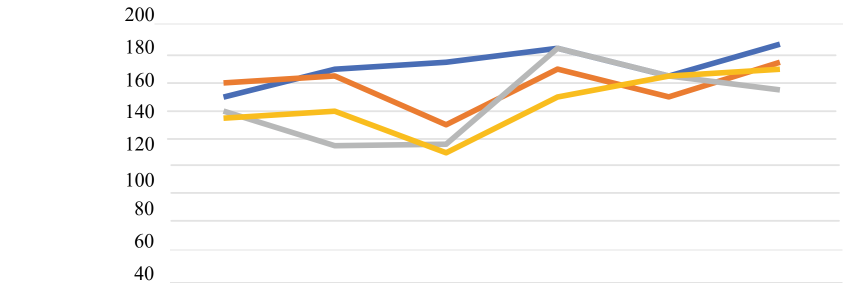
	Month	Jan	Feb	Mar	Apr	May	Jun
Series1	0	8.46	8.35	8.45	8.35	8.41	8.32
Series2	0	8.37	8.3	8.53	8.39	8.47	8.4
Series3	0	8.58	8.66	8.48	8.33	8.48	8.35
Series4	0	8.1	8.2	8.48	8.4	8.58	8.32

Fig. 5 pH Avg. monthly variation before treatment (Series 1, Series 2, Series 3, Series 4 representing here Zone-I, Zone-II, Zone-III, NITH)



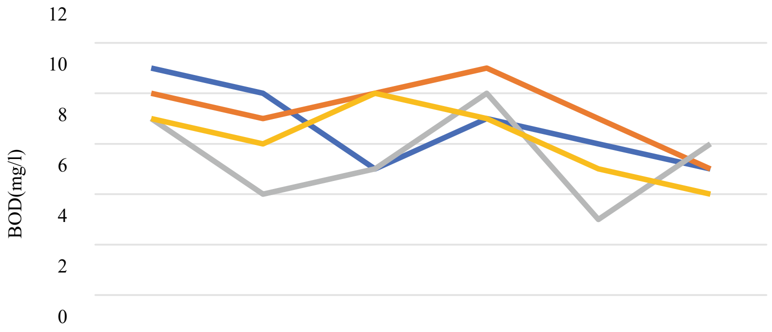
	Jan	Feb	Mar	Apr	May	Jun
Zone-I	7.54	7.92	7.87	8.05	8.09	8.06
Zone-II	7.9	8.04	8.16	8.02	7.09	8.05
Zone-III	8.1	7.79	8.13	7.93	7.93	7.85
NIT	7.86	7.94	8.03	7.98	7.94	7.89

Fig. 6 pH Avg. monthly variation after treatment



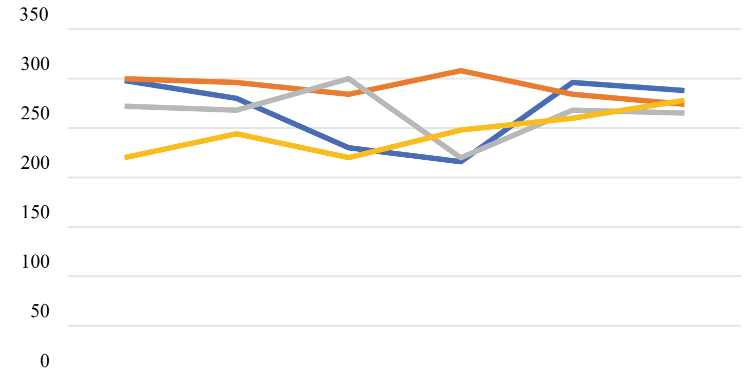
	Jan	Feb	Mar	Apr	May	Jun
Zone-I	150	170	175	185	165	188
Zone-II	160	165	130	170	150	175
Zone-III	140	115	116	185	165	155
NIT	135	140	110	150	165	170

Fig. 7 BOD Avg. monthly variation before treatment



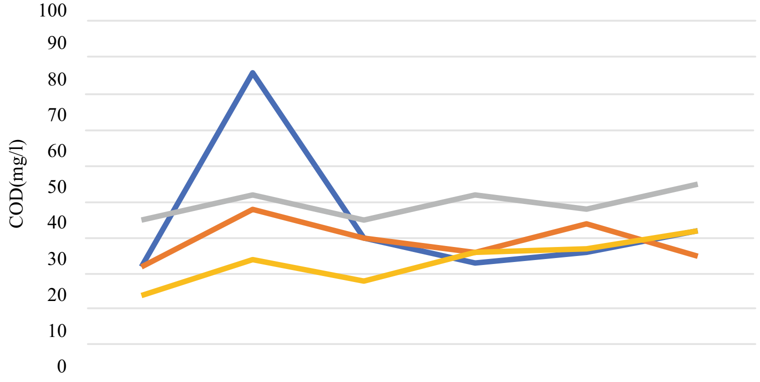
	Jan	Feb	Mar	Apr	May	Jun
Zone-I	11	10	7	9	8	7
Zone-II	10	9	10	11	9	7
Zone-III	9	6	7	10	5	8
NIT	9	8	10	9	7	6

Fig. 8 BOD Avg. monthly variation after treatment



	Jan	Feb	Mar	Apr	May	Jun
Zone-I	298	280	230	216	296	288
Zone-II	300	296	284	308	284	274
Zone-III	272	268	300	220	268	265
NIT	220	244	220	248	260	278

Fig. 9 COD Avg. monthly variation before treatment



	Jan	Feb	Mar	Apr	May	Jun
Zone-I	32	86	40	33	36	42
Zone-II	32	48	40	36	44	35
Zone-III	45	52	45	52	48	55
NIT	24	34	28	36	37	42

Fig. 10 COD Avg. monthly variation after treatment

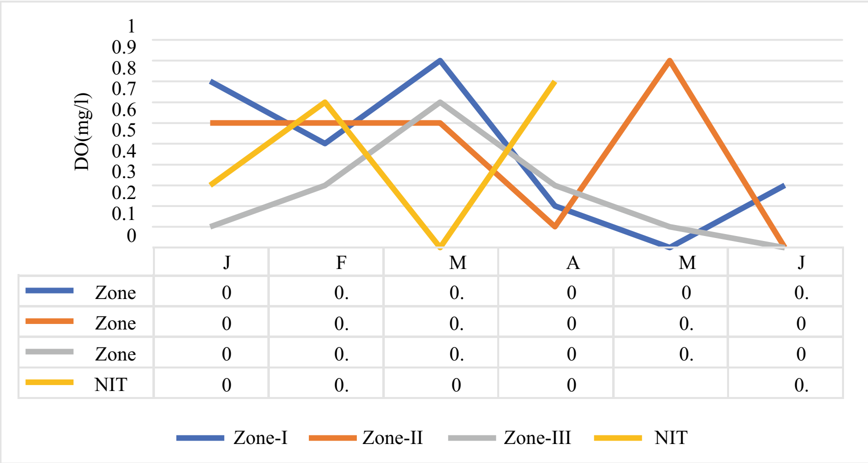


Fig. 11 DO Avg. monthly variation before treatment

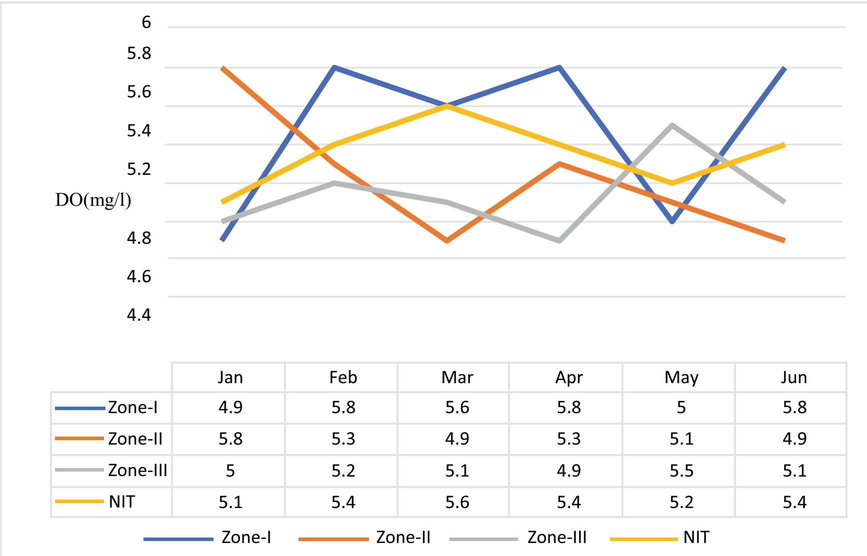


Fig. 12 DO Avg. monthly variations before treatment

5 Result and Discussion

5.1 Effluent Characteristics and the Success of Treatment

This study examined the parameters of the Hamirpur Campus sewage treatment plant, which include pH, DO, TSS, BOD, and COD, both before and after treatment. Before and after treatment, the average reductions were in pH, TSS, BOD, and COD.

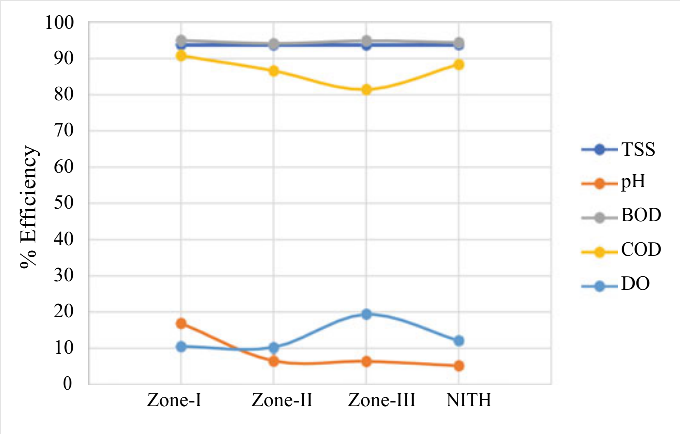


Fig. 13 Percentage efficiency of parameters

Following the therapy, the DO value rose by 12.04, 19.32, 10.21, 10.46 (Tables 1 and 2).

Table 1 Average parameter values before and after the treatment of four different plants are shown below and show the permissible limit as per CPHEEO1993 [8]

Parameters	Before treatment				After treatment			
	Zone I	Zone II	Zone III	NIT	Zone I	Zone II	Zone III	NIT
TSS	274	228.5	217	240	12.16	14.5	13.5	14.8
pH	8.39	8.41	8.475	8.36	6.98	7.87	7.94	7.94
BOD	172.2	158.33	146	145	8.67	9.33	7.5	8.17
COD	268	291	265.5	245	44.83	39.16	49.5	33.5
DO	0.45	0.46	0.25	0.41	5.61	5.16	5.13	5.35

Table 2 Efficiency in % for different parameters for four treatment plant

Parameters	% Efficiency				Permissible limit
	Zone-I	Zone-II	Zone-III	NIT	
TSS	94.83	93.65	93.77	93.82	6.5–8.5
pH	16.80	6.42	6.31	5.08	4.8 mg/l
BOD	94.96	94.1	94.86	94.36	<30 mg/l
COD	90.73	86.54	81.35	86.32	<250 mg/l
DO	10.46	10.21	19.32	12.04	<100 mg/l

6 Conclusion

The major conclusions were observed from the case study as discussed below:

- The value of DO percentage increased by 12.04, 19.32, 10.21, 10.46 in Zone- I, Zone- II, Zone-III, and NIT respectively after treatment when compared to the initial value.
- Bacteria and other microorganisms actively participate in wastewater at pH levels ranging from neutral to slightly alkaline i.e.,7 to 8. In the present scenario, Zone-I had more variation in pH as compared to the other three treatment plants due to variation in more active microorganisms present at Zone-I.
- TSS removal efficiency of Zone-I was higher when compared to other treatment plants.
- From January to July, trends in the wastewater samples from the WWTP showed a drop in the pH, TSS, BOD, and COD levels and an increase in the level of DO. According to experts, the treated effluent can be utilized to re-irrigate a golf course, greenway, park, or groundwater recharge. It can also be safely dumped into streams, rivers, bays, lagoons, or wetlands.

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A Paradigm Shift in Municipal Solid Waste Collection Containers and Vehicles in Urban Areas

Deval Singh, Anil Kumar Dikshit, and Sunil Kumar

Abstract The rapid increase and mismanagement of municipal solid waste (MSW) in developed and developing countries lead to environmental pollution. MSW at its initial stage can be easily converted into value-added products through an integrated approach of recycling, reuse and recovery (3R). Worldwide numerous efforts have been made to develop a systematic collection scheme using advanced integrated technologies. This paper aims to discuss the challenges and advancements in existing collection containers (household, community, and smart containers) and technological intervention in vehicle systems (front, rear, side-loading mechanism) preferably used for MSW management. The study is based on three major aspects, i.e., availability of technical resources and consumer acceptance, cost-effectiveness to manage the process, recent up-gradation and advancements. It reveals that the collection vehicles with the rear, front and side-loading lifting mechanisms are most commonly preferred in developed countries, comprising broad alleys, streets and well-planned city infrastructure. However, the handheld manual equipment (handcart and tricycle) and heavy duty vehicles (dumper/mini trucks) are primarily preferred in developing and less developing countries. The applications and working principles deliberated in this study will provide a valuable resource for researchers and policy makers to design and develop existing collection tools and technologies depending on the country's infrastructure development, social and economic status.

Keywords Municipal solid waste · Collection containers · Vehicles · Lifting mechanism · Resource recovery

D. Singh (✉) · A. K. Dikshit
Environmental Science and Engineering Department, Indian Institute of Technology Bombay (IITB), Powai, Mumbai 400076, Maharashtra, India
e-mail: devsiingh99@gmail.com

S. Kumar
CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur 440020, Maharashtra, India

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_10

1 Introduction

The collection of MSW has been considered an underrated and critical process to transform MSW into a resource [1]. The collection process can be called an intermediate facility between the MSW generator and the treatment/disposal facility [2]. The primary role of any collection scheme involves the efficient collection, segregation, preprocessing, handling, resource recovery, and safety for public health. The complete process demands higher capital investment and operational cost, followed by on-field operational difficulties. Apart from this, the present collection method is associated with different categorical problems such as handling, management, low recovery of resources, environmental contamination, and lack of appropriate technological intervention.

Furthermore, the traditional collection techniques and vehicle systems have caused an increase in fuel consumption rate and labor requirements for MSW management. Due to this, the MSW collection process demands 50% to 70% of the capital investment from the overall MSW management budget [3]. Studies have suggested that failure in these collection schemes can be resolved and managed by conducting self-awareness programs among citizens and facilitators [1, 3, 4]. However, this approach toward the long-term collection of MSW was found to be inconsistent. Therefore, it is essential to rebuild new pillars based on technical, environmental, social, economic, and legal aspects, as represented in Table 1.

Even with an efficient collection scheme, the ultimate success depends upon public participation and continuous technological advancements. To understand the intent of public participation in MSW segregation, Saphores et al. [5] surveyed 110 residents residing in a community [5]. As a survey, colored bins and information broachers were distributed among the residents. The study concluded that only 14% of residents actively segregated their MSW, and 41% have non-segregated their MSW. It was found that the residents' lack of intent and awareness was the major cause of the inefficient segregation of MSW.

In some cases, a lack of management, awareness, and training programs for MSW collectors was predominant, resulting in uneven segregation of MSW by the collector agent. In many developed countries, citizens are charged based on the quantity of MSW generated and this concept of unit pricing has forced the citizens to segregate their MSW as per the required standards. However, developing countries have failed to adopt this unique concept of unit pricing due to social acceptability, political issues, illiteracy, lack of technology, etc. Owolabi et al., (2016) suggested that the informal sector's collection and segregation of MSW are primarily predominant in developing and less developed countries [6]. Informal sectors include various categories, i.e., rag pickers, field workers, local vendors, recyclers, etc. Among all the categories, the community of ragepickers plays a vital role in the collection and segregation of MSW. They effectively segregate recyclable materials (plastic bottles, plastic bags, metals etc.) from dumpsites. The unhygienic condition is a significant concern for rag pickers deployed at such dump sites. There are no such feasible field-scale devices and technologies which these informal sectors can adopt for efficient collection,

Table 1 Pillars for sustainable collection of MSW [4]

Role	Aim
Technical	• The collection process highly influences the treatment technology. The technique used in the collection and pre-processing might lead to changes in the property of MSW. Therefore, it is essential to pre-process MSW depending on its physical and chemical properties • For example, pre-processing techniques, such as compaction can be used for dry MSW collected from residential areas and transported to their respective treatment facilities • Areas with less population should have efficient segregation techniques to motivate effective recycling and reuse
Environmental	• Modification in technology to reduce fuel consumption rate. Implementation of alternate technology for on-site recovery of value-added products from MSW • During the transportation of MSW, a vehicle system designed with an optimum routing technique might reduce the greenhouse emission caused by fossil fuel burning • An action plan to overcome the open dumping of MSW which can reduce air, land, and water pollution
Social	• Active participation of citizens to segregate MSW from the source • Effective awareness programs through digital media, rallies, street plays, etc • MSW management scheme for a particular city/town must create a wide range of job opportunities with initial training sessions
Economic	• Overhead fuel, maintenance and labor cost have to be recovered by collection fees paid by the citizens • The existing management scheme should be reliable to generate revenue from MSW
Legal framework	• Action plan to implement solid waste management (2016) rules and regulations • Revisions in policy and legal framework have to be implemented based on the necessity of the existing collection scheme and the overall budget allocated

segregation and transportation of MSW. However, the present review might motivate researchers, policymakers and industrial experts to overcome the issue pertaining to MSW management.

2 Role of Collection Containers in Handling and Transportation of MSW

MSW collection containers are intermediate facilities that allow waste storage at the household or community level before being transferred to processing and recycling facilities [7]. Collection vehicles are used to collect these containers either door-to-door or at collection points. The recycling process and uneven dumping at landfill sites can be improvised using different household or community container categories [7]. The collection containers are designed beyond their prescribed limit to avoid storage shortages [8]. Various types of container and collection technology have been developed in the past few decades, which has been discussed in this section.

2.1 Household Containers (HC)

It is a temporary MSW storage facility used at household, commercial and institutional levels, such as apartments, bungalows, rowhouses, schools, and other public places [9]. It is also known as manually operated containers. In the case of private living space, the container is manually handed over to the collector agent by the individual (waste generator). These containers are categorized as plastic bags, paper sacks, lifting bins, and bins with 2- and 4-wheels. The primary objective of such containers includes the collection of MSW on a daily or weekly basis.

The container with 2-wheels is lighter in weight and can be operated manually without any physical effort; preferred for in-house storage of MSW. The 4-wheels containers are difficult to manage as they are made of metal and plastic. Due to the higher carrying capacity and brake system, they are used on streets and sidewalks. Classifying containers based on their application is essential as it helps in reducing collection time, physical efforts, and fuel cost (caused due to halting of the vehicle). Collection vehicles are generally designed with automatic and manual container lifting mechanisms. In developed countries, collection vehicles with automated mechanical lifters are mounted on the rear-end to collect MSW from 2- and 4-wheel containers. Therefore, the container and vehicle systems are modified with a U-shaped lifting edge and arrest bars (upward moving bars) to lift the container. While in developing countries, collection vehicles with the manual lifting of containers are practiced. The vehicle system with no mechanical lifting of waste may cause direct exposure of hazardous to waste collectors [10] and inappropriate dimension for the container leads to extra physical efforts.

Developing countries like India have also preferred source segregation as an integral part of MSW collection. Ministry of Environment, Forests, and Climate Change (MoEF&CC) revised SWM rules (2016) with strict norms for collecting segregated MSW. As per the rules, the individual can be spot fined for littering and non-segregation of MSW. Therefore, the MoEF&CC has introduced the concept of 2 or 3-way containers (green, blue, and black coloured containers) to collect wet (kitchen waste), dry (paper, plastic, cardboard, rubber, and garden waste), and hazardous waste (E-waste, biomedical waste, bulbs, etc.) generated from residential areas. In countries with low population growth rate, the concept of 2-way containers across the streets or pedestrian pathways motivated citizens to avoid littering and open dumping of MSW. Some countries also prefer container applications with special inlet provisions, which only collect specific MSW, such as paper, plastic, and glass [9]. In some cases, single container volumes were divided into dual compartments (ratio of 50%-50% or 50%-40%.) to collect wet and dry waste separately.

The critical aspect of such practices was to involve public participation and spread social awareness among citizens. However, most Asian countries like India have failed to motivate citizens to participate in such practices. Influencing factors, such as literacy rate, living standard, stringent SWM policy, and social awareness must be considered while designing a collection scheme. The detailed application, capacity and specification for household containers have been discussed in Table 2.

Table 2 Different categories of household containers [9]

Types of containers	Application	Capacity (L)	Specifications
Plastic bags	Household	60–150	• The thickness of the bag is 0.06–0.08 mm • Polyethylene (PE) is used for manufacturing and is more suitable for incineration when compared with plastic bags made with polyvinyl chloride (PVC)
Paper sack	Household, commercial, and institution infrastructure	250	• Decomposable and eco-friendly • The quantity of MSW collection is higher compared with plastic bags • Not suitable for high-rise buildings as it requires a particular mechanism of janitors • Not ideal for pointed and sharp waste such as broken glass
Containers without wheels	Household	20	• Primarily suitable for residential houses
Container with 2-wheels	Household	400	• Not suitable for the large quantity of wet waste • Bottom-end wheels act as a stand that has to be tilted while unloading MSW
Container with 4-wheels	Household	400–1000	• Suitable for large quantity waste comprising of both wet and dry waste • Brake arrangement is required as the bins are placed near the streets or sidewalks
2-way container	Community	400	• Used to separate wet and dry waste
Small container for recyclable MSW	Community	660	• Segregation of recyclable MSW such as paper, plastic, glass etc. • Inlets are designed to collect specific MSW (paper, plastic, etc.)
Larger container for recyclable MSW	Community	2000–3000	• MSW is directly transferred to the vehicle with the specialized front-loading mechanism
Stationary container	Community	2000–12,000	• MSW is directly transferred to the vehicle with a specialized front-loading mechanism • Vehicle hydraulic mechanisms are used to lift the container

2.2 Community Containers (CC)

These types of containers are placed at the community level for a common group of residents in a particular area. Therefore, it is also known as stationary containers. It has a carrying capacity of 2 m3 to 12 m3, installed for >1000 residents residing in a colony (Nilsson, 2010). These containers are heavier and more durable than household small-size containers. It can be further classified as open-top, closed-top, heavy-duty, compactor, tanker, and compartment containers. The containers are designed for vehicle pick-up and drop systems. It can be moved using specialized vehicle lifting mechanisms. Generally, the containers are lifted and emptied using extended steel sleeves (along the lateral sides) by the front-loading vehicle system [5]. At the same time, the closed lid container hinged to the vehicle system opens automatically at a tilted angle of ~1350. The container comprises hinges attached to the extended steel sleeves with a front slope of 450. The hinges get coupled to the vehicle tailgate during the lifting mechanism, allowing the container to be raised vertically onto the top of the vehicle body. In some cities, hydraulic operated arms are preferred for containers exceeding 800 L capacity [9]. Recently modified vehicle frameworks comprise a cable winch that lifts the container and transfers its load onto the chassis. Containers are designed on a standard framework to make them compatible with vehicle frames, chassis, cables, and container hook. Besides this, it also requires a specific dimension of 2.5 m in height and 6.5 m in length [9]. MSW unloading is performed using the hinged tailgate mounted on the container, followed by a container tilting angle of 500 to 600 [9]. Recently modification comprises of electrically powered screw-compactor within the container system. The mechanized hydraulic push panels are installed inside the container, which can push the compacted waste outside the free zone [9]. However, the application of such an advanced container system is still less in most developing countries. The on-site application of different community container systems has been discussed in Fig. 1.

Some developing countries have managed to separate value-added recyclable matter by compartmentalizing containers. These containers allow a separate collection of injuries components, such as glass (broken pieces, bottles) and metals, which can be re-melted, reused, recycled, and refilled. The containers designed for regular MSW collection are incompetent to collect glass waste as this might cause damage to the truck container. Therefore, a separate open truck container with different compartments is preferred instead of a container used for commingled MSW. The containers with excess weight can be emptied using a hydraulic crane to transfer the waste from one container to other by gentling rolling it down from a minimum height [10]. Besides this, specially designed polyethylene containers (2 m^3) with a hinged flap, bottom opening and telescopic mechanism are used for glass, paper and plastic collection [9]. The container's inner part comprises a telescopic tube connected to the bottom and a lifting ring at the top. The mechanism to operate the crane and hook arrangement is to lift the container by using a ring at the top.

The less availability of space along the streets and curbs has caused significant concern in old cities and towns. Therefore, underground and semi-underground

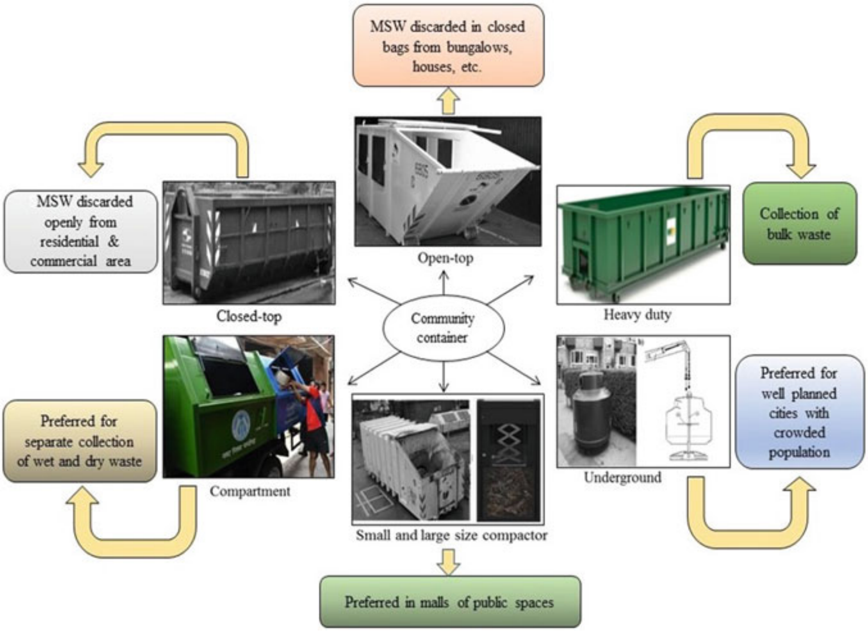

Fig. 1 Classification of collection containers based on their applications

containers are primarily preferred in European countries. Nowadays, these types of containers are used with the metal platform and inlet chute. The container is specified with the bottom opening to collect MSW and a crane mechanism with an electro-hydraulic platform to lift the container. In the late 1990s, Molok system was introduced to collect MSW. It is a cylindrical container installed underground for a community or a society. The bottom opening of a tank is restricted by a rope arrangement for MSW collection into the vehicles [9]. It also comprises of a side lining made of plastic used to lift and empty the container. The vehicle crane is used to lift the container, and the rope's bottom opening is opened over the vehicle container. The system was low in maintenance, capital cost and flexible to implement along the rod sides, industries and township [11]. However, the system was found to be less feasible with respect to changes in the characteristic of MSW, resulting in leakage due to wet MSW. The recently developed underground container systems are leak-proof and compact. In contrast, the newly developed underground container lifting and dropping mechanism have been more compatible than Molok.

2.3 Smart Container Technology (SCT)

An efficient collection system should prevent unnecessary collection costs and the overall budget of MSW management [12–14]; this demands an optimum number of vehicle counts and short routing system [12, 15]. This helps develop a flexible and reliable communication system between waste generators and collector agents. However, it can be achieved by Internet-based waste collection services (IB-WCS), which comprise of artificial intelligence (AI), geographical information system (GIS), global positioning system (GPS) and information communication technology (ICT) based system [12]. The integration of IB-WCS has enabled cost-effective monitoring, tracking and collection frequency of MSW. In most developed countries, private agencies and MSW management companies have developed cost-effective software tools to collect MSW from city areas.

3 Technological Advancements in Collection Vehicles

The primary module for a collection vehicle is to collect MSW from different container types and transport it to their respective processing facilities [16]. The aim is to reduce the collection time and avoid hazardous exposure to residents, field works and environment [16]. Payload and axel load are two types of loads that act on vehicles [10]. The chassis of a truck is the most crucial component for vehicle designing, which is based on gross vehicle weight (GVW) [10]. The components such as suspension, braking system, speed limit, and tires are dimensioned based on GVW [11]. As per the design standards of the European Union, GVW ranges from 3.4 tonnes to 35 tonnes; in some cases, it might exceed more than 35 tonnes [17]. The technical design load for truck axel with four wheels and frontal axel with two wheels should not exceed more than 13 tonnes and 10 tonnes, respectively. The addition of the third and fourth axel in-vehicle system might increase GVW, and excess weight can be managed [17]. However, GVW must be kept below the design limit to prevent pavement damage. In most developing countries, if the design limit is 11.5 tonnes, the vehicle is designed for only 10 tonnes, preventing pavement damage [17]. Nowakowski et al. (2020) suggested using electric vehicles instead of conventional petrol/diesel vehicles as it reduces air pollution and the cost of MSW collection [12]. Vehicle manufacturing industries have transferred their focus toward compatible E-vehicle design [18, 19]. The present section discusses different MSW collection vehicle along with its applications and design specifications.

3.1 Rear-Loading Vehicle System

It is one of the most common vehicle systems used across the globe [16, 20]. The design component includes the vehicle body, compaction, and lifting mechanism [16, 20]. The vehicle system can lift 120 to 1700 L capacity bins placed across the streets [20]. The classification of rear-loading vehicle systems based on their capacity has been discussed in Table 3. [8, 9, 12]. The vehicle body's comprises of an ejector panel which can be moved back and front (front to rear end). It has an average compaction rate of 0.6 tonnes per m^3, the control compaction can maintain a waste of 0.8 to 0.9 tonnes per m^3 [20]. The operational tools for the ejector, compactor, and lifting bin are powered by a hydraulic system [10]. During MSW loading, an ejector panel is placed at the back end (rear end) of the body, which implies counter pressure on waste pushed through the tailgate [16, 20]. Simultaneously MSW quantity inside the vehicle increases, which leads to displacement of the ejector panel to the frontal end through the push-in hydraulic cylinder [16, 20]. This process allows the vehicle body to retain maximum compaction and net load. Similarly, MSW unloading implies the tailgate's horizontal opening and displacing the ejector panel to the rear end through a push-out hydraulic cylinder globe [9, 20].

Nowakowski et al. (2020) suggested using a rear-loading vehicle with GVW up to 3.5 tonnes for areas with narrow collection lanes. Table 4 represents the vehicle standards as per their axel type [12]. The parameters include GVW, payload volume, fuel consumption rate, power capacity, workers per vehicle, and shifts for better design and application of vehicles in the collection.

Table 3 Classification of rear-loading vehicle system based on its capacity [8, 9, 12]

Author	Classification	Capacity (m^3)	Specification
SBM, (2020)	Small	5–6	4.5–5.5 tonnes/trip
	Medium	8–10	7–7.5 tonnes/trip
	Large	12–16	10–12 tonnes/trip
Nilsson, (2010)	Small	5–6	Used in narrow streets and alleys
	Medium	12	Skip (large open-top) containers are preferred
	Large	20–22	GVW of more than 25 tonnes
Nowakowski et al., (2020)	Small	10–15	GVM of 3.5 tonnes and used for narrow lanes
	Large	17–23	It consists of a hydraulic arrangement, which is preferred in suburban areas

Table 4 Vehicle standards as per their axel type [12]

Fuel type	Type of vehicle	GVW (tonnes)	Payload capacity (tonnes)	Payload volume (m^3)	Engine power	Fuel type
Diesel	3-axel	16	10,200	23	235	60
	2-axel	19	8140	17	175	45
	2-axel	3.5	360	5.5	107	17
Natural gas	3-axel	26	9500	19.5	250	112
	3-axel	26	8500	18.6	243	84

3.2 Side-Loading Vehicle System

It is an affordable technology built to reduce the labour cost and collection time [10, 21]. It has an automated collection system operated by the vehicle driver and a compactor system placed right behind the vehicle cabin [12]. The dropped MSW is pushed through a back end screw-compactors inside the container system. Ejection panels and tripping of vehicle containers are preferred for unloading. Side swinging arms are used to hold 2-wheel containers (200–400 L) placed near the kerbside, and these containers are emptied and placed back [21]. The operation is monitored by a CCTV camera placed on different sides of the vehicle [10]. Studies have proved that the operational mechanism of the side loading vehicle takes 20 to 30 s per stop. However, collection delays may be caused due to traffic, parked cars, etc. [22]. They are preferred not be used along the narrow streets and kerbs.

3.3 Front-Loading Vehicle System

It is a semi-automated vehicle system [16]. It is mainly deployed for residential and commercial zones with a container capacity of 2 to 10 m^3 [9, 23]. It has a front swinging lifting arm with a forward-pointing fork used for loading and unloading containers [23]. The MSW is unloaded using a horizontal tailgate and ejector panel [23]. The dimension is approximately 9.5 m of length, 4 m of height, 2.5 m of width, 30 m3 of volume, 32 tonnes of GVW and 14 tonnes of payload [12]. They are mostly preferred for the collection of heavy-duty waste (C&D waste), comprising of three to four axel chassis [23].

3.4 Light Motor Vehicle (LMV)—Mini Truck/Open Tractor

LMV-mini truck comprises hydraulic tripping containers with four openings to facilitate the transfer of MSW from primary to secondary collection vehicles. It is used for door-to-door collection of segregated MSW with a road width of less than 5 m [22]. It has a carrying capacity of 0.6 to 0.9 tonnes per trip and a leakproof mild steel body comprising a 1.5 m loading height [22]. It has a special arrangement to remove the central partition so that the segregated MSW can be stored for a specific time. LMV also comprises a special hydraulic tripping mechanism for loading and unloading of waste. As per SBMN, (2017) report, in most developing countries, MSW collection is carried out using open tractors or trucks with a trolley capacity of approximately 5 tonnes, potential to the risk health of field workers and collector agents [22]. Therefore, it is preferred to use LMV with a closed top to avoid the health hazards, foul smell and avail the provision for temporary storage of MSW.

Nowakowski et al. (2020) proposed a mobile E-waste collection vehicle comprising a harmony search (HS) algorithm for optimum vehicle routing [12]. Besides this comparative analysis with an artificially intelligent algorithm was performed to prove its effectiveness. The novel vehicle system was designed for faster collection of E-waste from the vehicle's right, left and rear sides. The trolley of the vehicle can be easily assembled in any other commercial vehicle available in market, similar to the small van, lorry and cargo trucks. The back end of the compartment is supported on a vehicle frame. The left and right sides of the compartment comprise shutters that can be used for waste collection. The inner compartment is feasible enough to rotate and move the waste from left to right based on its space availability. The results of the study proved that the HS algorithm could calculate a higher percentage (1.2% to 6.6%) of collection points compared to the conventional artificial intelligent algorithm. The vehicle system was found to be effective in densely populated cities, reducing parking time.

3.5 Heavy Motor Vehicle (HMV)—Dumper Truck

In many developed countries, the authority manages their MSW collection system by replacing filled bins with empty ones. These filled bins are transported to the transfer station, where MSW is segregated and processed further [21]. HMV such as Dumper trucks is used to carry this bin with overall size ranging from 2.5, 3, 4.5 and 7 m^3 [16]. It also comprises of hydraulic arrangement mounted overhead to lift the filled bins. Dumper trucks can be used to transport construction and demolition waste as their container has a density of 1 tonnes per m^3. It is estimated that dump trucks can serve 6 to 7 trips per 8 h within a radius of 15 km [22].

3.6 Handheld Tools

The tricycle is the most common device used across the city for MSW collection. It comprises 6 to 8 detachable containers with a 40 L capacity each [24]. The capacity varies from 300 to 350 L [24]. These containers are facilitated with latch arrangement to avoid any kind of spillage during travel [22]. It also comprises a special hydraulic tipping container. They are mainly used for door-to-door MSW collection from smaller lanes [22]. Fiagbe et al., (2011) presented a design for a lift-tipping mechanism mounted on MSW collecting tricycle [25]. The design components include a frame, tipping arm, bin, lifting bar and support. The special kinematic linkage chain was developed to connect different components of the tricycle. The traditional tricycle lacked the provision for tripping a container mounted on the back [25], resulting in difficulty in transferring MSW into the vehicle system. The study claimed a 1.2 m container lifting height, 370 tilted angle and 50 kg carrying capacity [25]. The lift-tipping chain is paddled in the reverse direction, allowing container lifting and tipping.

Hand-driven handcarts (two or three-wheeled) are the small-scale tools commonly preferred for door-to-door collection of MSW [24]. It can serve 15 to 20 families per trip [22]. The hands-on tools are mostly used in developing and less developing countries, as they allow easy access to small curbs and alleys. However, the present design and ergonomics of the tools can be modified depending upon environmental conditions, waste type, social adaptability and employers' satisfaction.

4 Conclusions

The collection and transportation encounters to be the major aspect of the MSW management scheme. The continuous increase in urban population has led to the increase in MSW generation growth rate, especially in urban areas. The present study discusses different technological advancements in collection containers and transportation vehicles in the past few decades. The study also aims to highlight transitional shift in traditional bulky collection containers and vehicle systems, which has led to the better recovery and recycling of value-added products from MSW. It has been observed that the application of the smart bins and container lifting mechanism in the vehicle system has led to feasible collection and transportation of MSW in most of the developed countries. However, the developing countries have failed to adopt this transitional shift in collection and transportation of MSW, which has led to the failure of the existing MSW management scheme. It is essential to consider the quantum of MSW, geographical stretch, public acceptance, cost-effectiveness and climatic conditions prior to adopting a collection and transportation technology.

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A Review of the Long-Term Viability of Municipal Solid Waste and the Impact It Has on People

Shrishti Sharma, Rajeshwar Singh Banshtu, and Adarsh Singh

Abstract The socioeconomic effects of improper waste disposal negatively affect society's capacity to effectively manage resources, utilize the land, and safeguard public health. Through the use of sustainable solid waste management, these challenges are tried to be solved. Resource recovery is one of the key objectives of sustainable solid waste management. An integrated trash creation, storage, collection, transportation, processing, and disposal system is known as a solid waste management (SWM) system. Waste is a byproduct of all living things returning substances to the environment; it is an inherent life cycle element. There are raw materials and energy in every commodity and product. We would be wasting precious natural resources if they were thrown away. Consequently, it is essential for sustainable waste management to: • Protect irreplaceable natural resources, • Prevent needless GHG emissions, • Protect people's health and the environment. Due to inadequate collection coverage, a lack of transport services, and a lack of suitable treatment and disposal facilities, inadequate solid waste management puts people and the environment at the danger of air, water, and land contamination [1].

Keywords Municipal solid waste · Environmental sustainability · Solid waste management

1 Introduction

India produces tons of trash each day for various purposes as a developing nation, but the disposal of the waste and methods of disposal so that it does not cause more problems for the next generation are the two fundamental issues. Whenever talking about sustainable waste management, we strive to decrease the quantity of solid

S. Sharma (✉) · R. S. Banshtu · A. Singh
National Institute of Technology, Hamirpur, India
e-mail: 21mce404@nith.ac.in

R. S. Banshtu
e-mail: banshtu@nith.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_11

waste generation disposed of in a landfill or by other waste management procedures like incineration. It also focuses on how the materials can be kept in such a way that they are in use as long as possible. The fundamental tenets of a sustainable waste management approach are polluter pays, producer responsibility, regionalization, prudence, waste management hierarchy, and sustainable development. In addition to improving energy generation, releasing precious land from landfills, generating jobs, and lowering transportation and coordination costs, and sustainable waste management are essential to fostering a healthy natural environment that benefits both human and animal health. In layman's words, sustainable waste management strategies aid in lowering pollution levels, generating energy, and protecting natural resources. The hierarchy of waste management understands that conserving resources and reusing them are the best ways to protect the environment.

1.1 Options for Sustainable Management Solutions

The connection between waste management and sustainability demands support from everyone, from private families to the highest levels of government. What can waste management professionals and local residents do to promote secure, affordable, and eco-friendly methods of garbage collection and processing?

Municipalities: Additionally, local governments have the power to reward or punish those who practice proper trash management. For local governments looking to enhance their recycling programs, the Environmental Protection Agency even provides a toolbox [2]. A city-level strategy is illustrated by the City of Baltimore, which unveiled Mr. Rubbish Wheel, a tool that leverages the river's current to assist it to collect trash in the port (Fig. 1).

Fig. 1 Heirachry of waste mangement. *Source* [3]

Small enterprises: Regardless of how strongly they are committed to the environment, small companies cannot compromise their capacity to make a profit. Therefore, they must continue to employ cost-effective and straightforward trash management techniques. Buildings that have achieved LEED (Leadership in Energy and Environmental Design) certification can be constructed. Other smart suggestions include gathering e-waste, doing an environmental audit, and minimizing single-use plastics. Employees may be able to save money on petrol, lessen pollution, and increase the lifespan of their automobiles with the use of a hybrid work-from-home policy in several fields.

Residences: It takes substantial effort and a shift in behaviour to reduce or recycle such rubbish. But it is possible. Local waste management firms can provide services like safe medical waste removal, recycle-by-mail programs, curbside pickup, recycling services, and simple ways to securely dispose of unwanted items from home improvement projects to make this process easier.

The management of solid waste has received attention from the state and federal governments of India, as well as from local municipal authorities. However, there are other obstacles and challenges that come along with this, some of which can be lack of source collection and separation, a lack of space, the disposal of electronic trash, lack of knowledge, etc. [2].

A comprehensive waste management strategy is also recommended by an author: utilize social scientific and natural science methods to address existing issues while aiming to avoid creating contemporary issues in the future. Since everything utilized in India was earth-based and often biodegradable, garbage was never a problem. They would also consume every last bit of a resource before discarding any inactive items [3].

When talking about waste management, pristine water and security are ossibly the biggest concern. Water contamination is often exacerbated by inappropriate waste management, and especially in larger cities, becomes a critical issue [4].

1.2 Importance of Sustainable Waste Management

- Initially, it creates space Waste that would eventually wind up on land, either dispersed or maybe consolidated in a landfill, if it were never controlled. Landfills are large and may occupy a lot of space. You may need to sustainably manage and limit your trash in some constrained spaces in order to get the most out of it.
- It both produces and saves money. After reusing or recycling a product, we will not need to buy more of the same thing. By not purchasing an item that can be recycled or reused, we will be able to save some money. Additionally, because there would be less waste, the organizations responsible for managing it will not be required to do it constantly. We can reduce our disposal expenses and increase profitability by increasing recycling. In keeping with the idea of money, sustainable waste management can assist some companies in making money.

Municipalities, for instance, might charge fees for collection and recycling in order to generate revenue. Institutions that produce a lot of garbage will be deterred from doing so, making them more environmentally conscious and sustainable.

- It improves sustainability. Sustainability is centered on effectively managing resources including trash, energy, and water. Enhancing our individual, business, governmental, or organizational sustainability may enhance our reputation as people, as people, as companies, as governments, and as organizations, respectively, bringing in higher caliber tenants, clients, and patrons to our operations. It also encourages volunteers, staff, and residents to participate.
- It curbs pollutants. The ecology is impacted differently by each garbage we discard. For example, food waste attracts flies and vermin, while pharmaceutical waste contaminates our water. Sustainable waste management has helped us to understand our junk and how to treat it.
- It is essential to preserving the ecosystem. Human beings are the main threat to the environment. Despite our rapid garbage production, we still have subpar waste management practices. Therefore, the core of environmental conservation is sustainable waste management, as it will both help to maintain and improve the environment, not just for humans but also for other species and future generations.
- It improves us as stewards of the planet and more responsible human beings. In order to thrive, humans need to produce garbage. Therefore, by disposing of our waste in an intelligent, efficient, and sustainable manner, sustainable waste management will help us become better, more accountable members of society. This opens the door to the creation of modern technologies, enhanced waste disposal techniques, and appropriate replacements for each form of rubbish. Composting food scraps and fruit waste, recycling plastic, and burning paper are just a few alternatives to putting everything in the trash (Fig. 2).

2 Impacts on Health

Illegal trash shipments and poor waste management can harm the environment and the general people. Sustainable waste management will help us become better, more responsible members of the society by helping us manage our rubbish in an intelligent, efficient, and sustainable manner. As a result of garbage leaks, contaminants such heavy metals and persistent organic pollutants (POPs) may be discharged into the atmosphere, harming human health. These pollutants may also pollute soils and water streams. Additionally, uncontrolled, or poor waste management results in local problems that may have a negative effect on the community's residents, such as landscape deterioration, local water and air pollution, and littering. Therefore, it is crucial for health reasons to manage trash effectively and environmentally soundly. Landfills and incinerators are frequently utilized to manage the last stage of garbage disposal despite the rising number of recycling initiatives. As a result, the majority of the evidence in the literature is for these plants.

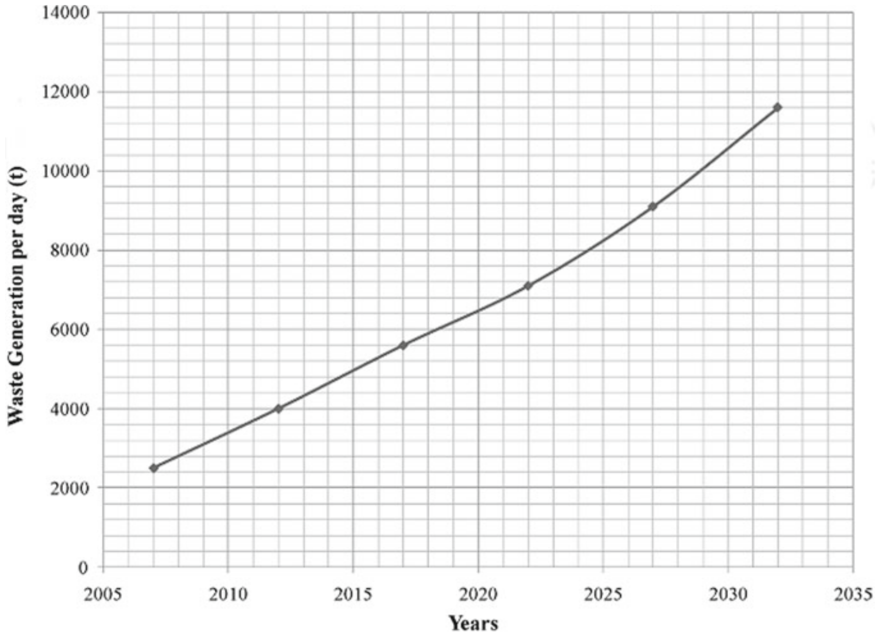

Fig. 2 Waste quantity expected for next 20 years. *Source* [11]

As discussed in the above paragraph about landfills and incinerators, commonly used to manage the municipal solid waste but little did we know that they have enormous impact on the health of human beings.

Systematic reviews have compiled the results of several studies on the potential health implications of living close to landfills. They primarily involve cancer and the results of pregnancies; more recently, respiratory disorders and irritation were also examined. (*Waste-Human-Health-Evidence-Needs-Mtg-Report*, n.d.). Numerous studies found correlations between exposure to odorous disposal sites, such as landfills, and population complaints including noise and other annoyance-related issues and non-specific respiratory ailments [1, 5, 8]. Non-Hodgkin lymphoma and other cancers have been linked to increased risk, but the total body of information is insufficient to draw clear conclusions. The most current evaluations [10] a significant research done in England that was mostly responsible for reaching this result [9]. Both previous and more contemporary investigations revealed negative impacts for hazardous waste, but when just urban solid wastes are considered, this becomes less evident. The most recent study has focused on health impacts that are less severe but have a greater overall impact since they are more prevalent in the exposed population.

Since the beginning of time, emissions from incinerators have changed significantly. This involves shifting health consequences, and it is challenging to articulate broad concerns for the health implications. The majority of research examining the health impacts of incinerators operating between 1969 and 1996 have found a measurable risk of certain malignancies in the local population, according to various evaluations of the relevant literature. A quantitative estimates of the increased risks of all malignancies, as well as stomach, colon, liver, and lung cancer, among populations residing close to solid waste incineration operations [6]. Other research studies show some intriguing but inconsistent findings for non-Hodgkin lymphomas and soft tissue sarcomas (Ranzi et al. 2011; Zambon et al. 2007; Comba et al. 2003). Several research studies also looked on congenital abnormalities. Particular focus has been placed on the elevated risk of urinary tract abnormalities. Despite the fact that the recent study offers added information on this finding, the findings regarding the effects on kids' or adults' respiratory health, whether chronic or acute, remained unclear.

3 Conclusion

The main cause of the rise in the output rate of municipal solid waste is population growth. However, the ordinary individual is also producing more trash on a daily basis. Waste discharge serves as a reflection of people's lifestyles and social interactions. As more people have become dependent on others for needs like food and services and as people have begun to value leisure time and convenience, the demand for packaged goods has soared. If source reduction does not begin, the production of municipal solid trash will keep rising. District to district and season to season, there are different garbage dumping methods. The features of municipal solid waste are influenced by the climate, social norms, per capita income, amount of urbanization, and industrialization. Waste production is often higher in urban than rural settings. Low production of organic material, ash, pottery, etc. is seen in high economic level societies [6, 7].

There is no denying that municipal solid wastes are a growing social and environmental burden worldwide. The public in many countries has been alarmed by reports of the short- and long-term environmental effects of the handling of solid waste in the past. The public's worries have made it extremely harder to locate new, suitable locations for landfills or incinerators. Environmental experts disagree with this notion in light of public health and the limited availability of natural resources. We must thus produce appropriate, secure, and cost-effective solutions. With regard to both our everyday lives and our industrial endeavours, waste discharge is unavoidable. Consequently, in order to preserve our comfortable living environment, it will be our external responsibility to provide adequate and efficient Garbage collection, transport, preliminary processing, recycling, and disposal. In order to limit the entire negative consequences of waste management on the environment, such as energy consumption, contamination of the land, air, and water, and loss of amenity, alternatives and their integration should be used in waste management systems. While it may seem like a pipe dream, true sustainability can only be achieved with total cooperation at all levels of government. All waste types should be managed in order to integrate them into the economy in order to achieve sustainable waste management, including sewage sludge, industrial, agricultural, and demolition wastes. This demonstrates that waste management is a political and economic issue in addition to being a technical one.

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Experimental Investigation on Cement Bricks Using Glass Powder as a Partial Replacement for Fine Aggregate

Pamu Yashwanth, Alugubelli Sanjana, K. Srujan Kumar Reddy, K. Akshitha Nived Sagar, and R. Kiran Kumar

Abstract In recent years, waste materials have been utilized in construction projects more frequently since they do not compromise the short- or long-term properties of concrete, which also provides a platform for their proper disposal. Glass waste powder is one of these things. Glass is indeed an inorganic fusion material which hasn't crystallized after being frozen to a hard state. Every year, millions of tonnes of waste glass are generated around the world. Glass debris is typically disposed of in landfills, which is not sustainable because silica does not decompose. To contribute to a more sustainable environment, our research attempted to use glass in the form of glass powder in the production of cement bricks. Glass powder in percentages of 2%, 4%, 6%, 8%, and 10% as a partial replacement for fine aggregate by weight was used to produce the bricks. The mechanical properties of hardened cement bricks, such as compressive strength and water absorption tests were studied. It was found that compressive strength and water absorption increased with an increase in the percentage of glass powder. Compressive strength enhancement is a desired characteristic for bricks, but an increase in water absorption may be recommended if it is within the permissible limits.

Keywords Inorganic fusion product · Sustainable environment · Glass powder · Quarry dust · Mechanical properties

1 Introduction

Waste is a major environmental concern in developing countries like India. Most municipalities dump 95% of their waste on the land, with the remaining 5% being used as an alternative approach. Particularly, glass trash is growing at a pace of 2–4

P. Yashwanth (✉) · A. Sanjana · K. Srujan Kumar Reddy · K. Akshitha Nived Sagar
Department of Civil Engineering, CVR College of Engineering, Hyderabad 501510, Telangana, India
e-mail: yashwanthpamu@gmail.com

R. Kiran Kumar
Lecturer in Civil Engineering, Government Polytechnic Nalgonda, Nalgonda, India

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_12

tonnes each year. Glass debris is a non-crystalline and non-biodegradable component that contributes to landfill hazards. However, those materials contain glass transformation states, which aid in the reversible change of amorphous substances into a molten state from a hard, generally brittle state. High demand exists for glass as an alternative material. Housing is in increased demand in India. The massive increase in construction activity throughout the years has made housing a major concern in today's society. The most basic building material for house construction is the traditional burnt clay brick. A brick is a type of building material that is composed of clay and is fired in a kiln. Nonetheless, this brick is created locally and has been promoted all over the world due to its ease of availability and inexpensive cost. Fired clay brick has been regarded as one of the strong and most durable building materials, manufactured from locally available clay and used throughout history. But due to the rapid increase in construction activities, the requirement for clay has also increased. Clay is a naturally available scarce resource, overexploitation leads to harmful effects on the environment. The alternative for fired clay brick is cement brick. The materials used in cement brick are cement, fine aggregate and coarse aggregate. Nowadays due to the unavailability of fine aggregate, quarry dust is used as a substitute. This work checks the feasibility of using glass powder as a partial replacement for quarry dust by assessing the criteria of compressive strength and water absorption, which are crucial for bricks used in buildings. Some of the sand and cement used to manufacture cement bricks were substituted with EFB fibre and SF. The brick samples' compressive strength, density, and water absorption characteristics were examined to establish their suitability for industrial application. There has been independent research regarding the utilisation of SF and EFB fibre in bricks, however, none have combined the two. It is known that brick's compressive strength rises by SF, while it is decreased by EFB fibre. This research looks into whether SF may be utilised to replenish the strength lost as a result of the EFB fibre in bricks. The study concluded that SF was able to restore the mix's decreased strength as a result of the addition of EFB fibre brick made of cement with 10% SF and 20% EFB had a comparable compressive strength (4% greater) to standard cement brick [1]. The physical and mechanical characteristics of solid cement bricks with broken clay bricks as recycled aggregates were investigated. Crushed brick aggregates (CBA) were used to substitute natural fine aggregate, coarse aggregate, or both at 0%, 50%, and 100% by volume. Irrespective of the cement or crumbled brick size amount, the compressive strength of CBA-containing mixtures dropped. The proportion of natural aggregates rising in the mix results in a systematic drop in compressive strength. It was discovered that regardless of the size of the crushed clay brick, the content of crushed clay raised, the solid cement bricks' unit weight decreased, and water absorption rose [2]. Glass powder was employed as a replacement material for fly ash in varying amounts in the study. There were two varieties of Fly ash bricks cast. Boron glass was used for fly ash bricks in the first kind, and soda lime was substituted for fly ash bricks in the second type. The manufactured bricks are cured for 7 days and then dried for 28 days at room temperature. The results of the tests reveal the brick's compressive strength by 20% boron and soda substitution. In comparison to Indian Standards, lime glass powder indicated 6.723 N/mm^2 and 6.150 N/mm^2 respectively. The sorptivity of the brick, bulk density, hardness, efflorescence, initial rate of absorption, and water absorption were all tested by the IS code [3]. The purpose of the research is to see how the compression strength and water-absorbing index of cement bricks are both impacted by sugarcane bagasse ash. Organic ash decreased the bricks' quality by increasing the water-absorbing index and diminishing the compressive strength. It is not suggested to mix unprocessed SCBA with cement bricks. The combination of sandy soil and clayey soil in bricks was unsatisfactory, and their compressive strength was lower than the norms without the inclusion of SCBA. The water absorption results show that adding, SCBA without any treatment amplified the bricks' porosity, but the material's compressive strength stayed within acceptable constraints [4]. The author's objective was to improve brick qualities such as mechanical and chemical characteristics. Adding chopped glass fibre increases compressive strength to some extent while adding more glass fibre diminishes compressive strength. During the first day of drying, the glass fibre securely binds the cement and sand mixture. The load-carrying capacity of the glass-burned brick is also increased by achieving the allowable compressive strength. Because of the utilisation of recycled PVC, manufacturing costs have been decreased, and it does not release any hazardous gases such as Greenhouse gases during production, making it an eco-friendly manufacturing process [5]. The author used cow dung in the bricks to partially substitute cement. Brick made from cow dung is thought to be a green construction material. The bricks are lightweight and environmentally beneficial. The brick produced by partially replacing cement with cow dung had a lower strength. The brick obtained through 10% replacement has been classified as a third-class brick. Cow dung ash can also be used as a replacement for clay. However, due to its poor compressive strength, the usage of cow dung ash with concrete is restricted. After replacing 10% of the cement with cow dung ash, the compressive strength obtained is equal to that of a standard M20 mix after 28 days. Splitting tensile strength and flexural strength were similarly low [6]. The aim of the research is to replace up to 30% of the cement in a soil–cement brick body with eggshell waste as a substitute raw material. The eggshell waste-added bricks had a higher density than the waste-free bricks. The standard bricks have higher water absorption ratings than the bricks made using eggshell waste. The eggshell wastage filler impact, which lowers the cured bricks' open porosity, is mostly responsible for this. The soil–cement bricks' mechanical strength was increased by adding eggshell waste. Eggshell waste was identified as a non-pozzolanic, calcite-rich material through characterization [7]. Cement kiln dust (CKD) is a by-product of the cement production process. Cement kiln dust is a thin powdered substance that resembles Portland cement in appearance. It is made up of micron-sized particles recovered from electrostatic precipitators during the cement clinker production process. According to the Code, the tested bricks' assessed qualities were all satisfactory. Between 59.9 and 213.3 kg/cm^2, the compressive strength was recorded. Directly from 3.8 to 5.9% water absorption improved, and density fluctuated between 2.1 and 2.2 g/cm^3 [8]. The author investigated the impact of sawdust on soil cement bricks and used ultrasonic equipment to test their mechanical qualities. The impact of sawdust inclusion on soil cement (specimens, bricks, and prisms) was studied using tensile, compressive, modulus of elasticity, and ultrasonic pulses. When sawdust was added to the soil, the strength of the brick reduced while its ductility increased. In the case of brick and prism, 0.5% saw dust increase both strength and ductility. It has a detrimental impact on clay soil [9]. Portland cement, recycled paper, water, and/or sand are the main components of the versatile material known as papercrete. Papercrete, a product made of these components, has been stated to be a low-cost alternative building material with strong sound absorption and thermal insulation, as well as a lightweight and fire-resistant material. The current study's goal is to use waste products like paper to supplement the costly and inaccessible traditional construction brick. The weight of standard traditional clay bricks is from 3 to 4 kg, but the weight of papercrete bricks ranges from 1 to 2 kg. The maximum weight is limited to less than 2 kg. The compression test findings revealed that papercrete bricks are only suitable for non-load-bearing walls. According to the study, bricks should not absorb more than 20% of their weight in water. Papercrete brick has a water absorption capacity of more than 20%, making it unsuitable for waterlogging and external walls [10]. After carbon fuels and urbanisation, cement production has expanded significantly in recent years, and it is currently the third greatest source of human carbon dioxide emissions. According to the author, worldwide pollutants in 2018 were 1.50–0.12 gigatonne CO_2 or around 4% of emissions from fossil fuels. From 1928 to 2018, total emissions were 38.3–2.4 gigatonne CO_2, with 71% of those emissions occurring after 1990 [11]. Lamp glass can be effectively recycled and used in the manufacturing of concrete, potentially reducing the quantity of deposited trash and cement use, resulting in a reduction of carbon dioxide pollutants in the atmosphere [12]. The experiment revealed that only when glass powder was utilised as a cement replacement did the air content and density of concrete change. In terms of mechanical characteristics, concrete specimens made with crushed glass aggregate had significantly lower compressive and splitting tensile strengths than concrete made with natural mineral aggregate. Regardless of the type of aggregate used, the compressive strength of concrete dropped when the glass powder was substituted for cement, but increased when aggregate was used in the place of cement increased while the compressive strength of the natural mineral aggregate decreased [13]. Given their comparable chemical composition, transparent and tinted glass powders might both be classified as pozzolanic materials under ASTM standards. The flow of glass-replaced mortar was discovered to be somewhat increased with glass powder content due to its cleaner nature. The ideal glass percentage is 20% when taking into account the 90-day compressive strength of both the mortar and concrete. The compressive strength was discovered to be 2% higher at this age than the control concrete specimen. In general, adding glass can cut the cost of producing cement by up to 14% while maintaining performance levels comparable to those of the material it replaces [14]. The relationship between fly ash and two main types of recycled glass powders with a microscale median size, one an industrial by-product and the other a consumer by-product, was explained in relation to the mechanical strength and durability performance of concrete. An overall improvement in the flexural, compressive, and mortar strengths of the concrete was seen during the late curing stages when glass powders were used to substitute cement. Glass particles were found to perform somewhat superior to fly ash or comparable in terms of strength [15]. Despite having 0%

absorption, the workability of regular concrete without a plasticizer declines as the rate of glass powder increases. The water that has been set aside recovers at the same time as the concrete hydrates over time, modestly increasing the strength of the concrete. The experiment results indicated that the glass powder played a key role in the application of the water reducer and glass powder, where an associated mechanism between the two operates to lower the amount of water while simultaneously improving workability and enhancing concrete strength [16]. In every percentage, the compressed earth bricks with ceramics had higher compressive strength than the control brick, a favourable effect on the compressed earth bricks' initial diffusion rate as well as their capacity to absorb water. In comparison to the other percentages, the results indicated that the brick, which contains 75% waste ceramic components, is the best percentage. Compared to the control brick and the other percentage, this percentage had the highest density and compressive strength. While 75% of ceramic recorded the lowest number compared to the other percentage for the water absorption and beginning rate absorption tests. It should be noticed that brick density rose along with the percentage of ceramic. The brick density is lower for the brick made entirely of ceramic than it is for the control specimen [17]. A compressive strength of around 32 MPa was obtained from geopolymer concrete containing Class C fly ash when it was activated during external exposure curing with an alkaline solution to fly ash proportion of 0.50. For up to 14 days, geopolymer concrete applications in the field can use external exposure curing. Following 28 days of external curing, the geopolymer concrete sample showed a drop in compressive strength. When the ratio of alkaline solution to fly ash was increased from 0.50 to 0.60, the compressive strength of the geopolymer concrete was only slightly improved. When quarry dust was used in place of sand 60 per cent of the time, the compressive strength increased at a faster rate [18]. In the early phases of exposure to 5% NaCl solution, the corrosion current density on steel in all of the SCC specimens was very low, and it increased with increasing exposure time. Corrosion activation was visible in the steel of the M1, M3, and M5 specimens. Even after being exposed to a 5% NaCl solution for more than two years, in the M2 and M4 specimens, it wasn't present. The self-compacting concrete specimens made with silica fume and powdered quarry dust have a low chloride permeability and are moderate in those incorporating fly ash or quarry dust powder [19].

2 Properties of Brick

Brick physical properties include shape, size, colour, and density. An ideal brick's basic shape is rectangular. It has crisp edges that are highly defined. The bricks' surface is smooth and regular. On the other hand, special-purpose bricks can be shaped in a wide range of other ways. Typically, these come in different versions of rectangles. The size of bricks used in construction differs from country to country and even within the same country. The optimal brick size in India is 19 × 9 × 9 cm, which, when combined with a mortar joint, provides a net dimension of

20 × 10 × 10 cm. These dimensions have shown to be extremely useful in handling and estimating quantities. The most prevalent colour of building bricks belongs to the class RED. It might be deep red, pale red, buff, or purple. Very dark colours of red indicate over-burned bricks, whilst yellow indicates under-burning. The type of clay used and the process of brick moulding have a significant impact on a brick's density or weight per unit volume. Normal bricks have a density that ranges from 1600–1900 kg/cubic meter. A single brick (19 × 9 × 9 cm) will weigh between 3.2 and 3.5 kg, depending on the density of the material.

Both compressive and flexural strength are mechanical qualities of bricks. The most important brick characteristic when used in load-bearing constructions is compression strength. The compressive strength of a brick is determined by the type of clay used and how much it was burned. It can fluctuate in India from 35–200 kg/cm^2. An ordinary type of construction brick must meet I.S.S. criteria by having a minimum compressive strength of 35 kg/cm^2. First-class and second-class bricks must have compressive strengths of at least 70 kg/cm^2 and 140 kg/cm^2, respectively. Bricks are widely used in construction situations where it is possible for loads to bend. As a result, they should be strong enough to withstand transverse stresses. Standard building bricks must possess flexural strength of more than 10 kg/cm^2. Best-grade bricks usually have flexural strengths greater than 20 kg/cm^2. The shearing strength of a good building brick should be 50–70 kg/cm^2 or above.

In addition to being strong and durable, excellent bricks should provide enough insulation blocking noise, heat, and cold. The density and porosity of bricks have a significant impact on their ability to conduct heat and sound. Heat and sound propagate more quickly through heavy, dense bricks. They, therefore, have unsatisfactory acoustic and thermal insulation qualities. Bricks should be designed to be light and durable while providing enough insulation. Brick durability refers to the longest period of time they can be utilised in construction before they lose their strength and integrity. Bricks that have been properly laid out have proven to be among the most stable building materials created by humans. Their lifespan is measured in hundreds of years.

3 Materials Used

3.1 Cement

As a binder, cement can bind other materials together which sets and hardens on its own. Cement used in construction can be classified as hydraulic or non-hydraulic. Hydration, a chemical reaction between anhydrous cement powder and water, causes hydraulic cement (Portland cement) to harden. As a result, they can solidify underwater or when continuously exposed to moist conditions. The chemical processes produce hydrates that are not particularly water soluble and thus extremely stable in water. Slaked limes, for example, harden by reactivity with ambient carbon dioxide

Table 1 Physical properties of Portland cement

Physical properties	Result
Specific gravity	3.12
Initial setting time	30 minutes
Final setting time	600 minutes (max.)
Normal consistency	25% to 30%
Density	1450 kg/m^3

and do not harden underwater. The raw components used to make cement are primarily lime, silica, alumina, and iron oxide. In this project, 43-grade ordinary Portland cement (OPC) confirming to IS 8112–1989 is used. The physical properties of portland cement are shown in Table 1.

3.2 Quarry Dust

Rock is crushed into different sizes during quarrying activities; the dust formed during the process is called quarry dust and is discarded as waste. As a result, it degrades into waste and adds to air pollution. Consequently, quarry dust ought to be employed in building projects to reduce construction costs, conserve building supplies, and make more efficient use of natural resources. Quarry dust has been utilised in a variety of construction operations, including building materials, road development materials, aggregates, bricks, and tiles.

3.3 Glass Powder

Glass powder is a good resource for recycling which is a pozzolanic material. Glass powder boosts the strength and durability of concrete when used in the right amounts. Glass is a non-toxic material that can be recycled and used repeatedly without losing any of its chemical characteristics. The properties of the glass powder should correspond to those of the cement. For use as aggregate in a range of applications, such as water filtration, grit plastering, and sand replacement, glass is crushed to specific sizes. The chemical composition of ordinary portland cement is shown in Table 2.

Table 2 Chemical composition of glass powder

Oxide	Percent content
CaO	60–67
SiO_2	17–25
Al_2O_3	3–8
Fe_2O_3	0.5–6
MgO	0.1–4
Alkalis (K_2O, Na_2O)	0.4–1.3
SO_3	1.3–3

4 Methodology

4.1 Mix Proportions

Quarry dust, cement, and glass powder, with 6 mm chips were utilized to make cement bricks (Table 3).

A total of 48 bricks were produced, with 8 bricks cast without glass powder and the remaining 40 bricks cast with 2%, 4%, 6%, 8%, and 10% glass powder substitution.

At 0% replacement (Conventional Brick)
8 Bricks → 4 Kgs: 16 kgs: 24 kgs
(cement) (quarry dust) (6 mm chips)
At 2% replacement
8 Bricks → 4 kgs: 15.68 kgs: 24 kgs: 0.32 kgs
(cement) (quarry dust) (6 mm chips) (glass powder)
At 4% replacement
8 Bricks → 4 kgs: 15.36 kgs: 24 kgs: 0.64 kgs
(cement) (quarry dust) (6 mm chips) (glass powder)
At 6% replacement
8 Bricks → 4 kgs: 15.04 kgs: 24 kgs: 0.96 kgs
(cement) (quarry dust) (6 mm chips) (glass powder)
At 8% replacement
8 Bricks → 4 kgs: 14.72 kgs: 24 kgs: 1.28 kgs

Table 3 Mix proportions

Sample	Cement%	Quarry dust%	6 mm chips %	Glass powder %	Total
S0	9	36.36	54.5	0	100
S2	9	35.63	54.5	0.73	100
S4	9	35.04	54.5	1.46	100
S6	9	34.31	54.5	2.19	100
S8	9	33.58	54.5	2.92	100
S10	9	32.72	54.5	3.63	100

Table 4 Mix design

Water cement ratio	Glass powder %
0.5	0
0.5	2
0.5	4
0.5	6
0.5	8
0.5	10

(cement) (quarry dust) (6 mm chips) (glass powder)
At 10% replacement
8 Bricks → 4 kgs: 14.4 kgs: 24 kgs: 1.60 kgs
(cement) (quarry dust) (6 mm chips) (glass powder)

4.2 Mix Design

The mix design is shown in Table 4.

4.3 Moulding of Cement Bricks

The brick mould is put on the ground and has a standard size of 28*10.5*15 cm. Apply the oil to the mould, then pour the mortar into the mould and compact it. After some time, the mould is removed from the bricks, which are then exposed to sunlight.

4.4 Curing of Cement Bricks

To attain the best strength and hardness, cement blocks must be properly cured. Cement requires a wet, regulated environment to harden completely. The cement paste hardens over time, initially solidifying and becoming firm but very weak, then strengthening in the weeks that follow. Over 90% of the final strength is normally reached in 3 weeks, though strengthening may continue for decades.

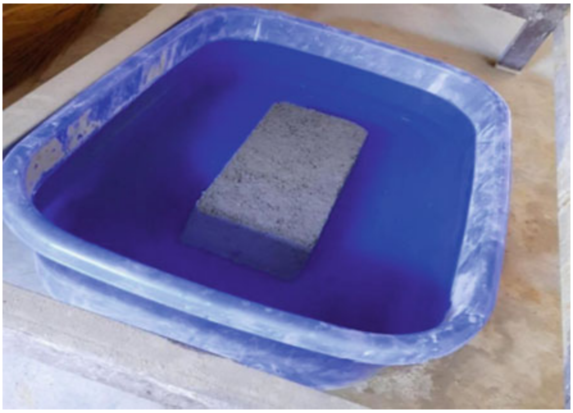


Fig. 1 Water absorption of cement bricks

4.5 Tests on Brick

4.5.1 Water Absorption

This test is used to calculate the percent of water absorbed by bricks. The sample is oven dried for 24 h before being immersed in water for 24 h as shown in Fig. 1. The weight difference before and after submergence is recorded, and the percentage absorption is determined. In any case, it should not be more than 20%.

4.5.2 Compression Test

One of the most essential engineering features of concrete that designers are concerned with is its compressive strength. It is a typical industrial practice to classify concrete based on grades. The Compressive Strength of the concrete cube or cylinder is represented by this grade. To estimate the concrete's compressive strength, cube or cylinder samples are typically tested in compression testing equipment. The test requirements vary by nation based on the design code. This single test determines whether or not the concreting was done correctly. The water-cement ratio, cement strength, the quality of the raw materials used to make concrete, and quality control throughout the production are only a few of the variables that affect the compressive strength of concrete.

5 Results

From experiments, it was found that the water absorption for samples S0, S2, S4, S4, S6, S8 and S10 is 2.6%, 4.8%, 5%, 5.1%, 5.4%, and 5.6% respectively as shown in Table 5. Figure 2 shows the variation of water absorption with different percentages of glass powder.

From experiments, it was found that the water absorption for samples S0, S2, S4, S4, S6, S8 and S10 is 4.3%, 4.4%, 4.8%, 4.9%, 5.3%, and 5.9% respectively as shown in Table 6. Figure 3 shows the variation of water absorption with different percentages of glass powder.

Table 5 Water absorption test results for 14 days

Percentage (%)	Initial weight (Kg)	Final weight (Kg)	Water absorption (%)
0	6.72	6.9	2.6
2	6.24	6.54	4.8
4	6.49	6.82	5
6	6.94	7.3	5.1
8	6.94	7.32	5.4
10	6.54	6.91	5.6

Fig. 2 Graph of 14-day water absorption

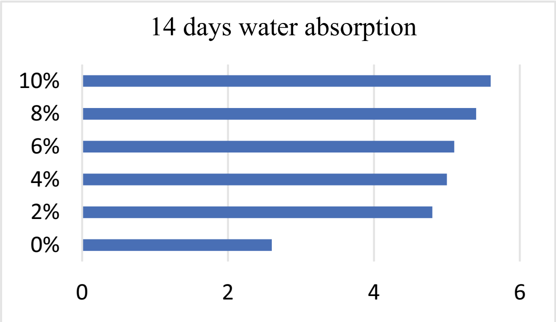
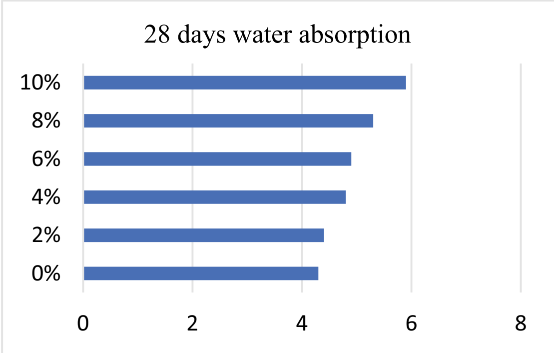


Table 6 Water absorption test results for 28 days

Percentage (%)	Initial weight	Final weight	Water absorption
0	7.05	7.36	4.3
2	6.91	7.22	4.4
4	6.25	6.55	4.8
6	6.89	7.23	4.9
8	6.71	7.07	5.3
10	6.44	6.82	5.9

Fig. 3 Graph of 28-day water absorption



From experiments, it was found that the average compressive strength for samples S0, S2, S4, S4, S6, S8 and S10 is 9.87, 10.37, 11.36, 12.18, 13.07, and 18.13 N/mm^2 respectively as shown in Table 7. Figure 4 shows the variation of compressive strength with different percentages of glass powder.

From experiments, it was found that the average compressive strength for samples S0, S2, S4, S4, S6, S8 and S10 is 11.15, 11.51, 13.31, 15.88, 17.97, and 20.26 N/

Table 7 Compression test results for 14 days (N/mm^2)

Percentage (%)	Compressive strength of brick 1	Compressive strength of brick 2	Compressive strength of brick 3	Average
0	9.31	10.45	9.85	9.87
2	10.12	10.02	11	10.37
4	11.67	11.11	11.31	11.36
6	12.2	11.95	12.41	12.18
8	13.29	12.47	13.45	13.07
10	17.76	18.68	17.96	18.13

Fig. 4 Graph of 14-day compressive strength

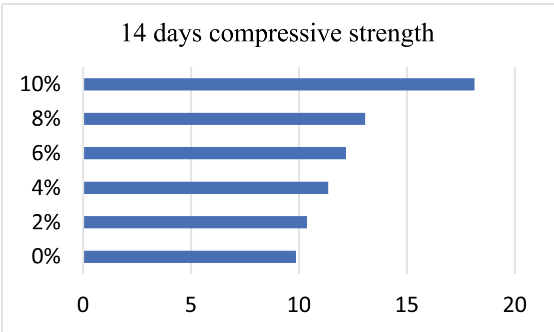


Table 8 Compression test results for 28 days (N/mm^2)

Percentage (%)	Compressive strength of brick 1	Compressive strength of brick 2	Compressive strength of brick 3	Average
0	10.35	12.25	10.85	11.15
2	10.97	11.61	11.95	11.51
4	12.66	14.42	12.87	13.31
6	15.79	16.39	15.54	15.88
8	17.98	17.58	18.37	17.97
10	20.62	19.93	20.24	20.26

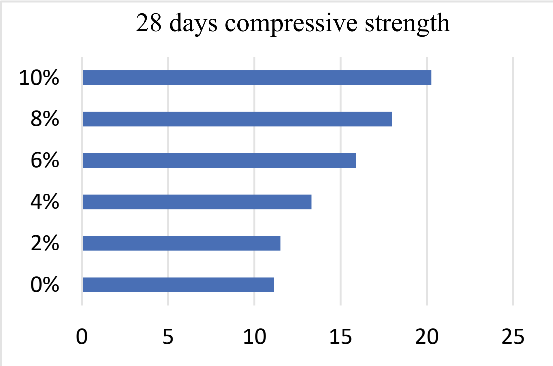


Fig. 5 Graph of 28-day compressive strength

mm^2 respectively as shown in Table 8. Figure 5 shows the variation of compressive strength with different percentages of glass powder.

6 Conclusion

As we all know, bricks are the most common building material used in construction, thus in our project, we tried to produce environmentally friendly cement bricks, with the main goal of reducing waste globally. In this case, we investigated several admixtures used in brick construction. As a result, we used glass powder in various amounts as an admixture, and we substituted sand with quarry dust for eco-friendly brick. The compressive strength values show that as glass powder percentage increases strength also increases as well as water absorption increases when compared to a conventional brick. Bricks should have increased compressive strength, however, if the increase in water absorption is within acceptable limits, it may be recommended. This brick can be used for both non-load-bearing walls and parapet walls.

Glass waste has additional benefits such as economic efficiency, removal of waste products, and elimination of the land requirement problem for depositing waste.

These bricks will help provide a healthy environment for the residents. This replacement is employed in the construction of prefabricated structures because of an increase in compressive strength. It is less expensive than conventional concrete combinations.

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Sewage Sludge—A Latent Biogold

Neelam Belani, Anurag Kandya, Virendra Kumar, Lalit Varshney, Darshana Patel, and Chaitanyamoy Ganguly

Abstract The water consumption in the country and the subsequent generation of the wastewater (domestic sewage) has increased by leaps and bounds because of the rising population and the associated activities. Sewage treatment is definitely a big challenge and adding to the complexity are the issues related to the by-product of the sewage treatment i.e., 'Sewage Sludge'. Approximately 144 kg of dry sewage sludge is generated per million liters of sewage treated in India and accordingly around 1.4 million tons (MT) of dry sewage is generated annually. As the wastewater management infrastructure is getting increased significantly, it will result in an increased quantity of wastewater treatment which would result in an increase in the quantity of dry sewage sludge. While sewage sludge is a good source of Organic Carbon, Nitrogen, Phosphorous and Potassium which are essential for plant growth it also contains heavy metals, pathogens and microplastics which have serious health implications on human health and agricultural productivity. If these pollutants are removed from the sewage sludge, then it can be used as a soil conditioner on a mass scale. Strategies like restricting the mixing of domestic sewage with the industrial wastewater can partially address the heavy metal contamination in sewage sludge, irradiation of the sewage sludge with gamma radiation can make it pathogen free while vermi-composting can reduce the microplastics' concentration in sewage

N. Belani (✉) · A. Kandya
Associate Professor, Civil Engineering Department, Pandit Deendayal Energy University, Gandhinagar, India
e-mail: neelam.bphd19@sot.pdpu.ac.in

V. Kumar
Head, Advanced Materials Section, Radiation Technology Development Division and Associate Professor, Homi Bhabha National Institute, Mumbai, Bhabha Atomic Research Center, (BARC), Mumbai, India

L. Varshney
Sr. Professor Homi Bhabha National Institute, Mumbai, India

D. Patel
Environment Engineer, Ahmedabad Municipal Corporation, Ahmedabad, India

C. Ganguly
Distinguished Professor Pandit, Deendayal Energy University, Gandhinagar, India

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_13

sludge. With this background, the present research was done to discover the success stories of the effectiveness of the Sewage Sludge as an organic soil conditioner and also to bring out the associated challenges. The outcomes of the study will significantly help the policy makers to strengthen the 'Organic Waste Management Strategy' focusing the sewage sludge and the researchers to address the bottlenecks associated with the effective utilization of the sewage sludge. All this would help in the country's mandate of moving towards organic farming and reduce its dependence on chemical fertilizers. It would also help in the country's 'Swachh Bharat Mission' leading a path to Clean India and Green India.

Keywords Sewage sludge · Gamma radiation · Wastewater · Organic farming

1 Introduction

In many nations, including India managing urban waste water has proven difficult because infrastructure development and laws have lagged behind population expansion and urbanization. Currently, in India, around 72,368 MLD of sewage is generated in the urban areas and 1,469 Sewage Treatment Plants (STPs) are installed to treat this; the installed capacity of the wastewater treatment is 31,841 MLD while the operational treatment capacity is 26,869 MLD which infers that around 37% of the sewage generated is treated. Efforts are being taken to increase the wastewater treatment capacity and under the Swachh Bharat Mission (Urban) 2.0 launched by Government of India in October, 2021, Rs. 15,883 crores have been allocated to States/UTs for wastewater/used water management [1]. The STP has two major outputs i.e. (i) Treated wastewater and (ii) Sewage Sludge. The average sludge generation rate in India is around 144 kg per MLD of the treated sewage as dry mass basis and thus it can be inferred that around 1.4 Million Tons (MT) of dry sludge is generated annually [2]. The annual sludge generation rate of countries like China, USA, UK, Italy and France is around 39 MT, 10 MT, 1.64 MT, 1.5 MT and 1.4 MT respectively [3, 4]. Looking to the present government's mandate of increasing the wastewater management infrastructure it can be inferred that the total sludge generation quantity would significantly increase and can cross 10 MT by 2030.

Sewage sludge which is either a liquid, solid or semisolid residue is composed of both organic and inorganic materials and chemicals, and is good source of Carbon, Nitrogen, Phosphorous and Potassium which are essential for plant growth but also contains bacteria, viruses, fungi, protozoa, helminths and variety of other pathogens. Thus, it necessary to understand the dynamics of Sewage Sludge as a resource along with the limitations outlined by various studies which can be used for strengthening the 'organic waste management strategy' and for improving both the quality and quantity of 'organic manure'. A robust organic waste management strategy will significantly help the country to move towards with organic farming and reduce the dependence on chemical fertilizers like urea whose annual consumption is around 33 million tonnes. The present paper is an effort in that direction which collates the salient findings of various studies of using sewage sludge as a resource and puts forward the way ahead.

2 Sewage Sludge as a Resource

Typical domestic sewage sludge contains around 20–40% Organic Carbon (OC), 3–5% Total Nitrogen (TN), 1–3% Total Phosphorus (TP), 1% and less Total Potassium (TK) and a large amount of other organic matter called Soil Organic Matter (SOM). All these are important organic nutrients required for plant growth.

Soil Organic Matter (SOM) is critical for the stabilization of soil structure, the storage and release of plant nutrients and the maintenance of water holding capacity which all depend on soil organic matter (SOM) which makes it an important indication of both agricultural production and environmental resilience [5]. Sewage sludge owing to its high organic matter content when added to soil improves its physical properties such as soil aggregate formation capability, bulk density, porosity and water holding capacity [6]. Better plant growth and increased productivity helps to ensure food security as the breakdown of SOM releases additional mineral nutrients, making them available for plant growth [5, 7]. In addition to this, the sewage sludge also increases the soil's cation exchange capacity (CEC) which helps in retaining essential plant nutrients within the effective root zone of plants [8]. High grain yield was observed by blending the sewage sludge along with chemical fertilizers [9].

Plants perform the most crucial function of photosynthesis with the help of chlorophyll found inside the chloroplast. It was inferred that plants grown with soil having 70% Composted Sewage Sludge (CSS) produced more amount of chlorophyll (2.13 mg/g) as compared to base soil [10], thereby suggesting the application of CSS in agriculture for improved quality of yield.

3 Challenges Associated with Sewage Sludge for Being Utilized as a Resource

Despite many advantages of using sewage sludge as a soil conditioner, there are still many challenges which need to be addressed. Few of them are enlisted below:

i. Presence of Heavy metals like Arsenic, Lead, Mercury, Cadmium
ii. Presence of Pathogens like Bacteria, Viruses and Parasites
iii. Presence of Micro-plastics.

Table 1 Heavy metals, their sources and health effects

No	Heavy metal	Waste water from different types of Industry [12]	Health effect [13]
1	Cadmium	Paints, Varnishes, Electroplating, casting, textile, soaps, detergents, pharma industry, etc	Kidney damage/skeletal damage
2	Mercury	Adhesives, Explosives, Fertilizers, Pesticides, Laboratories, Photographic Equipment's	Lung damage, Restlessness, anxiety, sleep disturbance, depression
3	Lead	Dyes and pigments, oil and waxes, Rubber, Leather, cosmetics and fragrances	Headache, Irritability, abdominal pain, memory deterioration, learning and concentration difficulties
4	Arsenic	Electric and Electronic components, lumber industry, laundries	Lung/Bladder/Kidney cancer, skin cancer and lesions, peripheral vascular disease

[a] Main Contaminants in sludge: S.M.C.P. da Silva, F. Fernandes, V.T. Soccol, D. M. Morita, Biological Waste Water Series Volume 6 [12], [b][13]

3.1 Presence of Heavy Metals in Sewage Sludge

Heavy metals in sewage sludge are of concern because they are non-biodegradable and get accumulated in plants [11], and subsequently enter the food chain of human beings posing a serious threat to their health. Table 1 shows the source of heavy metals in terms of wastewater generated from an industry and the impact which the respective heavy metal has on human health. The high content of Heavy metals in the sludge has been one of the major obstacles for its application in agriculture, however, their concentration in the sludge is highly variable.

3.2 Presence of Pathogens in Sewage Sludge

It was inferred from his research that significant number of pathogens present in the sewage sludge can pose a serious human health risk by entering into the food chain of human beings [14]. One liter of Fecal sludge contains E-coli in the range 10^6 to 10^7 and parasitic worms between 10^3 and 10^4 [15]. It also contains 6 log CFU fecal coliforms/g and 6–13 viable helminth eggs/4 g [16]. Several diseases such as diarrhea, cholera, typhoid, paratyphoid occur due to the presence of bacteria found in fecal sludge. In addition to the bacterial load, the presence of viruses such as human adenoviruses, enteroviruses, rotavirus, hepatitis-A virus and reo viruses have also been confirmed in fecal sludge. Presence of rotavirus in the sewage sludge was also reported [17]. Rotavirus poses adverse effect on human health. Sewage sludge also contains SARS-CoV-2 genetic material (RNA) in primary as well as thickened

Table 2 Viruses present in Sewage Sludge across the world [19]

No	Country	Type of Sludge sample	Type of Virus found	References
1	Brazil/Florianop-olis	Activated sludge	Adenovirus, Hepatitis A, Rotavirus, Poliovirus	[20]
2	USA	Anaerobically digested sludge	Herpesvirus, Papillomavirus, Coronavirus, Hepatitis A and C, Rubella virus, Adenovirus, Rotavirus, Enteroviruses and Hepatitis A virus	[4]
3	Thailand/Bangkok	Lime stabilized sludge	Norovirus	[21]
4	Spain/Ourense	Primary/Biological/Thickened/Digested sludge	SARS-CoV-2	[18]
5	Tunisia	Activated Sludge	Entero viruses and Hepatitis A virus	[22]

sludge [18]. Table 2 contains the different types of pathogens whose presence was reported in the different types of sewage sludge globally.

3.3 Presence of Microplastics

The presence of Microplastics was reported in the sewage sludge [23]. Potential sources of Microplastics can be bottle caps, plastic bags, bags, paper coatings, degraded utensils and containers, gaskets, irrigation pipes etc. [24]. These small to large size particles get transferred to the sewage sludge [25].

4 Conclusions and the Way Ahead

There is a definite need for controlling the surface water pollution which is happening because of the discharge of untreated or partially treated sewage from the cities/towns and industrial effluents in their respective catchment. In the coming times, not only the fraction of the sewage being treated will increase (which is 37% of now) but even more residential units will be covered in the sewerage network. This infers that in the coming years the quantity of the sewage sludge, which is around 1.4 MT/annum, will significantly increase and would most likely cross 10 MT/annum by 2030.

Looking to the typical characteristics of the sewage sludge, it can be inferred that it is an excellent soil conditioner ,however, there are many challenges associated to it which has to be addressed at the earliest so that it can safely used for agricultural purposes. Following are the key points which can be considered for addressing the challenges associated with the sewage sludge as a soil conditioner:

The challenge of 'presence of heavy metals in sewage sludge' can be greatly addressed if the industrial wastewater is not mixed with domestic sewage while performing the treatment. Attempt should be made to immobilize the heavy metals in sewage sludge so that they don't enter the food chain. Techniques like hydrothermal carbonization have revealed success for the heavy metals immobilization, however, more research is needed in this direction.

Pathogens in the sewage sludge can be removed by irradiating it by gamma radiation. Few research studies have revealed the dose-response relationship regarding gamma radiation and its impact on various pathogens and more studies are needed in that direction. In addition to this, the impact of the gamma radiation on the soil morphology and other physical properties also needs to be investigated to understand the overall impact of gamma radiation on sewage sludge.

Few studies have revealed that the micro-plastics content in the sewage sludge can be reduced by vermin-compositing but more studies are needed to confirm this observation.

There is a definite need for addressing all the challenges associated with sewage sludge which prohibits it for being used in the agricultural sector on a mass scale. If these challenges are addressed then definitely it will possible to use sewage sludge at a national scale and consequently reduce the country's dependence on chemical fertilizers (for instance, India's annual consumption of Urea is around 33 million tonnes) and move toward Organic Farming and Food security.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements The authors are grateful to Board of Research in Nuclear Science (BRNS), Department of Atomic Energy, Government of India for funding this Research work, and all the necessary support as and when required during the course of study and to Pandit Deendayal Energy University, Gandhinagar for providing all necessary support to carry out the research work.

Funding This research work is funded by Board of Research in Nuclear Science (BRNS), Department of Atomic Energy, Government of India.

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A Review on Use of Recycled Concrete Aggregate in Flexible Pavement

Medhavi Gupta and Praveen Aggarwal

Abstract The past few decades has seen rapid urbanization and population growth, which has increased waste production. When the generated waste is not properly disposed of or handled, the issue gets worse. The proper management of waste is essential for a nation's economic growth. Therefore, promoting economic and sustainable development along with environmental protection is the fundamental and primary goal of waste management. In all areas of civil transportation infrastructure, sustainable development is becoming more and more important for clear and important reasons. The construction of pavements requires a lot of virgin or natural aggregates. High environmental consequences caused by NA extraction have a detrimental effect on environmental protection and conservation. In order to lessen these environmental effects, a variety of different materials are procured through construction and demolition waste have been studied as a potential substitute for Natural Aggregate. In this study, the production of asphalt mixtures is reviewed with the use of Recycled Concrete Aggregate. The literature has been assessed based-on performance tests: Marshall stability, resilient modulus, dynamic modulus, Tensile Strength Ratio, Indirect tensile strength and Dynamic creep test. The majority of the research recommended substituting 40% RCA with Virgin Aggregate. Specifically for low-traffic roads, majority of the literature clearly shows RCA has probable scope for use in the creation of asphalt mixtures.

Keywords Sustainable development · Recycled concrete aggregate · Asphalt mix design · Marshall · SUPERPAVE

1 Introduction

With the scarcity of natural resources and the rise in solid wastes, various agencies are investigating different materials for use in construction projects. Sustainable and Eco-friendly projects are becoming the primary focus for every industry [1].

M. Gupta (✉) · P. Aggarwal
Department of Civil Engineering, National Institute of Technology, Kurukshetra, Haryana, India
e-mail: medhavi.muj@gmail.com

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_14

Construction activity in major cities is rapidly increasing as a result of urbanization and population growth. As a result, the demand for residential and commercial land use is increasing, resulting in urban area development [2]. Concrete, wood, bricks, glass, steel, ceramics, stones, etc. are various types of building materials that are suitable for construction projects of any size. Portland cement concrete (PCC) has been widely used in construction of bridges, roads, runways, buildings, etc. It is mainly composed of aggregates, cement and water. Stones are crushed to produce the aggregate. The need for a good aggregate is quite high to satiate the rapid growth of cement concrete Infrastructure. The rapid growth of construction of new structures in urban and suburban areas also led to the demolition of the older structures which has resulted in the production of large amounts of concrete debris. India has relevant waste management regulations, but due to their weak enforcement, construction firms place waste management and reduction at the bottom of their agenda due to the complexity of incorporating them into the existing system [3]. Recyclable material such as demolition aggregate could drastically reduce aggregate demand in the construction industry. Around 12.3 million tonnes of natural aggregate can be saved annually with proper recycling [4]. Solid waste management is a difficult task because it necessitates a landfill, high transportation costs, and efficient technologies for recycling or disposal of the Solid Waste material, and it also harms the environment. The disposal of construction and demolition (C&D) waste has become extremely difficult due to the oversaturation of C&D deposits and a lack of available landfills. As a result, one logical method for mitigating their negative effects is to use these materials in other industries. The concrete obtained from C&D waste can be recycled and used as an aggregate and is termed Recycled Concrete Aggregate (RCA).

2 Materials Reviewed

2.1 Recycled Concrete Aggregate

It is created as a result of demolition of infrastructure made of reinforced or unreinforced cement concrete. Large fractions of concrete are produced after the initial demolition, which could be divided into smaller ones. Recycled concrete has often been used to make concrete structures such as buildings, rigid pavements and runaways. Furthermore, it is employed in a variety of transportation infrastructure applications. Researchers and engineers all over the world have investigated incorporating recycled concrete as an aggregate in (HMA). It has the potential to significantly reduce costs, greenhouse gas emissions and energy consumption in the asphalt paving industry. The main aim of using RCA is to replace or minimize the use of virgin aggregates in HMA. When recycled, cement paste stays somewhat on the surface of RCA, setting them apart from virgin aggregates [5] is important. Table 1 shows the chemical composition of RCA based on XRF test results. The high amount of Calcium Oxide (CaO) is mainly due to the layer of cement paste over

Table 1 X-ray fluorescence (XRF) characterization of RCA [7]

Compound	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	Na_2O	K_2O	Cl	P_2O_5	SO_3	TiO_2	SrO	BaO
Percentage	49.2	6.25	1.94	1.42	1.33	0.19	0.14	0.10	0.07	0.63	0.19	0.04	0.09

the natural aggregate and its small amount in the aggregate. The natural aggregates of limestone and basalt along with cement mainly contain MgO, AL_2O_3, SiO_2 and Fe_2O_3 in small amounts. Additionally, alkaline compounds such as NaO and K_2O are also present in smaller fractions [6].

3 Assessment of Recycled Concrete Aggregate

Few studies have been conducted to date on the use of RCA as a complete or partial replacement for virgin aggregate in flexible pavement layers.

The research performed in Turkey evaluated the use of RCA in HMA by blending it with natural limestone aggregate in different proportions of 10, 20 and 30%. The HMA samples were prepared using the Marshall method. The asphalt binder used was of penetration grade 60/70. The Marshall stability value increased with increase in RCA content and decrease in OAC. Its highest value obtained was 14.55kN at OAC of 4.45%. At an OAC of 4.50%, the ITS value for 30% RCA content was 1080 kg while for the control mix, it was 954 kg at an OAC of 5.50% [5].

This study evaluated the asphalt mixture properties based on the Marshall design method. To prepare the asphalt mix, penetration grade 50/70 asphalt was used along with RCA in varying proportions of 20, 40, 60 and 80% and the remaining proportion of limestone aggregates. The maximum value of OAC was obtained as 4.8% for 80% RCA and it decreased as the RCA content decreases. The value of Marshall stability at 20, 40, 60 and 80% RCA was almost the same. The maximum value of TSR was obtained as 90% for 80% RCA. The stiffness modulus decreases with an increase in RCA. The rutting resistance was unaffected greatly by the partial substitution of limestone aggregate with RCA [7].

The research performed in Washington;,USA, investigated the use of RCA as an aggregate in the HMA design. The effects of RCA on HMA properties were evaluated using a mix design based on SUPERPAVE volumetric design by varying its proportion at 20, 40, 60, 80, and 100%. The asphalt binder used was of Performance Grade PG 58–28, and the virgin aggregate was basalt. The HMA mix design was carried out under AASHTO T323. The design load ranged from 3 to 10 million. The number of design gyrations (N_{des}) was 100, while the number of maximum gyrations (N_{max}) was 158. A Superpave Gyratory Compactor (SGC) was used for compaction. The mix's optimum asphalt content (OAC) increased as the RCA increased, indicating that the RCA is highly absorptive. The theoretical specific gravity (G_{mm}) and the bulk specific gravity (G_{mb}) decreased with the increase in RCA [8].

The research conducted in Iran used a combination of natural crushed limestone and RCA. The asphalt binder used was of penetration grade 60/70. The OAC of the virgin mixture and those containing 10, 20, 30, and 40% RCA was determined using the marshal mix design method and compaction was done using SGC. The OAC at 40% RCA was 6% and it decreased linearly with the decrease in RCA while for the control mix, the OAC was 4.9%. It shows that the recycled aggregates are more binder absorptive. The resilient modulus of the mixture containing 30% RCA is increased compared to the mix with NA. The maximum flow number value of 2712 was obtained for 30% RCA in comparison to 1920 for the virgin aggregates. The 30% RCA specimen had the least value of rut depth when tested for a wheel tracking test. Increase in RCA resulted in increase in TSR. It shows that C&D debris improves moisture susceptibility. The performance tests comprising of dynamic creep test, resilient modulus, and wheel tracking indicate that 30% RCA improves the rut resistance of the mix [9].

The investigation on mechanical properties of HMA with RCA by substituting RCA for virgin aggregates at the rate of 25, 35, 50 and 75%. The asphalt binder used was PG 52–34. The equivalent standard axle load considered was 0.3 to 1 million while the mix was prepared using the SGC at 76 gyrations. Rutting potential was evaluated using the asphalt pavement analyzer and rutting increased with the increase in the RCA. The dynamic modulus and resilient modulus of the HMA decreased with increase in RCA. The Tensile Strength Ratio (TSR) of 88% was achieved for 50% RCA specimen which was well above the minimum specification limit of 80% [10].

Turkey based researchers studied the effect of blending RCA with the limestone aggregate by varying the proportion of RCA from 0, 25, 50 and 75%. The asphalt binder used was of penetration grade 50/70. The HMA specimens were prepared based on the Modified Marshall Procedure at 140 blows and a minimum specimen height of 165 mm. The maximum value of OAC for the coarser mix was 6% when 75% RCA is used, whereas for the finer mix, the maximum OAC was achieved at 6.8% for 75% RCA. As RCA content increases, the OAC value increases for both coarser and finer mixes. Due to the fine proportion of the mixed aggregates and higher specific surfaces of RCA, an increase in the optimal asphalt contents is anticipated. Flow number which is a measure of rutting susceptibility was estimated on the basis of repeated creep tests. The specimens were prepared by varying the RCA content with fine and coarse limestone aggregates. A maximum flow number value of 4300 cycles was achieved for a blend of coarse aggregate and 75% RCA whereas a maximum flow number value of around 9600 cycles was recorded for the blend of fine and 25% RCA. When the RCA proportion is raised in the fine mixture, there appears to be a progressive decline in the flow number. For the coarser ones, this pattern changed to the contrary [11].

The research carried out in Malaysia investigated the performance of the asphalt mixture of RCA blended with coarse and fine granite by varying its proportion at 20, 40, 60, 80 and 100% for flexible pavement surfacing of Stone Mastic Asphalt (SMA). The bitumen used was of penetration grade 80/100. The mix designs were prepared using the Marshall method and the OAC for 40% RCA was found to be 6.5%. The highest value of marshal stability 12,665 kN was obtained for 80% RCA.

The resilient modulus value of 9339 MPa was obtained for 40% RCA which was almost similar to the resilient modulus value for the control mix. The ITS of the 40% RCA specimen was 1051.73 kPa which was similar to that of the control mix specimen. The 40% RCA demonstrated the highest value of 95% TSR for water resistance. The decrease in TSR over 40% RCA had the same pattern as the results for resilient modulus and tensile strength. The 40% RCA specimen proved to be the best rut resistant based on flow number [12].

An Iranian based study explored the use of RCA with limestone aggregates in different proportions of 0, 35, 70 and 100%. Two types of gradations were evaluated based on nominal maximum aggregate size (NMAS) of 19 and 25 mm. The penetration grade 60/70 asphalt binder was used. The HMA mixture was prepared based on the Standard Marshall design method. The maximum OAC came out to be for the 100% RCA specimen for both 19 and 25 mm NMAS and its values decreased with the decrease in RCA. For NMAS of 19 mm, 70% RCA resulted in the highest cycles to failure value of around 35,500 and 9000 at 5 and 40°C respectively. Substituting 100% RCA with virgin aggregate for 25 mm NMAS resulted in the highest cycle-to-failure value of around 25,500 at 5 °C whereas at 40 °C the fatigue life was approximately the same for all four proportions [13].

This study evaluated the use of RCA with dacite aggregate for fabrication of the asphalt concrete mixture using the Marshall method. The asphalt binder used was of penetration grade 60/70. The OAC for 100% RCA was 7% and decreased linearly with the decrease in RCA. The Marshall stability of 19.46 kN was obtained for a sample of 50% RCA and 50% fine aggregate. The results of dynamic and static creep tests indicated that RCA with fines shows less rutting that RCA with coarse aggregates. The maximum value of the resilient modulus was obtained as 1360 MPa at 25 °C when RCA and fine aggregate were mixed at 50% each. At 40 °C, the maximum resilient modulus was obtained as 710 MPa for a mix of 50% RCA and 50% coarse aggregate [14].

The research performed in China evaluated the scope of using coarse and fine RCA in place of limestone aggregates by varying its proportion. The asphalt binder used was A-70. The asphalt mix design was prepared using the Marshall mix design method for 26.5 mm NMAS. The maximum OAC was obtained for the specimen of 40% fine RCA and 60% coarse RCA. With an increase in RCA, the bulk density of asphalt mixtures gradually reduced. The values of residual Marshall stability and TSR were maximum for both 40% coarse and fine RCA. The values of dynamic stability for 20% fine and 40% coarse RCA were almost the same. The fatigue life of 40% fine RCA was closest to the control mix. The compressive resilient modulus for 20% fine RCA was 4.3% more than the control mix [15].

The research conducted in Kuwait investigated the use of RCA as large and small fragments in preparing the samples of asphalt concrete type-III. The other materials used in making the HMA were asphalt, crushed sand, natural sand and filler. The Marshall method was used to make the HMA samples. The OAC was found to be 7.2%. The value of Marshall stability increased as the binder content increased and it attained its peak value of 1825 kg at 7% asphalt content and then started to decline further. The loss of Marshall stability obtained was 24%. The value of inversion compression ratio obtained was 92%. The average value of wheel tracking rate of 0.93 mm/hour and 5.26 mm/hour was computed for samples conditioned at 45 and 70 °C respectively [16].

Jordan based study explored the use of RCA and RAP in combination by varying proportions of natural aggregates of crushed limestone, basalt and white-hard rocks with an NMAS of 19 mm to make samples of HMA. Furthermore, RCA and RAP were blended together in different proportions of 25, 50, 75 and 100%. The HMA samples were prepared using the Marshall mix design. The OAC obtained for limestone, White hard-rock and Hard-rock basalt aggregates were 5.42, 4.54 and 4.25% respectively. The Marshall stability value of 25% and 100% RCA were slightly more than 25% and 100% RAP samples while at 50 and 75%, RAP samples performed significantly better than RCA samples in terms of stability. The HMA mix composed of 50% RCA and 50% RAP resulted in a highest stability value of 17.51kN at 4.5% asphalt content. The increase in proportion of RCA blended with RAP resulted in increasing trend in the values of OAC [17].

The research carried out in Taiwan studied the effect of using slag cement paste as a pre-coated film over recycled concrete aggregate (PCRCA) by coating it with 0.25, 0.45 and 0.65 mm thick layers. The HMA samples were prepared based on Marshall method. Crushed stone aggregate of NMAS of 12.5 mm was replaced by the PCRCA in different proportions of 25, 50, 75 and 100%. Asphalt binder used was AC-20. The PCRCA coated with 0.25 mm thick coating paste was found to be of optimum thickness required based on the volume of the coating paste for HMA mixture. The ITS value increased as the PCRCA content increased and an opposite trend was observed in case of TSR values [18].

China based study investigated the use of RCA by varying its proportion by 30, 60 and 100% to make samples of Asphalt Treated Base (ATB-25). The asphalt binder used was Matrix asphalt No. 70 along with a coarse and fine aggregate of serpentine and limestone powder and filler material. The samples were fabricated using the Marshall mix design method. The value of OAC was obtained at 60% RCA content. The value of Marshall stability, residual marshal stability, TSR and low-temperature bending strain decreased with increase in RCA content. No direct relationship was found between dynamic stability and RCA content. It was found that ATB-25 mixtures containing RCA less than 60% satisfied all the required specifications [19].

The study performed in Canada evaluated volumetric properties of HMA fabricated with coarse RCA at various proportions of 0, 15, 30 and 60%. The mechanical tests on RCA revealed that coarse RCA exhibited better results in terms of adhered mortar loss and abrasion loss in comparison to other RCA literatures. As the RCA content increased, the OAC increased while the voids in mineral aggregate (VMA) decreased. Coarse RCA treated with several treatment methods gave far superior results than untreated coarse RCA samples [20].

4 Discussion

The fundamental testing on RCA is similar to that of natural aggregates. The mechanical resistance of RCA is evaluated mainly based on Los Angeles abrasion [21] and aggregate impact test while the preliminary tests are comprised of bulk specific gravity and water absorption of coarse aggregate (CA) [22], bulk specific gravity and water absorption of fine aggregates (FA) [23], flakiness and elongation indices [24], fractured faces [25] and sand equivalent test [26]. The summarized results of RCA are shown in Table 2. It can be observed that the specific gravity of coarse RCA was slightly lower than the natural aggregates which generally range from 2.5 to 3 while for fine RCA, it was found to be even slightly lower than the coarse RCA. The water absorption of the coarse and fine RCA was found be significantly higher than the natural aggregates due to voids present on the aggregate mortar layer. The mechanical behavior of asphalt mixtures is influenced by particle shape and geometry. In this regard, it is preferable to have rough and angles rough particles. Long and flat particles are undesirable in the mix because they tend to fracture during the manufacturing, construction, and useful life of the pavement [27]. The abrasion values in most of the studies was found to be below the acceptable limits. However, RCA was found to have significantly higher abrasion values than the natural aggregates [5, 10].

The Marshall stability test is an important performance test in various countries. The values of stability at different OAC are summarized in the Table 3. No fixed trend was found to exist between stability and increase in RCA content. However, in some studies it was found that stability first increased to a maximum value then started to fall. Furthermore, the OAC was found to be increasing with increase in RCA content. It was mainly due to voids present on the RCA surface which would

Table 2 Physical properties of RCA

Authors	Abrasion (%)	Bulk Specific Gravity (gm/cc)		Water absorption (%)		Fractured faces (%)
		CA	FA	CA	FA	
Topal et al. [5]	42.00	2.27	2.17	–	–	–
Bhusal et al. [8]	22.00	2.41	2.09	–	–	100
Fatemi and Imaninasab [9]	27.00	2.15	2.1	6.95	14.19	92
Mills–Beale and You [10]	43.00	–	–	2.34	–	93.8
Gul and Guler [11]	–	2.30	2.28	5.64	5.89	–
Nwakaire et al. [12]	18.70	2.52	2.49	4.80	7.80	–
Arabani et al. [14]	35.50	2.45	2.46	–	–	–
Naser et al. [17]	15.54	2.56	2.29	9.22	15.23	–
Lee et al. [18]	34.68	2.32	–	9.68	–	–
Hou et al. [19]	26.70	2.73	2.48	5.43	–	–
Bayati et al. [20]	23.57	2.29	–	5.91	–	89.9

Table 3 Summarized values of OAC obtained from literature reviews

Author	Type of VA	RCA (%)	OAC (%)	Stability (kN)
Topal et al [5]	Limestone	0	5.50	10.20
		10	5.20	9.70
		20	4.50	12.70
		30	4.45	14.55
Fatemi and Imaninasab [9]	Limestone	0	4.90	–
		10	5.20	–
		20	5.50	–
		30	5.70	–
		40	6.00	–
Naser et al [17]	Limestone, basalt and white hard–rocks	25	5.50	23.90
		50	6.00	7.67
		75	5.50	14.71
		100	5.50	25.37
Nejad et al [13]	Limestone	0	5.50	–
		35	5.70	–
		70	6.00	–
		100	6.20	–
Nwakaire et al. [12]	Granite	0	5.90	8.72
		20	6.20	9.89
		40	6.50	11.21
		60	7.00	11.84
		80	7.50	12.66
		100	8.00	11.19
Bhusal et al. [8]	Basalt	20	6.80	–
		40	7.40	–
		60	8.00	–
		80	8.50	–
		100	9.20	–
Lee et al. [18]	River crushed stone	0	5.78	14.86
		25	5.85	13.39
		50	6.00	14.25
		75	6.55	11.89
		100	6.62	11.72
Gul and Guler [11]	Limestone	0	4.90	–
		25	5.20	–
		50	5.50	–
		75	6.00	–

(continued)

Table 3 (continued)

Author	Type of VA	RCA (%)	OAC (%)	Stability (kN)
Hou et al. [19]	Serpentine aggregate and limestone powder	0	3.45	11.20
		30	3.53	10.50
		60	4.04	9.80
		100	3.38	8.50

absorb asphalt. In some case, it was found that the asphalt binder would plug the voids by forming a thin layer over it. On the other hand, it was observed that the asphalt binder penetrated inside the voids and completely filled them. Comparatively lower values of Marshall stability were observed in some studies in comparison to those of mixtures of the control mix. The obvious reason could be the presence of cement sand paste over the aggregate that experiences more abrasion during crushing and compaction of RCA.

The summarized performance tests' results of reviewed literatures are shown in Table 4. In most of the studies, no definite trend was observed in the values of ITS, TSR and resilient modulus. It could be mainly based on the type of aggregate and concrete grade that the RCA possess. Also, it could be due to the degree of damage in terms of abrasion, wear and tear the RCA has experienced during demolition and weathering. The flow number and fatigue life in terms of number or cycles to failure is a fatigue resistant parameter increased with increase in RCA indicating that mixtures containing RCA should perform satisfactorily. Majority of the studies suggested to use RCA in low traffic volume roads. Most of studies have been conducted on mixtures of limestone aggregate and RCA therefore it is difficult to conclude which proportion of RCA along with natural aggregate will prove to be the best.

5 Conclusion

This study reviews the use of Recycled Concrete Aggregate in Hot-Mix asphalt by using it as a complete or partial replacement of natural aggregate in wearing or binder course layers of flexible pavements. The following findings can be inferred from the literature reviews that were done:

1. The specific gravity of coarse and fine RCA was slightly lower than the specific gravity of Natural aggregates while the water absorption of RCA was significantly much higher than the natural aggregates.
2. Some researchers claim that substituting the coarse portion of NA with RCA improves mechanical performance, other researchers claiming that substituting the fine fraction is the optimum choice.
3. The OAC for the finer mixes was more than the coarser mixes and it increases as the RCA content increases. This is mainly due to absorption of the binder by aggregates and the decreased specific gravity.

Table 4 Summarized test results of performance tests on RCA mixtures

Author	RCA (%)	ITS (kN)	TSR (%)	Resilient modulus (kN)	Fatigue life (Cycles to failure)	Flow number
Fatemi and Imaninasab [9]	0	–	81	1782	–	1920
	10	–	86	2185	–	2319
	20	–	88	2385	–	2530
	30	–	90	2640	–	2712
	40	–	93	2410	–	2394
Mills–Beale and You [10]	0	–	92	1540	–	–
	25	–	90	1100	–	–
	35	–	89	930	–	–
	50	–	89	880	–	–
	75	–	74	720	–	–
Nwakaire et al. [12]	0	1058	91.5	9496	631	–
	20	980	90	10,286	531	–
	40	1052	95	9339	831	–
	60	870	91.5	7596	1071	–
	80	790	87	7137	1171	–
	100	789	76	6725	1781	–
Daquan et al. [15]	0	–	78	1163	–	–
	F–20	–	86	1214	–	–
	F–40	–	88	1065	–	–
	C–40	–	83	963	–	–
	C–50	–	55	856	–	–
	C–60	–	67	836	–	–
Lee et al. [18]	0	880	81.7	–	–	–
	25	935	79.2	–	–	–
	50	980	74.4	–	–	–
	75	985	71.2	–	–	–
	100	995	71.8	–	–	–

4. In most of the studies, the resilient modulus decreased with the rise in RCA content and 40% RCA content gave the most satisfactory results.
5. The flow number which is used as an indicator to rutting resistance increased with the increase in RCA content.
6. In most of the studies, the optimum value of TSR was obtained at 40% RCA.
7. Most of the studies concluded to replace 40% of the virgin aggregates by RCA. Where there is little traffic, RCA can be an effective substitute for fresh aggregate in HMA roads. RCA offer a wide range of possible applications in the production of asphalt mixtures.

More research is required on using RCA with other types of natural aggregates like basalt, granite, crushed river sand etc. to properly access the extent of use of RCA in surface and base course layers of flexible pavements. Furthermore, research can even be extended to incorporating RCA with natural aggregates in pavements of a runway. It will be a step ahead in promoting sustainable growth and conserving natural resources.

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Fabrication of Sustainable Unfired Brick Using Covid-19 Non-woven PPE Kit Waste and Paper Industry Sludge

Jhanvi Desai, Mehali Mehta, and Binish Desai

Abstract The coronavirus disease (COVID-19) pandemic has increased the global demand for personal protective equipment (PPE) to prevent public health emergencies. The majority of people choose face masks among all PPEs for protective purposes. PPE kits are made of a non-biodegradable material which is hazardous to human health as well as aquatic life and the environment. With the addition of more paper industries, waste generation is rapidly rising. The majority of the Paper industry's sludge is sent to the landfill site which produces harmful gases (CO_2 and methane) that leads to global warming. Consequently, it is necessary to manage such waste through sustainable means. This study focuses on the use of COVID-19 Non-woven PPE Kits including face masks (single use, surgical, N-95, etc.), and head cover with paper industry sludge for the fabrication of sustainable unfired brick. The 9 steps of sustainable unfired brick fabrication include disinfection of waste, mixing and crushing waste, moulding, demoulding, and drying unfired brick. Water absorption and compressive strength test were performed on fabricated unfired brick. The compressive strength test was observed to be 62.83 kg/cm^2 in fabricated unfired brick with 48% of disinfected COVID-19 non-woven waste, 32% of paper industry sludge and 20% of EETech binder. The sustainable unfired brick had a minimal carbon footprint.

Keywords COVID-19 pandemic · Non-woven PPE Kits · Paper industry sludge · Waste management · Sustainable unfired brick

J. Desai (✉)
Environmental Engineering, Sarvajanik College of Engineering and Technology, Surat, Gujarat, India
e-mail: jhanvidesai999@gmail.com

M. Mehta
Civil Engineering Department, Sarvajanik College of Engineering and Technology, Surat, Gujarat, India
e-mail: mehali.mehta@scet.ac.in

B. Desai
Eco Eclectic Tech. Group (EETech Group), Valsad, Gujarat, India
e-mail: binish@eetechgroup.com

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_15

1 Introduction

The coronavirus disease (COVID-19) was announced as a global public health emergency by World Health Emergency [4, 7, 18]. Service workers (e.g., doctors, surgeons, nurses, caregivers, etc.) and those treating COVID-19-infected patients should wear personal protective equipment (PPE) such as surgical gloves, face-masks, and aprons. More and more countries are advising people to wear facemasks before travelling to public locations. As a result of these recommendations, millions of personal protective equipment (PPE) are made and used on a regular basis during the pandemic. The approximate regular number of PPE (e.g. facemasks) utilised in India amounts to 203 Tonne per and India has committed to compulsory usage for their residents with reported COVID-19 cases [2, 11, 14]. According to CPCB info, Maharashtra is generating 19.02 tonnes of COVID-19 waste per day, followed by Kerala (23.71 TPD), Gujarat (21.98 TPD), Tamil Nadu (13.57 TPD), Uttar Pradesh (15.91 TPD), Delhi (18.79 TPD), West Bengal (5.72 TPD), and Karnataka (16.91 TPD). Millions of infected PPEs (e.g. facemasks and gloves) will end up as waste that could cause environmental and health risks if poorly treated [2]. The World Health Organization (WHO) has issued comprehensive instructions for the Proper disposal of PPE trash, which includes surgical masks, disposable gloves, and respirators used in the healthcare sector [13, 21]. Unfortunately, used face masks can almost everywhere be found from urban roads to parking spaces to local parks as the littering rises. Even if masks are deposited in waste bins or lie down at locations, because of the light nature of the masks, wind and rainwater will openly carry the masks to roads or to rivers and oceans, where plastic masks can be broken up into microplastics. Along with a list of reports of facemask and glove consumption by urban and domestic animals, there was photographic proof of fish and birds being caught in PPE. Furthermore, under controlled laboratory conditions, it has been shown that disposable face masks can release chemical pollutants and microfibers into the environment. Therefore, improper disposal of masks or misuse and poor waste management of the used personal protection equipment can cause problems for wildlife, or destroy animals and marine life [4, 16, 17, 19, 20]. As such, multidisciplinary teamwork is essential in battling the COVID-19 pandemic and reducing environmental risks involved with the disposal of used personal protective equipment.

The pulp and paper industries are one of the world's most polluted industries, particularly India. India produces 10.11 million tonnes of paper annually, 2.6 percent of the global paper production. Moreover, India is one of the world's fastest growing pulp and paper business, with annual per capita consumption growth of over 10 percent. Pulp and paper manufacturing are a capital-intensive, energy-intensive, and water-intensive industry. A paper mill generates approximately 40 to 50 kg of dry sludge (70 % primary sludge and 30 percent secondary sludge) in the production of one tonne of paper. Today, all of this sludge is disposed of by landfilling and spreading, resulting in substantial disposal expenses. Paper mill sludge can be used in brick, cement, construction, road construction, manufacturing of ethanol, production of lactic acid, animal feed manufacturing, composting, vermicomposting, paper-board industries and in the manufacturing of ceramic materials. Most recently, techniques like pyrolysis, direct liquefaction, oxidation of wet air, vapour reform, anaerobic digestion and gasification have also been proposed as other appropriate steps [1, 5].

On the other hand, the use of bricks grew dramatically due to increased civil and infrastructure projects. India is the world's second largest brick manufacturing sector, after China. One of the main ingredients needed for brick manufacturing is cultivable soil, which is particularly useful for farming. India has recognised in recent years that the continuous production of bricks has put an immense burden on natural resources and therefore threatened the future of agriculture [3, 6, 22]. Bricks are manufactured in kilns at around 1400 °C which requires burning a large amount of wood, resulting in the release of highly polluting gases such as carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3) and in some situations, fluorine and chlorine, which are all hazardous. Due to the massive amounts of toxic emissions generated, brick kilns are associated with severe health and environment problems [15].

Urgent multidisciplinary partnerships are expected in order to minimize the negative environmental impacts created by the fired brick manufacturing, COVID-19 pandemic and paper industry sludge. This study includes an innovative way of using Non-woven PPE generated from the COVID-19 pandemic and paper industry sludge in manufacturing of sustainable unfired brick.

2 Materials and Methods

The material used in this study are Non-woven PPE generated from COVID-19 Pandemic, and Paper industry sludge and binder developed by the EETech group. The used PPE generated from COVID-19 pandemic were infected hence, it is required to disinfect as per CPCB guidelines. Non-woven PPE Wastes were disinfected by the EETech group. Paper industry sludge was collected from the industry to perform this study. Properties of Non-woven PPE wastes and Paper industry sludge are as follows:

2.1 Properties of Non-woven PPE Wastes from COVID-19 Out Break

Nonwovens are flexible, porous, products consisting of one or more fibre layers.

The separate fibres may either be preferentially oriented in one direction or may be deposited in a random manner. Chemical, thermal, or mechanical processes bond them into textile products.

The Non-woven fabric is light in quality, made primarily from poly-propylene resin, and feels good to the touch; The material of the non-woven fabric doesn't absorb water, its moisture content is basically zero, it has good water repellence, is porous, is breathable and is easy to keep the cloth secure and easy to wash; Because polypropylene is a chemically passive substance, it can prevent moths and has good corrosion resistance; The material most commonly used to make them is polypropylene, either 20 or 25 g per square meter (gsm). Polypropylene is the key raw material in the manufacturing of Non-woven PPE. Properties of Homopolymer polypropylene, Copolymer polypropylene are described in thebelow Table 1.

Table 1 Properties of polypropylene

ISO or UL test	Property	HPP[a]	HPP-filled	CPP[b]	CPP-filled
ISO1183	Specific gravity	0.90–0.91	0.97–1.27	0.89–0.91	0.98–1.24
ISO62	Water absorption (%)	0.01–0.03	0.01–0.09	0.03	0.01–0.02
ISO527	Tensile strength (MPa)	31.03–41.37	24.13–110.32	27.58–37.92	17.24–68.95
ISO527	Elongation at break (%)	100–600	1.5–80	200–500	2.2–50
ISO527	Tensile modulus (MPa)	113.7–155.1	258.5–689.5	89.6–124.1	34.4–241.3
ISO178	Flexural modulus (MPa)	117.2–172.3	144.8–689.5	89.6–137.9	144.8–661.9
ISO180	Notched Izod impact strength (J/m)	21–75	32–641	59–747	32–214
ASTMD 785	Hardness, rockwell R	80–102	75–117	65–96	81–105
ISO8302	Thermal conductivity (W/(mK))	0.22	0.25–0.51	0.22	0.25–0.51
ISO11359	Coefficient of thermal expansion (10^{-4} m/m−°C)	1.4–1.8	0.27–0.90	1.08–1.80	0.36–1.08
ISO75	Deflection temperature (°C)				
	At 1.80 MPa	49–60	54–166	49–60	47–138
	At 0.45 MPa	107–121	104–149	85–104	77–152

([a]Homopolymer polypropylene, [b]Copolymer polypropylene).
Source Maddah HA [12]. Polypropylene as a Promising Plastic: A Review. *American Journal of Polymer Science*, *6*(1). https://doi.org/10.5923/j.ajps.20160601.01

2.2 Properties of Paper Industry Sludge

Paper industrial sludge has a moisture content 65–70%, presence of SiO_2, Al_2O_3, CaO, etc. shown in Table 2.

2.3 Methodology

Methodology flow chart represents the process of waste utilization for fabrication of unfired brick. Experimental work carried out for manufactured unfired bricks were divided into two categories which are given below:

1. Fabrication process of unfired bricks
2. Test performed after unfired brick fabrication

Table 2 Properties of paper industry sludge

Property	Value
Moisture content	65–70%
Ph	6–7.6
Total solids (TS),%	1.0–2.0
VS (% of TS)	65–97
Nitrogen (% of TS)	3.3–7.7
SiO_2	14.56
Al_2O_3	10.02
K_2O	0.6
CaO	5.37
Zn	1701.1
Cu	52.3
Mn	252.2
Fe	3600.4
Cr	20.7
Cd	0
Co	0

Source Goel & Kalamdhad [5, 6]. An investigation on use of paper mill sludge in brick manufacturing. *Construction and Building Materials*, *148*. https://doi.org/10.1016/j.conbuildmat.2017.05.087

2.3.1 Fabrication Process of Unfired Bricks

Process for fabrication of unfired brick carried out with waste collection, crushing of waste, sieve analysis, mixing of waste, moulding, demoulding and drying of the sample. The process is shown in a flowchart in Fig. 1.

COVID-19 Pandemic Non-woven PPE waste collected is disinfected as per CPCB guidelines. According to the CPCB guidelines waste was stored in a separate bin for 72 h and while disposing the waste from the bin, care should be taken such as gloves, shield, etc. Organic disinfectant was used for disinfection of PPE waste.

Paper industry sludge Collected from industries. Non-woven PPE waste generated from covid-19 pandemic was crushed in a crusher by the EETech group.

Figure 2 Shows disinfected and crushed COVID-19 Non-woven PPE wastes. Paper industry sludge is shown in Fig. 3.

Sieve analysis of the waste is carried out using a 1 mm sieve. Size of waste less than 1 mm will pass from the 1 mm sieve and retained waste further transfer to crushing. Minimum size of the material will help to achieve a proper bond and strength while fabrication of the sustainable unfired brick is acheived. Sieve analysis was done for equal and homogeneous Particles. Sieve analysis of COVID-19 Non-woven PPE wastes carried out in a 1 mm sieve is shown in Fig. 4.

After Sieve analysis mix the waste in proper proportion. Mixing of Primary and secondary waste in selected proportion. Primary and Secondary waste will change

Fig. 1 Methodology for fabrication of unfired brick

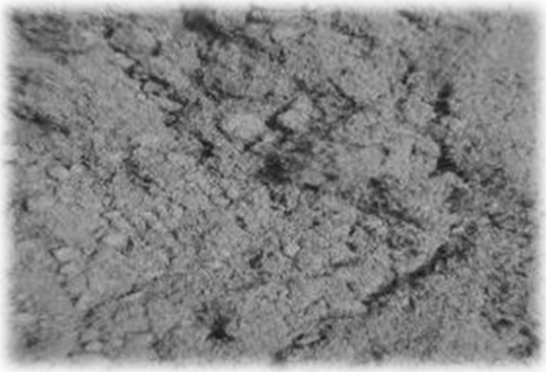


Fig. 2 Disinfected COVID-19 pandemic non-woven PPE wastes

Fig. 3 Paper industry sludge

as per proportion. Prepare mixer of waste by adding Binder which is developed by EETech Group. Gently add water with proper quantity in wastes while preparing mixer.

Proportion of COVID-19 outbreak non-woven PPE wastes and Paper industry sludge are given in Table 3 which varying in different proportions with different binders. Binder which is developed by the EETech Group was used in proportions of 10% and 20% with different percentages of waste (Figs. 5 and 6).

Mixing of waste for fabrication of unfired brick in of standard size at Eco Eclectic Tech Group office by using the binder which is developed by the EETech group [8].

After mixing of wastes, the prepared waste mixture is taken in the mould in 3 equal layers. By using a tamping rod give 25 blows to each layer or keep it on the vibrator to remove air voids. Mixed wastes filled in the mould of standard size 20cmx10cmx10cm which is fabricated at the EETech group office by using the binder which is developed by the EETech group.

Fig. 4 Sieve analysis of wastes

Table 3 Proportion of COVID-19 Non-woven PPE wastes and paper industry sludge

Sr.No	Sample	Proportion of material		
		Cement/binder (%)	Covid-19 (non-woven) waste (%)	Paper industry sludge (%)
1	A1	Binder 10%	36	54
2	A2		54	36
3	A3		27	63
4	A4		63	27
5	B1	Binder 20%	32	48
6	B2		48	32
7	B3		24	56
8	B4		56	24

After moulding when brick become partial dry and access amount of water will absorb demould that sample of unfired brick carefully without deforming corners of sample as shown in Fig. 7.

Demould the sample of brick from the mould and kept it for sundry (Fig. 8). Generally sundried of period of the sample is 48–72 h but it will vary according to the season.

2.3.2 Test Performed After Unfired Brick Fabrication

After fabrication of sustainable unfired brick water absorption test and compressive strength test were performed. Water absorption test was carried out to determine moisture presence in brick when the condition is extreme. The water absorption test can be used for check durability of brick which include its quality and behaviour of

Fig. 5 Mixing of wastes

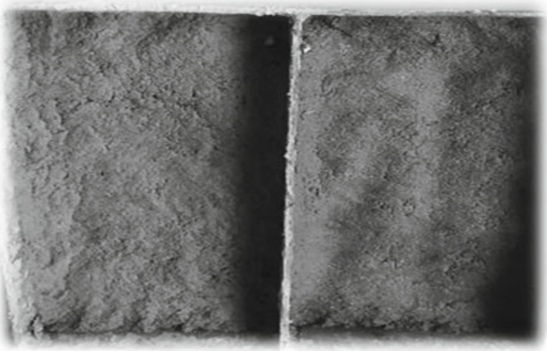
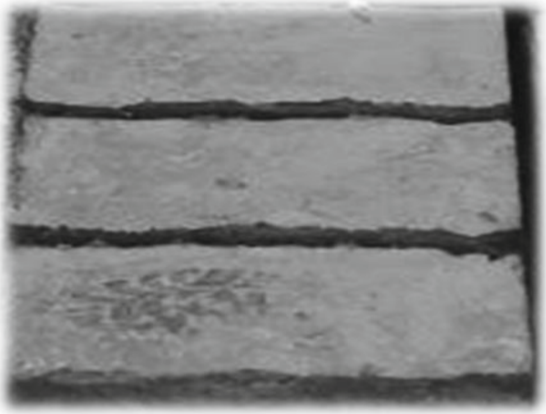


Fig. 6 Moulding

Fig. 7 Demoulding

Fig. 8 Sundry of sample



the brick in different weather conditions. Procedure for water absorption test is as follows:

Step 1: Samples were first dried in sunlight.

Step 2: Take the weight of dry sample and record the reading of sample.

Step 3: Then, immersed the sample in water at room temperature for 24 h.

Step 4: After 24 h samples were taken out from water.

Step 5: Wiped the sample with damped cloth to remove trace of water that may be present in water and kept it for 3 min.

Step 6: Take the weight of the wet sample and record the reading of the sample.

Step 7: Calculate the water absorption in percentage.

$$\text{Water absorption in percentage} = \frac{\text{Weight of wet sample} - \text{Weight of dry sample}}{\text{Weight of wet sample}}$$

Figure 9 Shows 20 × 20 × 20 cm size sample immersed in water for 24 h. After water absorption of 24 h remove samples from water keep it for 3 min and clean the surface of samples with damp clothes. Take the wet weight of the sample to find the percentage of water absorption

As shown in Fig. 10. Compressive strength test was performed in the compression testing machine (CTM). Compressive strength test was carried out to determine the load carrying capacity and ability of the material to resist failure or crack of brick under compression. Procedure for the compressive strength test is given below.

Step 1: Prepared unfired bricks were tested after it completely dried.

Step 2: Kept sample in compression testing machine between two ply wood plates.

Step 3: To hold sample in correct position plywood sheets were used during testing.

Step 4: Start the compression testing machine and apply the load on the sample.

Step 5: Apply the load till the sample starts breaking.

Step 6: Record the applied load.

Fig. 9 Water absorption of sample

Fig. 10 Compressive strength of the sample

3 Results and Discussion

This research work investigated the suitability of COVID-19 non-woven PPE wastes and paper industry sludge used in different proportions for manufacturing of unfired brick. For unfired brick fabrication from wastes currently there are no standards are available. According to the Indian Standards (IS) IS 3495 1–4 (1992) and IS 1077 (1992) [9, 10] for conventional clay brick compressive strength should be greater or equal to 40 kg/cm^2 and water absorption between 12 and 15%.

As shown in Fig. 11. Results of water absorptions are shown in graph. Water absorption of samples A1, A2, A3, A4, B1, B2, B3 and B4 are 12% to 15% which are as per the standard limit given in the IS3495 1–4 (1992).

A1 and A2 achieved 15% and 14% water absorption respectively. Wastes proportion of A1 10% is Binder + 36% COVID-19 wastes + 54% Paper industry sludge and A2 is 10% Binder + 54% COVID-19 wastes + 36% Paper industry sludge. A3

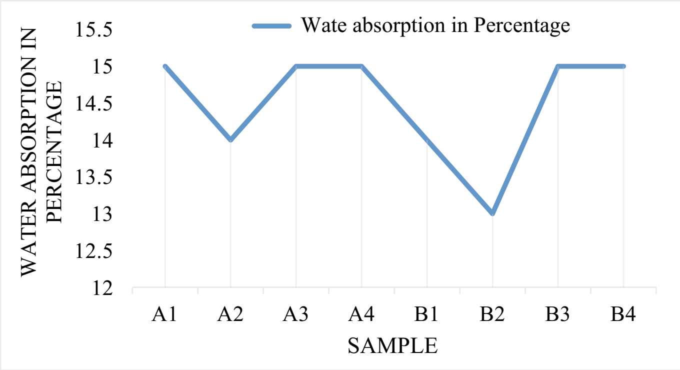


Fig. 11 Water absorption test results

and A4 achieved 15% water absorption. Wastes proportion of A3 10% Binder + 27% COVID-19 wastes + 63% Paper industry sludge and A4 10% Binder + 63% COVID-19 wastes + 27% Paper industry sludge.

B1 contains 20% Binder + 32% COVID-19 wastes + 48% Paper industry sludge and B2 contain 20% Binder + 48% COVID-19 wastes + 32% Paper industry sludge which has 14% and 13% water absorption respectively. B3 contains 20% of Binder + 24% COVID-19 wastes + 56% Paper industry sludge and B4 contains 20% of Binder + 56% COVID-19 wastes + 24% Paper industry sludge which has water absorption of 15% and 14% respectively are within standard limit as given in the IS3495 1–4 (1992).

As per IS 3495 1–4 (1992) and IS 1077 (1992) the standard limit for compressive strength is 40 kg/cm^2. According to the results in Table 4 and shown in Fig. 12, B1 sample from 20% of the binder developed by the EETech group was with 32% COVID-19 wastes + 48% Paper industry sludge has a compressive strength of

Table 4 Results of compressive strength test

Sample	Binder (%)	COVID-19 (non-woven) wastes (%)	Paper industry sludge (%)	Compressive strength in Kg/Cm^2
A1	10	36	54	28.2
A2		54	36	33.75
A3		27	63	17.6
A4		63	27	23.6
B1	20	32	48	41.2
B2		48	32	62.83
B3		24	56	55.9
B4		56	24	58.7

Final compressive strength test results are shown in Table 4

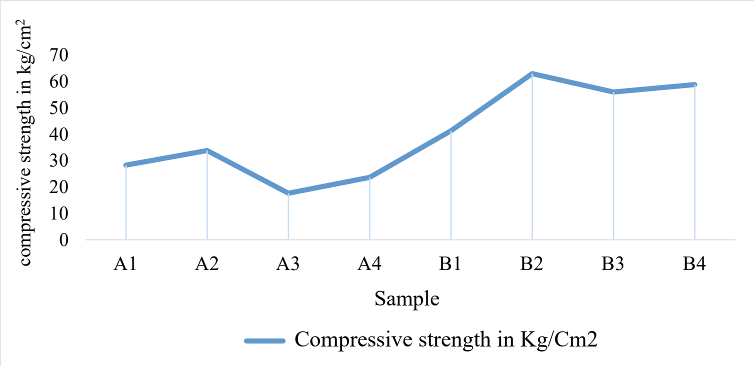


Fig. 12 Result of compressive strength test

41.2 kg/cm^2, sample B2 contains 20% of the binder developed by the EETech group with 48% COVID-19 wastes + 32% Paper industry sludge has 62.83 kg/cm^2 of compressive strength, B3 sample from 20% of the binder developed by the EETech group with 24% COVID-19 wastes + 56% Paper industry sludge has compressive strength of 55.9 kg/cm^2, B4 Sample from 20% of the binder developed by the EETech group with 56% COVID-19 wastes + 24% Paper industry sludge has 58.7 kg/cm^2 of compressive strength that are feasible for commercial use in the construction industry.

4 Cost Analysis of Unfired Brick from Wastes

Costing of unfired brick from covid-19 (non-woven material) waste and Paper industry sludge is given in Table 5.

Commercially selling cost of conventional clay brick is 6 RS. Cost of unfired brick from Covid-19 (non-woven material) with Paper industry sludge is 2.8 RS. and Cost of unfired brick from Paper industry sludge is 2.5 RS. Cost of both unfired bricks from waste is less than conventional clay brick which is economic, commercially viable and eco-friendly.

5 Significance of Research

The COVID-19 Non-woven PPE wastes have increased across the world, creating a new environmental challenge. This waste ends up in the incineration and landfills. Emissions from incinerators creates air pollution issues and residue ash required landfilling or so, the combustion of plastics gives rise to highly toxic pollutants. Utilisation of this waste as a resource lead to proper waste management.

Table 5 Cost analysis of unfired brick from wastes

Description	Per unit	Amount in Rs
Raw material		
Paper industry sludge	Per Kg	0.2
Binder (EETech group)	Per Kg	4.6
Covid-19 disinfection	Per brick	0.1
Labour cost	Per brick	0.5
Brick finishing and other exp	Per brick	0.8
Total capital cost	Per brick	1.9
Selling cost (add 15 to 20% for extra expenditure)	Per brick	2.8
Cost of unfired brick from Covid -19 + paper industry sludge	Per brick	2.8
Cost of unfired brick from Paper industry sludge	Per brick	2.5

Majority of Paper industries' waste are sent to the landfill site which produces harmful gases (CO_2 and methane) which are greenhouse gases and contribute to global warming. Landfills create a serious environmental concern due to groundwater pollution, land degradation, soil pollution, air pollution. This impacts the climate through methane emissions and potential health hazards.

Further, Emission of huge quantity of toxic elements from brick kilns is causing serious health hazards. The brick kilns emit toxic fumes containing suspended particulate matters rich in carbon particles and high concentration of carbon monoxides and oxides of sulphur (SOx) that are harmful to eye, lungs and throat.

This study includes utilization of COVID-19 non-woven PPE wastes and Paper industry sludge as a key raw material for constructive end product as a building material such as unfired brick which helped to stop the waste transfer to landfill and reduce the effect of global warming and climate change. Unfired brick consumes around 11 kg of waste per square meter, and it will be best solution for waste management.

Unfired brick from COVID-19 non-woven PPE and Paper industry sludge has good water absorption capacity and high compressive strength. Unfired brick from wastes is durable and light in a weight. It is 100% recyclable after its end of life. Less amount of CO_2 emission compares to conventional clay brick as it burns in kilns. It is economic and energy efficient as its unfired brick. Unfired brick from wastes are commercially available at low prize compared to fired red clay brick.

6 Conclusion

This study proposed a new approach for reducing COVID-19 pandemic wastes and paper industry sludge in fabrication of sustainable unfired brick. This study demonstrated the feasibility of wastes with the binder for unfired brick.

It was noted that unfired brick from 10% binder (EETech group) + 54% COVID-19 non-woven PPE wastes + 36% Paper industry sludge has a compressive strength of 33.75 kg/cm^2. Sample A1, A2, A3 and A4 has strength less than the standard limit 40 kg/cm^2 as per IS 3495 1–4 (1992) and IS 1077 (1992).

Samples B1, B2, B3 and B4 have good compression strength and water absorption capacity. Sample B2 from 48% COVID-19 Non-woven PPE waste with 32% Paper industry sludge and it contains 20% of Binder which is developed by the EETech group. It has a compressive strength of 62.83 kg/cm^2 and water absorption is 13% which is higher than all the samples that are included in this study. All the parameters of sample B2 are as per IS 3495 1–4 (1992) and IS 1077 (1992). Sustainable unfired can use commercially in construction industry.

7 Comparison of Unfired Brick with Conventional Brick

The cost of fabricated unfired brick is Rs. 2.8 and the cost of conventional brick is Rs. 6 so unfired bricks are economical. Unfired bricks are lightweight compared to conventional red clay bricks. Unfired bricks have less carbon footprint in comparison to the red clay brick.

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Estimation of Short-Lived Climatic Pollutants (SLCPs) and Other Pollutants Generated from the Solid Waste Management (SWM) Surat, Gujarat

Meet Dhamsaniya, Dipti Christian, M. A. Shabiimam, and Shivam Kapoor

Abstract Rapid growth in urbanization and increasing population have accelerated the amount of solid waste generation. It has been reported that 70% of solid waste is unscientifically disposed in landfill sites and open dumping grounds. Solid Waste Management (SWM) is of critical importance to society. Various types of solid waste generated within a city contain a mixture of different types of waste composition. The various activities of solid waste management contributed to the emission of Carbon dioxide, Oxides of Nitrogen, Oxides of Sulphur, Particulate Matter and Short-Lived Climatic Pollutants (SLCPs) such as Methane and Black Carbon. This paper discusses the above pollutants emission for Surat city. Solid Waste Emissions Estimation Tool (SWEET) developed by U. S. Environmental Protection Agency was used to analyze the pollutants. This study also provides knowledge of environmental impacts due to current waste management practices in Surat city. This study's outcomes may be helpful for selecting alternative scenarios in solid waste management to reduce the environmental pollution in Surat city.

Keywords Solid waste management · SWEET tool · Short lived climatic pollutants · Surat

M. Dhamsaniya (✉) · D. Christian · M. A. Shabiimam
Department of Civil Engineering, School of Technology, Pandit Deendayal Energy University, Gandhinagar 382007, India
e-mail: meet.dmten21@sot.pdpu.ac.in

D. Christian
e-mail: dipti.cmten21@sot.pdpu.ac.in

M. A. Shabiimam
e-mail: shabiimam.ma@sot.pdpu.ac.in

S. Kapoor
Department of Environmental Engineering, Government Engineering College, Bhuj 370001, India
e-mail: shivamkpr.gec@gmail.com

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_16

1 Introduction

Solid waste generation in Indian cities and urban areas has recently experienced an increase due to improved citizens lifestyles, the growth of different industries and population expansion [1]. Waste generation creates a tremendous negative impact on the surrounding environment and thereby harms the natural resources required for a growing economy. The number of resources in nature is limited and the capacity of the natural environment to assimilate the waste is decreasing day by day as the quantity of waste generated increases continuously [2]. Amongst the different types of waste, municipal solid waste (MSW) is of critical importance as it contains different types of waste generated from urban areas. The MSW generally consists of household waste, garden and park waste, and commercial and institutional waste. It can be further categorized as organic waste like food, fruit and vegetable waste and inorganic waste like paper, plastic, metal, glass etc. [3].

According to CPCB Report on solid waste management and generation, the total quantity of solid waste generated in India is 160038.9 TPD of which 152,749.5 TPD waste is collected at a collection efficiency of 95.4%. Out of the total amount, 50% of waste is treated (79,956.3 TPD) and 18.4% of the waste is landfilled (29,427.2 TPD) while 31.7% (50,655.4 TPD) remains unaccounted [4, 5]. For the state of Gujarat, 10,373.79 TPD solid waste is generated per year of which 10,332 TPD is collected and 6946 TPD is treated while 3385.82 TPD is landfilled [4].

Waste Management creates a negative impact on the environment, in that one of the major sources is Short-lived climate pollutants (SLCPs). SLCPs are the pollutants that remain in the atmosphere for a short time of period than Carbon dioxide but their harmful impacts on the environment are higher than others. After Carbon dioxide, SLCPs such as Black carbon, Methane, tropospheric ozone, and hydrofluorocarbons are the most significant contributors in global greenhouse effects. These SLCPs contribute around 45% of the current global warming. It is anticipated that these pollutants could contribute up to 50% of the Global warming if no effort is made to reduce their emissions in the following decades [6] (Table 1).

Table 1 Lifetime and climatic impacts of SLCPs [6]

Sr. No	Pollutant	Lifetime in atmosphere	Climatic impacts
1	Hydrofluorocarbons (HFCs)	15 years	1500x
2	Black Carbon (BC)	Few weeks	900x
3	Methane (CH_4)	12 years	84x
4	Carbon dioxide (CO_2)	100–1000 years	1x

Where x = climatic impact of Carbon dioxide on the environment

1.1 Study Area

Surat is located in the western part of India along the banks of river Tapi. It is the second cleanest city in India and is one of the fastest developing cities in Gujarat. Surat city has undergone an increased population growth from 27.02 lakh in 2001 to 44.67 lakh in 2011 (65.33%) [1]. Surat city has a population of around 69 lakhs (estimate for the year 2022) that generates around 2300–2400 TPD of Municipal solid waste [7]. Surat Municipal Corporation (SMC) is the government body responsible for handling all activities related to waste collection and disposal. The Surat Municipal Corporation is divided into seven zones that are further divided into different wards [8].

The need for solid waste management was realized after the plague of 1994 and consequently, the Surat solid waste management plan was developed on the basis of the Chennai solid waste management system [8]. The main steps involved in solid waste management plan are indicated in the Fig. 1.

The primary collection of solid waste occurs via the Door-to-Door collection system that is partly outsourced and partly handled by the department itself. SMC had outsourced five agencies namely Jigar Transport Co, Swachatha Corporation, Western Imaginary Transcon Pvt. Ltd, Global Waste Management Cell Pvt. Ltd. and Om Swachatha Corporation to carry out the collection work in the different zones of Surat city in the year 2021 [7].

Segregation of waste at the source is carried out to separate recyclable waste and transport it to Material Recovery Facility (MRFs) under the guidelines provided in Swachh Bharat Abhiyan. In addition, to achieve proper collection and management of hotel waste, 18 vehicles are deployed by the hotel association in coordination with SMC. The waste collected from the door-to-door collection system is then transported

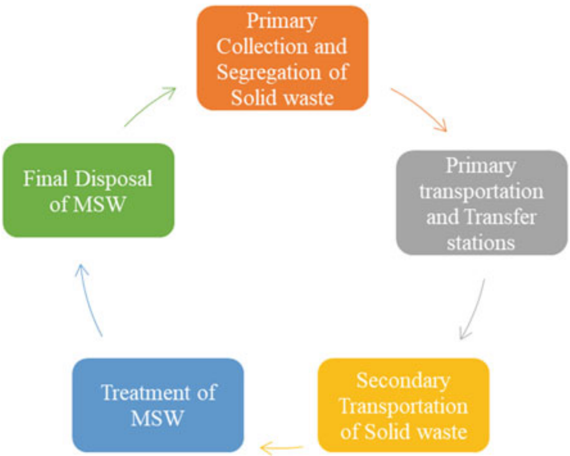

Fig. 1 Main components of MSW management plan [7]

to a transfer station. At present, there are eight transfer stations in Surat city. The secondary transport of solid waste occurs from the transfer station to the disposal site at Khajod [7].

The waste received at the Khajod site is treated if possible or disposed properly in an open space of about 6,12,000 m^2. The treatment process generally consists of segregating the received urban MSW into different classes like wet organic, dry organic, recyclable or inert. The treatment process is then carried out based on the type and composition of solid waste. The entire solid waste management system developed by SMC is depicted in the Fig. 2.

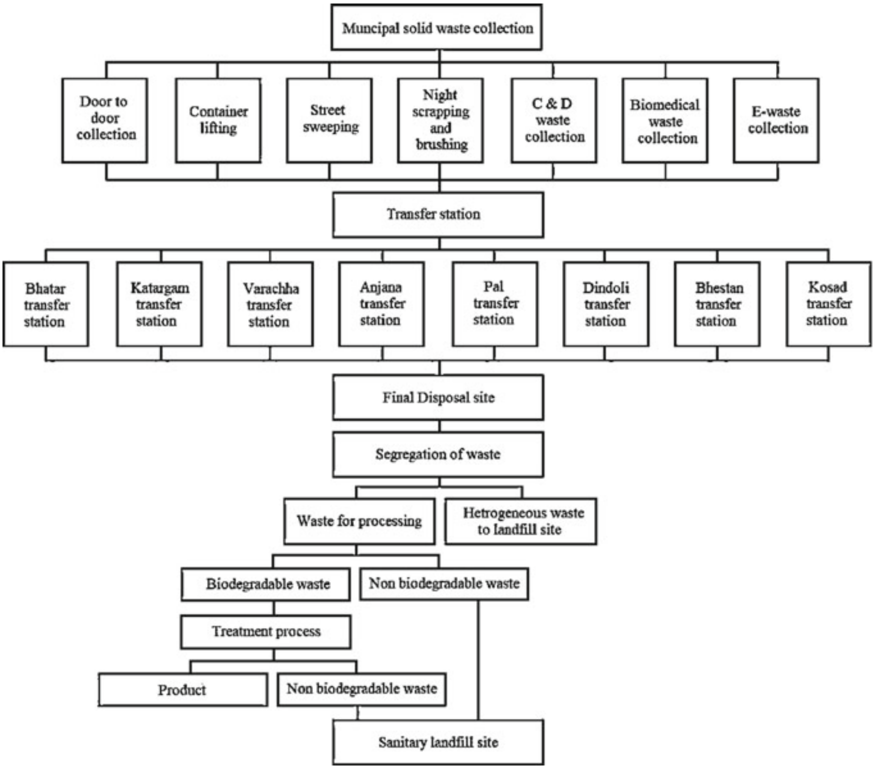

Fig. 2 Solid waste collection and disposal system [7]

Table 2 Composition of MSW [7]

Composition	Percentage (%)	Waste (metric tons per year)
Food waste	46.3	3,90,952
Green	8.00	67,551
Wood	4.70	39,686
Paper/cardboard	4.63	39,095
Textiles	13.07	1,10,362
Plastic	9.30	78,528
Metal	3.32	28,034
Glass	3.48	29,385
Tyres	2.57	21,701
Other waste	4.63	39,095
Total	**100**	**8,44,389**

2 Materials and Methods

2.1 Status of MSW in Surat City

The composition of solid waste generated from Surat city generally consists of plastics, glass, textile waste, metals, food waste and bio-medical waste. The table given below gives details about the different compositions of waste (Table 2).

2.2 SWEET Tool

The Solid Waste Emissions Estimation Tool (SWEET) was developed by the U. S. Environmental Protection Agency Climate and Clean Air Coalition under its Municipal Solid Waste Initiative. It is an excel based tool that calculates the different emissions resulting from MSW activities like waste collection and transportation, waste handling equipment like bulldozers and wastes disposal activities (landfill, burning, composting etc.). The pollutants such as methane, black carbon, carbon dioxide, nitrogen oxides, sulfur oxides and particulate matter can be quantified using this tool. The emissions can be quantified in terms of metric tons of carbon dioxide equivalent or metric tons. The results can be presented in tabular or graphic forms for individual sectors or for the entire study area as a whole [9]. The solid waste generation data and composition data were obtained from the SMC database and an estimate of emissions of different pollutants was carried out using SWEET tool for 2021 [10].

3 Emission Measurement

The total emissions resulting from different activities of solid waste management depends upon the quantity of waste generated and the composition of waste generated in the city [11]. In addition, landfill options and landfill locations adopted in Surat city also influence the total emissions. To determine the different emissions, the regional data of solid waste collection, its composition, vehicular activities related to transport, waste disposal in the form of composting, burning, recycling and disposing in landfill sites was fed into the SWEET tool.

In this study, two scenarios were developed for estimating the emissions and evaluating the impacts associated with waste management activities. These scenarios were as follows:

1. Business-As-Usual (BAU): It is also called as baseline scenario and it indicates the current practices of waste management that are followed by Surat Municipal Corporation.
2. Alternate Scenarios: The alternate scenarios are developed from the baseline scenarios with certain emission reduction measures such as reducing possibilities of open burning of waste, converting uncontrolled landfill sites into controlled landfill sites etc. from year 2025. In this study, three different emission reduction changes were introduced to analyze their impact on the total emissions. These changes are as follows:

    I. Increasing the composting and recycling of waste to reduce the emissions resulting from unsanitary burning or uncontrolled landfill at the disposal site.
    II. Changing the fuel type for the low-duty vehicles that are used for the primary transportation of solid waste. In the baseline scenario, diesel vehicles are used for transportation. While in this scenario, diesel vehicles were replaced by petrol (50%) and natural gas (50%).
    III. Reduce open unsanitary burning of waste that occurs in the areas where solid waste is not collected.

4 Result and Discussion

In this study, emissions of Short-Lived Climatic Pollutants (SLCPs), Carbon Dioxide (CO_2), Methane (CH_4), Black Carbon (BC) and gaseous pollutants like Sulphur Dioxide (SO_2) and emissions of Particulate Matter (PM_{10}) were analyzed. Total Emission obtained for each pollutant for both scenarios from the year 2005 to 2060 are listed in Table 3. In this, alternate scenarios are starting from the year 2025.

The emissions for the short-lived pollutants considered in this study like Black Carbon, Carbon Dioxide and Methane are tabulated in Table 4.

The emissions of Particulate Matter and Sulphur Dioxide estimated from base year 2005 and projected year 2060 are tabulated in Table 5.

Table 3 Total emissions in BAU and alternate scenario

Year	Total emissions (metric tons CO_2 Eq.)	
	BAU	Alternate scenario
2005	1,96,244	1,96,244
2010	3,60,661	3,60,661
2015	5,46,282	5,46,282
2020	6,98,098	6,96,206
2025	9,64,263	7,81,584
2030	13,28,653	4,61,422
2035	18,35,502	5,77,246
2040	12,31,394	5,06,549
2045	11,72,676	5,78,178
2050	14,04,677	7,44,773
2055	18,31,915	9,99,214
2060	24,67,197	13,62,566

Table 4 Total emissions of SLCPs in BAU and alternate scenario

Year	Carbon dioxide (metric tons)		Black Carbon (metric tons)		Methane (metric tons)	
	BAU	Alternate scenario	BAU	Alternate scenario	BAU	Alternate scenario
2005	56,943	56,943	56	56	3,398	3,398
2010	79,769	79,769	78	78	7,837	7,837
2015	1,11,760	1,11,760	108	108	12,464	12,464
2020	1,35,753	1,35,753	126	126	16,473	16,473
2025	1,88,989	41,411	176	100	22,670	22,586
2030	2,62,476	57,514	244	139	31,108	9,080
2035	3,64,538	79,878	339	193	42,855	10,340
2040	2,92,559	68,192	375	249	21,250	5,582
2045	4,06,318	94,708	520	346	10,315	3,278
2050	5,64,311	1,31,535	723	480	6,326	2,474
2055	7,83,739	1,82,681	1,004	667	4,538	2,181
2060	10,88,490	2,53,715	1,394	926	3,551	2,130

Figures 3 and 4 provide a comparative analysis of Carbon Dioxide, Black Carbon and Methane observed during BAU and alternate scenarios. A major reduction can be observed in the Methane emissions that are released in the atmosphere at the landfill site. This can be due to the increase in recycling and composting percentage in the alternate scenario. Similarly, the emissions of Black Carbon and Carbon Dioxide that are released due to the open burning of waste can also be reduced by restricting and

Table 5 Total PM_{10} and SOx emissions in BAU and alternate scenario

Year	PM_{10} (metric tons)		SOx (metric tons)	
	BAU	Alternate scenario	BAU	Alternate scenario
2005	228	228	43	43
2010	322	322	60	60
2015	456	456	83	83
2020	606	606	94	94
2025	845	805	131	44
2030	1,174	1,120	181	62
2035	1,631	1,557	252	86
2040	514	262	289	107
2045	714	362	402	149
2050	992	502	558	206
2055	1,377	696	775	287
2060	1,913	967	1,076	398

limiting the practices of waste burning and increasing awareness among residentials and citizens.

Figure 5 provides total emission in Metric tons CO_2 equivalent observed during BAU and alternate scenarios. The total emissions reduced from 24,67,197 metric tons CO_2 Equivalent to 13,62,566 metric tons CO_2 Equivalent. The percentage reduction due to the proposed control measures is 45%. Figure 6 provides total CH_4 emission in Metric tons observed during BAU and alternate scenarios. The total Methane emissions in the BAU scenario indicate a peak in the year 2035 and a consequent gradual decline of 3,551 metric tonnes in 2060. However, the emission of Black Carbon and Carbon Dioxide indicates a gradual rise. Similarly, total Methane emissions for the alternate scenario with different mitigation schemes indicate reductions.

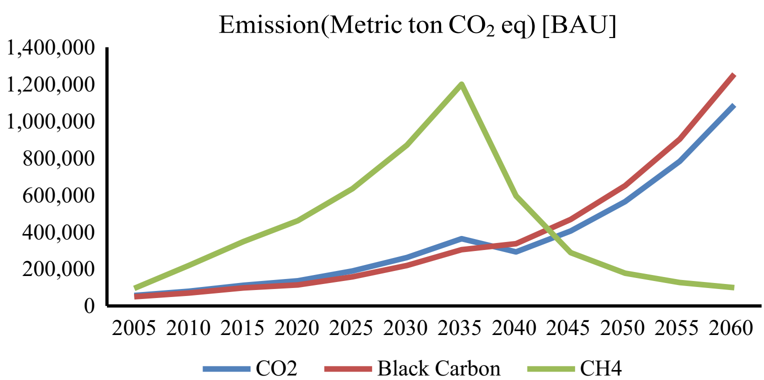

Fig. 3 Emissions in BAU (Metric tons CO_2 eq.)

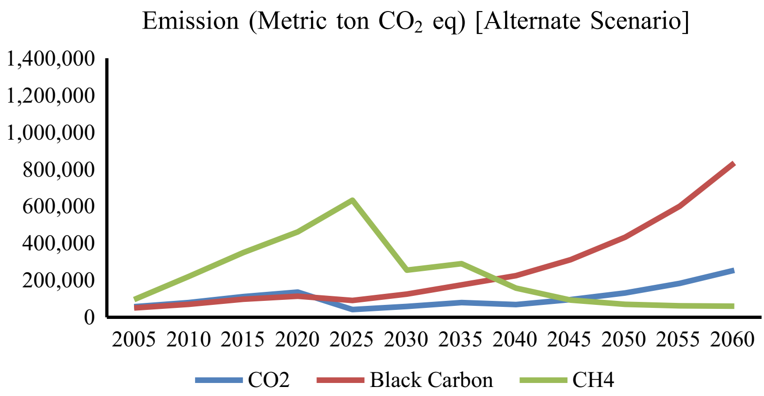

Fig. 4 Emissions in alternate scenarios (Metric tons CO_2 eq.)

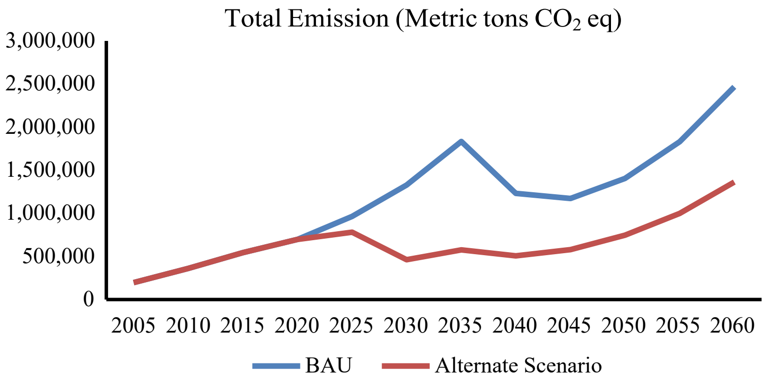

Fig. 5 Total emissions for BAU and alternate scenarios (Metric tons CO_2 eq.)

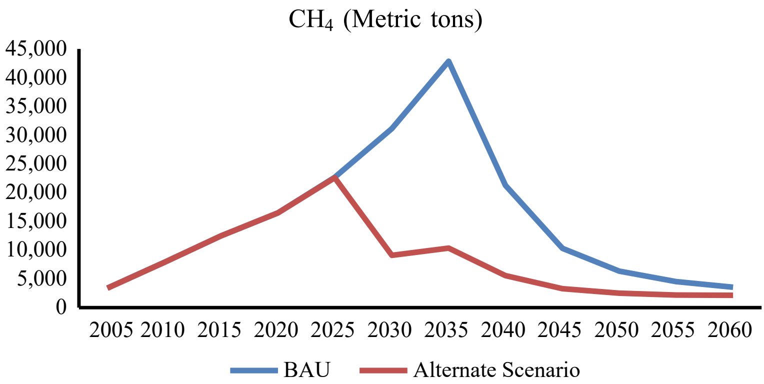

Fig. 6 Total methane emissions for BAU and alternate scenarios (Metric tons)

Figure 7 provides total SOx emission in Metric tons observed during BAU and alternate scenarios. Emissions of SOx are released in the atmosphere due to primary and secondary transportation activities facilitated by the use of light-duty and heavy-duty vehicles. In the BAU scenario, the SOx emissions increase gradually to 1076 Metric Tons in the year 2060. However, the replacement of light-duty diesel vehicles with petrol and gasoline vehicles indicates a considerable reduction of 63% in SOx emissions of 398 Metric Tons in 2060. While, Fig. 8 provides PM_{10} emission in Metric tons observed during BAU and alternate scenarios, emissions of particulate matter are released into the atmosphere at the landfill sites with total projected emissions of 1913 Metric Tons in the year 2060 for BAU conditions. In the alternate scenario, the PM_{10} emissions decreased by 49% with projected emissions of 967 Metric Tons in the year 2060. This reduction can be attributed to the reduction of open unsanitary burning of solid waste in the emission reduction measures.

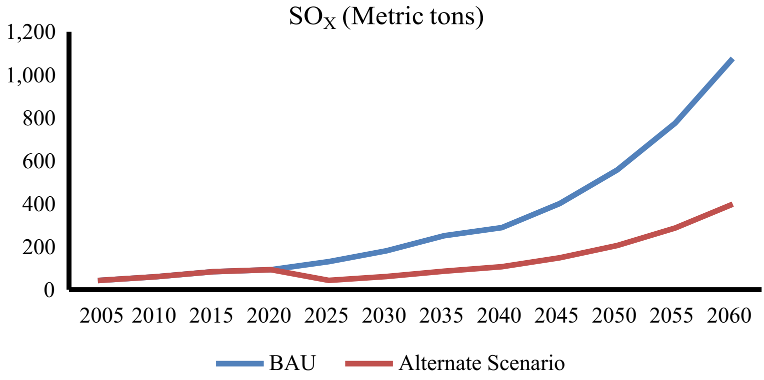

Fig. 7 Total SOx emissions for BAU and alternate scenarios (Metric tons)

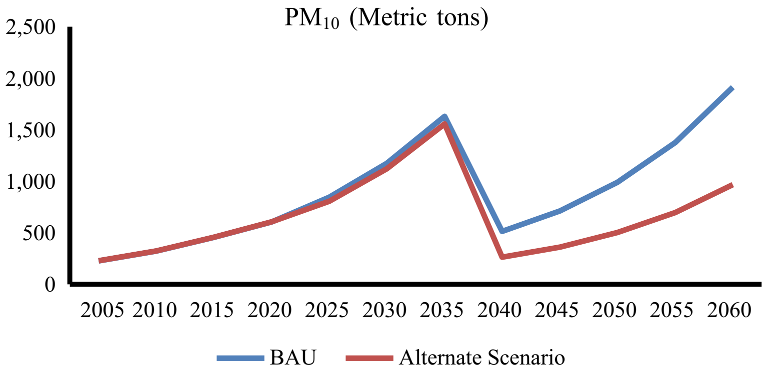

Fig. 8 Total PM_{10} emissions for BAU and alternate scenarios (Metric tons)

Similarly, Fig. 9 provides total CO_2 emission in Metric tons observed during BAU and alternate scenarios. The emissions of CO_2 that are released in the atmosphere due to open unsanitary burning of solid waste show a projected rise of 10,88,490 Metric Tons in 2060. Alternate scenarios can lead to 77% decrease in CO_2 emissions with 2,53,715 Metric Tons in the year 2060. Figure 10 shows total Black carbon emission in Metric tons observed during BAU and alternate scenarios. The emissions of Black Carbon resulting from open unsanitary burning of solid waste can be reduced by 34% with projected values of 1394 Metric Tons in BAU and 926 Metric Tons in the alternate scenario.

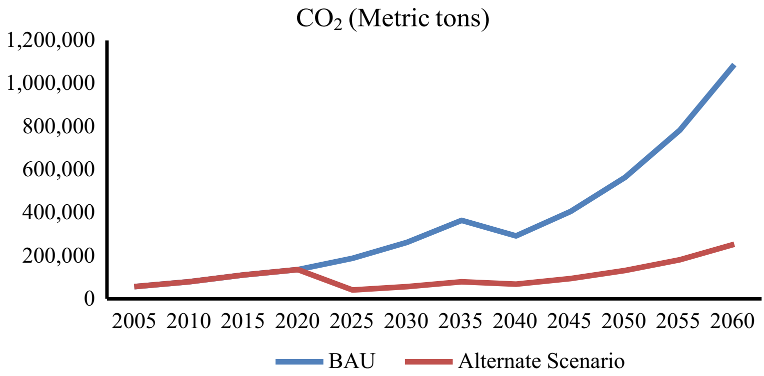

Fig. 9 Total CO_2 emissions for BAU and alternate scenarios (Metric tons)

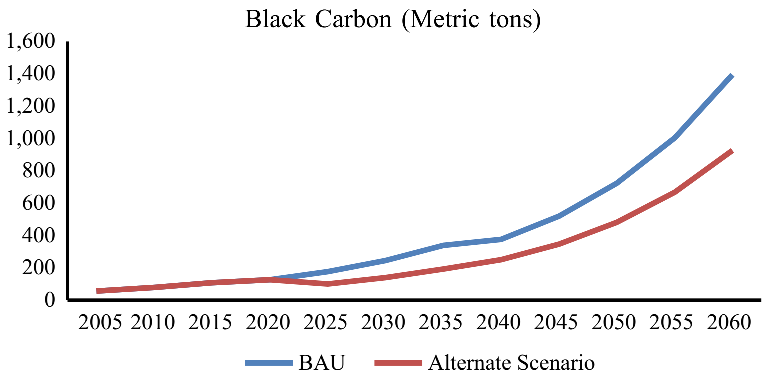

Fig. 10 Total black carbon emissions for BAU and alternate scenarios (Metric tons)

5 Conclusion

Surat Municipal Corporation (SMC) has an efficient waste handling and management facility that can pave the path for making Surat a zero-waste city. From this study, it can be deduced that there is a well-planned and well-executed collection system for the different zones identified within Surat city. In addition, the majority of the waste generated is collected and transported to the landfill site where it is disposed of properly. However, different emission reduction measures can be introduced to reduce the emissions that are harmful to human health and the environment. By changing the fuel type of low-duty vehicles used in the primary collection and transportation of solid waste, SOx emissions can be reduced by 63%. Also, by increasing composting and recycling of solid waste at the urban level and reducing open unsanitary burning, the total emissions of harmful pollutants like Carbon Dioxide, Methane and Black Carbon can be reduced by 45%. This can be achieved by increasing awareness among the citizens regarding the harmful effects of the uncontrolled burning of waste at local levels. In addition, waste segregation into recyclable and compostable types can also reduce the Methane emissions generated at landfill and disposal sites.

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A Review on Plastic Waste Management Using Life Cycle Assessment Approach

Divyashree Yadav, Vaishali Sahu, and Akanksha Mathur

Abstract Life cycle assessment is a method for estimating the environmental impact of any product for its span of life. Plastic waste management is the only solution to prevent plastic pollution and all the problems associated with it. Plastics can be divided into two types: thermoset plastics and thermoplastics. Most of the World's total plastic consumption comprises thermoplastics. There are four methods available for plastic waste management in which Chemical and thermal recycling method is advantageous since it can process heterogeneous mix of plastic waste. This work is aimed to review all the types of thermoplastic waste management options, evaluating various environmental parameters through life cycle assessment and list the limitations and gaps of conducted research on the same.

Keywords Plastic waste · Sustainability · Waste management · LCA (Life Cycle Assessment)

1 Introduction

Plastic is a flexible substance that is frequently utilised in a variety of ways for a variety of applications, including packaging, domestic, and medical [1]. The world generates about 400 million tons of plastic waste every year which is a great concern for Environment. Plastics are classified as thermoplastics and thermoset plastics. Thermoplastics are mostly consumed worldwide as compared to thermoset plastics

D. Yadav (✉)
Department of Civil Engineering, Lingaya's Vidyapeeth, Faridabad 121002, India
e-mail: divyashree@lingayasvidyapeeth.edu.in

V. Sahu
Department of Civil and Environmental Engineering, The NorthCap University, Gurugram 122017, India
e-mail: vaishalisahu@ncuindia.edu

A. Mathur
Department of Mechanical Engineering, The NorthCap University, Gurugram 122017, India
e-mail: akankshamathur@ncuindia.edu

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_17

and its applications are single use. One of the biggest issues with plastics is that many of them are exceedingly strong and take a very long time to disintegrate [2]. Used plastic can pose serious social and environmental problems that hinder the achievement of the Sustainable Development Goals (SDG's). In order to decrease the quantity of solid waste that is landfilled or burned, sustainable waste management aims to keep resources in use for as long as possible. Plastic waste can be managed by various methods available like re-extrusion, mechanical recycling, chemical and thermal recycling, reusing in construction/highways/plantation etc. and recycling into new products. It is hard to identify the best process to manage plastic waste out of the above stated methods. Additionally, the life cycle assessment can be used to compare and evaluate the specific environmental effects that these processes have. With numerous studies in this area, a broad range of LCAs have been done on plastic trash for sustainable management. This study is focused to review the previous work done by deliberating and comparing the outcomes.

2 Plastic Wastes

2.1 Plastic Wastes

Polymers serve as the primary component of a wide variety of synthetic or semi-synthetic materials known as plastics. Polymers are typically manufactured by human industrial systems. Most modern plastics are derived from fossil fuel-based chemicals such as natural gas and oil. The majority of contemporary plastics are made from chemicals based on fossil fuels, like natural gas and oil. However, more recent industrial processes use derivatives derived from renewable resources like corn and cotton. Between 1950 and 2017, an estimated 9.2 billion tonnes of plastic were manufactured. More than half of this plastic has been manufactured since 2004. In 2020, 400 million tonnes of plastic were created (Environment, U. N. (2021–10-21)) [3]. By 2050, it is predicted that yearly worldwide plastic production will exceed 1.1 billion tonnes if current trends in plastic demand hold true. Thermoplastic resin and thermosetting plastics are the two basic groups into which most commonly used plastics fall. When heated, thermoplastics soften whereas thermosets solidify, maintaining their original shape. For instance, thermoplastics include things like soda bottles and PVC pipes while thermosets include things like kettles and plugs. The thermoplastics listed in Table 1 make up the majority of the plastic used worldwide [2].

Despite being around for 100 years, plastics' annual production and usage are still growing tremendously. The State of Plastics report from the United Nations Environment Program (2018) states that bags, food wrappers, plastic bottles, and cigarette butts are the most often encountered waste plastics. The utilization of plastic waste in various industries for reuse, recycling etc. is important for sustainable waste management and helps improve environmental conditions.

Table 1 Categories of thermoplastics [2]

Type	Abbreviation	Description	Example use
Polyethylene terephthalate	PET/PETE	Extruded and moulded from transparent, robust, and lightweight polyester	Plastic bottles (soft drinks, water)
High density polyethylene	HDPE	Compared to LDPE, it is less flexible and has a medium amount of opacity	Water bottles, shampoo bottles, milk jugs
Polyvinyl chloride	PVC	Strong, lightweight, and plasticizers can increase flexibility	Plumbing pipes, doors, windows, credit cards
Low-density polyethylene	LDPE	Excellent clarity and modest stretch	Plastic bags, squeezable bottles, food containers, bubble wrap
Polypropylene	PP	Robust with a nice finish	Bottle tops, drinking straws, hot food containers
Polystyrene	PS	Cheap plastics that are somewhat stiff	Disposable foam cups, plastic cutlery, coat hangers
Polycarbonate	PC	Transparent and highly resistant to impact	Eye protection, shatter proof glazing, barriers

2.2 Sustainable Waste Management

Using resources for as long as feasible while reducing the amount of solid waste that is landfilled or burned are the goals of sustainable waste management. Nevertheless, waste is produced before the product is manufactured in the current linear economy. The entire product lifecycle should be the focus of a more thorough approach to sustainable waste management. This lessens the detrimental environmental, social, and economic effects of the twenty-first century. There are numerous strategies to enhance sustainable waste management, but most of them adhere to the waste hierarchy pattern of the 4 Rs (reduce, reuse, recycle, and recover) of garbage, as depicted in Fig. 1.

Fig. 1 Sustainable waste management hierarchy

At the Rio + 20 meeting in 2015, the 2030 Agenda for Sustainable Development was considered with the participation of world leaders and international non-governmental organisations. Among the biggest issues of our day are rising inequality, resource depletion, environmental degradation, and climate change.

The Sustainable Development Goals (SDGs), an action plan with 17 core objectives, were created with the primary purpose of reducing poverty [4]. Here is a list of the SDGs.

End poverty (SDG1). End hunger (SDG2); health and well-being (SDG3); quality education (SDG4); gender equality (SDG5); clean water and sanitation (SDG6); Decent Work and Economic Growth (SDG8); Industry, Innovation and Infrastructure (SDG9); Reducing Inequality (SDG10); Sustainable Cities and Communities (SDG11); Responsible Consumption and Production (SDG12); (SDG13); life under water (SDG14); life on land (SDG15); strong institutions of peace and justice (SDG16); partnerships to achieve the goals (SDG17) (de Sousa, 2021).

It's crucial to keep in mind that plastic garbage has a limited shelf life and needs to be properly disposed of if there is any plastic remained. Since 2007, The Sustainability Tripod has been seeing a big worry for the environment, particularly plastic contamination of water bodies and the connection between economy and health [5]. In the following part, the associated advantages and disadvantages of sustainable plastic waste management are described and reported from an LCA perspective.

2.3 Life Cycle Assessment

This is an approach for evaluating environmental aspects related to the complete life cycle of a product. The most important application is the analysis of life cycle stage contribution to overall environmental impact, primarily to prioritize product and process improvements and to compare products for internal use.

LCA is a powerful decision-making method for waste control and remedy processes [6]. ISO 14040 (2006) [7] therefore defines four bases for conducting LCA studies;

Stage 1: The goals and scope are intended to define how much of the product lifecycle to include in the evaluation and what the evaluation should provide. This step provides criteria and specific times for system comparison.

Stage 2: The flow of materials and energy within the product system is described in this step through inventory analysis, with a focus on how they interact with the environment, the raw materials they use, and their environmental emissions. All important processes and subordinate energy and matter flows are described later.

Stage 3: To calculate impact, data from inventory analysis is used. In this stage, the metrics findings for all impact categories are shown in detail. The importance of each impact category is evaluated by normalisation and eventually also by weighting.

Stage 4: Lifecycle interpretation includes critical evaluation, identification of data sensitivity, and presenting of outcomes.

The most frequent life-cycle assessment (LCA) studies focus on cradle-to-grave and cradle-to-gate systems. Cradle to gate refers to a product's carbon footprint from the time it is produced until it reaches the store, whereas cradle to grave refers to the entire lifecycle of a product. Nonetheless, companies and researchers are free to select the LCA analysis style that best fits their goals and intended uses. For a specific category of environmental hazards, each Life Cycle Impact Assessment (LCIA) technique seeks to produce an impact score (climate change, human toxicity, resource depletion, etc.) [2]. Further, this study will reflect LCA studies based on sustainable waste management related to plastic waste as described in the next section.

3 LCA Studies in Context of Plastic Wastes

To evaluate the environmental effects connected with waste-to-energy efforts, LCA has been introduced. According to the reviewed studies listed below, existing LCA studies are analyzed, key technical parameters and methodological issues are identified, and recommendations for LCA evaluation are provided.

Researcher [8] conducted a thorough and integrated life cycle analysis of the available grocery bag options from birth to death. This covers dealing with industrial procedures, transportation distances in urban settings, and environmental effects from the viewpoint of cities where spent heat waste predominates. management. Their research enabled validation in densely populated urban regions, provided fresh insights into the environmental impact of various supermarket bag solutions, and highlighted opportunities for future advancements. Critical integrated lifecycle evaluations help targeted waste avoidance programmes, effective resource management, a smaller environmental impact, and policy development. In cities like Singapore with sparse waste disposal infrastructure, the research compares the environmental effects of utilising HDPE plastic bags to standard alternatives. Switching to paper and cloth bags increases the ecological footprint and increases harmful effects, such as global warming and probable ecotoxicity, according to their research, which is a significant finding. Ahamed [8] advised selecting plastic bags that can be used repeatedly and are reusable. In all other cases, we advise using single-use HDPE bags rather than kraft paper or single-use biodegradable alternatives. However, another observation was that minimizing overall consumption could significantly reduce environmental impact. One way to avoid overusing plastic bags is to reuse or recycle single-use HDPE bags.

The researcher [2], analysed six factors, including the Purpose and Scope, Functional Units, Impact Assessment Categories, System Boundaries, Geographic Context, and Uncertainty Analysis, to analyse the research advancement in these areas in relation to LCA. Their research covered a range of related studies on recycling plastic waste, with each taking a different approach to defining system boundaries. The choice of whether to include or exclude factors like transportation had an impact on the study's findings, demonstrating the significant influence it can have. Moreover, quantitative comparisons of the effect outcomes were made between these studies on the management of mixed plastic waste and similar research to see how context and parameter selections affected the results. Overall, this analysis discovered that, in the majority of research evaluating waste disposal technologies, mechanical recycling emerged as the environmentally preferable choice.

The researchers [9], meant to investigate waste plastics, particularly polyethylene terephthalate (PET), which is added to paving, concrete, mortar, and asphalt mixtures. In this situation, life cycle assessment (LCA) is a tool we employ to gradually increase the sustainability of our processes and products. An analysis of the current literature shows that research on plastic waste in building materials focuses sustainability on alternative waste destinations. As plastic waste originates from various production chains, the need for more comprehensive assessments such as LCA, which provide more quantifiable data, are identified and alternative methods and goods become more sustainable. By LCA, this study helps to increase the sustainability of alternative building materials. In addition to the environmental benefits to the construction sector for future work, an economic valuation of recycled plastics can be considered that can measure the impact of savings achieved by incorporating PET. Studies have been able to confirm that a number of factors, such as the percentage fluctuation of various construction materials, contribute to the usage of PET waste in the construction industry.

The Researchers [1], using life cycle analysis (LCA), 1 kg of plastic waste was treated for end-of-life (EOL) in India and Indonesia. Based on the EOL mix, which included mechanical recycling, co-treatment in cement kilns, incineration, and sanitary landfills, the environmental impact of general landfill and general incineration was compared. Climate change, cumulative energy demand, water scarcity and marine ecotoxicity, human toxicity, land area acidification, fossil material depletion, particulate matter generation, and urban land usage were the nine environmental impacts that were taken into account. In all nine areas, it was discovered that India's EOL treatment of plastic waste had a lower environmental impact than Indonesia's. This was attributed to India's high rate of mechanical recycling. According to hotspot analysis, landfills are the main cause of marine ecotoxicity and open burning is a significant contributor to climate change. Plastic waste recovery rate, percentage of unrecovered plastic trash burned in the open, percentage of plastic waste recycled, and the percentage of virgin plastic substituted with recycled plastic granules were shown to be the most sensitive parameters, according to sensitivity analysis.

By 2030, increased investments in mechanical recycling might not only reduce uncontrolled plastic waste but also help India and Indonesia reach their carbon emission reduction obligations under the Paris Agreement. This is according to an analysis of possible future scenarios. Future waste management investment decisions in both countries can be supported by the study's findings.

The Author [10], introduced alternate approaches to the waste issue, like recovering valuable fuels from plastics using thermochemical processes. A life cycle analysis (LCA) was performed to explore eight plastic waste treatment scenarios using the Gabi LCA software, as shown in Table 2. In a land-scarce country, consider the scale and size of each method of recycling and collecting plastic waste.

Table 2 Compilation of LCA scenarios [10]

Scenarios	Brief description	Reference flow of waste plastics in tonnes/year and percentage recycled/recovered (in brackets)			
		MR	WTE	P	G
1	Recycling rate of 7.24% sent to MR; the rest of is sent to WTE	59,500	762,700	0	0
		7%	(93%)		
2	Recycling rate of 10.64% sent to MR; the rest of is sent to WTE	87,500	734,700	0	0
		11%	89%		
3	Recycling rate of 7.24% sent to MR plus potential P; the rest of is sent to WTE	59,500	732,700	0	0
		7%	89%		
4	Recycling rate of 7.24% sent to MR plus potential G; the rest of is sent to WTE	59,500	687,700	0	75,000
		7%	84%		9%
5	Recycling rate of 7.24% sent to MR plus potential P + G; the rest of is sent to WTE	59,500	657,700	30,000	75,000
		7%	80%	4%	9%
6	Recycling rate of 10.64% sent to MR plus potential P + G; the rest of is sent to WTE	87,500	629,700	30,000	75,000
		10%	77%	4%	9%
7	Recycling rate of 10.64% sent to MR plus potential 2 × P; the rest of is sent to WTE	87,500	674,700	60,000	0
		10%	83%	7%	
8	Recycling rate of 10.64% sent to MR plus potential 2 × G; the rest of is sent to WTE	87,500	584,700	0	150,000
		10%	71%		18%

This article explains that both the potential environmental advantages and disadvantages of managing plastic waste depend significantly on the chosen plastic recycling/conversion technology and the pertinent available (or combined) capabilities. According to the LCA model's final normalised and weighted results, scenario 7 was determined to be the best alternative in comparison to the reference example (total = 5.0), and the normalised and weighted results (total = 3.2) were determined to be the lowest. But keep in mind that the final rating is based on the normalisation and weighting factors assigned in accordance with the environmental effect and sustainability indicators considered important. The results could be altered by using a different set of normalisation and/or weighting variables. The findings demonstrated the potential environmental advantages and disadvantages of various combinations of four plastic recycling methods and their associated capabilities. To make it possible to choose the best option from the eight situations, standardisation and weighting were performed.

Authors [11], aimed to give an overview based on published literature-based LCA studies on PSW processes. LCA evaluates the environmental performance of pyrolysis processes in particular through a thorough evaluation and analysis. Antelava [11] published studies on the effects of PSW on the environment have revealed that post-treatments using thermochemistry, such as gasification, incineration, or pyrolysis, can lessen such effects compared to landfills. Moreover, the process of pyrolysis has the benefit of producing bio-oils and charcoal with a high calorific value, which can be used in other systems as fuel for the plant's own consumption or as an alternative to fossil fuels. Pyrolysis thus promotes sustainable environmental solutions for waste management and conforms with the environmental requirements of ISO standards 14,040 and 14,044. Yet, even if LCA isn't specifically mentioned in relation to environmental assessment, it is still viewed as an integrated tool that takes into account both the suggested methodology and the whole process' life cycle costs.

The Researcher [12], gave a critical assessment of how plastics fit into the Sustainable Development Goals (SDGs) and covered its advantages and disadvantages. Plastics undoubtedly play a significant part in contemporary society, sustainable development, and the accomplishment of the 2030 Agenda. But plastics not only have benefits, they also have worrying drawbacks that have environmental, social and economic impacts that could adversely affect the success of the 2030 Agenda. Poor disposal can both exacerbate socio-environmental issues and help solve issues that need for the requisite training and sincere commitment from all spheres of society.

4 Major Findings and Way Forward

One of the most prevalent types of plastic debris found in the water are plastic food bags [13–16]. We still do not fully understand the effects of plastic pollution on terrestrial and marine ecosystems, which continues to constrain our understanding of these repercussions. The production of plastic bags uses two procedures that are the dirtiest and printing. The machine's high energy consumption, poor efficiency, and use of chemicals like alcohol and ink were all identified as factors, and their modification would further lessen the impact of plastic bags on the environment. According to [8], reducing the usage of plastic bags is an effective way to lessen the environmental impact of food bags.

Alhazmi [2] advise a careful comparison of his LCA approach, the system's objectives and constraints, and the local elements that affect the process itself when comparing other LCA studies. The research on the reuse of plastic waste in the construction industry, according to [9] has mostly concentrated on the topic of alternative recycling of this trash, even if it is less significant.

5 Conclusion

The results of this review will help address future LCA decisions on plastic waste management. Depending on the input factors and any regional differences, LCA results can vary greatly. To provide more targeted recommendations, more research may be done to estimate the environmental impact of disposing of plastic garbage in various places. Separating plastic trash thrown on land from plastic waste discharged in the aquatic environment will be the focus of future work with continued method development to measure the impact of plastics in the oceans, with the possibility for better results [1]. Mechanical recycling has proven challenging and is not commonly used in Singapore due to the complicated and frequently contaminated plastic waste composition. Future study on PSW management must take into account both social and economic implications, which are two important areas. Moreover, geographic location is a significant factor that needs to be taken into account in future investigations [11].

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Techno-Economic Analysis of Municipal Solid Waste Gasification

Atul Singh and S. K. Patidar

Abstract The main objective of the paper is the check the feasibility and viability of the MSW Gasification project. In this paper, the total population of the city Varanasi is studied, and the total waste generated per capita per day is studied through which total waste generated by the city was analyzed. The main focus is on the RDF/SRF which is used for combustion at last for electricity generation. A brief on the composition of SRF is also studied. Also the percentage of RDF generated by the city is discussed. For the purpose of economic analysis, calculation of energy and power was done. For economic analysis, two terms have been analysed, i.e., Net Present Value (NPV) and Levelised Cost of Electricity (LCOE).

Keywords Municipal solid waste (MSW) · Energy · Power · Gasification · Net present value (NPV) · Levelised cost of electricity (LCOE)

1 Introduction

Today the growth of population is increasing at a very fast rate. Due to this, the generation of MSW is huge, and the collection of MSW has become a major problem for all countries. The improper management of MSW leads to various hazardous substances in our environment causing pollution in our environment [13]. Leachate generation causes soil and water pollution and the second is air pollution [8]. Exploitation of fossil fuels also releases GHGs into the environment [10]. Electricity generation

A. Singh (✉)
Environmental Engineering, Department of Civil Engineering, National Institute of Technology Kurukshetra, Haryana 136119, India
e-mail: 0711atul@gmail.com

S. K. Patidar
Department of Civil Engineering, National Institute of Technology Kurukshetra, Haryana 136119, India
e-mail: skpatidar@nitkkr.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_18

through coal is around 75% of total power generation. Electricity production is also through renewable sources (wind, solar, biomass) ("coal," n.d.). In Varanasi, the total waste production is around 650 MT/Day [5]. Data tells that only 75.7% of MSW is collected out of total MSW produced; also, around 1,31,547 ton CO_2 equivalent GHGs is generated from MSW (Sourabh Manuja and The Energy and Resources Institute, 2020). Varanasi has a population of 14,41,251 in 2018. The rate of growth of Indian population was 17.6% in the last decade (Srivastava et al., n.d.). Nowadays, renewable energy such as tidal, solar, biomass, wind and geothermal is most widely used [14]. The main objective of this study is to analyse the whole plant's incoming waste and the energy generated from the waste and the total sales of electricity; for this purpose, we calculate the NPV value. With this, we can know whether the plant can be set up in that particular area or not. The incoming waste at the site also plays an important role in deciding the area where the plant has to be set up. There are various steps in preparing MSW for energy recovery which means it should go through various processes which are listed as primary separation, mechanical separation, thermochemical conversion and power generation [9].

1.1 Primary Separation

In this basically the recycleable are separted including the metals.

1.2 Mechanical Separation

In this, production of SRF takes place which may involve various steps such as sorting, pre-shredding and size screening.

1.3 Thermochemical Conversion

In this process, the SRF recovered will be fed into the combustion zone. Production of syngas will take place which further after cleaning is used for electricity generation that has a high calorific value [2].

The flowchart given fully describes the process of sorting in Fig. 1. Process flow can be seen in Fig. 2 ("SWM-plan-24th-march-2019.pdf," n.d.).

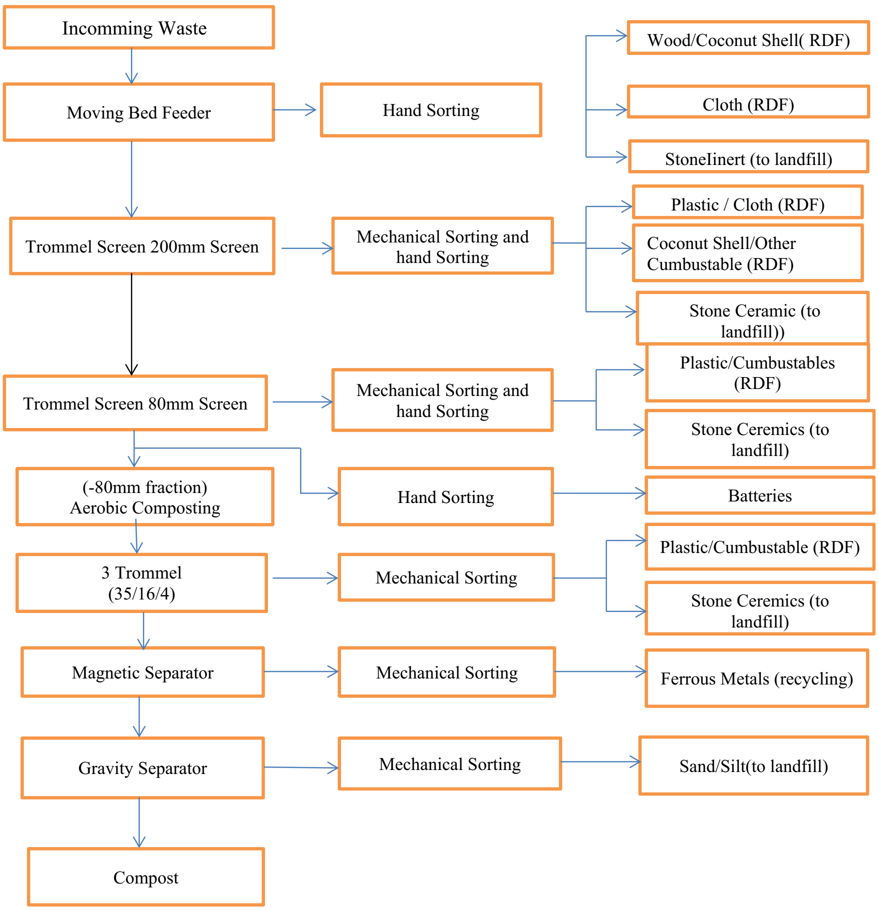

Fig. 1 Sorting process of MSW

2 Materials and Methods

2.1 Population and Waste Production

The population of Varanasi city in the year 2018 is 14,41,251. And the average waste produced by every single person is 0.45 kg/c/d. Waste generated based on population is 576.5 MT/Day. Total waste generated in one day = waste generated per capita per day x total population of the city. Similarly, total waste production in a single year = waste production in one day × 365, Table 1 can be referred from [5].

SRF consists of paper, wood, cardboard, plastics, cloths, etc. [7]. Table 2 can be referred to from [12]. The conversion of energy can be determined through the Mendeleev equation [11]:

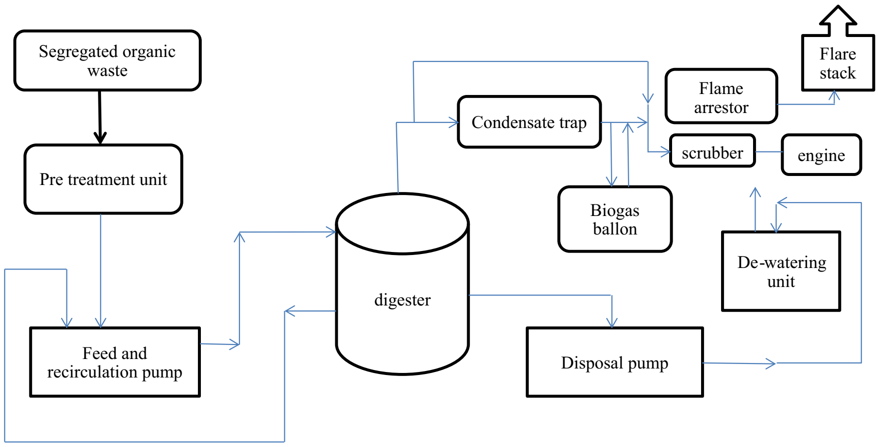

Fig. 2 Process of flow

$$\text{LHV}_{SRF} = 339.13.\text{C} + 1029.95.\text{H} - 108.85.(\text{O} - \text{S}) - 25.12\text{W} \quad (1)$$

C = Carbon content, H = hydrogen content, O = oxygen content, S = sulphur content, W = water content.

Table 1 Waste composition table

Waste composition	Percentage
Paper	4.13
Plastic	17.8
Glass	1.16
Metal	4.32
Cardboard	10.52
Kitchen waste and leaf	48.5
Inert	6.1
Cloth	4.2
Rubber leather	3.09

Table 2 Solid recovered fuel composition

Composition	Percentage
C	51.7
H_2	7.0
O_2	40.25
N	1.20
S	0.3
Cl	0.76

Now for the calculation of each type of waste, the composition and the percentage of each type of waste is given in Table 2. The calculation can be done as follows:

$$R_r(\mathrm{t}) = \frac{F_r R(t)}{100} \quad (2)$$

where R(t) = total mass waste generated.

F_r = percentage of each waste.

R_r (t) = mass waste of each type of waste.

Gasification values for LHV should be taken on a dry basis. Gasification power can be calculated by the following expression [13]:

$$P_{ot} = \sum_{i=1}^{n} \frac{R_r LHV_{tot} \eta}{3600 \Delta t} \quad (3)$$

where R_r = flow of each waste (kg/y).

LHV_{tot}= lower heat values (kj/kg).

η = energy conversion efficiency.

Δt = total number of hours yearly.

3600 = hours to seconds conversion.

P_{ot}= power generated from the waste.

Now if we talk about the process, i.e., gasification and incineration, the gasification process takes additional processes like recycling (plastics, glass and metals) and shredding for all this power is consumed. This is called consumed power which is lost for performing those processes. On the other hand, incineration does not require any pre-treatment. So the consumed power in this case would be zero. Energy (E) produced can be calculated from the following equation [13]:

$$\mathrm{E} = \frac{(Pot - Pp).\Delta t.Fc}{1000} \quad (4)$$

where P_p is consumed power or pre-treatment power and it is taken as 12% of total power generated; Fc is equipment capacity factor adopted as 80%.

For further economic calculations, it is necessary to determine the investment cost for the whole process. The investment cost of gasifiers can be calculated from the below equation:

$$I_{GAS} = \mathrm{K}(0.993).\mathrm{Rs} \quad (5)$$

I_{GAS} = gasifier investment.

K = correction of inflation.

R_S= mass flow of dry waste (kg/y).

The working capital was 10–20% of the total investment cost, i.e., 28.5 × .15 = 4.275 cr.

Now, the economic analysis was performed for this technology. The value of NPV was Rs 21 crore for the given year, and the value can be calculated by the following equation [1]:

$$\text{NPV} = \sum\nolimits_{j=1}^{m} \frac{(E.T) - C_{om}}{(1+i)^{j}} - I \tag{6}$$

NPV = Net present value.
E(t) = energy generated by the equipment (MWH/Y).
T = energy sales rate.
J = years of analysis.
m = useful life of a project.
I = investment cost.
i = interest rate.

The average rate of power from NTPC power stations was 2.5 (Rs/kwh) (“electricity cost NTPC.pdf,” n.d.).

Another method used for the analysis of the project is levelised cost of electricity (LCOE) [3]:

$$\text{LCOE} = \frac{\sum\nolimits_{t=0}^{n} (\frac{C+M_t}{(1+r)^t}}{\sum\nolimits_{t=0}^{n} \frac{Et}{(1+r)^t}} \tag{7}$$

C is the initial capital cost.
M_t is the annual operation and maintenance cost in year t.
E is electricity generation in year t.

3 Results and Discussion

As discussed above, the methodology of the energy calculation was covered through Eq. 4 and the value was demonstrated in Table 3, For the plant to be feasible, the values of saving generated must offset the annual installation cost and operating and maintenance cost. The value of net present value (NPV) through Eq. 6 comes out to be positive and it is 21.6 crore. The total installation calculated was 28.5 crore. The working capital comes out to be 4.75 crore. So according to net present value, it is the indication of plant feasibility. The second parameter is levelised cost of electricity (LCOE) through Eq. 7 which tells the cost of electricity generation from the technology and the value is shown in Table 3.

Table 3 Economic calculations

Financial indicators	Values
Total power	38,525 (kw)
Total energy	237,585 (mwh)
LHVsrf	19,296 (kj/kg)
NPV	21.6 Cr
LCOE	1.48 Rs
Installation cost	28.5 Cr

4 Conclusion

The result highlights the plant is economically feasible. The total installation cost has been demonstrated in Table 3. On the basis of installation and operation and maintenance costs, the value of Net Present Value (NPV) comes out to be positive which denoted the viability of the project. So the amount of waste dumped at the plant site is enough to make the plant viable as the NPV value comes out to be positive. The LCOE is the minimum cost to sell the electricity for the entire life of the project to make the project viable and the value is calculated and it is 1.48 Rs. The study shows that it treated the waste generated across the city and also prevents the environment from pollution.

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Sustainable Technological Options for Industrial Effluent Treatment in Common Effluent Treatment Plants: A Review

Aakanksharaje Gaekwad, M. A. Shabiimam, and Dhruvin Sojitra

Abstract The Common Effluent Treatment Plants are considered an essential infrastructure for wastewater management worldwide. They provide an economical and one-point solution for wastewater by offering a specific treatment scheme for all types of industrial effluent having various characteristics. Developing countries like India are growing in the industrial sector vigorously. It is essential to meet the environmental effluent discharge standards for medium and small-scale industries. This study discusses the treatment schemes adopted by various CETPs in India. This review paper also discusses the multiple technologies CETPs use for industrial clusters. Since most of CETPs in India use conventional treatment methods, it is evident that innovative and efficient technologies must be deployed. This review study provides various advanced technologies, including advanced oxidation processes (AOPs) like Electro Fenton, Ozonation, Photocatalysis, Cavitation and Membrane technologies. Overall, the paper provides a brief overview of the current scenario in CETPs and the potential adoption of cutting-edge technology for improvements in wastewater treatment.

Keywords CETP · Advanced oxidation process · Membrane treatment · Chemical treatment

A. Gaekwad · M. A. Shabiimam (✉) · D. Sojitra
Department of Civil Engineering, SOT, Pandit Deendayal Energy University, Gandhinagar 382426, India
e-mail: shabiimam.ma@sot.pdpu.ac.in

A. Gaekwad
e-mail: Aakanksharaje.gmten21@sot.pdpu.ac.in

D. Sojitra
e-mail: Dhruvin.smten21@sot.pdpu.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_19

1 Introduction

1.1 General

In recent times, developing countries like India have seen major industrial sector growth to meet the demand of their ever-increasing country population. More and more entrepreneurs and industrialists are establishing manufacturing facilities in India owing to government initiatives like “Make in India”. This enlargement of the industrial sector is constantly affecting the environment due consumption of resources, and the generation and discharge of industrial effluent into the water bodies severely affecting the natural ecosystem. In India, many industries are Micro, Small, and Medium enterprises (MSMEs). According to the Ministry of MSME, any manufacturing company with a turnover of less than 5 crores is classified as a micro industry, one with a turnover of less than 50 crores as a small industry, and one with a turnover of less than 250 crores as a medium industry. These MSMEs generate huge employment and contribute about 45% toward the country’s manufacturing output [25]. At the same time, these MSMEs produced more hazardous waste overall than major industries [6]. The industries also produce a large amount of industrial effluent and toxic chemicals. This kind of toxic discharge is extremely undesirable and poses a risk to human health [21]. These industries are mandated to treat the effluent at a certain level before discharging it into the water bodies. Common effluent treatment plants (CETPs) are the most preferred option to treat this wide range of wastewater. The CETPs not only provide an economical solution for the MSMEs but also facilitate the regulators to manage and inspect the treated wastewater at one location.

1.2 Status of CETPs in India

The concept of CETPs has been successfully implemented across India’s several industrial sectors, including tanneries, textiles, chemicals, pharmaceuticals, fertilizers, and many more. India today has several industrial sectors that regularly produce various types of wastewater. According to the Ministry of Environment, Resources, and Climate Change’s 2016 report, India presently has 193 CETPs in operation to treat industrial wastewater before discharging. Most of the time, for the installation and operation of CETPs, the central and state governments each contribute 25% of the overall costs, with member industries and financial institutions covering the remaining cost. It is observed that while the contribution to investment varies from nation to nation, the contributing party remains the same. The regulatory agencies have set the discharge standards in accordance with the Environment Protection Rules of 1986 in order to enhance the performance of the CETPs. The discharge standards for CETPs in India are shown in Table 1.

Table 1 Wastewater discharge standards

Parameters	Into inland surface waters	On land for irrigation	Into marine coastal areas
pH	5.5–9.0	5.5–9.0	5.5–9.0
BOD [3 days at 27 °C]	30	100	100
Temperature	Should not be greater than 40 °C	–	45 °C
Suspended solids	100	200	(a) For process waste water-100 (b) For cooling water effluent 10% above total suspended matter of effluent cooling water
Dissolved solids (inorganic)	2100	2100	–
Total residue chlorine	1.0	–	1.0
Ammonical nitrogen (As N)	50	–	50
Total Kjeldahl nitrogen (as N)	100	–	100
COD	250	–	250
Arsenic (As)	0.2	0.2	0.2
Mercury (Hg)	0.01	–	0.01
Lead (Pb)	0.1	–	1.0
Cadmium (Cd)	1.0	–	2.0
Copper (Cr)	3.0	–	3.0
Zinc (Zn)	5.0	–	15
Chloride (Cl)	1000	600	–
Fluoride (F)	2.0	–	15
Sulphate (SO4)	1000	1000	1000
Sulphide (as S)	2.8	–	5.0
Phenolic compounds (C_6H_5OH)	1	–	5.0

1.3 Characteristics of CETP

The CETPs are performing unsatisfactorily due to a wide range of issues. CETPs are meant to deal with such solutions and are designed to treat heterogeneous effluent efficiently [46]. Industrial wastewater comes a vast characteristic variation, making difficult for CETPs to treat and meet the discharge standards. Factors like the choking of the plumbing system, damages in treatment units, etc. can severely affect the treatment ability of the CETPs leading to the lower quality of the treated effluent [26]. The operation and maintenance of individual treatment units, a limitation of trained labour, and variations in influent quality and quantity are some other issues encountered by CETPs. The efficacy of CETP may potentially be impacted by wastewater containing organic pollutants and phenolic chemicals. The wastewater characteristics change from industry to industry. Table 2 shows the type of wastewater that different types of industries produce as effluent. Due to the enforcement of strict discharge standards, the CETPs need to treat the wastewater as per the norms effectively. The CETPs also struggle with operational cost funded by the member industries, because they are constantly concerned about the money being spent on wastewater treatment with their profits. Thus, in order to achieve the discharge norms, there is a great demand for newer technologies to treat various types of wastewater at a cheap cost and with minimal investment. Implementing a new technology can undoubtedly result in the efficient treatment of industrial wastewater and the preservation of the water bodies.

Table 2 Characteristics of various CETPs

Parameters	Moosvi and Madamwar [23]	Pathe et al.	Kumaret al. [13]	Sivgami et al. [43]	Rohitbhai et al. [36]	Singh and Kumar [42]
pH	7.5–8.0	5.5–10.8	7.7	–	7.33	9.2
COD (mg/L)	3000–5000	3253 ± 319	1727	1500–5000	1600	8100
Colour (NTU)	–	–	–	–	2124	550
TDS (mg/L)	–	14,625 ± 416	18,920	–	13,453	4761
BOD (mg/L)	500–650	1247 ± 99	–	–	–	4047
TS (mg/L)	24,000–33,000	–	–	–	–	–
TSS (mg/L)	5000–5400	5852 ± 377	–	200–700	–	19.51
Chlorides (mg/L)	1900–2000	8207 ± 1243	9017.2	–	–	57.14
Sulphates (mg/L)	2000–3500	1557 ± 46	374.2	–	–	238.09
Iron (Fe)	–	0.430 ± 0.032	–	–	–	15.54
Lead (Pb)	–	0.025 ± 0.0004	–	–	–	2.50
Zinc (Zn)	–	0.211 ± 0.014	–	–	–	0.0

2 Treatment Techniques

2.1 Coagulation and Flocculation

The coagulation and flocculation processes are the most popular and often employed methods for treating municipal and industrial effluent. The Egyptians are known to have used Alum (aluminium sulphate) for the settlement of the floating particles in the water as early as 1500 BCE. At present, this method is widely used to treat wastewater on a large scale for the removal of suspended particles and reduction of organic and inorganic pollutants [40]. Coagulation and flocculation can be divided into two parts: (1) intense mixing of the added coagulant with the wastewater by constant stirring, and (2) floc formation from the small particle by medium agitation. Following these two stages, flocs get settled in the form of sludge and the wastewater is sent to the next treatment unit for further processing [45]. The main aim of coagulation and flocculation is to remove suspended particles. These suspended particles always remain in suspension because they always repel each other due to their negative charge, hence coagulation and flocculation are essential to settle them [47]. In the coagulation process, chemicals and/or electric charges are used for the effluent treatment. Two types of coagulants are used primarily for the coagulation process (1) iron-based and (2) aluminium-based [31].

Numerous research has been done to establish the suitability of coagulation and flocculation in the existing treatment plants. Authors in Haydar and Aziz [12] treated the tannery wastewater by chemically enhanced primary treatment (CEPT) which earlier was treated without coagulation in the primary treatment plant. The utilization of alum showed excellent efficiency compared to ferric sulphate and ferric chloride. Also, the wastewater colours are not dark in the case of alum. Following the use of coagulation and flocculation by CEPT in tannery wastewater, the concentration of TSS and Chromium reduced below the discharge standards but further treatment was necessary to decrease the COD below standard limits [12, 29]. Additionally, it has been demonstrated that overdosing on coagulants can result in organic overloading while not influencing the effectiveness of the treatment. In a treatability study by Gotvajn et al., it was observed that ferric chloride could more efficiently treat tannery landfill leachate than alum [11]. Therefore, it is crucial to understand the sufficient dosage and the coagulant t is appropriate for adequate wastewater treatment (Table 3).

2.2 Fenton Process

The Fenton process is a combination of chemical treatment processes aimed to remove organic and inorganic pollutants from water and wastewater using an oxidation process with hydroxyl radicals. •OH. Fenton's technique involves the use of iron salts and hydrogen peroxide to generate hydroxyl radicals. A ferrous ion is oxidized by hydrogen peroxide to a ferric ion, a hydroxyl radical, and a hydroxyl anion. When Fe^{2+} and H_2O_2 react under acidic conditions, a large amount of •OH is generated.

Table 3 Wastewater treatment by coagulation-Flocculation

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
Coagulation	CETP wastewater	pH 9.5 Alum dosage 200 mg/L	Turbidity	98.7%	Haydar and Aziz [12]
			TSS	94.3%	
			COD	58.7%	
			Chromium	99.4%	
Coagulation-flocculation	Petroleum refinery wastewater	$CuSO_4$ Dose 0.74 g/L pH 11	COD	55%	Singh and Kumar [42]
			Turbidity	97.8%	
			TDS	92.2%	
			Colour	94%	
		$FeCl_3$ = 0.20 g/L pH 7	COD	52%	
			Turbidity	80%	
			TDS	95.5%	
			Colour	92%	
		$CuSO_4$ + $FeCl_3$ = 0.20 g/L pH 7.122	COD	81%	
			Turbidity	93%	
			TDS	95%	
			Colour	95.2%	
Coagulation	Palm oil mill biogas plant wastewater	$FeCl_3$ = 8000 mg/L	Colour	82.6%	Zahrim et al. [51]
Coagulation	Tannery landfill leachate	$FeCl_3$ = 100 mg/L	TSS	97%	Gotvajn et al. [11]
			COD	45%	
			Turbidity	99.5%	
Coagulation	Synthetic wastewater	Alum dose 0.4 g/L pH 7	Turbidity	97.96%	Kumar Karnena et al. [14]
Coagulation	Textile industry wastewater	$FeCl_3$ = 4000 mg/L pH 4	COD	54%	Rana and Suresh [34]
Coagulation	Dairy industry wastewater	Alum 240 mg/L	COD	35%	Qasim and Mane [32]
	Sweet snacks industry wastewater		COD	67%	
	Ice-cream industry wastewater		COD	58.76%	

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH^-$$

The Fenton process produces little iron sludge, has a wide working pH range, and the catalyst can be easily removed after the reaction (Table 4).

Table 4 Wastewater treatment by fenton process

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
Fenton	CETP dye wastewater	pH 3–5 Agitation speed 100 rpm	COD	39%	Rohitbhai [36]
			Colour	59%	
Fenton	CETP wastewater	pH 4 Contact time 60 min $H_2O_2 = 4$ ml $FeSO_4 = 1$ mg room temperature	COD	64.35%	Lalwani and Devadasan [17]
			BOD	68.57%	
Fenton	Textile wastewater	pH 3 $FeSO_4 = 0.2$ gm/lit $H_2O_2 = 0.1$ ml/lit Mixing at 130 rpm for 2 min Slow mixing at 30 rpm for 18 min	COD	98%	Patil and Raut [30]
			Colour	89%	
Fenton	Dye intermediate	pH 3 Fe^{2+}: H_2O_2 3:3 Retention time 60 min	COD	75.8%	Pani et al. [27]
			NH_3-N	78.6%	
Fenton	Dye intermediate	20 mL H_2O_2 (30%) • 10 mL Fe^{+2}(2%) • Treatment time 20 mi	COD	86%	Patel and Patel [28]
Fenton	Pharmaceutical wastewater	H_2O_2/COD ratio = 3 H_2O_2/Fe ratio = 1 pH = 3	COD	66.5%	Chavan et al. [5]
			Colour	99%	
Fenton	Tannery wastewater	H_2O_2/COD = 0.875 • Sorbent mass concentration was 12.66 mg/L • Contact time 120 min	COD	58.4%	Vilardi et al. [48]
			Total Phenol	59.2%	
Fenton	Chemical lab	Fe^{2+} 50 mg/L H_2O_2 50 mg/L pH 2.8 at 80 °C	TOC	88%	Ramirez [33]

2.3 Cavitation

Cavitation is the phenomenon through which bubbles develop, expand, and then instantly collapse at various locations in the reactor in nanoseconds, producing significant energy. Cavitation is further divided into four categories. Acoustic cavitation (AC), Hydrodynamic cavitation (HC), Optical cavitation, and Particle cavitation are the four types of cavitation. Due to their simplicity in implementation and operation as well as their ability to produce good cavitational ability, hydrodynamic and acoustic cavitation are frequently chosen over all other modes.

Hydrodynamic cavitation was used to treat the pesticide industry's effluent for a variety of time periods. After 75 min, 90.55% of the COD and 83.21% of the colour removal were observed [9]. The breakdown of p-nitrophenol was observed by using hydrodynamic cavitation, and it was also observed that the consumption of energy was two times lower than the acoustic cavitation [4]. Sivakumar and Pandit [44] treated the cationic dye rhodamine B using HC. In their study, and it was observed that HC is more energy efficient than AC. Also, HC was shown to treat more effluent in a single operation (50 L), while acoustic horn treated only 1.5 L of effluent [44]. Effluent from the wood finishing industry was treated with an HC reactor, where its COD reduction was observed until 2200 rpm [10]. Hydrodynamic cavitation can also be combined with Fenton to improve the effectiveness of pollution removal. Ultrasound and HC with Fenton were used to treat municipal and industrial wastewater. The COD removal of 24.9% from municipal wastewater was observed by using ultrasound treatment, while 44.3% COD removal was obtained for industrial effluent when treated with HC and Fenton combined [10] (Table 5).

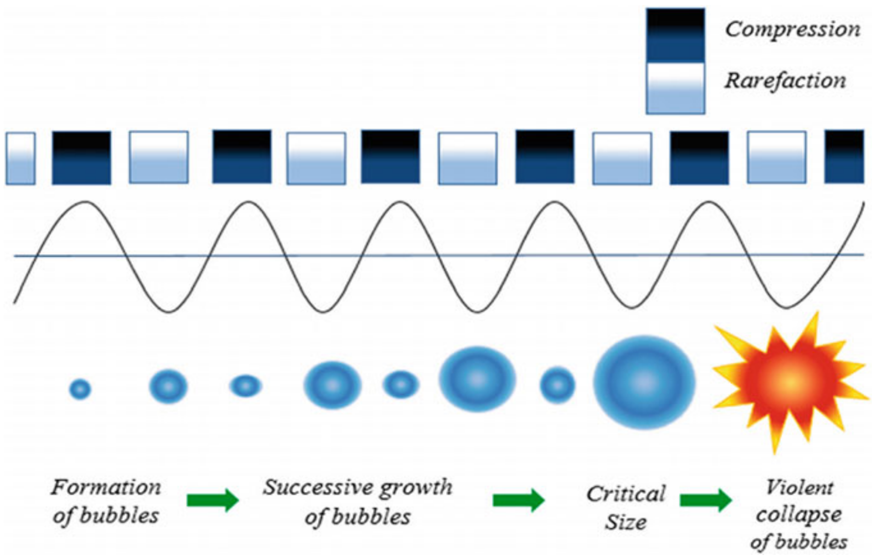

Table 5 Wastewater treatment by cavitation process

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
AC/Fe (II)/ H_2O_2	CETP wastewater	Fe(II):H_2O_2 = 1:5 Power = 125W Frequency = 22 kHz pH = 3 Time = 60 min	COD	83.53%	Lakshmi et al. [16]
AC/O /MgO	CETP wastewater	pH = 9 Time = 60 min	COD	88.66%	Agarkoti et al. [1]
AC/Fe2 + / H2O2/Air	CETP wastewater	Fe(II)/H_2O_2 = 0.1 Power = 150W pH = 2 Time = 60 min	COD	95.2%	Agarkoti et al. [2]
HC/Fe(II)/ H_2O_2	CETP wastewater	pH 3 Inlet pressure 4 bar	COD	87.4%	Lakshmi et al. [16]
HC/O/MgO	CETP wastewater	pH = 9 Time = 60 min	COD	88.336%	Agarkoti et al. [1]
HC/Fe2 + / H2O2/Air	CETP wastewater	Fe(II)/H_2O_2 = 0.1 Power = 150W pH = 2 inlet pressure = 4 bar Temperature = 30 ± 2 °C Time = 60 min	COD	97.28%	Agarkoti et al. [2]
HC	Pesticide wastewater	Time = 75 min	COD	90.55%	Gaekwad and Patel [9]
			Colour	83.21%	
HC/Chlorine	Dye intermediate wastewater	pH 6.9 Time 60 min	COD	74.15%	Shah [41]
			Color	84.06%	
HC	Pharmaceutical wastewater	Time 90 min	COD	80.36%	Brahmbhatt [3]

2.4 Ozonation

In recent times, ozonation has become a perfect and effective alternative to chlorination. The ozonation is a quick process and requires less reaction time (approx. 10 to 30 min). Along with odour removal and toxic contaminants reduction ozone can also remove colour and produce less sludge. Heterogeneous and homogeneous catalytic ozonation are the two primary forms of catalytic ozonation used in wastewater treatment.

In their study, Qian [50] showed that ozonation combined with a biological aerated filter could lower the COD in textile wastewater below 50 mg/L. Ozonation can be used for pharmaceutical wastewater treatment. For pharmaceutical wastewater, it has been found that ozonation can remove 97% of the chemicals, and its removal effectiveness rises when combined with H_2O_2, which exhibits a 99% removal efficiency [35]. Adsorption on the surface of activated carbon in combination with ozonation has been suggested as a promising approach for the removal of organic pollutants [35]. In a sewage treatment plant effluent, the impact of ozone exposure on wastewater was investigated. It has been found that exposure to ozone for even a brief period of time can result in significant reductions in pollutants like COD, TN, TOC, colour, and turbidity [18]. Combining ozonation and phytoremediation can eliminate 90% of the inorganic carbon, 60% of colour, and 84% of COD from tannery wastewater [39] (Table 6).

2.5 Photocatalysis

Photocatalysis is a new process that is being researched for large-scale implementation. In this technique, wastewater is exposed to ultraviolet (UV) radiation in addition to Fe2 + and H_2O_2 to speed up the oxidation process. According to the studies, photocatalysis is the most prominent technology among the AOPs, followed by hydrodynamic cavitation. This process produces nearly no waste, making it ideal for creating a sustainable and environmentally beneficial solution.

Authors in [49] reported 79% colour removal from the distillery effluent while using solar radiation as a source of external energy in the photocatalytic process Vineetha et al. [49]. Methylene blue was degraded using N-doped TiO_2 as a photocatalyst. After 180 min of irradiation, there was full decomposition [20]. The biochar and TiO_2 combination was used to remediate the textile wastewater. It was found that using a hybrid composite system may produce 99.2% photodegradation efficiency, compared to 42.6% for TiO_2 and 85.2% for pure biochar when used individually [8].

2.6 Membrane Techniques

Membrane technologies have recently caught the research community's attention, raising their authentications in real-world scenarios due to their ability to treat wastewater. In the event of primary and secondary treatment failure, tertiary treatment processes like membrane technologies can be used to fulfill the discharge regulations. Based on pore size and membrane pressure, they can be divided into four major classes 1. Micro Filtration (MF), 2. Ultrafiltration (UF), 3. Nanofiltration (NF), and 4. Reverse Osmosis.

Table 6 Wastewater treatment using ozonation

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
Ozonation	Tannery effluent	pH 7.6 Ozone 1.5 g O3/g of COD Time 90 min	COD	60	Saranya and Shanthakumar [39]
Ozonation and phytoremediation			Inorganic carbon	90%	
			Colour	60%	
			COD	84%	
Ozonation-biological aerated filter (O3-BAF)	Textile wastewater	Ozone dose 35 mg/L Retention time 2.5 h	Colour	90%	Wu et al. [50]
			COD	35%	
Ozonation	Winery wastewater	pH 4 Reaction time 180 min Ozone dose 100.1 mg/ min	COD	12%	Lucas et al. [19]
Ozonation	Textile wastewater	pH 7 Reaction time 50 min Ozone dose 7 mg/L	Colour	100%	Constapel et al. [7]
Ozone/UV	Winery wastewater	pH 4 Reaction time 180 min Ozone dose 100.1 mg/ min UV lamp 36W	COD	21%	Lucas et al. [19]
Ozone/UV	Olive mill wastewater	pH 3 Reaction time 180 min Ozone dose 12 g/L UV lamp 14 W	COD	29%	Lafi et al. [15]

The use of membranes is an appealing method that is rapidly being employed to replace traditional techniques in wastewater treatment. Using nanofiltration, COD and TDS in the effluent can be eliminated up to 96–99.5% and 98–99.5%, respectively. This technology can be used to achieve both low discharge norms and zero liquid discharge circumstances. Moreira et al. [24] tried to achieve ZLD conditions

Table 7 Wastewater treatment by membrane process

Treatment	Type of wastewater	Optimum parameters	Parameters	Result/ observation	References
MF-NF	Textile wastewater	–	Colour	98.5%	Moreira [24]
			Dye	92%	
Ceramic micro-filtration	Textile wastewater	Porosity 40.2% Mean pore diameter 0.27 µm Flexural strength 55 MPa	COD	25%	Saini [37]
			TDS	31%	
			BOD	39%	
			Turbidity	21%	
			Sulphates	34%	
			Chlorides	33%	
			Colour	26%	
			TSS	100%	
Ceramic microfiltration	Textile wastewater	Porosity 48.15%, Pore size 1.12 µm, Water permeability 922 L h – 1 m-2 bar-1 mechanical strength 6.1 MPa	Turbidity	99.9%	Manni et al. [22]
			COD	69.7%	
UF polymeric membrane (100 kDa)	Oily wastewater		TSS	94.1%	Salahi et al. [38]
			TDS	31.6%	
			Turbidity	96.4%	
			Oil & grease	97.2%	

for textile wastewater treatment. They obtain a 98.5% of colour removal and 92% of Dye removal by utilizing the combination of membranes and AOPs in their experiment. This membrane technology can also achieve up to 97.2% removal efficiency for oil and grease [38]. The main disadvantage of membranes is that they are very expensive and emit fouling odours after a short period of use, demanding frequent cleaning, which increases the expense of maintenance (Table 7).

3 Conclusion

The common effluent treatment plants play a crucial role in the ecosystem of industrial wastewater management. To decrease pollution as much as possible, rules and enforcement are becoming more stringent. Due to technological advancements, regulators are now continuously monitoring the performance of CETPs in India through online monitoring systems. As a result, CETPs around the country are now constantly monitored, ensuring that they function properly. The efficiency of CETPs in treating wastewater must be maintained and improved if regulatory standards have to be met. Due to increased influent volume, ageing infrastructure, and poor operation and maintenance of existing CETPs, a massive amount of substandard effluent is currently being discharged into the environment. The present review discusses the novel techniques currently being used in the CETPs. AOPs like Fenton, Photocatalysis, Cavitation, and Ozonation are some of the promising technologies which have been discussed and that can be applied individually or with a combination of the existing technology with a high potential of reducing the contaminants. It has been observed that photocatalysis provides a better option in the case of all AOPs. Fenton has been widely applied to reduce COD and colour from the colourant. Many studies have demonstrated the benefit of combining two or more techniques to enhance pollution removal efficiency. The combination of Fenton and UV has shown enhanced efficiency, suggesting a possible treatment approach that can be employed in CETPs. It has been found that CETPs in Gujarat have implemented newer technologies such as Fenton and hydrodynamic cavitation in their existing facilities. This shows that CETPs are actively seeking the adoption of more unique technology in their existing plants to cut operating costs and improve reliability to meet standards. Overall this paper has highlighted the importance, and recent findings and covered sustainable options for treatment which if applied can be beneficial for the operating CETPs in terms of finances and will help achieve the discharge standards.

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A Review on Crumb Rubber Content in Modifying Asphalt to Save the Environment from the Solid Waste Crisis

Shailja, Ambika Behl, and Saraswati Setia

Abstract Crumb rubber is one of the major wastes which causes environmental pollution. Crumb rubber is the waste, generated from tires of trucks, buses, cars, etc., if it is burned air pollution occurs as it releases toxic gases, or if landfilled, the fertility of the soil decreases as it is a non-biodegradable waste material. The waste tires can't be reused or recycled safely without any threat to the environment. The best raw materials are used to manufacture a truck or passenger car tire. However, at its end of life, a tire poses a great environmental challenge owing to its highly engineered nature, which makes it non-biodegradable. A tire consists of natural rubber, synthetic rubber, plasticizers, carbon black, silica, and other metallic components from its original formulation. These constituents can find use in other fields, the rubber component can be used to modify bitumen to construct roads. Therefore, this review paper attempts to discuss how bitumen's physical properties (viscosity, penetration value, softening point) and rheological properties (viscoelastic behavior) change after adding crumb rubber in different proportions. The review paper discusses how the addition of crumb rubber into bitumen, lowers bitumen's temperature susceptibility. Temperature sweep tests can be used to determine the sensitivity of CRMB to temperature. The storage modulus (G'), loss modulus (G"), and phase angle (δ) also increased. Overall, the review study demonstrates that incorporating crumb rubber into bitumen not only extends the lifespan of the flexible pavement but also, reduces the quantity of discarded tires that contribute to pollution.

Shailja (✉)
Transportation Engineering, National Institute of Technology, Kurukshetra, Haryana 136118, India
e-mail: shailja_32112420@nitkkr.ac.in

A. Behl
Flexible Pavement Division, CSIR-Central Road Research Institute, Delhi 110025, India

S. Setia
Civil Engineering Department, National Institute of Technology, Kurukshetra, Haryana 136118, India
e-mail: ssetia@nitkkr.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_20

Keywords Crumb rubber · Bitumen · Terminal blend rubber asphalt · Activated crumb rubber

1 Introduction

Any Nation's progress directly depends on infrastructure. Over the past two decades, traffic volume has increased and the demand for stronger or long-lasting pavements from pavement engineers has also increased. A new method of pavement design is being developed by the researcher to improve the performance of roads. One of the promising ways is to use Crumb Rubber in bituminous road construction to not only improve the durability, strength, aesthetics, and economy but also help to reduce pollution that occurs due to waste tires. In 1990, the Environmental Protection Agency (EPA) estimated that out of the 242 million waste tires generated that year, 78% of the tires were either stockpiled, landfilled, or illegally dumped. While some states burn waste tires this is only a temporary solution because of the tires. Landfilling waste tires have also become more and more expensive as landfill space has decreased. The waste tires of vehicles cannot decompose easily and release toxic black pollution, harming the environment. Today, the availability of waste tires is enormous, because the increasing population of our country increases the number of vehicle users. Using crumb rubber in bitumen modification not only increases the life of flexible pavement but also helps to save the environment from waste tires. Gómez-Hernández et al. [4] presented that the presence of sulfur and carbon content increases the temperature stability of the binder. They studied the change in the properties of bitumen after adding different proportions of crumb rubber by performing various tests such as softening point test, penetration test, elastic recovery test, viscosity test, MSCR test, frequency sweep, aging index, rutting parameter, fatigue parameter, temperature failure, etc.

The one drawback of using crumb rubber is that it is too viscous because of which there are chances of phase separation when it is mixed with bitumen. However, the existing criteria for preparing crumb rubber-modified bitumen is to mix the CR (crumb rubber) at a particular shear rate, with only swelling and physical properties considered and the percentage of adding CR is restricted to 20% [5]. The activation treatment and terminal mix can increase the amount of crumb rubber, which lowers the amount of environmental pollution brought by waste tires. The activated crumb rubber-modified bitumen can be prepared by physical, mechanical, chemical, and biological treatment methods, while the terminal blend is prepared by increasing the duration of mixing with high temperature and a constant shear rate [15]. The fatigue and aging resistance of activated crumb rubber-modified asphalt (ACRMA) can be significantly increased by a revolutionary way of preparation that uses ultrasonic treatment [17]. On the waste tire, gamma irradiating activated crumb rubber has a substantial impact on high-temperature stability and aging resistance [7]. According to the J integral method, chemically modified crumb rubber has better cohesiveness with asphalt and aggregate and performs twice as well in terms of criteria for fracture cracking as crumb rubber-modified asphalt (Mull, Stuart and Yehia, 2002). Additionally, fatty acids and organosilanes can help in the preparation of activated crumb rubber, preventing the separation of crumb rubber from bitumen during transit and high-temperature storage [13]. To increase its storage stability at high temperatures, crumb rubber can also be activated by combining it with a polymeric compatibilizer [3]. The terminal blend rubberized asphalt (TBRA) is the newly adopted method that can be prepared using fine CR, increasing the duration of mixing. The desulfurization reaction and continuous dissipation of CR with bitumen improve the separation problem at high temperatures, give fatigue resistance, and improve the low-temperature performance of crumb rubber-modified bitumen (CRMB).

According to [11] the following characteristics of bitumen are improved by the addition of crumb rubber:

- It helps to increase the consistency of the binder at higher temperatures to decrease the plastic deformation behavior of bitumen.
- It helps to increase bitumen's flexibility and elasticity behavior at low temperatures to prevent the pavement from cracking.
- It increases the adhesion properties of bitumen with aggregate.
- It offers aging resistance, which helps to slow down the initial aging and hardening of pavement.

In this paper, the changing physical and rheological properties of bitumen after adding crumb rubber are discussed which not only enhances the properties of the bitumen but also helps to decrease its environmental impact. The different methods (activated crumb rubber, terminal blend) of preparing crumb rubber is also discussed which increases the crumb rubber content in bitumen while preparing the blend helps to reduce the pollution caused by waste tires.

2 Material

Various researchers used crumb rubber from waste tires and bitumen to study the properties of crumb rubber-modified bitumen (CRMB). From many research papers, it has been found that if the size of the crumb rubber is less than 300 μ with a wide surface areait helps it to swell and absorb the bitumen efficiently. The perfect time, temperature, and shear rate of mixing play an important role in the interaction between bitumen and crumb rubber [8].

Authors in Mashaan et al. [10] used bitumen having physical properties shown in Table 1 and the crumb rubber consists of the chemical composition shown in Table 2.

Authors in Wang et al. [15] used activated crumb rubber modified asphalt (ACRMA) having ductility value, softening point, penetration value, and viscosity of 18.9 cm, 78.2 °C, 42 dmm, and 2.89 pa.s respectively. They take this property of ACRMA and compare it with terminal blend rubber asphalt (TBRA) and natural crumb rubber blend (CR) by performing various tests.

Table 1 Properties of the base bitumen binder

Test properties	Results
Viscosity at 135 °C (Pa.s)	0.65
G*/Sinδ at 64 °C (Kpa)	1.35
Ductility at 25 °C (cm)	>100
Softening point (°C)	47
Penetration at 25 °C (d-mm)	88

Table 2 Chemical components of Crumb Rubber used in the study

Major rubber component	Tire rubber
Acetone extract (%)	11.0
Rubber hydrocarbon (%)	50.5
Carbon black content (%)	32.5
Natural rubber content (%)	34.0
Ash content (%)	6.0

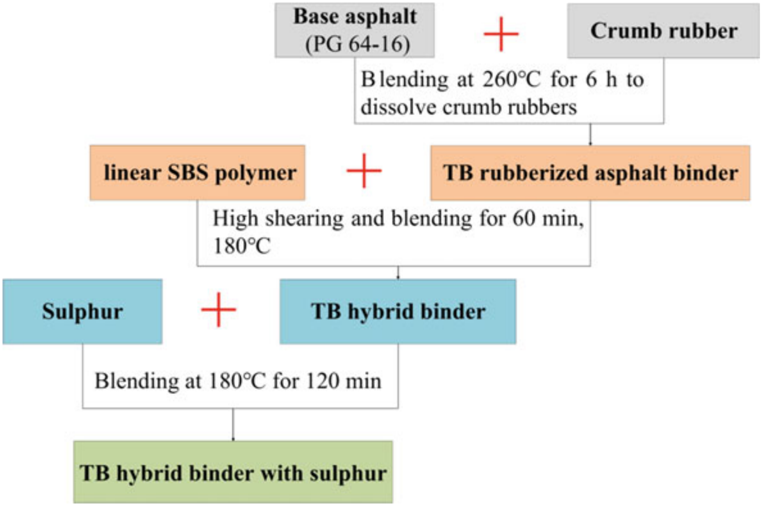
2.1 Mechanism for Asphalt and Crumb Rubber Mixture

Previous studies have shown that crumb rubber degrades and loses some of its long-term storage ability when combined with bitumen. The dispersion of rubber particles and the physical interaction of bitumen and crumb rubber particles are key factors in the enhancement of crumb rubber-modified bitumen properties. Temperature and time duration for digesting the crumb rubber with bitumen is a highly important factor that influences the dispersion of rubber with bitumen. Authors in Venudharan and Biligiri [14] compared coarser, finer and well-graded rubber. Rubber that is finer and smaller than 300 μ will disperse flawlessly with bitumen because it has a larger surface area and can absorb bitumen more quickly. The finer powder of rubber not only helps to increase the rate of dispersion but also helps to increase its prolonged storage capacity at high temperatures. In this paper, the duration of mixing crumb rubber with bitumen is 90 min at 170–180°C and blended at 2000 rpm.

Authors in Wang et al. [15] compared the 50% terminal blend rubber asphalt, the 50% activated crumb rubber modified asphalt, and the 20% crumb rubber modified asphalt. Activated crumb rubber modified asphalt was heated at 180 °C for 50 min at 2000 rpm and terminal blend rubber asphalt is prepared by mixing rubber with bitumen at 260 °C for 6 h at a stirring speed of 400 rpm, 20% crumb rubber modified asphalt was prepared by heating the asphalt at 180 °C, adding crumb rubber to it, and blending it for 1.5 h. After preparing all these different blends the authors observed that 50% ACRMA > 20% crumb rubber > 50%TBRA in rutting resistance while 50%TBRA has better fatigue resistance properties than 20%CR and 50%ACRMA. Using CR not only improves pavement service life but also saves the environmental problem as 50% of Crumb Rubber is used here.

Authors in Mashaan et al. [10] mixed bitumen, and crumb rubber at 180 °C for 1 h at the speed of 200 rpm while authors in Venudharan and Biligiri [14] kept all the criteria same, they only changed the speed of the stirrer i.e., 2000 rpm.

Authors in Wang and Huang [16] prepared a hybrid terminal blend as below



2.2 Constituents and Concentration of Crumb Rubber

Crumb rubber, sometimes known as waste tire rubber, is a mixture of synthetic natural rubber that also includes carbon black, an antioxidant, filler material, and an oil-soluble extender made from asphalt. Using either the dry method (where the tire crumb rubber substitutes the amount of aggregate and is then mixed with bitumen) or the wet approach, leftover tire crumb rubber is combined with bitumen at a specific time and fixed temperature to create asphalt rubber (in this crumb rubber is mixed with bitumen before making asphalt concrete mix). By using the dry technique, the bitumen and crumb rubber are not thoroughly combined [6], but it is also noted that the dry method yields 2 to 4 times as much crumb rubber as the wet technique does [2]. This review study covered the wet approach, in which bitumen and crumb rubber are combined before mixing (Fig. 1).

According to laboratory tests, the penetration value, softening value, viscosity, elastic recovery, and complex shear modulus of asphalt all rise linearly as the amount of crumb rubber is increased [8]. These findings demonstrate how asphalt rubber affects the functionality and rheological characteristics of bitumen. Additionally, it helps to reduce distortion during the installation and maintenance of flexible pavement. It also helps to reduce the resistance of bitumen to temperature susceptibility.

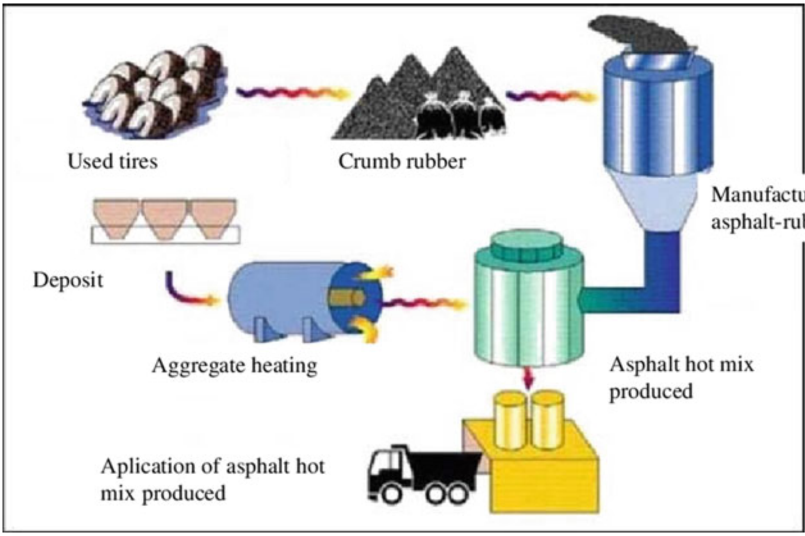


Fig. 1 Wet process method

Authors in Wang et al. [15] showed in their study that a 20% concentration of crumb rubber, activated crumb rubber modified asphalt and terminal blend rubber asphalt is prepared by using 50% crumb rubber by weight of the mix. Therefore, it is observed that if we are pre-treating the crumb rubber or preparing a terminal blend then 50% CR can be used.

Authors in Mashaan et al. [10] prepared the blend by increasing the concentration of crumb rubber (4%, 8%, 12%, 16%, and 20% by weight of bitumen). In this paper, it was observed that the elastic recovery, viscosity, and softening point of asphalt increase and penetration value decreases.

Authors in Wang and Huang [16] prepared the terminal hybrid blend with sulfur by adding CR at various doses (0%, 5%, 10%, 15%, and 20% by weight of base binder) with bitumen of PG 64–16, and SBS (3% by weight of the terminal blend (TB) rubberized asphalt).

2.3 Crumb Rubber Particle Size and Grinding Process

Waste tires are crushed to make crumb rubber, a unique material free of fibers and metals. The dispersion of crumb rubber particles in bitumen is greatly influenced by the size of the crumb rubber. The size of crumb rubber should be less than 300 μ because it is observed that [10] the smaller size or fine-graded crumb rubber will disperse completely at 160–180 °C with bitumen. Crumb rubber that is smaller will have more surface area and can absorb bitumen faster. It also solves the problem of settling in prolonged storage at elevated temperatures. The two processes for making

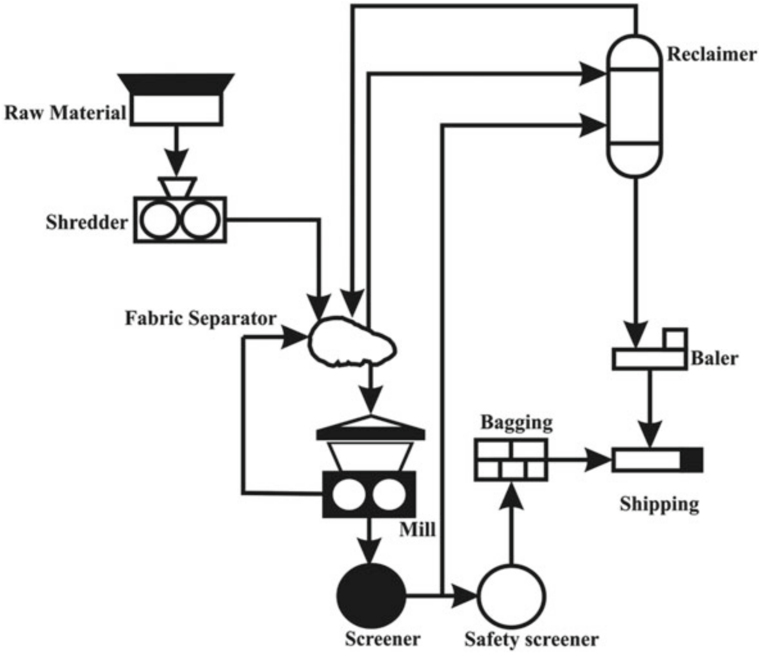


Fig. 2 Ambient grinding process

crumb rubber are the cryogenic technique and ambient grinding. In the ambient grinding method, the crumb rubber is kept in a cracker mill, and the crumb rubber is cut into small pieces at ambient temperature, where the particle having a rough surface is found, while in the cryogenic method, the crumb rubber is hardened by freezing it, using nitrogen liquid until it becomes brittle and then the rubber is cut into small pieces by a hammer. The resulting particle consists of smooth, clean, and flat particles. This method is quite expensive than ambient grinding as nitrogen is used in this method (Figs. 2 and 3).

2.4 CRMB Chemical Alterations

The link between the crumb rubber and bitumen is altered when CRMB is chemically modified. Typically, this is present in the final blend process that has been improved using particular chemicals and activators. Authors in Wang et al. [15] added Crumb Rubber to terminal blend rubber asphalt (50% by weight of mix) with neat bitumen PG 64–16, and the mixing process was of 6 h at 260 °C and 400 rpm to sufficiently degrade the Crumb Rubber. Due to the desulfurization and homogeneous dispersion of CR in this process, the segregation issue was resolved and a better result was obtained in terms of crack resistance at low temperatures. In this study, it was also

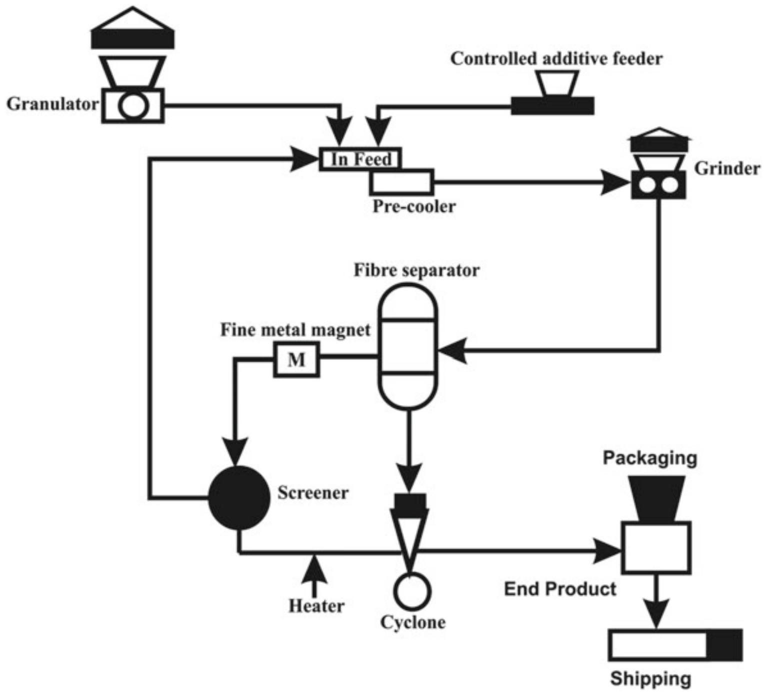


Fig. 3 Cryogenic grinding Process

found that altering the physiochemical characteristics of CR via physical, chemical, mechanical, and biological treatment methods help to increase the storage stability of crumb rubber. Authors in Ibrahim et al. [7] utilized the radiation-based activation approach and studied how it lowers cracking resistance at low temperatures. To enhance the qualities of CRMB, authors in Kocevski et al. [9] prepared the terminal blend by using the grafting technique, in which the surface of the bitumen was modified by bulk polymerization of acrylic acid. This process can also help to increase the viscosity and failure temperature of crumb rubber-modified bitumen. Authors in Wang and Huang [16] prepared the hybrid terminal blend at various dosages of CR by mixing styrene butadiene styrene and sulfur and compared it with the styrene butadiene styrene modified asphalt (SBSMA).

3 Aging Properties of CRMB

The process of binder aging involves the oxidation and loss of the bitumen's lightweight component. As the binder ages, it also gets harder and develops fractures due to high stiffness. (1) Short-term aging happens when the mix is prepared and spread out over the road surface. The short-term aging of the binder is simulated in the lab by using the Rolling Thin Film Oven Test (RTFOT). (2) Over the course of the pavement's useful life, long-term aging takes place. A pressure aging vessel test is conducted to simulate the long-term aging (PAV) of bitumen.

Authors in Wang et al. [15] performed tests on the RTFO sample and PAV sample to evaluate the aging of the binder. They calculated the phase angle aging index (PAI), which is the ratio of phase angle at the aged condition to phase angle at unaged condition (δaged/δunaged), and the complex modulus aging index (CAI), which is the ratio of the complex shear modulus value of the aged binder to complex shear modulus value of the unaged binder (G*aged/G*unaged).

In the oxidation process, the aromatics in the bitumen binder are converted into asphaltene which can be observed from the FTIR test of the aged and unaged binder. When carbonyl formation occurs, the binder becomes harder, and its viscosity increases.

The following Data of ATR-FTIR was presented by authors in Wang et al. [15] (Fig. 4).

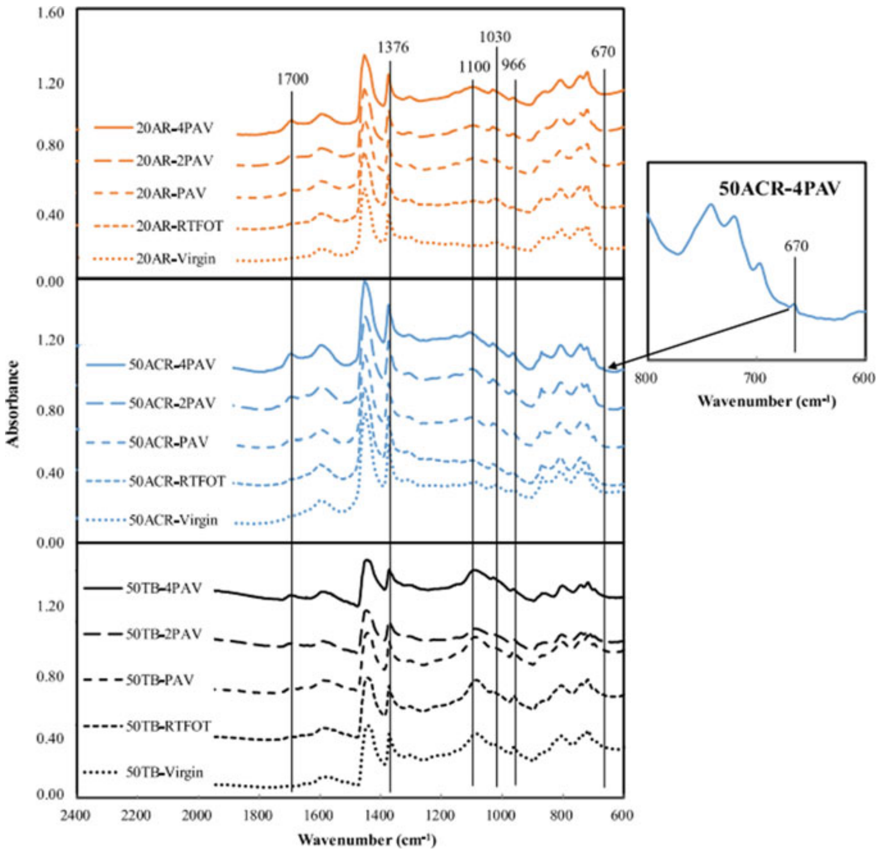


Fig. 4 Shows the aging of 20AR, 50ACR, 50 TB

Where, 20AR- 20% Asphalt rubber, 50 TB- 50% terminal blend, 50ACR- 50% Activated crumb rubber, and PAV, 2PAV, and 4PAV are Pressure Aging Vessels for 20 h, 40 h, 80 h.

4 Advanced Test Performed on CRMB

4.1 Rheological Property Test

The dynamic shear rheometer test is used to categorize binders according to their performance grading (PG) and to determine the complex shear modulus (G*), storage modulus (G'), loss modulus (G''), and phase angle (δ) for the binder's aged and unaged circumstances. Authors in Wang et al. [15] used a DSR test to calculate G*, G', G'', and on aged and unaged conditions of the binder in the range of 34 °C to 88 °C with the increment of 6 °C in order to compare these properties of various binders. The test used 20% rubber, 50% activated crumb rubber mixed with bitumen, and 50% terminal blend rubber asphalt.

Authors in [10, 11] perform the DSR Test at 76 °C to get information about the rheological properties of CRMB and found changes in the values of G*, G', G'', δ at a greater extent as they increased the percentage of CR from 4 to 20%.

4.2 Frequency Sweep Test

Under loading circumstances that are controlled by strain, a frequency sweep test is performed. A master curve for the complex modulus (G*), phase angle (δ), loss modulus (G''), and storage modulus (G') at a reference temperature is plotted using the frequency sweep test. At 5 °C, 15 °C, 25 °C, 35 °C, 45 °C, 55 °C, 65 °C, and 75 °C, [15] frequency sweep tests were performed on 20AR, 50ACRMA, and 50TBRA for the aged and unaged binders. The sigmoidal model and time–temperature superposition principle (TTSP) was used to plot the master curve of G*, G', G'', at the reference temperature of 25 °C. The frequency they chose varied between 0.1 Hz and 30 Hz.

Authors in Mashaan et al. [1] performed a frequency sweep test to determine the complex shear modulus (G*), phase angle (δ), and complex dynamic viscosity (G*) at temperatures between 40 and 60 °C. Using cross-model and SPSS software, these factors are utilized to calculate the Zero Shear Viscosity (ZSV) of binders.

4.3 Multiple Stress Creep Recovery (MSCR) Tests

To assess the potential for permanent deformation of the binder, multiple stress creep recovery tests are carried out. In order to allow the binder to recover, a creeping force is given for 1 s and then withdrawn for 9 s during the dynamic shear rheometer test. The test is conducted twice, the first time at low stress (0.1 kPa) for 10 creep recovery cycles and the second time at 3.2 kPa for the same number of cycles (Fig. 5).

The test gives the value of recovery (R) and non-recoverable compliances (J_{nr}). The blend has a higher R-value and a lower J_{nr} value means its rutting resistance is high as compared to the other blend. Authors in Wang et al. [15] performed the MSCR test at 64 °C, 70 °C, 76 °C, and 82 °C on 20AR, 50ACR, and 50 TB. Authors in Venudharan and Biligiri [14] performed an MSCR test on all the short-term aged asphalt and asphalt rubber binder at the temperature of PG. The J_{nr} and R-values are obtained by performing the MSCR test and it was found that the fine crumb powder has a higher R-value as compared to a well-graded and coarser crumb rubber.

Authors in Wang and Huang [16] performed an MSCR test and observed that the styrene butadiene styrene-modified asphalt (SBSMA) has a lower J_{nr}-value at 0.1 and 3.2 kPa, respectively than that of hybrid terminal blend-modified asphalt. Therefore, it shows that the hybrid terminal blend has a lower rutting resistance compared with SBSMA.

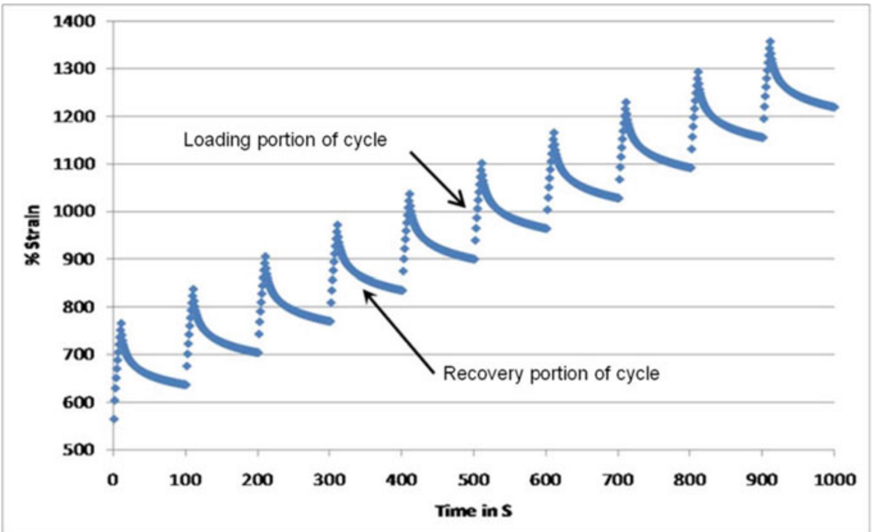


Fig. 5 For R and J_{nr}- value

4.4 Bending Beam Rheometer (BBR) Test

The bending beam rheometer test demonstrates the binder's ability to withstand cracking at low temperatures. The BBR test evaluates the low-temperature stiffness(s) and relaxation characteristics of the PAV-aged binder.

According to the low-temperature method of ASTM 6648, authors in Wang et al. [15] performed a BBR test to measure the stiffness (S-value) and creep rate or slope (m-value) of the 20AR, 50ACR, and 50 TB after PAV at -12 °C, -18 °C, -24 °C, and -30 °C. For the PAV aging condition, Tsp and Tmp demonstrate the low-temperature performance of the binder at an S-value of 300 MPa and m-value of 0.3.

$$T = Tmp - Tsp$$

If the value of ΔT is greater than 1 and the value of ΔT is less than 1, the stress relaxation performance of the binder is controlled by the S-value and m-value respectively.

The result obtained by Wang et al. [15] is described below (Fig. 6).

5 Conclusion

There are various types of Bitumen modifiers such as Trinidad lake Asphalt, plastomeric thermoplastic polymer [polyethylene (PE), Ethylene vinyl acetate copolymer (EVA), Ethylene methyl acrylate copolymer (EMA)], Elastomeric thermoplastic polymer [Ethylene terpolymer (ETP), styrene butadiene styrene block copolymer (SBS), styrene-butadiene (SB)], Natural Rubber (NR), crumb rubber (CR) which help to enhance the physical and rheological properties of asphalt.

After studying the papers of various authors it becomes evident that using crumb rubber in a flexible pavement increases the life of the pavement and helps to protect the environment from toxic gases released from waste tires if burnt or landfilled. The main conclusions observed are mentioned below-

1. It is found that if activated crumb rubber is used or a terminal blend is prepared then 50% CR can be used which gives better results in fatigue cracking as well as in rutting resistance. To prepare activated crumb rubber there are different methods such as gamma irradiation, ultrasonic treatment, fatty acid and organosilane, polymer compatibilizer used by [3, 7, 13, 17] respectively, while the terminal blend can be prepared by increasing the duration of mixing at constant shear and temperature due to the desulphurization and the ease to be dispersed with bitumen solves the segregation problem occurring at a high temperature.
2. To utilize the property of crumb rubber properly while mixing it with bitumen, the gradation, size, temperature, and time duration for preparing the blend plays an important role in the dispersion of crumb rubber in the bitumen. The size

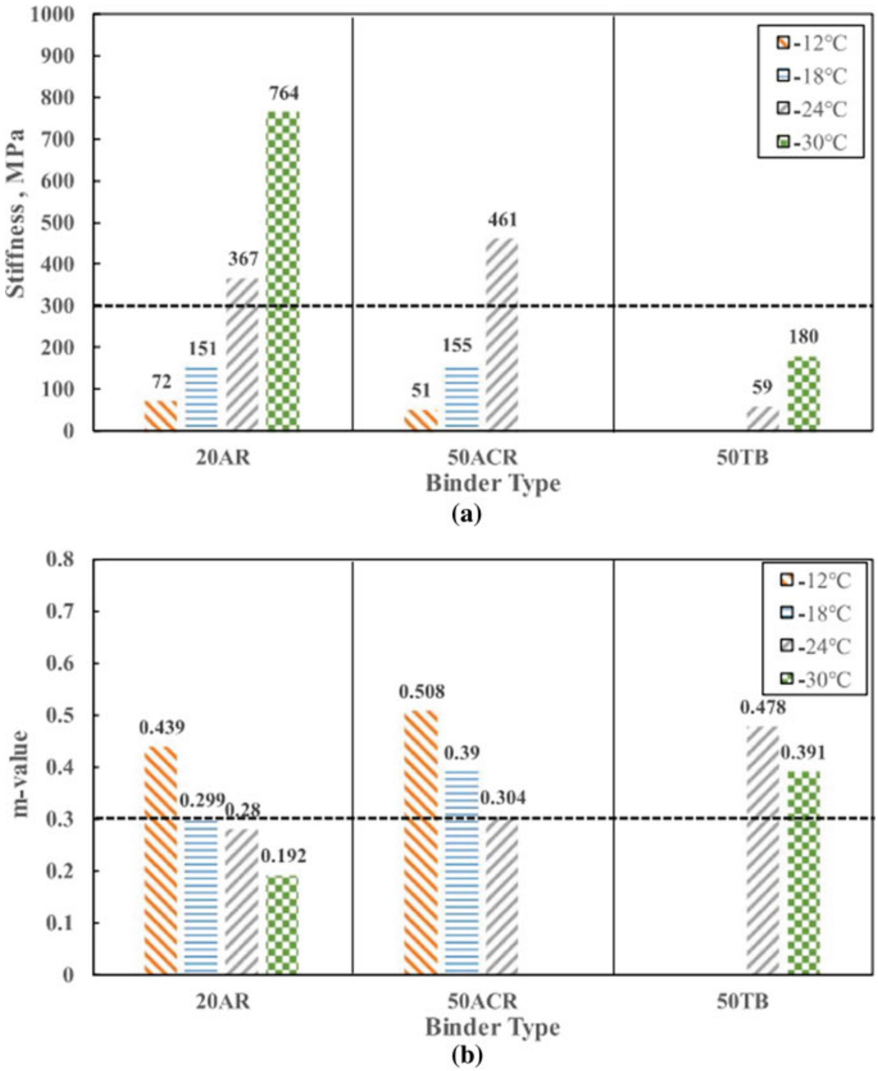


Fig. 6 After PAV aging: **a** Stiffness and **b** m-value of 20AR, 50ACR, and 50 TB

of the crumb rubber should be <300 μ, minimum time duration of 60 min. and temperature varies between 160 and 180°C.

3. From various research papers, it is observed that crumb rubber-modified bitumen is a good alternative to polymer-modified bitumen as it not only helps to increase the life of the flexible pavement by giving good fatigue and rutting resistance but also helps to save the environment from this solid waste. The MSCR test is

conducted to indicate the rutting resistance capability of the bitumen while the BBR test is conducted to indicate the fatigue resistance capacity of the bitumen.

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Treatment of Dairy Wastewater by Electrocoagulation Process Using Iron Electrodes

Chandrakant S. Watawati and C. B. Shivayogimath

Abstract The present study focused on dairy wastewater treatment with a help process of electrocoagulation. In a batch reactor with a 1 L capacity, iron electrodes were used as sacrifice electrodes. The dairy waste had a pH of 9.0, 255 NTU turbidity, a COD of 3000 mg/L, and was white in colour. For COD, colour, and turbidity removal, the optimal working parameters, including voltage, pH, and electrolysis time, were found to be 30 V, 8 pH, and 60 min, respectively. The highest removal rates for COD, colour, and turbidity were 98%, 89%, and 86%, respectively. The study's results demonstrated that electrocoagulation employing iron as a sacrificial electrode can be used as a successful alternative method for dairy wastewater.

Keywords Dairy wastewater · (EC) Electrocoagulation · Iron electrodes · Chemical oxygen demand (COD)

1 Introduction

In today's world, milk and milk products are essential. The most fundamental and essential elements of nutrition are milk products like curd, butter, yoghurt, etc. India now produces more milk than any other country in the world. There are about 94.5 million tons of milk produced annually. The per capita availability of milk has improved to 250 gm/day due to the increasing milk output. In India, the demand for milk and milk-derived products is anticipated to rise to 191.3 million tons in 2020. Dairy industries are anticipated to grow more over the future decades because milk production is crucial to the Indian economy.

C. S. Watawati (✉) · C. B. Shivayogimath
Civil Engineering Department, Basaveshwar Engineering College, Bagalkote, Karnataka, India
e-mail: cswatawati@gmail.com

C. B. Shivayogimath
e-mail: cbsmath15@gmail.com

C. S. Watawati
Department of Civil Engineering, Rural Engineering College, Hulkoti, Gadag, Karnataka, India

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*,
Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_21

The current issue with the dairy business is that it produces a lot of wastewater, and that effluent contains a lot of fat, casein, and inorganic salts. These provide high BOD, COD, oil, and grease contributions that exceed CPCB discharge limitations. Wastewater released on land will have an impact on the quality and structure of the soil. Some wastewater may also percolate into the groundwater below, where it will have an impact on the groundwater's quality. When wastewater from the dairy or milk processing industries is discharged without treatment, the issue is more significant. Because they contain a significant organic content, they are consequently characterised by high levels of biological oxygen demand (BOD_5) and chemical oxygen demand [1]. The dairy industry employs a number of wastewater treatment techniques, including electrochemical treatment and membrane systems [2]. The majority of the time, biological approaches, including the activated sludge process that is used to treat dairy effluent. Lateef et al. [3], reverse osmosis membrane [4], anaerobic sequencing batch reactor [5], up flow anaerobic sludge blanket reactors [6] that are highly energy-intensive, while anaerobic treatment of dairy wastewater exhibits relatively low nutrient removal, necessitating extra treatment for the effluent produced. On the other hand, physical and chemical treatments are used, but they will ultimately result in the development of more sludge.

The alternative method for treating the dairy effluent is electrocoagulation (EC). A consumable electrode is used in the EC process. There are three steps in the EC procedure. (1) Coagulation agents are produced when the sacrificial electrode is electrolytically oxidized. There occurs (2) break down of emulsions, particle suspension, and instability of pollutants; and (3) gathering of the destabilized into flocks. Electrocoagulation process is not only used for organic wastewater but also for the treatment of heavy metals, textile wastewater [7], landfill leachate [8] etc.

The advantages of the electrocoagulation process include simple equipment, easy operation, economical treatment, and low maintenance cost with minimum sludge production. However electrodes need to be replaced periodically and electricity should be available at cheaper rates. In this research work the EC process using iron electrodes was used for dairy wastewater treatment. Response surface methodology was employed to determine the optimum conditions for COD, color & turbidity removal.

Dairy effluent used in this study was collected from a well-established industry. The dairy treatment system consists of the primary treatment followed by the secondary treatment. The sample was randomly taken from the effluent treatment plant and placed in a plastic can. Then, it was immediately transport to the laboratory and preserved in a freezer at 4 °C before further analysis. The parameters of the examination of the dairy effluent were reported in Table 1 and were analysed in accordance with conventional procedures [9].

Table 1 Characteristics of dairy wastewater

Sl. no	Characteristics	Value
1	pH	9
2	BOD (mg/L)	967.68
3	COD (mg/L)	3000
4	Turbidity (NTU)	255
5	Total solids (mg/L)	1950

2 Materials and Methods

2.1 Background

The batch reactor used for the EC tests was 150 × 100 × 100 mm. The maximum capacity of the reactor, which was used of acrylic, was 1500 mL. But for the study, a sample with a volume of 1000 mL was employed. Four monopolar parallel iron plates with measurements of 90 × 90 × 1 mm were utilized to make the electrode sets (two anode and two cathode electrodes). The electrodes were spaced one centimeter apart. Monopolar parallel mode electrode connections were made to a DC power source that ranged from 0 to 30 V and 0 to 2 A. An electromagnetic stirrer was employed to mix the homogeneous solution. The electrodes were rinsed with HCl solution following each experiment.

The experimental setup of EC process is shown in Fig. 1.

2.2 Experimental Design

In this study, the experimental design was carried out using the design expert software (version 7.0). Voltage, time, and pH were three independent variables that were used using three level response surface experimental designs. The 20 tests themselves were planned. In Table 2, experimental parameters are displayed.

The optimum parameters are automatically provided by the software. This software uses optimization to maximize the removal of COD, colour, and turbidity, respectively. Table 3 contains the actual experimental design matrix.

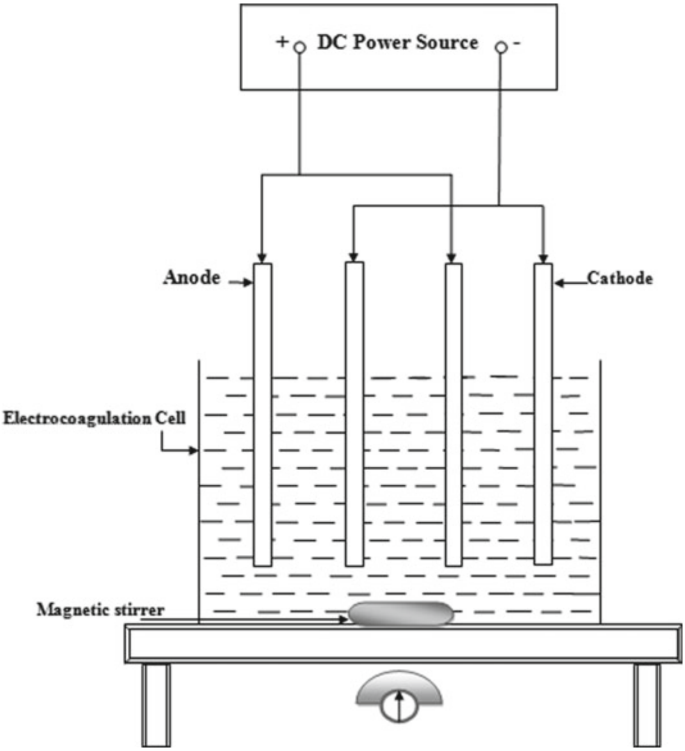

Fig. 1 Representation of electrocoagulation process

Table 2 Experimental time, voltage, and pH levels for composite designs

Variable	Parameter	Level			
		−1	+1	−α	+α
X_1	Time	16	60	1.00056	74.9994
X_2	Voltage	10	30	3.18207	36.8179
X_3	pH	4	8	2.63641	9.36359

3 Results and Discussion

3.1 General

Using standard procedures, the wastewater from the dairy industry was analyzed for characteristics like pH, BOD, and COD.

Table 3 Experimental design used to maximize time, voltage, and pH

Run	Time	Voltage	pH
1	16	10	4
2	60	10	4
3	16	30	4
4	60	30	4
5	16	10	8
6	60	10	8
7	16	30	8
8	60	30	8
9	1	20	6
10	75	20	6
11	38	3.2	6
12	38	30	6
13	38	20	4
14	38	20	8
15	38	20	6
16	38	20	6
17	38	20	6
18	38	20	6
19	38	20	6
20	38	20	6

To maximize operating parameters, a 2^3—factorial central composite experimental design with 20 experimental runs were performed. Table 4 shows the design matrix along with experimental findings using iron electrodes.

3.2 Experimental Results Obtained from Iron Electrodes

Equations 1, 2, and 3 illustrate the second order polynomial equation for COD, colour, and turbidity removal.

$$\begin{aligned}\%\ \textbf{of COD Removal} = {} & +133.95705 + 1.75625 * X_1 - 0.86437 * \\ & X_2 - 47.11974 * X_3 - 0.047528 * X_1 * \\ & X_2 - 0.21560 * X_1 * X_3 - 0.11606 * \\ & X_2 * X_3 + 0.011686 * X_1^2 + 0.094268 * X_2^2 \\ & + 4.90716 * X_3^2 \end{aligned} \quad (1)$$

Table 4 The results shown here for COD, turbidity and color obtained from RSM

Run	Time	Voltage	pH	% of COD removal	% of Turbidity removal	% of Color removal
1	16	10	4	58	53.33	38
2	60	10	4	77.77	81.56	69
3	16	30	4	58	87.05	65
4	60	30	4	81	81.17	82
5	16	10	8	62	9.47	60
6	60	10	8	88.88	46	78
7	16	30	8	59	81	81
8	60	30	8	97.77	89	86
9	1	20	6	12	9	6
10	75	20	6	77.77	86.27	85
11	38	3.2	6	35.55	37.25	38
12	38	30	6	75.55	83	78
13	38	20	4	77.7	89.01	84
14	38	20	8	91.11	78.83	63
15	38	20	6	33.33	88.68	82
16	38	20	6	33.33	88	85
17	38	20	6	33	88.35	82
18	38	20	6	33	88	82
19	38	20	6	33	88	82
20	38	20	6	33	88	82

$$\textbf{\% of Turbidity Removal} = +14.23160 + 3.28862 * X_1 + 3.46550 * X_2 - 14.25297 * X_3 - 0.040170 * X_1 * X_2 + 0.041455 * X_1 * X_3 + 0.55787 * X_2 * X_3 - 0.027622 * X_1^2 - 0.89530 * X_2^2 - 0.13504 * X_3^2 \tag{2}$$

$$\textbf{\% of Color Removal} = -62.12063 + 2.94494 * X_1 + 4.33811 * X_2 + 6.43\, X_3 - 0.011 * X_1 * X_2 - 0.071 * X_1 * X_3 - 0.068\, X_2 * X_3 - 0.020\, X_1^2 - 0.060 * X_2^2 - 0.149 * X_3^2 \tag{3}$$

3.2.1 COD Reduction is Influenced by pH and Time Variables

The results of different experimental conditions for COD removals are shown in Figs. 2 and 3.

The experiments were run with iron electrodes with monopolar parallel and observed COD removal at different pH, time and voltages. It was observed that the maximum COD elimination of 98% occurred at pH 8, voltage 30 V, and time 60 min. When equilibrium conditions are reached, the voltage no longer significantly affects the efficiency of the EC process; rather, it mainly affects the removal kinetics of each parameter. This shows that the maximum ability of EC to remove the milk components of the dairy effluent is unchanged by the applied voltage. It is generally known that voltage is the key controlling factor of EC, although increasing voltage just reduces the time required to achieve the maximum removal yield for all pollution indicators. An approximate amount of iron that is dissolved from the anode per unit of time, which increases with voltage as indicated by Faraday's law, can be used to measure the effect of EC. There are almost equal amounts of coagulant species as shown in figure. The findings clearly indicate that COD elimination during the EC process increases with time.

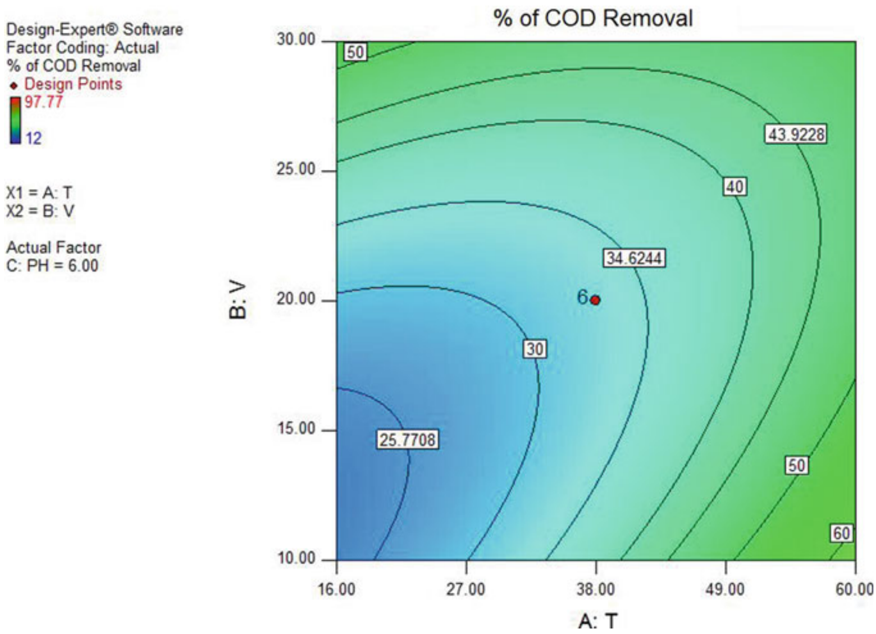

Fig. 2 Isoresponse contour plots showing the effects of time and voltage on the percentage of COD reduction

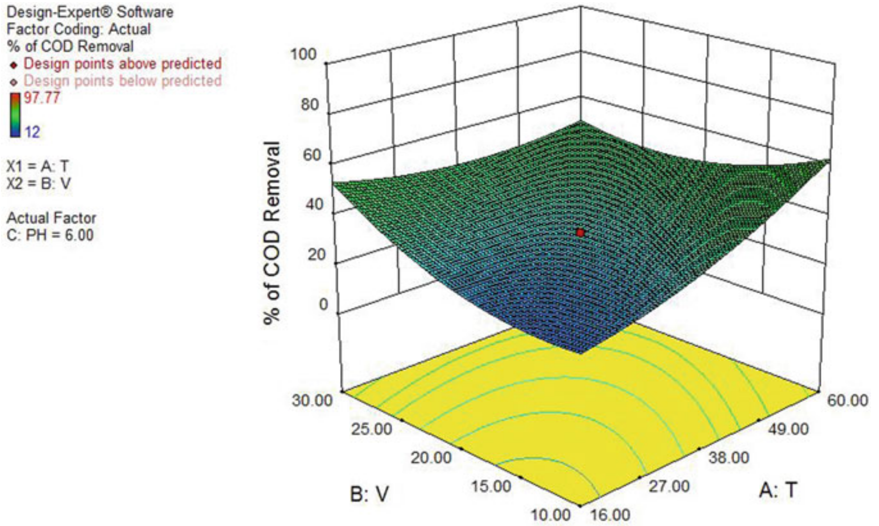

Fig. 3 Response surface plots indicating the percentage of COD elimination under various voltage and time conditions

3.2.2 Effect of Varying Voltage and pH on the Reduction of Turbidity

Electrocoagulation process with iron electrodes were used to remove the turbidity from the dairy wastewater and results showed that at 4.0 pH, 20 V and time of 38 min the maximum turbidity removal was 89% during this process and shown in the Figs. 4 and 5.

3.2.3 A Study of the Effects of Voltage and Time on Color Removal

The studies were conducted with various color removal parameters, and the findings indicate that pH 8 with 30 V achieved the greatest color removal of 86% at 60 min of the EC process. Dairy wastewater was found to be nearly colorless at this stage, as shown in Figs. 6 and 7.

3.2.4 Comparision of Experimental and Predicted Design Values

Electrodes made from iron were used in the experiment. Figures 8, 9, and 10 illustrate experimental and predicted removals of COD, turbidity, and colour. The results highlight that the experimental findings and the predicted data exhibit good agreement.

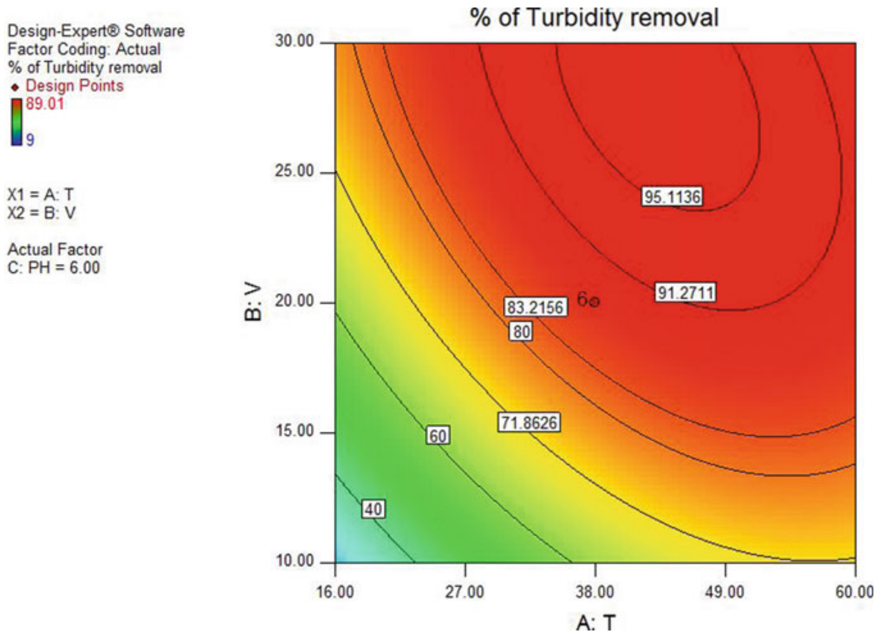

Fig. 4 Isoresponse contour graphs indicating the percentage of turbidity removed as a function of time and voltage

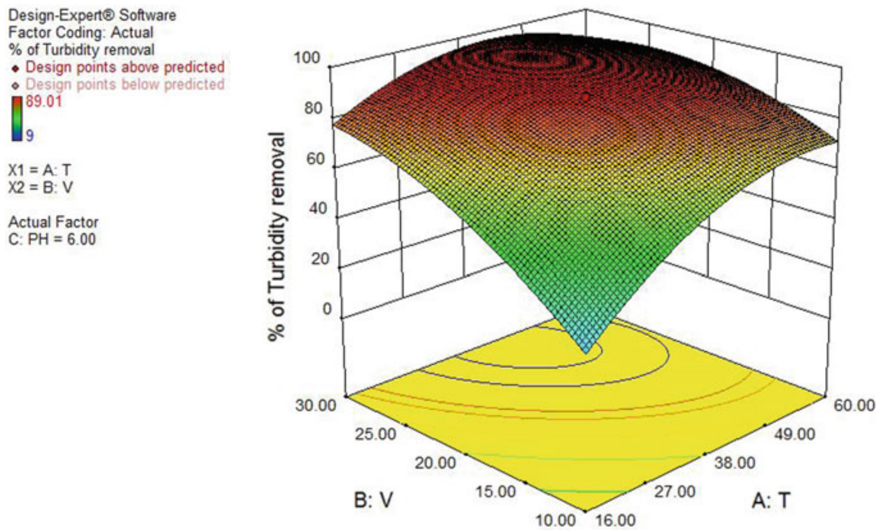

Fig. 5 Response surface plots show the percentage of turbidity removal under different voltage and time conditions

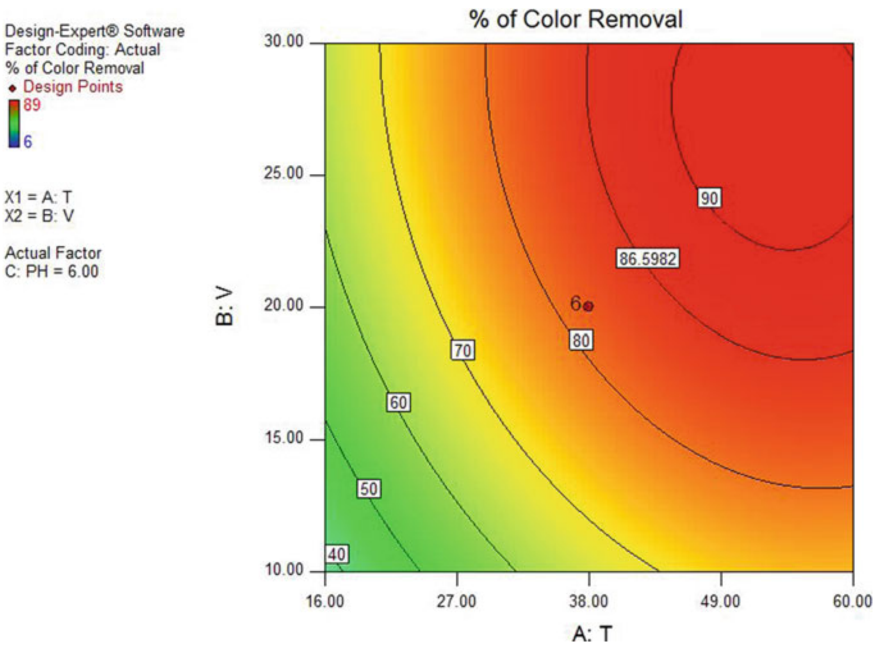

Fig. 6 Isoresponse contour graphs displaying the effects of voltage, time, and colour removal percentage

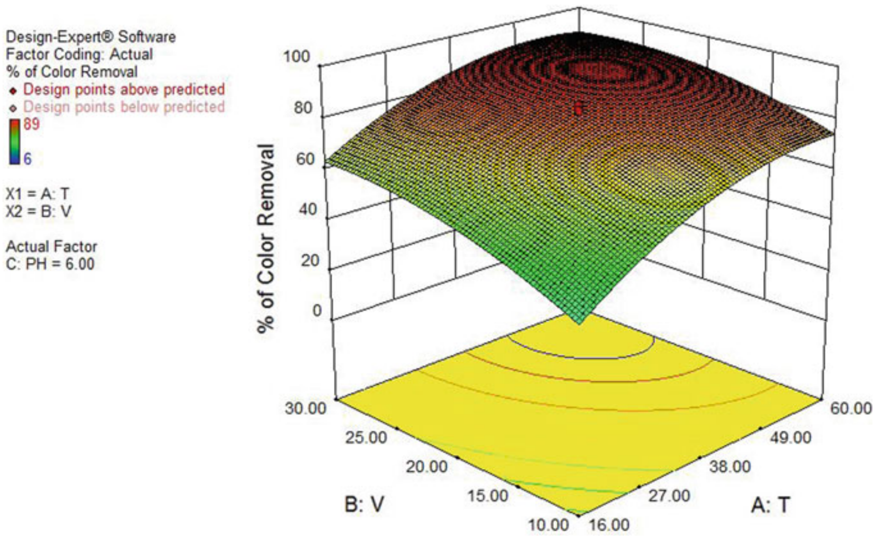

Fig. 7 Response surface plots showing the effect of voltage, time, and colour removal percentage

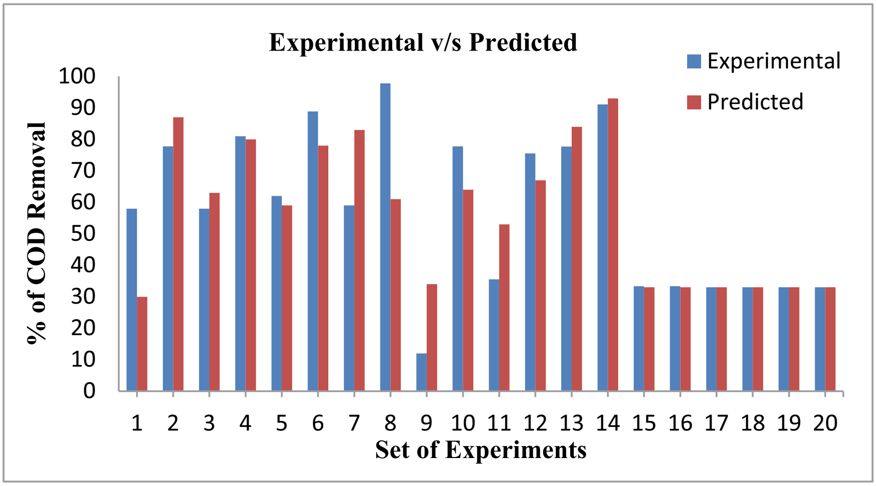

Fig. 8 Representation of COD reduction by experimental and predicted results in %

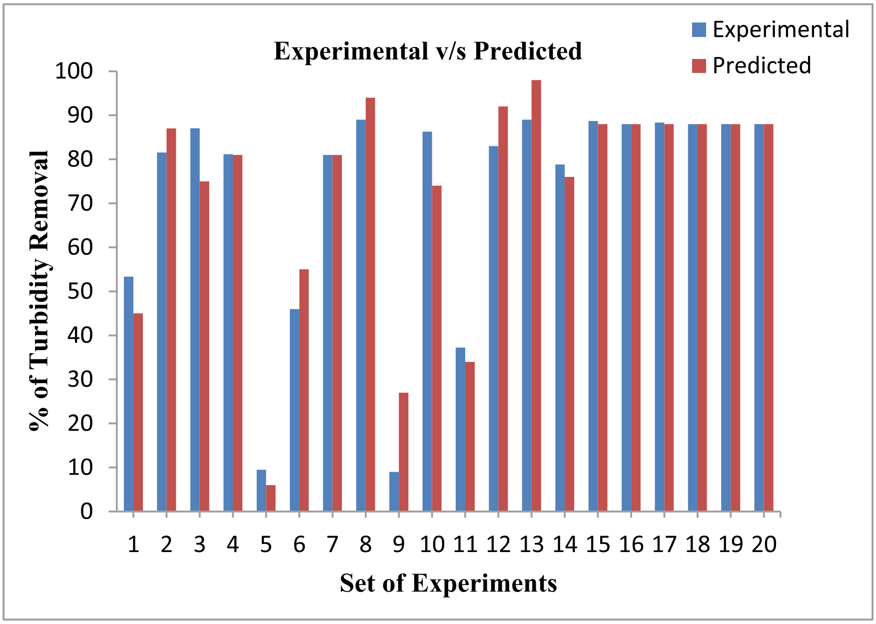

Fig. 9 The percentage difference between experimental and predicted turbidity removal

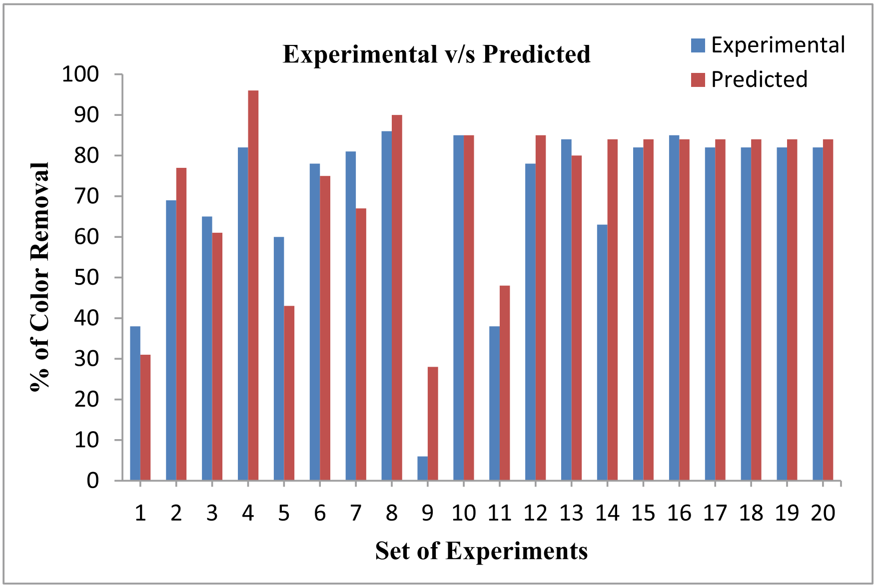

Fig. 10 Representation of color removal experimental versus predicted results in %

3.2.5 Electric Energy Consumption

In the present study electrodes are used as iron for treatment of dairy wastewater. The energy consumption calculated for optimum removal efficiency of COD for iron electrodes is calculated by using this Eq. 4.

$$\text{Electric energy consumption} = \frac{\text{Ivt}}{(X_0 - X_t)V} \tag{4}$$

where I is current (A), v is voltage, t is electrolysis duration (hour), X0 is initial COD concentration in mg/L, Xt is final COD concentration in mg/L and V is volume of the sample in the experiment.

The electric energy for iron electrodes was found to be 0.001103 kWh/kg COD.

4 Conclusion

The sample was analysed for different characteristics like pH, COD, BOD and turbidity etc., as per standard methods. Experiments were carried out with iron electrodes with monopolar parallel electrodes. The RSM software 7.1.6 was used to optimise the different operating parameters like pH, time and voltage. The maximum COD, turbidity and color removal from iron electrodes were 98%, 89%, and 86%

respectively. The experimental and predicted results show that there is a very good agreement between experimental optimum data and predicted data. The electric energy for iron electrodes was found to be 0.001103 kWh/kg COD. The above result shows that EC process was feasible for dairy wastewater.

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Selection of Landfill Leachate Treatment Methods According to the Age of Landfill Leachate

Anuj D. Bhatt, Ujjaval P. Sarvaiya, and Kunwar D. Yadav

Abstract Municipal Solid Waste (MSW) is a major issue in India. San-Pedro, L., Méndez-Novelo, R., Hernández-Núñez, E., Flota-Bañuelos, M., Medina, J., & Giacomán-Vallejos, G. (2020). Selection of the activated carbon type for the treatment of landfill leachate is achieved by the fenton-adsorption process. Molecules, 25(13). https://doi.org/10.3390/molecules25133023-21; a total of 160,038.9 TPD solid waste is generated in India, of which 29,427.2 TPD is landfilled. Leachate is commonly a high-strength wastewater generated from landfilling operations and its strength varies over its age in a specific landfill, where treatment technologies are classified according to the age of the landfill (i) Immature leachate (Landfill age is less than 5 years), and (ii) Mature leachate (Landfill age is more than 5 years). Immature leachate contains COD value of more than 10,000 mg/L and biodegradability index is more than 0.5, whereas mature leachate contains COD value of less than 10,000 mg/L and biodegradability index is less than 0.5. This paper provides a general overview of landfill operation, characteristics of landfill leachate, factors affecting the strength of leachate, and available leachate treatment methods and also reviewed the currently applied treatment methods together with different combinations of technologies considered regarding their COD removal efficiency. The objective of this paper is to select various combined alternative treatment methods according to their age in terms of cost-saving and increasing each unit's effectiveness. Treatment technologies are divided into 3 categories that are (i) Physico-chemical process, (ii) Biological process, and (iii) Advanced process. Among these treatment methods a combination of the Physico-chemical and biological process is suitable for immature leachate, whereas to treat mature leachate, an advanced process is required along with the combined Physico-chemical and biological process.

A. D. Bhatt (✉) · U. P. Sarvaiya
Environmental Engineering, Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat 395007, India
e-mail: P21en023@ced.svnit.ac.in

K. D. Yadav
Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat 395007, India

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_22

Keywords Landfill · Leachate characteristics · Leachate treatment · Physico-chemical process · Biological process · Advanced process

1 Introduction

Solid waste is generated in the country at a rate of 160,038.9 TPD, of which 152,749.5 TPD is collected at the efficiency of 95.4%, out of which 79,956.3 TPD is treated, and 29,427.2 TPD is disposed to the landfill. 50,655.4 TPD, or 31.7% of the total amount of waste generated, remains uncounted. Per capita, Solid waste generation in 2020–21 was a total of 119.07 gm/day which was 118.68, 132.78, 98.79, 121.54, and 119.26 gm/day in years 2015–16, 2016–17, 2017–18, 2018–19 and 2019–20 respectively. The maximum quantity of per capita solid waste is generated in Delhi followed by Lakshadweep and the lowest was in Assam followed by Meghalaya. In the year 2020–21, a total of 1924 landfill sites were identified, of which 305 have already been constructed, 126 are under construction, 341 are in operation, 17 are complete, and 11 have been capped. When there aren't enough scientifically designed landfills, trash is dumped at dumpsites. Based on information from SPCBs/PCCs, the country has 3184 dumpsites, among which 234 have already been reclaimed and 8 have been switched into landfills.

Leachates are defined as the liquid effluent, generally generated from moisture present in the waste, the degradation process and the amount of rainfall that percolates through the landfill. Leachate is commonly a high-strength wastewater with chemical oxygen demand (COD), biochemical oxygen demand (BOD), pH, heavy metals, dissolved organic matters (DOM), Total Kjeldahl nitrogen (TKN), inorganic salts, and toxicity. According to Adhikari and Khanal's [3] study, water leaves the landfill in the form of saturated vapour and through transpiration. The residue of the water is either kept by the wastes or converted into leachate. Landfill leachate contains highly complex constituents and it is extremely toxic in nature if the leachate percolates through the ground and meets the groundwater it causes several diseases. Figure 1 shows the modern sanitary landfill design together with its components (such as leachate and gas collection provisions, capping and liners).

2 Landfill Stabilization

The stabilization of the solid waste occurs in five consecutive and typical phases. The rate of decomposition and the creation of biogas defer from phase to phase, which shows the activity of microorganisms is diverse respectively to different phases in the landfill. According to Kjeldsen et al. [20], biodegradation of MSW-produced liquid and gases occurred in a landfill through five or additional sub-phases. It also is subject to the situations created inside the landfill, that is, physical, chemical, microbial and climatic conditions. Figure 2 shows the pathway of anaerobic degradation

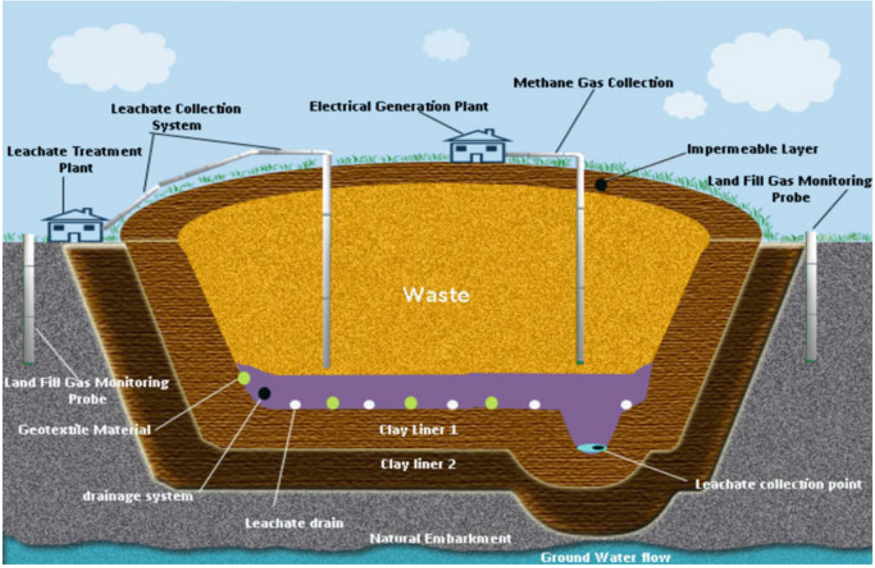

Fig. 1 Sanitary landfill design [6]

processes which occurred in landfill ecology after municipal solid waste is landfilled and displays the chronological phases of landfill stabilization [34]. The details of the waste degradation process for leachate and gas production studied by Tamru and Chakma [34], and Adhikari et al. [2], are as follows:

(a) Phase I: Initial adjustment phase

It is the time taken by microbes to adapt to new environmental conditions and food, as the landfill ecology develops sufficient moisture contents. Accumulation of moisture is important to trigger microbial activity; this is known by the initial lag time. In this stage, easily biodegradable organic fractions of MSW are aerobically decomposed by aerobic microbes with the help of available oxygen that was trapped in covered soil and solid waste porosity. This process produces CO_2, H_2O and partially decomposed organic matter through significant temperature rise. The leachate generated in this phase is mostly due to moisture content in waste, not by means of decomposition.

(b) Phase II: Transition phase

Aerobic decomposition finishes quickly and begins anaerobic breakdown because waste contains little oxygen. The heat generated by aerobic decomposition and a decrease in moisture content in waste favour the anaerobic environment. As the landfill ecosystem changes, nitrate and sulphate can serve as electron gainers in the reduction of oxygen, reducing nitrogen gas and hydrogen sulphate. The constant drop of reduction/oxidation values in the landfill environment would enhance anaerobic microbial activity to convert organic matter into carbon dioxide and methane gases. At the end of this phase, huge concentrations of COD, volatile organic acids (VOA),

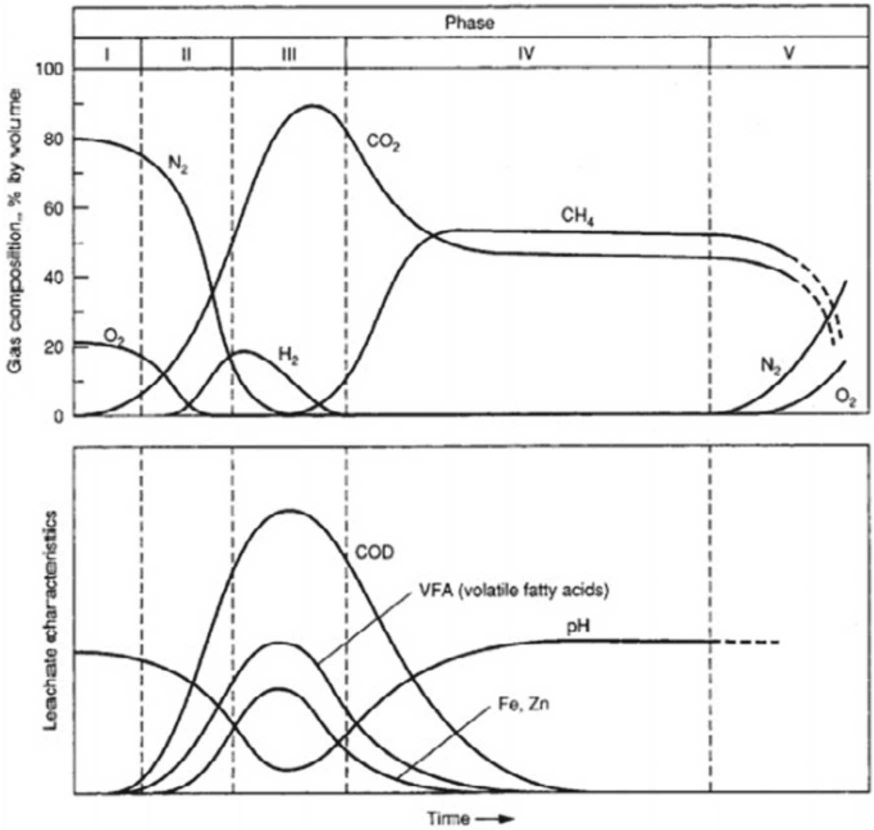

Fig. 2 Phases of landfill gas and leachate composition [34]

BOD and low pH values can be detected in the leachate. Moreover, during this time, the concentration of nitrogen gas drops significantly while the concentration of carbon dioxide gradually increases.

(c) Phase III: Acid phase

In this phase production of VOAs, hydrogen, ammonia and CO_2 are high due to hydrolysis and biodegradation of organic matter by microorganisms. The first stage of the acid formation phase is hydrolysis, which is the process of converting complex organic compounds such as lipids, proteins and nucleic acids into smaller elements. In the second phase, the molecular compounds of the hydrolysis processes are transformed into simpler molecular compounds and afterwards into acetic acid (CH_3COOH), fluvic acid, humic acid and other complex organic acids. The major leachate characteristics which are generated in this phase are BOD and COD which could further lower the pH values and resulted in increasing the values of heavy metals. Also, a vast quantity of hydrogen gas and a minor quantity of nitrogen gas are generated.

(d) Phase IV: Methane fermentation phase

In this phase, intermediate acids are used up by methanogens (methane-forming) microorganisms and converted into methane and carbon dioxide gases. The excessive consummation of organic acid in this stage increased the pH value to 6.8–8.0 and reduced BOD, COD and conductivity concentration. The other manifestation of this phase is that the heavy metals' concentration reduced and mobilized in the leachate because of complexation and precipitation caused by a higher pH value.

(e) Phase V: Maturation phase

In this phase, biodegradable elements are already diminished and more refractory compounds are remaining, the landfill gas production decreases significantly, and the leachate characteristics remain at a constant level. In the landfill leachate, some organic compounds do not decompose such as humic and fluvic acid and remain residue, pH levels increase and moreover, sulphate and nitrate could change into sulphides and ammonia. During this phase, heavy metals are progressively removed by precipitation.

3 Landfill Leachate

3.1 Characteristics

Due to the complicated solid waste deposited in landfills, leachate contains a variety of pollutants, which can be classified into dissolved organic matter (DOM), high chemical oxygen demand (COD), biochemical oxygen demand (BOD), heavy metals, chlorinated organic and inorganic salts, and ammonia, and its colour is dark in nature [10].

Adhikari et al. [2], described the factors affecting the composition of the MSW landfill leachate quantity. The age of a landfill as well as the processes that go on at that age have quite a lot to do with what leachate comprises. There are several other key factors that can influence the way MSW landfill leachate is generated. Some of the factors are say, waste composition, moisture content, depth of waste, available oxygen, temperature, waste processing, age of landfill, co-disposal with inclinator ash, and toxicity. Leachate characteristics can significantly be affected by shredding or baling of the waste. Leachate from shredded waste is very contaminated during the early stages of the stabilization process.

Organic waste contributes to leachate generation in most cases. Landfills of greater depth offer more contact times among the liquid and solid phases, which rise leachate strength. The temperature in the landfill sites is a typically uncontrollable factor and influences the leachate quality. Water percolation and moisture are one of the most significant factors influencing the stabilization of waste and leachate quality (Table 1).

Table 1 Landfill leachate characterization according to the age of landfill

Parameters	Young	Medium	Old
Age (years)	<5	5–10	>10
pH	6.5	6.5–7.5	>7.5
COD (mg/L)	>10,000	4000–10,000	<4000
BOD/COD	0.5–1.0	0.1–0.5	<0.1
TKN (mg/L)	1500–4500	400–800	75–300
Organic compound	80% VFA	VFA + 5–30% humic and fumic acid	Humic and fumic acid
Heavy metals	Low to medium	Low	Low

Source [3, 9, 26, 29, 30, 35]

High moisture availability can eliminate the majority of waste pollutants in the early phase. However, anaerobic microbial activity is an important factor which governs leachate strength under a low flow rate. Leachate from co-disposal sites contained higher COD, sulphide, and organic acids with low molecular weight such as acetic acid and formic acid. In addition, a higher amount of these acids can reduce the pH value and increase metal concentration in the leachate. However, sulphides tend to restrain metals because of the low solubility of most metal sulphides.

The above table is concluded as 2 types of landfill leachates are immature and mature landfill regarding the biodegradability of the leachate. The leachate reaches a peak after nearly two to three years afterwards a gradual decline in succeeding years. On the whole, leachate from new landfills will be high in BOD and COD and will then slowly decline. However, BOD/COD ratio decreases as the age of the landfill increases. Similarly, Total Kjeldahl Nitrogen (TKN) and ammonia decrease as time increases. Moreover, pH increases with time. It reflects the decrease in the concentration of the partially ionized free volatile fatty acids [2].

Kamaruddin et al. [19], studied heavy metal concentration in MSW landfill leachate and mentioned that decreases respectively to the age of the landfill. Generally, solubility decreases as pH increases moreover and with time humic substances are formed, that create strong complexes with heavy metals and transfer them into the environment. Heavy metal concentration is comparatively low in stabilized landfill leachate compared to other water quality parameters like TKN, BOD and COD. Hence, they are eventually less concerned with the design of leachate treatment.

3.2 Available Methods

Leachate is difficult to be treated to meet the discharge standards because of its inconstant structure and a high proportion of recalcitrant materials. Landfill leachate is generally treated using conservative treatment methods which are available for wastewater treatment. Conventional landfill leachate treatment methods are widely classified into three major groups that are (i) Physico-chemical processes such as adsorption, air stripping, ion exchange, chemical precipitation, Coagulation-flocculation, and flotation and many others (ii) Biological processes such as aerobic and anaerobic processes and (iii) Advanced processes such as advanced oxidation processes (AOP) and membrane filtration (Fig. 3).

Generally, the BOD/COD ratio of a mature leachate is below 0.5 which cannot be treated with the biological process stage so the removal of recalcitrant compounds is one of the main concerns in leachate treatment (Fig. 4).

Physico-chemical treatments (such as air stripping, Flotation, coagulation-flocculation, adsorption, ion exchange, etc.) work together or with biological processes. The biological process is more effective for the treatment of immature leachate in comparison to mature leachate because as shown in Table 2 it consists higher BOD/COD ratio and that characteristic is favourable for the secondary treatment process. However, advanced treatment is more favourable for mature leachate.

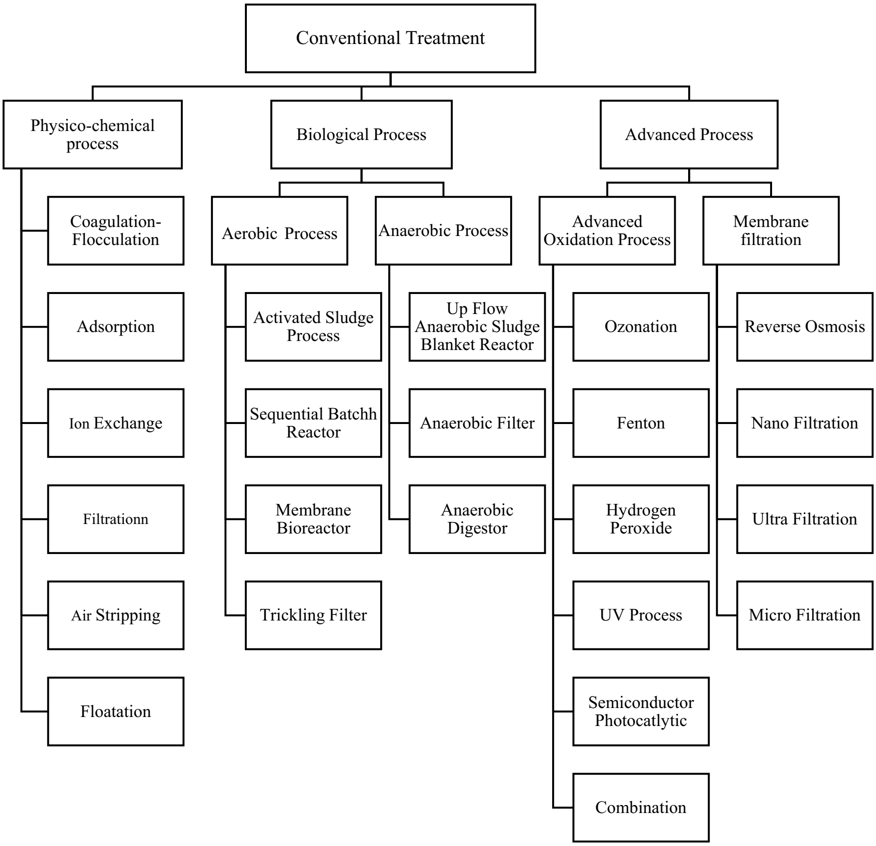

Fig. 3 Available treatment methods

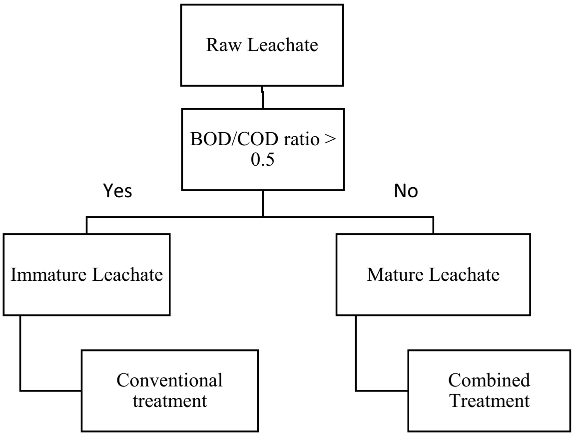

Fig. 4 Selection of the appropriate treatment according to the biodegradability of leachate

Table 2 Landfill leachate characterization according to the age and biodegradability index

Parameters	Immature	Mature
Age (years)	0–5	5–15
pH	6.0–7.0	7.0–8.5
COD (mg/L)	10,000–80,000	800–10,000
BOD/COD	0–0.5	0.5–1.0
TKN (mg/L)	1000–4500	75–1000
Organic compound	80% VFA	VFA + humic and fumic acid
Heavy metals	Low to medium	Low

The selection of a suitable treatment method for the treatment depends on the age and characteristics of the landfill leachate.

3.2.1 Physico-chemical Process

Coagulation-flocculation is a regularly accepted pre-treatment method to remove suspension particles (organic and/or inorganic) and colloidal particles or particles that remain discrete in the solution and cannot be removed by conventional physical treatment methods (such as sedimentation, and clarifiers). The idea behind coagulation and flocculation is that you can make particles in suspension less stable by adding coagulants and flocculants and reducing the repulsive forces amongst particles which is necessary for floc formation to happen and to avoid stable conditions. The destabilized particles form flocs with a bigger proportion, which are precipitated. Generally, alum, ferric chloride and PAC (poly-aluminium chloride) are used as coagulants [10, 15, 21].

In adsorption, contaminants are moved from a liquid to a solid surface. Pollutants are bound to the surface by adhesive force and deposited onto the porous surface. Organic pollutants are effectively absorbed by certain adsorbents because they are more selective than others in attracting substances to the surface. Normally, activated carbon is used as an adsorption material because it has a high ratio of surface area to volume, a microporous structure, and a reactive surface [19, 29, 33].

Ion exchange takes ions out of an aqueous solution by exchanging ions between the contaminants and the exchange medium. Without a permanent change in solid structure, ion exchange happens. Most ion exchange materials are resins made from synthetic organic materials with ionic functional groups. In ionic functional groups, transferrable ions are attached, which may be natural polymeric or inorganic materials [19].

Air stripping is a decent technique to reduce ammonia concentration in leachate. All forms of ammonia will transform into a gas that liquefies in wastewater when the pH reaches 11. By adding NaOH to the stripper to keep the pH around 11, dissolved NH_3 can be taken out of the wastewater. Air stripping follows a first-order reaction since the rate of mass transfer from the aqueous to gaseous phase depends on the initial value of ammonia. Additionally, it improves the removal of organic wastes. The water surface was the main place where ammonia was lost [11, 29].

3.2.2 Biological Process

The most efficient and cost-effective method of accomplishing the desired result is thought to be an Activated Sludge Process (ASP). ASP is a suspended growth process, containing three basic components. Microorganisms that treat the water are kept in suspension and aerated in a reactor. The reactor also has a liquid–solid separation unit, which is a secondary clarifier, and a recycling system that directs an essential number of solids removed back into the reactor. The idea behind activated sludge is that a group of microorganisms are constantly fed organic matter and oxygen in the reactor. Microbes eat organic matter and transformed it through a process called aerobic metabolism. Some of the organic matter is turned into new microbial biomass, and some of it is turned into carbon dioxide (CO_2), water (H_2O), and minerals. A portion of sludge to recycle with the incoming leachate is to ensure a proper F/M ratio [29, 36, 37].

The rotating biological contactor (RBC) is an attached growth technology. It is made up of round plastic discs that are mounted in the middle of a horizontal shaft. These discs are about 40% submerged in the reactor and are gently rotated by either a mechanical mechanism or by compressed air drive. Microbes available in the leachate are stuck to the disc and form a biofilm, which assimilates the organic content [37].

A sequential Batch Reactor (SBR) is a system based on a fill and draws mechanism. Unlike the traditional continuous flow, the reactor volume in the SBR technology changes over time. It is a process that all biological treatment phases, primary settling, aeration and biodegradation, secondary settling, extraction of treated leachate from the reactor without disturbing the settled sludge as well as nitrogen and phosphorous removal done in a single reactor [18, 19, 29].

The MBR (Membrane Bioreactor) system is fundamentally composed of two main portions: (1) the bioreactor, which is responsible for biodegradation and (2) the membrane component for the separation of biomass and treated water. An MBR is a conventional hybrid biological treatment system and liquid–solid separation using membrane filtration. MBR can be divided into two types: one with the membrane submerged and another with the membrane on the outside. MBRs have a lot of potential for treating leachate from landfills, especially mature leachate, which has a low BOD/COD ratio [17, 23].

The TF is an aerobic treatment system that utilises microorganisms attached to a medium to remove organic matter. The trickling filter starts up when the biofilm developed and got used to the leachates. Microorganisms that developed on the rocks, plastic, or wood filter medium consume the organic matter in the leachate and degrade the substrate. As for high COD and BOD leachate treatment Trickling filter may not be a feasible treatment but for High Ammoniacal Nitrogen removal TF may be a good solution. Due to the low cost of the filter media, biofilters are an interesting and attractive way to remove nitrogen [19, 30].

When high volumetric organic loading rate values are provided in UASBR (Up Flow Anaerobic Sludge Blanket Reactor), it has displayed higher performance efficiency compared to other kinds of anaerobic reactors. The process temperatures reported have generally been 20–35 °C for anaerobic treatment with UASB reactors. Generally, as per the literature process temperature should be in the range of 20–35 °C [30].

AF (Anaerobic Filter) is a biological reactor with a fixed bed and one or more filtration chambers that are linked together. As the leachate flows through the filter, particles get stuck and the active biomass attached to the surface of the filter material degrades organic matter. Usually, AF is run in the up-flow mode because it is not as much of a possibility that the fixed biomass will be washed out [23].

Anaerobic Digestor (AD) is a group of processes that microorganisms use to degrade organic materials when oxygen is absent. AD is often used as a source of renewable energy, and it produces biogas that contains methane, carbon dioxide, and a small portion of other gases. The treatment of landfill leachate by AD can be applied as single-stage and two-stage AD [23].

3.2.3 Advanced Process

Ozone can be used to treat landfill leachate well since it has a high oxidative power (that is $E^0 = 2.08$ V). Organic compounds changed their molecular structure through ozone, which also oxidises them to make them more biodegradable so that the biological treatment process can work efficiently. Ozone can oxidise supplementary compounds in 2 different ways: (i) by direct reacting with dissolved substances, or (ii) by indirect reaction, through hydroxyl radicals [14].

In the Fenton process, Fe(II) ions readily get oxidised into Fe(III) within a minute in the presence of excess hydrogen peroxide. This method proceeds through 4 steps: (i) pH adjustment, (ii) Oxidation process, (iii) Neutralization and coagulation, and (iv) Precipitation. The major problems with the Fenton process are the high cost of chemicals and the creation of an iron sludge, which is iron that has been oxidised [14, 31].

The UV process works by providing energy to chemical compounds in the form of radiation. Furthermore, the radiation is absorbed by the reactant molecules, which are then pushed into excited states and may start more reactions. In general, when compared to other AOPs, UV alone is not displayed as an effective treatment [16].

For these treatments, a semiconductor (such as TiO_2 or ZnO) is exposed to UV light with a wavelength shorter than 390 nm. When UV light has more energy than the band gap, it can cause photoexcitation, which moves an electron from the valence band to the conduction band. This leaves an empty spot at the edge of the valence band. That space will be able to turn a wide range of organic substrates into radical cations [16]. Combined processes of the above AOPs are widely accepted such as UV/Semiconductor photocatalytic, UV/H_2O_2, Ozone/ H_2O_2, Ozone/UV, Catalytic ozonation, Photo-Fenton, etc.

Reverse Osmosis (RO) is a process that involves anion removal by applying pressure to feed water, which passes through a semi-permeable membrane. It works on high pressure with dissolved solids at the rejection side. But two problems have been found that make it hard to use pressure-driven membrane processes, especially RO, to clean up leachate from landfills: membrane fouling, which requires a lot of pre-treatment or chemical cleaning of the membranes that cuts the life of the membranes and decelerates the process. Another problem is the generation of a lot of concentrates that are made [28, 30].

Nanofiltration is a pressure-driven membrane separation process. The semi-permeable separation layer lets only water and its parts with a molecular weight of less than 200 Da through. NF is a complex process that depends on micro hydrodynamic and interfacial activities taking place at the surface of the membrane and inside of the membrane's nanopores. NF technique provides a versatile method for controlling organic, inorganic, and microbial pollutants and the other satisfying water quality [19, 24, 30].

Size exclusion is the primary ultrafiltration (UF) removal mechanism. UF is a way to separate things using a membrane with pore size in the range of 0.01 and 0.1 m. It works to remove macromolecules and particles, but depends on the material that makes up the membrane. Although it cannot remove low molecular weight organic solutes and salts, UF can be used to remove the larger molecular weight components of leachate that tend to foul RO membranes [5, 19, 30].

MF is still interesting whenever a good way to remove colloids and suspended matter, such as before another membrane process (that is UF, NF, or RO) or in combination with chemical treatments with a pore size in the range of 0.05–10 μm. But it cannot be used separately on its own [30].

Table 3 Treatment efficiency of different methods

Method	Initial COD (mg/L)	Reduction (in %)
Coagulation-Flocculation	1200–8810	39–75
Adsorption	625–9500	38–90
ASP	2000–5000	46–92
SBR	2560–15,000	48–75
AD	800–66,660	20–95
UASBR	3000–64,000	58–98
AF	3750–14,000	60–95
O_3	330–14,600	2.5–80
O_3/H_2O_2	480–2000	28–97
O_3/UV	1280–26,000	47–63
H_2O_2/UV	760–26,000	22–96
H_2O_2/Fe^{2+}	1050–10,500	14–70
H_2O_2/Fe^{2+}/UV	440–1150	70–78
NF	500–2295	60–80
RO	200–3000	86–99

Source [14, 19, 23, 30]

3.3 Treatment Efficiency

See Table 3.

4 Propose Methods for Leachate Treatment

Based on the literature review and the efficacy of different technologies treatment methods are proposed according to the age of landfill leachate i.e., mature or immature. different flow diagrams for immature landfill leachate are discussed below.

4.1 Proposed Methods for Immature Leachate

For immature leachate the best feasible treatment option could be to divert that leachate to the already existing either STP (Sewage Treatment Plant) or CETP (Common Effluent Treatment Plant) because as landfill get older it will generate less quantity of leachate and characteristics will be altered often. Possible treatment methods as per efficiencies stated in different literature are proposed to get maximum output at the same time by minimizing the complexity. There are 3 alternatives are suggested based on global acceptance and simplicity.

Coagulation—flocculation with a primary clarifier is recommended to reduce total suspended and settleable solids, organic matter, and heavy metal concentration in the landfill leachate. Biological processes are provided to lessen organic matter, total solids and ammoniacal nitrogen load. If the ammonia load is on the higher side trickling filter is a feasible option, whereas if the solid concentration is in a greater quantity MBR is the most viable option. Moreover, many studies have shown MBR as the most worthwhile option for landfill leachate treatment. Air stripping is suggested for ammoniacal nitrogen elimination. Adsorption is recommended to overcome heavy metals, colour, remaining solids and organic matter problems, generally, ACF (Activated Carbon Filter) is used as an adsorbent. Floatation is suggested if the concentration of TSS is on the higher side. Whenever adsorption is used, it is recommended to use filtration as a pre-treatment to overcome the clogging problem. Filtration techniques should be selected depending on the quantity of the generated leachate if it's on the higher side MGF (Multi Grade Filter) is a better option and if on the lower side PSF (Pressure Sand Filtration) is a more feasible option (Fig. 5).

4.2 Proposed Methods for Mature Leachate

Diversion of mature leachate to the STP or CETP is not viable because it consists of a low biodegradability index that could affect secondary process efficiency. Based on the quantity and quality of generated leachate and considering treatment methods accessibility 3 alternatives are provided. As per many studies carried out for landfill leachate treatment by AOP, Fenton, Photo Fenton, O_3/H_2O_2, and O_3/UV give higher COD removal together with enhancing biodegradability index. Membrane filtration controls organic, inorganic, and microbial pollutants, but if membrane filtration is used a lot more chemical treatments are required to overcome the clogging problem and it will also generate concentrated leachate.

If the biodegradability index is between 0.1 and 0.5 and a high COD concentration, it is suggested to adopt an advanced oxidation process and for a biodegradability index, less than 0.1 membrane filtration process as advanced treatment is recommended. AOP is recommended to be implemented before the secondary process to enhance BOD/COD ratio and membrane filtration is suggested to adopt after the secondary process to reduce excess impurity load in an outlet. Adoption of the filtration technique is based on the total solid concentration if the concentration is on the lower side implementation of MF and NF in series and if on the higher side, UF and RO in series should be provided.

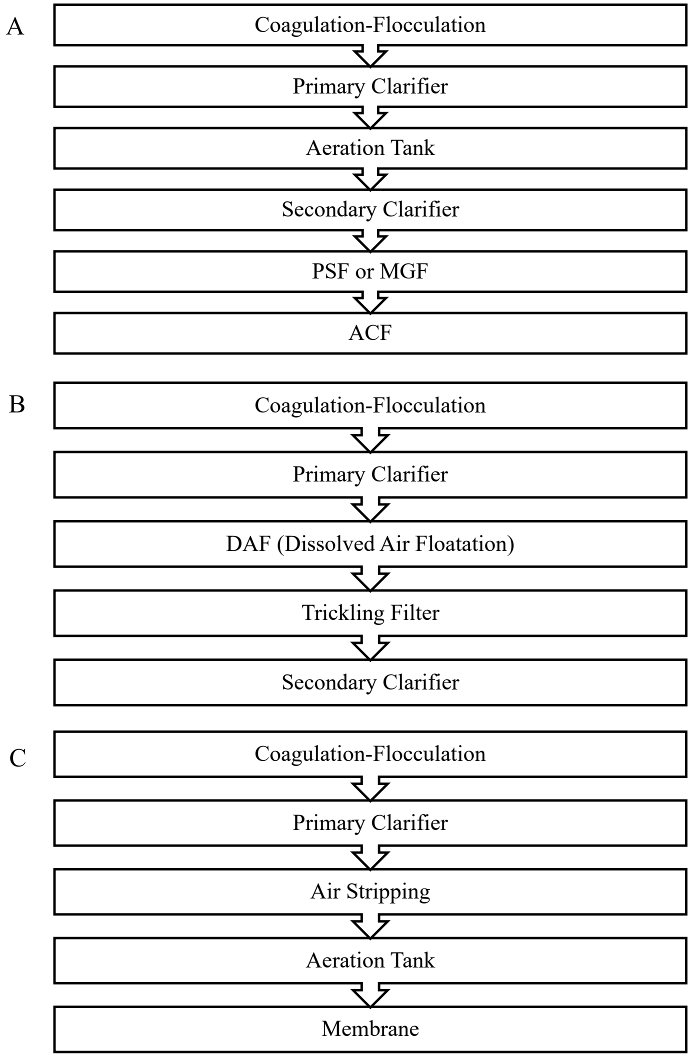

Fig. 5 Process flow diagram of immature landfill leachate treatment

Selection of AOP is based on the biodegradability index, economic feasibility, COD concentration after primary treatment and simplicity of the technique. As observed by many reviewers, the advanced oxidation process provides higher efficiency in acidic environmental conditions. When a treatment plant needs to be run simply and economically, the Fenton process is recommended, while O_3/H_2O_2 and H_2O_2/UV are suggested for implementation whenever deep mineralization is required and the production of sludge is a key concern (Fig. 6).

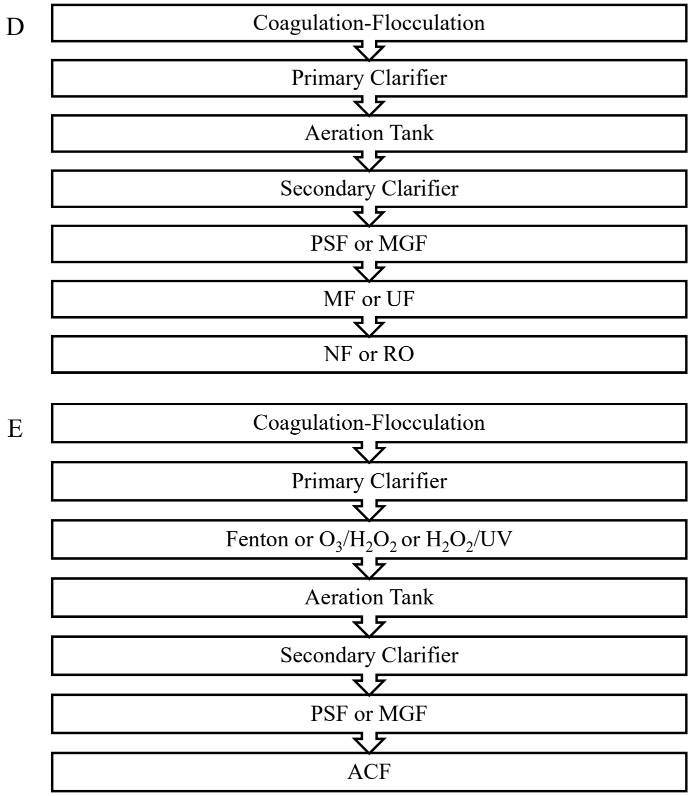

Fig. 6 Process flow diagram of mature landfill leachate treatment

4.3 *Cost Analysis of Proposed Treatment Methods*

Comparative cost analysis in a broader way is considered. Leachate treatment cost depends upon initial characteristics, the quantity of leachate, discharge standards, chemicals and media used, the selection of treatment methods and their volume and efficiency. ASP cost is lesser than MBR but higher than TF. DAF is costlier than sand filters and ACF whereas air stripping has an economical advantage. In advanced treatment, Fenton is a cheaper process whereas O_3/H_2O_2 and H_2O_2/UV are comparatively costly treatments [8, 22, 27, 32]. The capital cost of coagulation-flocculation with a primary clarifier, ASP, TF, and MBR is in the range of INR (Indian Rupee) per MLD (million litres per day) 0.08–0.2, 10–25, 10–20, and 20–45 million respectively. However, the capital cost of PSF, MGF, ACF, O_3/H_2O_2, UF and RO is in the range of INR per MLD 0.02–0.06, 0.05–0.08, 0.02–0.05, 1.0–3.0, 0.6–1.0, 0.8–2.0 million respectively [1, 4, 12, 13, 25].

5 Conclusion

Over the years, many sustainable ways to treat highly polluted leachate from landfilling operations have been suggested and implemented. Here are several important opinions from long discussions concerning how to treat leachate generated from landfill operation while obtaining the utmost efficiency of each treatment method.

Due to human activities and the age of landfill leachate refractory compounds change over time. Therefore, modification of treatment technologies is required at a different stage of generation to ensure treatment effectiveness is consistent. Leachate has been divided based on the biodegradability index into 2 categories as immature and mature leachate for simplicity in the selection of treatment methods. Immature leachate can be treated by conventional methods whereas additional attention is required for mature leachate generated from the landfill.

By considering key factors such as leachate characteristics, capital cost, simplicity, and global adaptability of treatment methods a systematic approach is suggested to select appropriate treatment technologies. Discharge standards may not be attained by either the biological process or Physico-chemical or advanced process alone. Thus, the combination of these treatments regarding their initial characteristics is recommended.

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Monitoring of Municipal Solid Waste Operations in Urban Areas: A Review

Ashwani Kumar, Yash Choudhary, Amit Kumar, Sudhir Kumar, and Nand Kumar

Abstract The urban solid waste management system is in a dismal state, especially in developing countries like India. These poor MSW management practices have a negative impact on public health, the environment, and climate change. Contemporary urban cities are embracing the concept of a "smart city," which uses information and communication technologies, Internet of things and machine learning to enhance the quality of solid waste management for sustainable development. These technologies can monitor the solid waste operations in real-time thus playing a crucial role in supervising municipal solid waste for an informed decision by an authority. This study to review the technological tools and software to monitor the solid waste operations in an urban area. The advanced technologies, including sensors, integrated development environments, and software platforms for data acquisition and processing being utilized in solid waste management, have been reviewed and deliberated upon. Lastly, the study discusses the challenge of implementing a monitoring system for cities in developing countries like India.

Keywords Municipal solid waste · Machine learning · Artificial intelligence · Internet of Things · Urban areas

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A. Kumar · Y. Choudhary · A. Kumar (✉) · S. Kumar
Department of Civil Engineering, Malaviya National Institute of Technology Jaipur, Jaipur, India
e-mail: amitrathi.ucf@gmail.com

A. Kumar
e-mail: ashwanikumardubey95@gmail.com

Y. Choudhary
e-mail: 2020pce5152@mnit.ac.in

S. Kumar
e-mail: skumar.ce@mnit.ac.in

N. Kumar
Department of Architecture and Planning, Malaviya National Institute of Technology Jaipur, Jaipur, India
e-mail: nkumar.arch@mnit.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_23

1 Introduction

Waste management involves all the steps necessary to handle waste from the point of generation to its final disposal. This includes waste collection, transportation, processing, and disposal. In our country, urban local bodies often allocate a significant portion i.e. up to 95% solely to waste collection [3]. Currently, the waste management system is largely manual, leading to a lack of accurate data on waste generation and collection and hence its processing and disposal.

For collection, the placement of trash bins, collection points, disposal sites, and recycling stations are often not well-planned. Waste collection is also not always based on demand, and drivers are responsible for determining the routes for waste collection. This can lead to inefficient collection, with some bins being emptied while others overflow. In addition, the resulting mismanaged waste can be more costly to re-collect and can pose an environmental threat. The inefficiency in complete coverage also leads to increase in litter generation [16, 39]. For transportation, there may by under-utilization of vehicles and their routing may need optimization. Moreover, if a driver misses a customer, then it may be difficult for the customer to lodge a formal complaint [23].

On the aspect of waste processing, the municipalities in India are lagging a lot [38]. Only 21% precent of the total waste gets processed in India [43]. Moreover, the efficiency of the processing facilities is either unknown or very low [19]. The quality of the products obtained from these processing plants is also not desirable in majority of the cases [50]. Despite these shortcomings with waste processing, still worse is the disposal aspect of the waste management in Indian municipalities. Only a few municipalities have engineered landfill facilities out of the total of thousands of cities/towns in India [11]. These facilities without an engineered measure are known as waste dumps and are causing several hazards for the living beings and the environment around them [17].

Recently advanced technologies like Internet of things, machine learning and GIS have become increasingly important in waste management (SWM) in order to acquire data, process it and infer the important conclusions from it [25]. Systems that do not utilize these technologies often face limitations in terms of collection monitoring, optimizing the route, and inefficiency of waste disposal systems. To address these issues, technologies such as radio frequency identification (RFID), geographic information systems (GIS), and global positioning systems (GPS) are used in a number of ways e.g. ensuring service at the consumer-end, remotely monitoring the waste transfer station and the collection vehicles [8, 25, 47]. For example, artificial intelligence can be used to automatically determine the level of a waste container. Additionally, genetic algorithms can be used to optimize the collection and transportation component of the solid waste in order to reduce the fuel consumption and pollution (air and noise). While many investigations focus on static data for routing optimization, it is important to also consider real-time data in order to address future challenges and develop solutions that anticipate potential issues. The monitoring

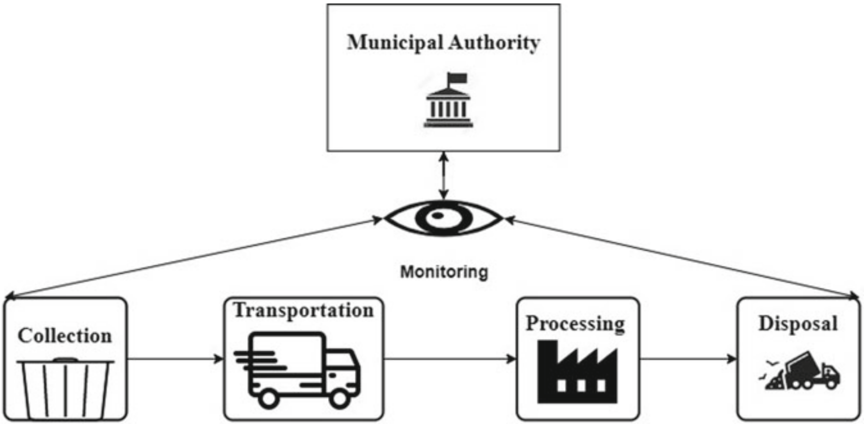

Fig. 1 Solid waste management system in an urban area

system also plays a crucial role in the supervision of municipal solid waste (MSW) [12, 14] (Fig. 1).

This study to review the monitoring of solid waste operations in an urban area. The advanced technologies including sensors, integrated development environments, software platforms for data acquisition and processing being utilized in solid waste management have been reviewed and deliberated upon.

2 Methodology of Review

In this section, the selection method for the literature utilized in the study has been explained. The literature was searched using a number of search terms e.g. "waste bin level detection" or "municipal waste management" or "garbage level detection" or "municipal solid waste management" or "waste collection" or "waste monitoring" or "trash bin level monitoring" or "bin level monitoring systems" or "smart bin" or "route optimization" or "IoT waste collection" or "machine learning waste processing"). The literature was mainly searched on online platforms e.g., Google scholar and sciencedirect.com. The inclusion criteria was the relevance of a study to monitoring of municipal waste operations in an urban area. The publications related to other kinds of specialized waste e.g. industrial waste were excluded.

3 Result and Discussion

This section describes the findings of the literature review regarding monitoring of solid waste operations. Figure 2 present the flow of information for monitoring of solid waste operations using advanced technology in monitoring.

3.1 Monitoring of Collection and Transportation

The management of waste collection involves significant financial resources and the coordination of complex logistics. The main problems of the existing solid waste collection process and management system are summarized as follows [4] (i) lack of the information about the collecting time and area whenever a waste collecting vehicle starts from its origin; (ii) lack of the proper system for monitoring of fill-levels of the trash bins to be emptied; (iii) Inability to track the collection vehicles and the waste collection in real time. It leads to wastage in time in responding to cases like truck accident, breakdown, and long-time idling. The residents also find it difficult to contact the concerned authorities if the collection vehicle missed their street.

These problems can be alleviated by employing smart technologies for the waste collection [3, 47, 54]. A number of smart technologies (Table 1) have been applied in the waste collection stage for various purposes such as to identify and locate waste

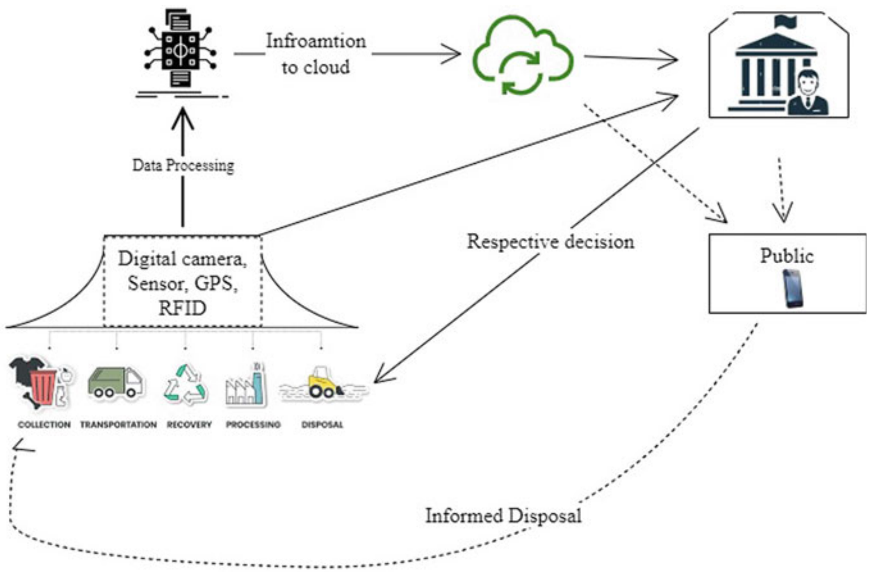

Fig. 2 Monitoring of solid waste management process using ICT and AIoTs technologies

Table 1 Technologies for waste collection

Function	Data collection	Data processing	References
Waste bin status alert	Ultrasonic sensor, GSM Module, RFID	Data processing & communication	Yahya et al. [59]
	Weight and proximity sensor	Rash berry PI with smart M-3 platform	Catania and Ventura [8]
	Metal sensor, IR sensor, RFID Tag, and ultrasonic sensor,	Arduino UNO controller	Padal et al. [42]
	Gas sensor; infrared (IR) sensor for level detection; a load cell to detect the weight,	LPWAN (Low Power Wide Area Network), a Web app, Raspberry Pi, LoRa gateway	Bharadwaj et al. [5]
Collection and waste around bin monitoring	RFID, GPS, and Camera	GPRS/GSM	Arebey et al. [4]
Segregated collection	Camera with ultrasonic sensor	MATLAB, Arduino UNO controller	Vicentini et al. [53]

objects at their source allowing for initial source separation through the use of robotic systems or helping citizens to sort their household waste [35, 44] (Fig. 3). Mittal et al. [35] developed an app 'SpotGarbage' to assist in solid waste management. The SpotGarbage app utilizes computer vision to automatically identify and locate garbage in real-world images. Singh and Chaudhary [48] designed a system that collects information on uncollected roadside garbage from the public and uses computer vision to verify the accuracy of the submitted information. The real-time monitoring of door-to-door collection has helped various municipalities in India to be more accountable, transparent, and efficient in their waste collection process [36]. For the waste collection process, while Surat utilizes RFID and GPS, Vapi has employed the concept of digital code/number in their municipality [36].

Researchers have been exploring the use of "smart bins" equipped with Computer Vision (CV) to detect the amount of trash (e.g., empty, partially full, or full) and notify municipal departments for waste collection [1, 26, 45] (Table 1). Moreover, the work on the smart bin has been extended to automatic segregation of the disposed waste in the bin [27].

This approach also involves using the smart-M3 Platform, which integrates communication technologies such as RFID, GPS, GPRS, and GIS with a camera to create a solid waste monitoring system [4, 8]. An Internet of Things (IoT) based solution was developed to address the solid waste management crisis in Bengaluru, India, by studying the existing system and designing a protocol stack to improve its reliability and efficiency. The idea behind this approach is data collection and processing related to the movement and location of each vehicle, and the fill-level of waste bins to decide the bins to be emptied. At the same time, a number of parameters

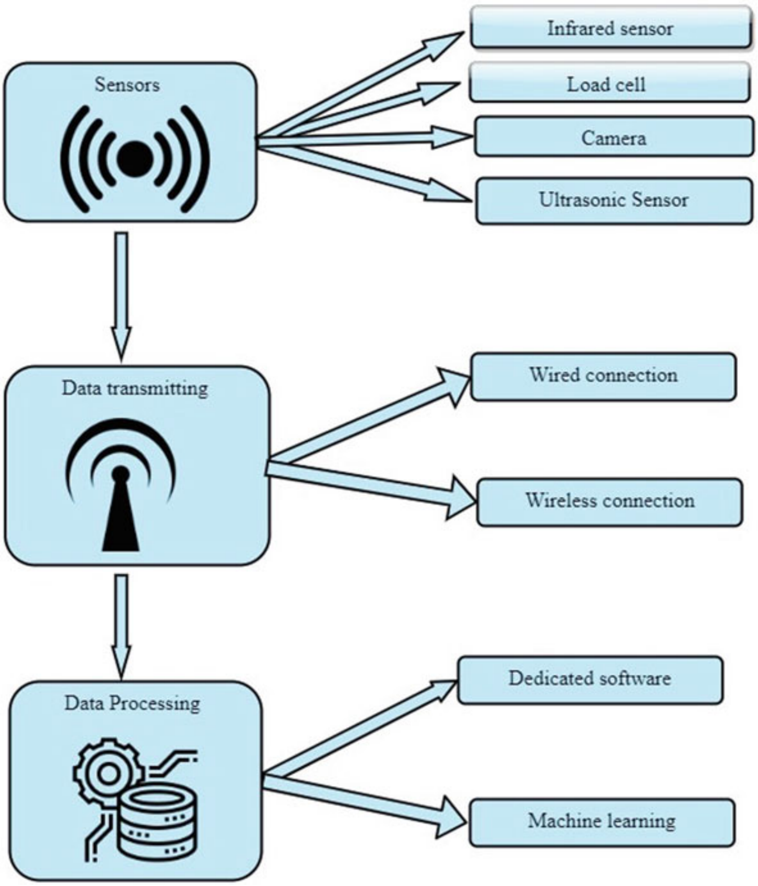

Fig. 3 Working flow diagram of collection and transportation

may be optimized e.g., total distance travelled, the number of vehicles needed, and environmental impact of the solid waste management.

It is very important to know the fill-level of waste bins in advance to better plan the waste collection from [59]. This system aims to improve the management of collection services for both the managers and citizens. By providing real-time information on the status of trash bins, the system can facilitate efficient schedule management and allow for better route planning for collection trucks, which are typically deployed randomly. Additionally, a signal/message can be sent to alert the concerned authorities about the bin being full and ready for collection. The message generally includes the bin ID, bin status, the time and its location.

The another study employs the Internet of Things (IoT) for the operation of a smart bin to detect and reports the level of solid waste to the municipal authorities for further action [57]. The system consists of several components (Fig. 3) [4, 57]: (i) hardware requirements may include a smart Bin equipped with sensors (level, weight and ultrasonic sensors or a camera; (ii) GSM module to enable communicating using internet with a server; (iii) A database with information related to all the residents and the waste bins including their location and routing information; (iv) An integrated development environment for image processing [4].

Waste transportation is a significant component of MSW collection [19]. Several researchers have applied operational research techniques to optimize the transportation route and other factors in solid waste management systems (Table 2) [2, 7, 22]. The objective of the routing model is to minimize the number of vehicles per fleet, the travel time, and the total distance required for complete coverage. At the same time, geographic information systems (GIS) can be very useful for routing and transportation modelling.

GIS allows you to store, analyze, and visualize spatial data, which can be very useful for routing and transportation analysis [2, 28, 41, 56]. GIS can be employed to create maps of a study area showing the locations of roads, intersections, and other important features, and then use these maps to help you analyze and visualize different routing scenarios. GIS can also be used to overlay other types of data on top of the spatial data, such as population data, land use data, or traffic data. This can be useful for understanding the context in which a transportation system operates and for identifying factors that may affect routing and transportation patterns. In addition, GIS can be used to create interactive maps that allow users to explore different routing scenarios and visualize the results in a visual and intuitive way. This can be very useful for communicating results to decision makers and stakeholders, and for helping to identify the most effective routing strategies for a given area.

Table 2 Monitoring of transportation of solid waste

Function	Data collection	Data processing	References
Route optimization of transport	Waste collection data, GIS, GPS	Prediction and optimization algorithms (Such as correlation analysis, support vector regression, particle swarm optimization)	Ahmad et al. [2]
Satellite vehicle tracking	GIS location tracking	GSM, G-Target CLI, G-Target SVR, ArcGIS software	Jovičić et al. [28]
Routing and scheduling	GPS	GIS-based decision support system	Fan et al. [22]
Optimization of waste collection for billing purpose	RFID reader with GPS receiver in vehicles, tag in trash bins	Decision Support System framework based on Constrain Logic Programming	Nielsen et al. [41]
Estimating waste transfer station delays	On-board GPS receiver to collect spatial data of vehicles	Geographic Information System (GIS) with geofence,, GPRS module and geofences MINTAB statistical software	Wilson and Vincent [56]

The route optimized with simple optimization may use a number of parameters for analysis such as total predicted waste amount for a grid; truck current location; truck current capacity remaining; truck total capacity; truck nearest bins; total waste collected; frequency of bins collected and other parameter [2]. Ahmad et al. [2] used these above-mentioned data to minimize the distance travelled by the vehicle. Optimal route index is defined as the maximum waste collection for minimum distance by the vehicle as shown in Fig. 4.

The savings in route optimization may also lead to fuel savings and ultimately to environmental benefits. For this purpose, a system for vehicle tracking "G-target AVL" by satellite was utilized [28, 41]. The system consists of G-Target device installed in the vehicle, server's software G-Target SRV communicating between G-Target device and user's computer. The system allows the user to remotely collect information about vehicle movement at the city map [28, 41].

The delays for vehicles at transfer stations can also be studied in transportation. A study by [56] found that the arrival times of trucks at a waste transfer station can be accurately predicted using a normal probability distribution based on GPS data and the transfer station database. The study indicated that the collection models based on normal distribution of arrival times can be used with confidence. The study also

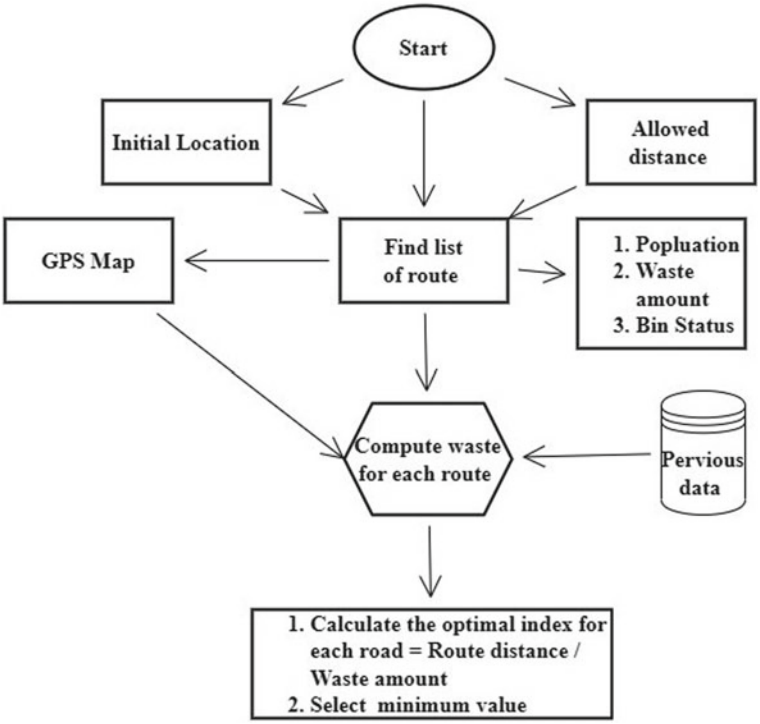

Fig. 4 Route optimization in SWM transportation

inferred that there were also significant differences in the length and location of the lines at different facilities e.g., at one facility the longest waiting period was at the weighing scale, whereas the trucks were not able to easily access the tipping floor at the other facility. Furthermore, [41] proposed to use RFID technology for validation purposes. This ensures that the right (potentially dangerous) waste is collected and a correct statement of cost is billed to an individual customer [41].

3.2 Monitoring of Treatment and Disposal

After the collection and transportation, comes the treatment and disposal of the municipal solid waste. The quantities generated for municipal solid waste in urban area are huge. Moreover, the waste consisting of several different components e.g. food wastes, leaves and wooden logs, paper, plastic, metal, glass, etc. needs to be segregated for efficient waste management [46]. As source segregation is not practiced generally in developing countries, the collected mixed waste need to be processed for separation into different components. Moreover segregation is being practiced in a number of waste processing facilities across the world, its effective monitoring is not being done [14, 24]. The continuous monitoring and collection of data is also required to be in order to make the required adjustments and assessing the performance of processing facility [29, 40].

Waste segregation is done either mechanically or manually in solid waste processing facilities [34]. As manual segregation involves being in contact with waste for segregation [34], researchers worldwide have been actively exploring automated sorting techniques [24]. Actually, the fraction of studies involving utilization of robotics is much higher in case of automated waste sorting as compared to that in waste collection.

A computer vision-based waste classification system in waste sorting facilities typically and includes both hardware and software components [31]. The hardware component usually consists of a low-cost camera, which acts as the “eyes” of the system by capturing images of the waste objects. The software component consists of a series of computer algorithms that serve as the system’s “brain” by analyzing the images and identifying the types of waste based on certain characteristics. Together, the hardware and software enable the system to automatically sort the waste into different categories for appropriate processing or recycling. Waste classification has been attempted by many studies using AIoTs technology given in Table 3 [31] for example, classification of waste stream into bio-degradable and non-biodegradables components [46]; or into general waste, compostable waste, recyclable waste and hazardous waste [51]; or into paper, plastics, wood and metals by [51].

A machine learning model has the following three steps for automated waste classification (as shown in Fig. 5): (i) Forming the dataset (i.e., data collection, annotating data set, feature extraction); (ii) training the model on dataset collected and; (iii) and validating the model [58]. The convolutional neural network (CNN) is a state-of-the-art algorithm that is the backbone of a broad spectrum of image

Table 3 Monitoring of treatment of solid waste management

Function	Data acquisition	Processing technique	References
Waste profiling	Digital camera	Machine learning with inception v3 based on CNN algorithm	Shaikh et al. [46]
Solid waste sorting	Digital camera	Erdas Imagine v9.3 (ERDAS IMAGINE is specially designed to extract information from images;)	Wagland et al. [55]
Classify waste types	Digital camera	Machine learning using CNN architecture (VGG-16, ResNet-50, DenseNet-121)	Srinilta and Kanharattanachai[51]
Waste segregation	Inductive and capacitive proximity, moisture sensor	ATmega328 micro-controller, Wi-Fi with ThingSpeak IoT based platform	Mapari et al. [34]
Waste sorting for solid recovered fuels	Optical belt scale (laser triangulation), Weighing belt scale,	Statistical analysis	Curtis and Sarc [14]
Street waste classification	Digital camera	YOLOv3 a CNN based machine learning model	Cui et al. [13]
Monitoring of composting	Quartz crystal microbalances (QCM)	MATLAB software	Dickert et al. [18]
	Resistive temperature detector (RTD) and capacitive sensor	computer system board (ALIX 3d3) with an AMD LX800 processor	Casas et al. [6]
	Capacitive and thermocouple sensor	Arduino IDE development platform and the Weka software	Moncks et al. [37]
Thermal waste treatment	Distributed control system (DCS)	A serve model based on energy balanced method	Trojan et al. [52]

classification related tasks [31, 46]. Model training is done with training environment or machine [46]. Table 3 has few examples of waste classification using the machine learning model.

Most of the studies tend to oversimplify the waste recognition problem e.g. assuming waste objects dataset consisting of objects from plain and well-control background [31]. Although authors in [13] used real time image for waste classification but only three categories i.e., domestic, decoration, and large waste. Another

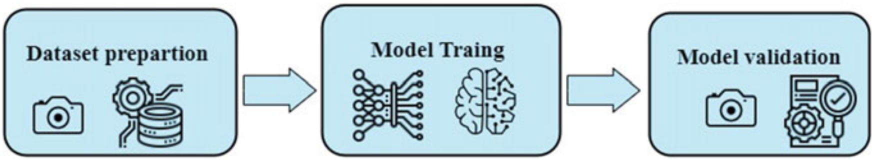

Fig. 5 Process flow of waste classification using machine learning

weakness is the inability of the camera to sense materials' physiochemical properties [31]. As a solution, data from different types of sensors e.g. camera, weight meters, near-infrared spectroscopy (NIR) and inductive sensor, can be analysed together to take advantage of the capabilities of other sensors [31, 34].

The treatment of biodegradable fraction of waste is a complex task in itself requiring continuous monitoring. Some of the major factors influencing biodegradation are moisture content, oxygen concentration and fermentation temperature. These parameters can be carefully monitored and adjusted using sensors [9, 10, 60]. Casas et al. [6] studied a composting process by wireless monitoring of temperature and moisture with the sensor, transceiver and microcontroller.

The utilities of these sensors can be highly improved by making use of machine learning for processing the data collected from these sensors [37]. Moncks et al. [37] used capacitive and thermocouple sensor along with Arduino IDE development platform to collect and analyse the data for initial training of the machine learning model. Thermal waste treatment can also be monitored by measuring mass flow rates, temperature, and pressure in the facility and analysing it using computer-based mathematical models [52] (Table 4).

Disposal is the final step of solid waste management. In developing countries, vast quantities of the solid waste are being disposed in open dumpsites [11, 17, 30]. Various technologies can be used to monitor illegal activities like dumping in open dumpsites and, performance of an engineered landfill during waste disposal (Table 4).

Big data is increasingly advocated as a powerful instrument for identifying the cases of illegal solid waste dumping site [30]. For predicting the illegal dumping activities, the authors first collected the data of red-flag indicators by field survey to develop an analytical model. Finally, the model is trained, calibrated, and evaluated before application to the big data set to identify illegal dumping cases from the database [30].

On the other hand, sensors can also be used for various parameters responsible for determining the performance of an engineered landfill e.g. monitoring of various emissions like greenhouse gas and leachate [32]. A number of studies have employed sensors for measuring gaseous emissions, pH, electrical conductivity and moisture content and temperature in the landfill [21, 32]. The data collected from the sensor were sent to cloud based IoTs using Arduino to send SMS alert to authorities in case a parameter exceeded the threshold [32]. Some studies have recently pioneered the use of remote sensing technologies for monitoring the emissions of landfill gas or its individual components [33, 49].

Table 4 Monitoring of disposal of solid waste management

Function	Acquisition technology	Processing technique	References
Identify illegal construction waste dumping	Field survey	Big data analytics by developing illegal dumping filter (IDF) MySQL	Lu [30]
Parameter monitoring	Gas sensors; pH sensor; Electrical conductivity sensor	Arduino Uno with an IoTs platform	Mabunga and Magwili [32]
Methane concentration mapping	Hex copter UAV with a laser-based methane detector, GPS	GIS software, MATLAB code, T-distribution	Emran et al. [21]
Environmental impact of solid waste dumpsites	Remotely sensed Landsat satellites	Land Surface type, Temperature, Soil Adjusted Vegetation Indices	Ekeu-wei et al. [20]
Monitoring of methane emission from landfill site	Remote sensing (AVIRIS-NG)	Web based methane source finder (MSF)	Cusworth et al. [15]

4 Conclusion

The management of municipal solid waste in urban areas have a number of problems associated with it. This study reviews various publications from literature employing advanced technologies for data acquisition and analysis for collection, transportation, treatment and disposal of the municipal solid waste.

For collection and transportation, the main thrust is on complete coverage of establishments, remotely observing the fill-level of waste bins and route optimization by using various sensors for data collection and analysing the data using software like GIS or IDE involving machine learning. For treatment and disposal of the waste, these advanced technologies are being used to automatically segregate the waste, monitor the performances of various process including an engineered landfill and identifying the malpractices such as illegal open dumping of the waste. These technologies and system make a promising case for their deployment in the solid waste management but need more research studies before acceptance by all the municipalities (large, medium or small).

However, they also suffer from a number of challenges which hamper their wider acceptance in the solid waste management system. The first and foremost challenge is the lack of studies involving field testing of these systems over long-term periods. This may answer doubts regarding their efficacy over long-term including the productive life and the maintenance involved. Yet another challenge is their reliance on expensive network structures, such as the GSM and GPRS technology. Wireless sensor networks (WSNs) may be alternatively helpful, but, have their own shortcomings such as the need for energy supply to sensor nodes and the potential for signal attenuation when crossing high-rise buildings. One limitation of many existing waste management systems is their inability to provide real-time status information to operators. While some systems may be able to provide semi-real-time data with certain delays, there is a need for systems that can provide real-time information to facilitate proper planning of waste collection schedules or routes.

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Red Mud—Its Properties and Application in Geotechnical Engineering

Yogesh Kapri and Ashwani Jain

Abstract Extensive research studies are carried around the globe in order to explore the engineering properties and effective utilization of Industrial waste in an adequate way. This is done for conservation of naturally available resources and prevention of waste formation which otherwise becomes inevitable. Red Mud which is often referred to as Bauxite Residue is the waste produced during aluminium extraction from the ore of bauxite. While World's production of bauxite residue stands somewhere near to 150 million tons/annum, India itself produces 9 million tons annually. Limited studies have been carried around to understand the Engineering properties of this waste and challenges associated with its potential use in the field of Geotechnical Engineering. One of the major hurdles in the disposal and effective utilization of Red Mud is its high alkalinity with pH range 10.5–13.5. This study also helps us to find a solution for the problem of disposal of Red Mud which is also considered hazardous. Overall this review shows effective use of Red mud in the area of geotechnical engineering.

Keywords Red mud · Bauxite residue · Alkalinity

1 Introduction

In year 2021 India's Alumina production stand alone is at 6.97 million metric tons making it one of the top producers in the world. Every year with the increase in demand of Alumina the production too increases. With every single ton of alumina production, we have 1–1.5 tons of waste generated during the process. This waste is referred to as the residue of bauxite commonly referred to as Red Mud. Red Mud is produced while extracting the alumina from bauxite ore in the Bayer's process. It is a

Y. Kapri (✉) · A. Jain
Department of Civil Engineering, National Institute of Technology, Kurukshetra, 136119, India
e-mail: yashkaprilives@gmail.com

A. Jain
e-mail: ashwani.jain@nitkkr.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_24

highly alkaline waste with the value of pH in the range of 10.5–13 [1, 2]. Bauxite ore is either digested by the Bayer's Process or with the help of the Sintering Process, where nearly 95% of the plants prefer using the Bayer's Process for the extraction of alumina and the rest 5% either uses the Sintering Process or both the processes in combination [3, 4]. One of the major issues is stockpiling of this waste which is a serious threat to the nearby surroundings. Some of tragic incidents include the Alumina Plant situated in Hungary where one of the disposal area collapsed followed by Collapse in the Xiangjiang Wanji Aluminium Plant which negatively impacted the nearby areas significantly. Other possible negative impacts include contamination of plants, causticity of native soil and release of Potentially Toxic Elements PTEs. However with continuous efforts to understand the details about the properties of the material, innovative ideas to transform waste into a potential substitute for use in the field of engineering can solve the problem of its disposal and can lead to effective utilization of this waste in a sustainable and environmental friendly manner.

2 Objective of Review

The Prime objective of doing this study is to Gain knowledge in details about the Physical, Chemical and Mineralogical attributes of Red Mud and discover its areas of application in the Field of Geotechnical Engineering. In addition to that various geotechnical properties of Red Mud were assessed which can be beneficial for use in the field of Engineering. Various parameters of Red Mud of different origins of our country like specific gravity, particle size distribution, chemical composition, morphological characteristics and pH are discussed in details and reviewed to get the thorough understanding of the material based on which its utility in the field of Geotechnical engineering is analysed. Subsequently challenges associated with it hindering in its utilization as a potential industrial waste were studied and remedies to those challenges were studied. Overall this study helps in better understanding of Red Mud, its properties and Pro and Cons associated with its uses in the field of Geotechnical Engineering.

3 Material and Its Characteristics

3.1 Specific Gravity

Red Mud has higher value of specific gravity when compared to natural soils varying from 2.6 to 3.7. As per the study it was observed that this variation in the value is generally due to change in the origin of the investigated red mud. Higher values are generally due to the existence of iron rich phases [5–7]. Table 1 consists of various values of specific gravity of red mud of our country as suggested by various authors.

Table 1 Specific gravity of samples for various refineries across country

Location of refinery	Specific gravity
Damanjodi, Odisha	2.85–3.45
Renukoot, Uttar Pradesh	2.85–2.97
Muri, Jharkhand	

Table 2 % fraction of particles for various refineries across country

% Fraction	Nalco, Damanjodi	Hindalco, Renukoot	Hindalco, Muri
Gravel	0	0	0
Sand	5–15	10–14	17
Silt	43–76	43–57	51
Clay	22–35	29–39	32
USCS	ML	MI	MI

3.2 Particle Size Distribution

For any material one of the prominent properties which governs its complete behaviour inherently is Particle Size Distribution. This helps us to recognize the various percentage fraction of particular sizes and also helps us to find the specific size fraction present in majority. There is a broad variation observed in size as well as in the range of particles that varies from coarse sandy grains down to even less than a micron level depending upon the process of extracting alumina, alumina plants and bauxites used. From the table it can be said that large fractions are of silt and clay and more than 90 % of fractions passes the 75 micron sieve [2, 5, 7–11] (Table 2).

3.3 Chemical Composition

Thorough study of chemical composition of the bauxite residue is essential to determine its unique effect on different properties, which can subsequently help in discovering new areas of application. This can also help us to identify potential additive which can be used to stabilize red mud and is environmental friendly too. As per Evan [12] the chemical compositions of the red mud commonly reported are Iron Oxide (5–60% by weight), Silicon Dioxide (3-50% by weight), Aluminium Oxide (5–30% by weight), Titanium Dioxide (<15% by weight), Calcium Oxide (<14% by weight) and Sodium Oxide (<10% by weight) [12]. From various literature reviews it is stated that major constituents of Red Mud produced by various alumina refineries are Fe_2O_3, Al_2O_3, SiO_2 and CaO. In addition to these major constituents some minor components present are Na_2O, TiO_2 etc.

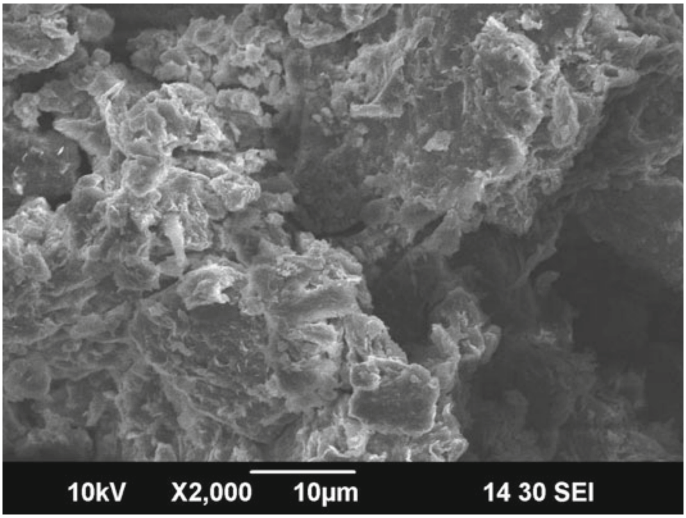

Fig. 1 SEM image of black cotton soil

3.4 Morphological Characteristics

These Characteristics helps us in identifying features like topography of surface, shape, size of the particle and their respective variations. These characteristics can be derived from Energy Dispersive X- ray Spectroscopy (EDS) and by the analysis of images from Scanning electron Microscope (SEM) [13]. These characteristics are effective in determining the efficiency and to discover the compatibility of the stabilising additive. Furthermore morphological studies can be used to study the aggregation and interlocking of the particles before and after addition of the stabilising agent [13]. The consequences which morphology had on the critical internal friction angle of Red Mud particles were studied by Jerves et al. [14] where he concluded that its value decreases when the angularity of the particle increases. SEM images of Red Mud from NALCO, Damanjodi, Koraput are shown in Fig. 2 depicting their morphological features. From the pictures it can be seen that Red Mud comprises of particles of different shapes that is from rounded to angular and from elongated to spherical. The study by Das et al. reported the irregularity of shapes and variation in sizes (Fig. 1).

3.5 pH

pH denotes the Potential of hydrogen which is a scale to measure the acidity and basicity of the material. From various studies it is observed that pH of Red Mud is generally higher than other waste materials like fly ash whose pH is around 5.5

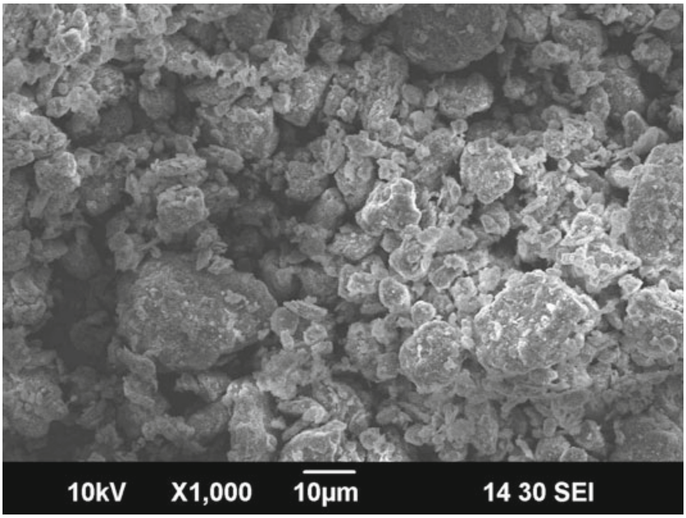

Fig. 2 SEM image of red mud

Table 3 pH for various refineries across the country

Property	Nalco, Damanjodi	Hindalco, Renukoot	Hindalco, Muri
pH	10.7–11.5	10.2–11	

but on the other side it is comparable to steel slag whose pH lies in the range of 10.6–12.9 [15]. High alkalinity is generally due to the fact because residue are not washed properly after digestion with caustic soda (NaOH), therefore particles of Na_2CO_3 and $NaAL(OH_4)$ remain there in liquid form or on the surface of Red Mud prior to discarding. Higher alkalinity can hinder the chemical reaction of particles when mixed with stabilisers or can affect the mobility of elements, thus it becomes essential to reduce the alkalinity levels of Red Mud. Optimum level of pH 8 was suggested by Babu [16] in order to obtain elemental equilibrium and reducing the harmful impact on the environment. Various studies have shown that pH of Red Mud can be lower by using CO_2 as an additive [17], gypsum [18–20], fly ash [21], cow dung [22] etc. (Table 3).

3.6 Potentially Toxic Element

Environmentalist have shown that concerns regarding the utilization of Red mud is due to the possible leachability of PTE's like Ni, Cu, Ba, Zn etc into the environment. These elements are present in different concentrations which depend on factors such as chemical composition of Bauxite ore, method of extraction etc. The studies related to leaching of PTEs from Red Mud with variation of pH are limited [23]. During the studies it was found that most of the PTEs concentration were found in permissible limits as per the standard of USEPA, with just few exceeding limits. Thus, Red Mud can be considered as a non-hazardous material without impact on the environment [23–27].

4 Review on Geotechnical Properties

The sector of Geotechnical Engineering is one of the most prominent sector where Red Mud can be used efficiently as an industrial waste material. Red Mud possess almost same physical as well as mechanical properties as that of Clay and some type of the sandy soils [28]. Therefore it becomes necessary to do detailed analyses of geotechnical properties of Red Mud in order to discover new application areas.

4.1 Consistency Limits

The study of various literature shows that Red Mud can exhibit plasticity behaviour where most of the studies classify Red Mud as inorganic silts of low to high plasticity type material that is ML or MH. The values of Liquid limit and Plastic limit vary from the range of 38–64% and 5–22% respectively which generally depends upon the location and origin of the Red Mud, grade of bauxite Ore, its mineral and chemical compositions and production technique. Villar et al [29] also suggested the influence of the grade of the bauxite ore and extraction process on consistency limits of Red Mud originated from Brazilian rain forest (Table 4).

4.2 Linear and Volumetric Shrinkage

Shrinkage characteristics are influenced by parameters like percent fraction present in the material, mineralogy of the particle, and the different types of the exchangeable cations present in the material. Significant shrinkage is observed in minerals where the concentration of Na+ ions is considerably low, particles having finer sizes and

Table 4 Consistency limit for various refineries across the country

Consistency Limit	Nalco, Damanjodi	Hindalco, Renukoot	Hindalco, Muri
Liquid Limit	21–45	40–45	39.89
Plastic Limit	16–36	30–35	36.08
Plasticity Index	5–7	5–14	3.81

minerals have low crystalline degree [9]. Furthermore various papers has suggested lower values of linear shrinkage (<6%) and Volumetric Shrinkage (<2%) in case of Red Mud which contains significant amount of Na+ ions and finer particles is present in quantity more than 90 percent [9, 30–32]. The prominent reason behind this lower shrinkage values can be due to the low plasticity characteristics and low degree of crystalline minerals [31, 33]. Red Mud falls in the category of non-critical (low degree of expansiveness) due to significantly low shrinkage values [34]. Compressibility is an essential property to classify Red Mud as ML (Silt with Low Plasticity), even though it possesses similar behaviour as of CH soils [35]. Based on various studies it is observed that its compression index varies from 0.202 to 0.56 [8, 28, 35, 36]. It possesses lower values of compressibility in addition to that for similar values of plasticity index between Natural Clay and Red Mud, where Red Mud shows lower compression index. Therefore Lower Compressibility makes Red Mud a suitable substitute to Natural soil.

4.3 Shear Strength

Various studies has suggested that Red Mud yields good compressive strength despite of its high alkalinity [37, 38] and strength behaviour is comparable to clayey or sandy soils [6].

Red Mud consists of fine fractions in significant quantity, which tends to adsorb water subsequently leading to poor contacts between grains thus reducing the resistance against applied stresses. Untreated Red Mud has Unconfined Compressive Strength varying from 150 to 250 Kpa as suggested by Jain [39] and Panda et al. [1]. Red Mud also has higher undrained shear strength as compared to uncemented clay which is due to the high frictional resistance offered by particle morphology and fraction as stated by various authors [40]. In addition to that high values of friction angles $26^{-}45^{0}$ were observed in case of Red Mud which is almost similar to that offered by coarse sand [41]. Furthermore Cohesion values reported by various authors fall in the range of 7–20 Kpa. Alam et al. further support these finding after evaluating the sphericity of Red Mud Particles and suggested that frictional resistance increases with decrease in sphericity. The values of Cohesion and Shear Strength as found by Srivastava [42] were 1.77–7.7 and 29–131 Kpa respectively which validates the above findings.

4.4 Hydraulic Conductivity and Compressibility

Kalkan [43] suggested a potential use of Red Mud in the modification of the clay liner system which reduces the cost of stabilisation as Red Mud is available is huge quantity as industrial waste material. One of the key property which makes a Geomaterial potential to be used as a Waste Containment Liner or Cover Systems is permeability

[8]. Low hydraulic conductivity is a result of effective compaction [44] or by filling the pores with fine materials [9, 43]. Due to presence of 90 % of fine particles (<0.075 mm) Red Mud has generally Low Hydraulic Conductivity as these fine particles fills the pores. The value of hydraulic conductivity was determined as 10^{-6} cm/s by Gore et al. with help of rigid and flexible wall permeameter method. This value obtained is comparable to values of Natural Clay samples (10^{-9} to 10^{-6} cm/sec) [41] which can be further improved with stabilisation to compile with the guidelines of UESPA to be used as a Clay Liner that is less than 10^{-7} cm/sec [45].

4.5 CBR- California Bearing Ratio

CBR test is done in Construction Materials to evaluate the strength of subgrade materials. It is prominently used to evaluate the thickness of the subgrade. The soil possessing poor strength characteristics in the subgrade can subsequently lead to cracks, rutting and formation of potholes therefore making it obligatory that the subgrade material should possess enough CBR according to respective standards. Stabilised Red Mud has higher Soaked CBR value as compared to unsoaked CBR as suggest by Jitsangiam and Nikraz [38]. Red Mud can be potentially used as a stabilisers to strengthen weak soils as suggested by Mukiza et al. [46]. Similarly Deelwal et al. also found an increase in the CBR value of Red Mud with addition of 8% of hydrated lime and 1% gypsum [47]. Furthermore it can be concluded that Red Mud can be seen as a potential use in Roads and Pavements, consuming large quantities and therefore solving the problem in its disposal and environmental issues related to it [36, 46].

5 Application of Red Mud in Geotechnical Engineering

Substantial research has been carried out to study the areas of application of Red Mud and its use as a raw material for production of various building materials like bricks, blocks and cement industry etc. Red Mud is also effective in soil stabilisation or can be used as a geopolymer, used as an additive in cement, mortars and concretes. Outside the field of engineering it can also be used for recovery of metals like iron, titanium etc and can be effectively used in pollution control.

For a waste material to be selected in the geotechnical applications it has to meet with the standard of various engineering properties and comply with code specifications. Red Mud can be effectively used as a fill material for construction of embankments, Clay liners, Foundations and structural fills as it possesses low compressibility characteristics. In general values of specific gravity for Red Mud of different origin lies in the range of 2.7–3.7 which meet all the requirements of the material to be used in the construction of embankments. Panda et al. [1] suggested that the values of liquid limit and plasticity index of treated red mud very well lies in the range as suggested by IRC 37 [48] and IRC SP 20 [49] therefore making it suitable to be considered as a resource material in the pavement layers.

Particle size analysis observed that Red mud contains a huge fraction of fines which subsequently leads to its low hydraulic conductivity characteristics. Taha and Kabir [50] also suggested that Red Mud can be effectively used as a liner material where pollution to the environment can be averted by avoiding the migration of pollutants. Furthermore Rubinos et al. [9] also observed the low values of hydraulic conductivity and supported the above mentioned statement. Large quantities of fines along with low linear and volumetric shrinkage makes Red mud a suitable choice for building material such as bricks etc [51] but the only hindrance is the low strength which is below 7 Mpa which is a standard set by BS 3291 [52] which makes it necessary to stabilise Red mud before use.

6 Gaps and Need of Research

1. The research community would find it easier to identify potential geotechnical applications if there were a thorough review of the physical, chemical, mineralogical, and leaching characteristics and how they affect the geotechnical properties of the Red Mud.
2. The primary method used to report the physical, chemical, strength, and leaching characteristics of the Red Mud samples examined in this study involved extensive laboratory testing. It should be noted that studies on a smaller scale are typically carried out in controlled environments, which frequently do not mimic real-world situations. Red Mud in the field, on the other hand, may be exposed to harsh environmental and climatic conditions that may or may not be able to be imbibed by laboratory scale tests.
3. Regulations governing the transportation and storage of alkaline materials, as well as complexity factors like high alkalinity, are found to be the main compelling reasons for the field's paucity of studies, particularly those involving the Red Mud.
4. There are few studies that address the chemistry of solid alkalinity or solutions to reduce it. There is a wealth of opportunity to reduce alkalinity levels of Red Mud using chemical or microbial treatment techniques.
5. As opposed to conventional soils, Red Mud calls for neutralisation, then stabilisation. This can be done either by using a sequential approach, where one method comes first and then the others, or by using an integrated approach, where neutralisation and stabilisation are done simultaneously. This may allow for high rates of Red Mud utilisation across a range of Geotechnical engineering applications.
6. There is no doubt that using chemical additives for stabilisation or neutralisation pollutes the environment or produces by products of secondary reactions. At this point, microbial treatment techniques are seen as promising because they

can transform Red Mud into an environmentally benign substance while also transferring other advantageous properties.

7. Various practical scenarios, such as Red Mud-liner interaction, which would help in determining the viability of Red Mud to be selected in clay liners and hydraulic barrier applications, or selection of suitable clay liner systems which would withstand the extreme alkaline environments typically encountered in wastes like the Red Mud, require detailed study of the hydraulic conductivity of raw Red Mud and that amended with various additives.
8. There are hardly any studies examining the impact of phase composition on the geotechnical and Geo-Environmental behaviour of the Red Mud discussed in the literature. To recycle the Red Mud more effectively, the future tasks related to the interdependence would need to be defined.
9. Further research is required to determine the long-term leachability of undesirable chemical constituents from Red Mud used in engineering applications under varying environmental and climatic conditions.
10. Considerations for the triple bottom line (environmental, economic, and social) sustainability should be used to evaluate the sustainability of new and creative large-scale engineering applications for Red Mud.

7 Conclusion

Thorough review with the help of the available literature on the physical, chemical and the mineralogical properties of Red Mud and its areas of application in the field of Geotechnical Engineering has led to the conclusion mentioned below.

1. There is rise observed in the demand and production of alumina with every year passing by which subsequently is leading to huge amount of waste generation in form Red Mud and Problems related to its Disposal.
2. Limited studies have been done to understand various properties of Red Mud in details like physical, chemical, morphological, and other characteristics which is hindering the process of its utilization and finding new areas of applications.
3. High alkalinity of Red mud needs to be lowered to acceptable limits to achieve elemental equilibrium and subsequently reducing its negative impacts on the environment. Effective stabilisation of the waste material needs to done for the improvement in the strength characteristics to enlarge the horizon of application of Red mud. Shear strength parameters that is Friction angle for Red mud is similar to that of the sand.
4. Red mud can be effectively used for the construction of embankments, has an application in Clay Liner and can be used as a geomaterial in structural fill [53, 54].

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Performance Evaluation of a Common Effluent Treatment Plant (CETP): Reliability Analysis and Removal Efficiency Assessment

Dhruvin Sojitra, Anurag Kandya, and M. A. Shabiimam

Abstract It is important to have a common wastewater treatment facility to treat the effluent coming out of numerous units because many small and medium-sized businesses cannot afford to have their own effluent treatment facilities. One such CETP has been established in Rajkot district, Gujarat for a textile manufacturing cluster, to treat wastewater at a common treatment facility. This study aims to evaluate the CETP's removal efficiency by utilizing the data received from the GPCB website. CETP's treatment efficiency in terms of pollutant removal was assessed using data collected over 6 years period. An established methodology known as reliability analysis was used to assess the mean concentration required to achieve the confidence level at different ranges. In addition, the observed level of confidence in the CETP's operation was determined. The primary water quality indicators, which include pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammoniacal Nitrogen (NH_3-N), and Phenolic compounds, were utilized to evaluate the CETP performance. Overall, the CETP showed good treatment efficiency and reliability with discharge standards. It was noted that CETP failed to control suspended particles in the effluent, which can be related to the poor performance of the clariflocculator and secondary clarifier.

Keywords Wastewater treatment performance · Reliability analysis · Removal Efficiency · Effluent quality · Performance evaluation · Common effluent treatment plant

D. Sojitra · A. Kandya · M. A. Shabiimam (✉)
Department of Civil Engineering, SOT, Pandit Deendayal Energy University, Gandhinagar 382426, India
e-mail: Shabiimam.ma@sot.pdpu.ac.in

D. Sojitra
e-mail: dhruvin.smten21@sot.pdpu.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_25

1 Introduction

With over more than 1400 dye and printing factories present in the textile cluster of Rajkot, these industrial units produce a lot of effluents during textile washing. The purpose of the current experiment is to evaluate the performance of a CETP that is used to treat wastewater produced during the washing process of textiles. The CETP uses a conventional treatment technology and receives 7 MLD of wastewater on average. The sources of effluent are small-scale textile producers, printing, process-out, dye intermediates, and domestic waste.

For small to medium-sized businesses, Common Effluent Treatment Plants (CETP) for the textile industry are one of the practical solutions for efficient wastewater treatment. It is important to have a common wastewater treatment facility to treat the effluent coming out of numerous units because many small and medium-sized businesses cannot afford to have their own effluent treatment facilities. Common effluent treatment plants have a primary and secondary treatment system that complies with the regulations for discharge into land surface waters. A flash mixer and a clariflocculator are employed in the primary treatment procedure to remove COD, SS, and to a lesser extent BOD in a significant amount. While, secondary treatment consists of an aeration tank and a secondary clarifier where BOD, COD, and SS are substantially removed. Prior to 1990, the Jeedimetla CETP in Hyderabad was the only one in operation. The Government of India's Ministry of Environment & Forests (MoEF) launched an innovative financial support program for CETPs in 1991 to ensure that small and medium-sized enterprises (SMEs) would grow in a sustainable manner. To take advantage of the operation's scale, the CETP concept was chosen to treat mixed wastewater at the end of the pipe. In addition, the CETP reduces the number of discharge sites in an industrial estate for improved enforcement and frees up qualified personnel for efficient effluent treatment.

2 Material and Methods

2.1 Introduction to Study Area

In this study, textile industries' effluent from a cluster of industrial facilities in Gujarat, India, was collected and treated using a CETP. The member industry was generating harmful effluent while washing clothes with freshwater. After being cleaned, the dyed textiles release harmful chemicals in the wastewater, which then enter the CETP as effluent, indicating that they are highly polluting and that proper treatment procedures would be needed before disposal. In the CETP under study, the influent was treated using a conventional mode of treatment in which it was first put through a primary treatment process made up of an equalization tank and a primary clarifier, and then it was treated using a secondary process made up of an aeration tank and a secondary clarifier.

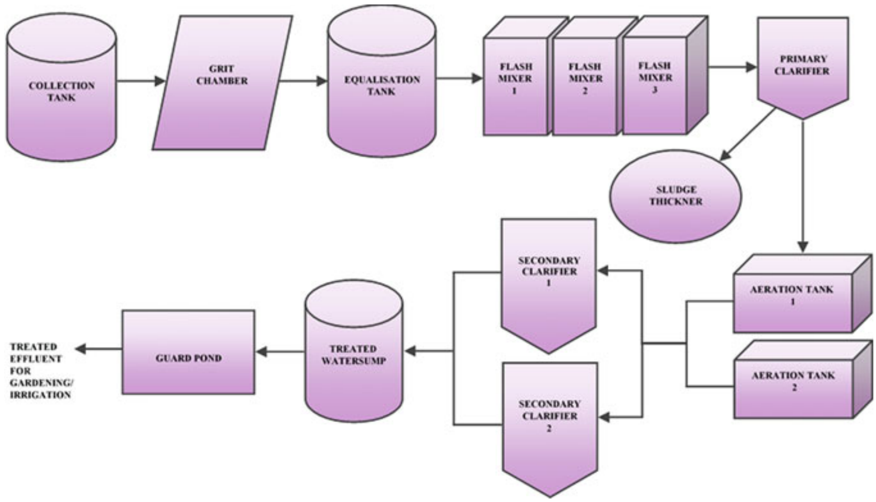

Fig. 1 Treatment scheme of the CETP

The CETP was developed to provide a mixture of physical, chemical, and biological processes by incorporating all necessary equipment such as a grit chamber, equalization tank, flash mixer, primary clarifier, aeration tank, secondary clarifier, sludge thickener, treated water sump, and guard pond.

The raw influent that this CETP has been designed to treat should have pH in the range of 10.5–12, Biological Oxygen Demand (BOD) not more than 350 mg/L, Chemical Oxygen Demand (COD) not more than 1000 mg/L, Suspended Solids (SS) not more than 2000 mg/L, NH_3-N not more than 75 mg/L and phenolic compound not more than 5 mg/L (Fig. 1).

The CETP collects wastewater in a receiving collecting sump with the use of a channel connected with Washing Ghats, which transport the raw effluent from the member industries. The raw effluent collection sumo has a diameter of 16 m. Before the collection sump, it is flowed through a cable rake bar screen to filter out the debris and textiles fibers.

The wastewater from the collection sump is then transferred through a grit chamber where sand and other bulky inorganic materials like rags, metal, and other inorganic materials are removed. There are two 8.30 × 8.30 m grit chamber units present in the CETP. Grit in the first settling tank can cause unwanted abrasive wear and damage on mechanical components and sludge pumps, clog by deposition, and accumulate in sludge storage tanks and digesters if it isn't removed in initial treatments. Therefore, grit removal is necessary to prevent abrasion of the parts of the pumps and other mechanically moving machinery.

The wastewater with no grit or debris is then collected in an equalization tank. The equalization tank has a diameter of 43 m and is circular in shape. At present, neutralization is not being carried out due to the presence of sodium silicate in the wastewater, which converts the wastewater into jelly form after the addition of any acids. The presence of sodium silicate also corrodes the sensors placed inside the units for continuous monitoring. The CETP only treats alkaline wastewater, and the treated alkaline water is discharged.

There are three flash mixers of size 6 × 6 m to dose the chemicals in the wastewater for coagulation and flocculation. Currently, polyaniline (Pani) is utilized as a coagulant. The Pani functions as an adsorbent and interacts with suspended particles to form floc to increase the weight for sedimentation. The acid, such as Pani, is stored in a separate tank, which has a dimension of 5 × 13.5 m.

Following the chemical dosing in the flash mixer, the flocs are removed in the primary clarifier in form of sludge. The primary clarifier is 39 m in diameter and is used to remove settleable solids from the incoming raw wastewater. Removing all settleable and floating solid waste with a high oxygen demand is the main function of the primary clarifier. This is the last unit of primary treatment. The main function of the primary unit can be attributed to the removal of suspended solids and to some extent the removal of solids that have high oxygen demand (BOD). The sludge obtained from the primary clarifier is sent to the sludge thickener to remove the excess moisture in the sludge. The sludge obtained from the primary clarifier is transferred to the sludge thickener to remove the excess moisture in the sludge and the thickened sludge is sent to the TSDF site for disposal. The sludge thickener's diameter is 20 m.

Secondary treatment is applied to the wastewater after primary treatment to lower the pollutant level below the discharge limitations. The wastewater is initially given an aeration treatment, in which aerators in an aeration tank purge fresh air (or oxygen) into the wastewater. Turbulence at the air–liquid interface is created by mechanical aerators, which entrains air into the liquid [1]. As a result, an activated sludge process is created, which breaks down and digests organic components before removing them from wastewater by a secondary clarifier. Some of the sludge from the secondary clarifier is returned to the aeration tank in order to maintain the Food to Mass ratio (F/M). The CETP uses a 30 m length and 30 m breadth of two aeration tanks. The secondary clarifier releases treated water after removing the extra sludge produced due to the activated sludge process. There are two secondary clarifiers of 33 m in diameter functioning at the CETP.

The treated wastewater is collected in a treated water sump of 26 m in diameter. It is then either returned to the Washing Ghats to be utilized in the washing process or sent to a near dam for irrigation purposes. The treated effluent is first held in the guard pond to minimize the risk of contamination before it is reused. These guard ponds are used to prevent the effluent from contaminating the natural river or lakes.

The pH should be between 6 and 9, COD should be less than 250 mg/L, BOD should be fewer than 100 mg/L, SS should be less than 100 mg/L, NH_3-N should be less than 75 mg/L, and phenolic compound should be less than 1 mg/L, according to the CETP's discharge standards limit set by GPCB.

2.2 Removal Efficiency (RE)

The Gujarat Pollution Control Board (GPCB) monitors each CETP in the state and publishes monthly reports on their inflow and outflow. This information is accessible and available online through the GPCB's website. Using these data collected over the past 6 years, the performance of the CETP was evaluated. Data for a few months were missing since there was no sampling carried out for that month due to various reasons. A CETP is said to be in proper operation when it releases the treated wastewater within the boundaries established by the regulatory authorities. Therefore, outlet parameters were compared to the GPCB discharge limits. A treatment plant's removal efficiency (RE) is measured as the percentage of variation between a particular parameter at the plant's inlet and outlet [2]. In this study, the effluent quality parameters BOD, COD, TSS, NH_3-N, and phenolic compounds are used to calculate the values of Removal Efficiency (RE) to assess performance. RE values for each of the five parameters are calculated on monthly basis using the following formula:

$$\text{Removal Efficiency}(\%) = \frac{(X\text{inlet} - X\text{outlet})}{X\text{inlet}} \times 100 \tag{1}$$

where X is the values of BOD, COD, TSS, NH_3-N, and phenolic compounds at respective locations.

2.3 Concept of Reliability Analysis and Coefficient of Reliability (COR)

A CETP's effectiveness depends on understanding the functioning of the process. The reliability of a wastewater treatment plant is determined by its ability to maintain acceptable effluent parameters regardless of fluctuations in influent load [3]. Regarding a CETP, reliability can be defined as the frequency with which the CETP meets the specified effluent standards limits [4–6]. Due to temporal unpredictability, the quantity and quality of the influent generation are significantly affected, so the treatment plant should be designed to discharge treated effluent with specific quality parameters remaining below a predetermined discharge threshold. To determine this threshold, Niku et al. (1979) developed a method based on a predictive model [7]. Their method associates the required threshold value with the average concentration of a parameter. Several authors over the past 25 years have used or consulted this methodology [8–11], which has been used and suggested in two significant textbooks [4, 12].

The threshold value (t) or mean concentration of treated effluent to be maintained for the highest compliance is determined for a particular pollutant parameter in a CETP's treated effluent to maintain pollutant discharge standards with compliance at all times. It is as follows:

Table 1 Cumulative probabilities of standard normal distribution for given confidence threshold [13]

1-α (%)	$Z_{1-\alpha}$
99.9	3.090
99	2.326
98	2.054
95	1.645
90	1.282
80	0.842
70	0.525
60	0.253
50	0.214

$$t = \mathrm{COR} \times \mathrm{Cs} \tag{2}$$

where t is the average concentration of the treated effluent that must be maintained to achieve optimum compliance and COR is the coefficient of reliability.

The model of coefficient of reliability (COR) was proposed by Niku et al. [7] using the given mathematical equation:

$$\mathrm{COR} = \sqrt{\mathrm{Cv}^2 + 1} \times \exp\left\{ - Z_{1-\alpha} \sqrt{\ln\left(\mathrm{Cv}^2 + 1\right)} \right\} \tag{3}$$

Here Cv is the variation coefficient for the selected outlet data for a particular parameter, Standard deviation (S.D.) of a value divided by the mean of the same value gives Cv; $Z_{1-\alpha}$ is a standardized normal variate that relates to the chance of no exceedance at a confidence level of (1-α), where α is a probability that the discharge standards will be met [9]. Table 1 shows the value of $Z_{1-\alpha}$ along with the confidence threshold.

2.4 Expected Compliance with Prescribed Discharge Standards

Using actual effluent values for each parameter, an expected percentage of compliance with the prescribed discharge limits can be determined once the CV values are measured. Niku et al. [7] previously used an equation in which the normal and lognormal values of parameters, as well as the Cv, are taken into account. The following simple and straightforward equation is used to estimate the observed compliance rate of CETPs.

$$Z_{1-\alpha} = \frac{\ln Xs - \left[\ln t\prime - \frac{1}{2}\ln\left(\mathrm{Cv}^2 + 1\right)\right]}{\sqrt{\ln(\mathrm{Cv}^2 + 1)}} \tag{4}$$

where *Xs* is the allowable outlet limit and *t'* is the obtained mean of the concentration in mg/L at the outlet.

The value of (1-α) is determined by calculation based on the desired percentage of compliance. The area covered by the standardized normal curve is represented by the value of $Z_{1-\alpha}$. This value can also be found in mathematical textbooks dealing with statistics and probability [14].

The theoretical model presented above was utilized to calculate the CETP's daily reliability. It was implemented based on monthly observed concentrations of specific parameters used to monitor the treated effluent quality.

The two programs that were utilized to analyze data were IBM's Statistical Package for the Social Sciences (SPSS) and Microsoft Excel (MS Excel 13). Using Cv values, similar calculations can be done to determine the reliability level. By analyzing the monthly effluent characteristics utilized for determining the quality of treated effluent, this mathematical model was used to investigate the daily reliability of CETP.

3 Results and Discussion

The primary goal of this study is to evaluate the overall performance of a CETP by evaluating the facility's influent and effluent characteristics. The CETP revealed a considerable number of differences in the parameters during the examination. The CETP is designed to treat influents with COD levels of 1000 mg/L, BOD levels of 350 mg/L, SS levels of 2000 mg/L, NH_3-N levels of 75 mg/L, and PC levels of 5 mg/L. The range of any parameter can demonstrate the variation in influent, and it can be directly linked to the functioning of the CETP. With such high fluctuations in influent characteristics, it becomes difficult for the CETP to operate properly. Except for pH, all parameters have a wide range of inlet values. The value of inlet for COD varied from 161 to 1329 mg/L, for BOD it was 26 to 429 mg/L, for SS it was 42 to 2408 mg/L, NH_3-N it was 2.8 to 140 mg/L. Table 2 shows the descriptive statistics of the effluent characteristics for the CETP obtained from the GPCB official website.

3.1 Removal Efficiency for All Pollutants

3.1.1 pH

The pH value is one of the critical and frequently used parameters in water chemistry. The pH measurement is a major objective in wastewater treatment [15]. There is a possibility of expanding member industries or even more wastewater from a new industrial cluster being sent to the CETP for treatment in the future. The pH of the influent fluctuates depending on the type of industry. To address the challenge, the

Table 2 Descriptive table of the CETP

Parameters	N	Minimum	Maximum	Range	Mean		Standard deviation	Cv	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Standard error	Statistic	Statistic	Statistic	Standard error	Statistic	Standard error
pH inlet	52	8.29	11.4	3.110	10.77	0.075	0.539	0.050	−2.722	0.330	9.535	0.650
pH outlet	56	6.79	9.72	2.930	8.79	0.067	0.504	0.057	−0.997	0.319	3.311	0.628
COD inlet	52	161	1329	1168	466.99	37.376	269.524	0.577	1.419	0.330	1.834	0.650
COD Outlet	56	50.5	524	474	219.313	15.873	118.786	0.542	0.658	0.319	−0.027	0.628
BOD inlet	52	26	429	403	148.029	12.98	93.602	0.632	1.190	0.330	1.062	0.650
BOD outlet	56	15	165	150	64.423	5.261	39.372	0.611	0.778	0.319	−0.042	0.628
SS inlet	52	42	2408	2366	421.288	74.272	535.584	1.271	2.504	0.330	5.920	0.650
SS outlet	56	212	5200	5179	629.964	152.527	1141.409	1.812	2.706	0.319	7.296	0.628
NH_3-N Inlet	52	2.8	140	137	20.45	2.995	21.599	1.056	3.705	0.330	18.240	0.650
NH_3-N outlet	56	0.278	25	24.722	4.778	0.799	5.98	1.252	2.240	0.319	4.941	0.628
PC inlet	52	0	2.2	2.2	0.209	0.062	0.45	2.156	2.944	0.330	9.348	0.650
PC outlet	56	0	1.26	1.26	0.11	0.036	0.273	2.482	2.714	0.319	6.972	0.628

CETP must be designed accordingly. CETPs are typically designed for pH values ranging from 6 to 9, implying that the wastewater is neither excessively acidic nor highly alkaline. Due to this majority of the CETPs performs neutralization at the first stage. If the CETP is receiving highly acidic influent, it can be neutralized by adding strong alkaline chemicals like Sodium Hydroxide (NaOH) and vice versa if the influent is high in alkalinity, it can be neutralized by adding strong acidic chemicals like Sulfuric Acid (H_2SO_4).

In the present study, the CETP's pH remains highly alkaline (around 11 pH) because of the presence of sodium silicate, and it is discharged only in an alkaline medium with a minor pH drop (around pH). In various observations, pH variation can be observed for inlets where the influent has a pH of less than 10.5. Despite this, the outlet pH is usually within the range of 6–9, showing compliance with the GPCB limit.

3.1.2 Chemical Oxygen Demand (COD)

The amount of COD eliminated can be used as a benchmark to evaluate the overall performance of the CETP and its treatment capabilities. It shows how much oxygen is needed to chemically oxidize organic and inorganic substances [12].

The removal efficiency of the COD was in the range of −35 to 88%. The CETP under study gets COD of less than 750 mg/L, which is less than the 1000 mg/L COD inlet limits. There are only two cases observed where COD was 1274 and 1329 mg/L exceeding the inlet limit of 1000 mg/L. Although the CETP was successful in significantly lowering COD concentrations below the discharge limit of 250 mg/L in most cases, the CETP discharged effluent that exceeded the allowable limit 22 times. The reason for this could be a fluctuation in the influent received, aeration tank malfunction, or overall secondary treatment performance.

3.1.3 Biological Oxygen Demand (BOD)

The Biologic Oxygen Demand quantifies the level of oxygen required by bacteria to break down degradable organic matter in any wastewater into simpler compounds. The BOD parameter is very important when the wastewater has the o used for irrigation purposes after the treatment. For any water body, BOD demonstrates the ability of dissolved oxygen to preserve biological matter in water bodies. As a result, CETP must discharge the BOD within the allowable level. High BOD levels can cause eutrophication, which reduces the overall health of the water body.

The CETP has performed well in maintaining the BOD level below the discharge limit most of the time. The observed removal efficiency was in the range of −34 to 91%. The CETP has always received BOD less than its allowable limit of 350 mg/L. CETP has only received wastewater with high BOD levels twice, at 419 mg/L and 429 mg/L, respectively. Even though BOD has been significantly reduced, the CETP has discharged wastewater 9 times with a value greater than the discharge limit.

Although it can be noted that the exceeding values are very close to the discharge limit of 100 mg/L.

3.1.4 Suspended Solids (SS)

The Suspended Solids are the particles of soil, clay, biological solids, wastewater particle, and decaying organic debris that floats in wastewater. Untreated suspended particles can contribute to drainage system blockage and cause harm to other systems. It can be removed by using pre-treatment chemicals such as pH neutralizers or polymers, followed by sedimentation or filtration. The overall SS removal efficiency of the CETP can be used to evaluate the performance of clariflocculators and clarifiers employed in the CETP.

The CETP under study here has failed to control the SS concentration. The removal efficiency for SS showed a wide range of variation, ranging from −356% to 9%. For SS, the CETP has an intake limit of 2000 mg/L concentration, and CETP has received effluent with less than 1000 mg/L excluding seven cases where the concentration of SS was higher than 2000 mg/L. The CETP has shown very poor treatment efficiency in terms of SS removal. For 31 times, the CETP discharged wastewater that exceeded the discharge limit of 100 mg/L. It shows the poor functioning of the clarifiers present in the CETP. In some cases, a higher SS concentration in the influent can also be the cause of incompetence.

3.1.5 Ammoniacal Nitrogen (NH_3-N)

The presence of Ammoniacal Nitrogen in the wastewater can increase the growth of vegetation present in the water body leading to the problem of eutrophication. Eutrophication can deteriorate the quality of an aquatic body by reducing the amount of sunlight that enters in it due to excessive plant and algae development.

The removal efficiency for NH_3-N ranged from −36 to 97%. The CETP under investigation has no NH_3-N problems because it has always received wastewater with lower NH_3-N concentrations. The CETP has an inlet limit of 75 mg/L for NH_3-N and an outlet limit of 50 mg/L. Based on the analysis, the CETP received NH_3-N concentrations of less than 50 mg/L for the entire duration, excluding four cases. Still, there is a reduction in NH_3-N concentration which can be observed at outlet concentration. The CETP has shown 100% of compliance with the GPCB discharge limit in the case of NH_3-N.

3.1.6 Phenolic Compounds (PC)

Human health is adversely affected by phenolic compounds because they cause necrosis, digestive problems, and liver and kidney damage. At concentrations less

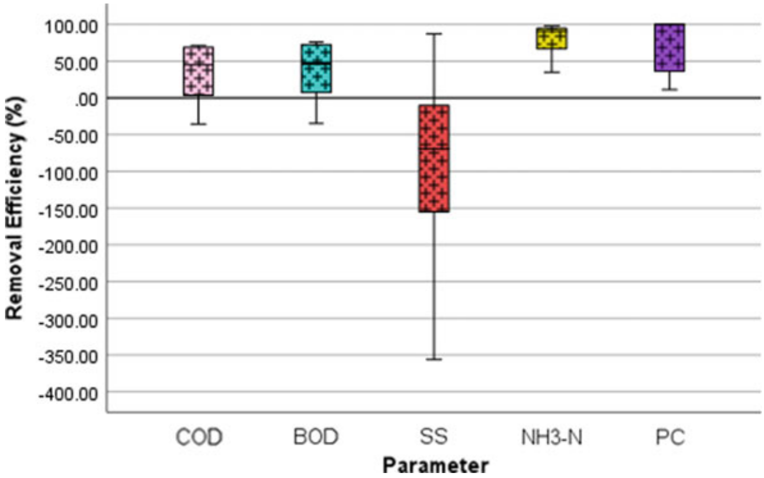

Fig. 2 Observed removal efficiency for all parameters

than 1 mg/L, they are also harmful to other biological organisms and deteriorate marine ecosystems [16].

The CETP has also maintained a high compliance rate for phenolic compounds. The removal efficiency was 19–100% The CETP has a discharge limit for PC of less than 1 mg/L. Except for three cases, the CETP has received PCs with concentrations of less than 1 mg/L the rest of the time. The CETP failed to comply only once when the PC concentration was 1.26 mg/L.

The CETP was found to have an average removal efficiency of 52.95% for COD removal, 54.79% for BOD removal, −6.1% for SS, 74.93% for NH_3-N removal, and 71.12% for PC removal (Figs. 2, 3 and 4).

3.2 *Reliability Analysis*

The coefficient of variation (Cv) for all available data was calculated for all specific parameters at the outlet. The coefficient of reliability was obtained using equation no. 3. The COR was calculated for a confidence threshold range of 60–95% because less than 60% confidence threshold indicates very poor performance treatment results. It can also be assumed that any CETP operating at a confidence level of 50% is completely unreliable and necessitates the implementation of significant changes in the plant rather than minor modifications.

The design concentration can be obtained by using equation no. 2. Table 3 shows the design considerations to be adopted for achieving a compliance rate of 60–95%. Here COR is a function of Cv, where it can be observed that if more variation is observed in the effluent quality it decreases the reliability of the plant. The variability

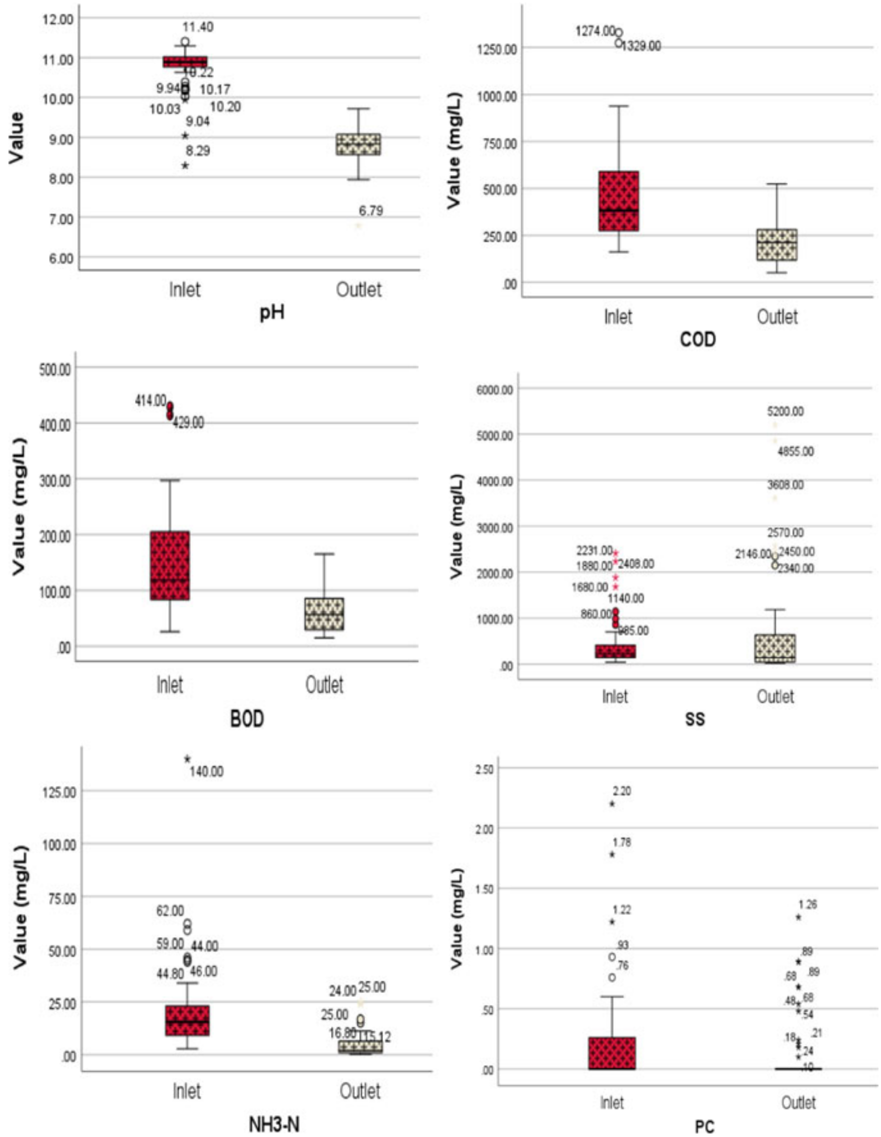

Fig. 3 Box plot chart for parameter concentration

of the suspended Solids and Phenolic Compound is very high, causing the CETP to exceed the discharge limit after operating at a confidence level of 70%. This means that if the CETP is operated at a 70% confidence level, it may not meet GPCB standard limits for SS and PC parameters. The lowest PC value was 0 mg/L, and the highest values differed according to member facility discharges and treatment conditions. As a result, the standard deviation (SD) of PC values was significantly more than

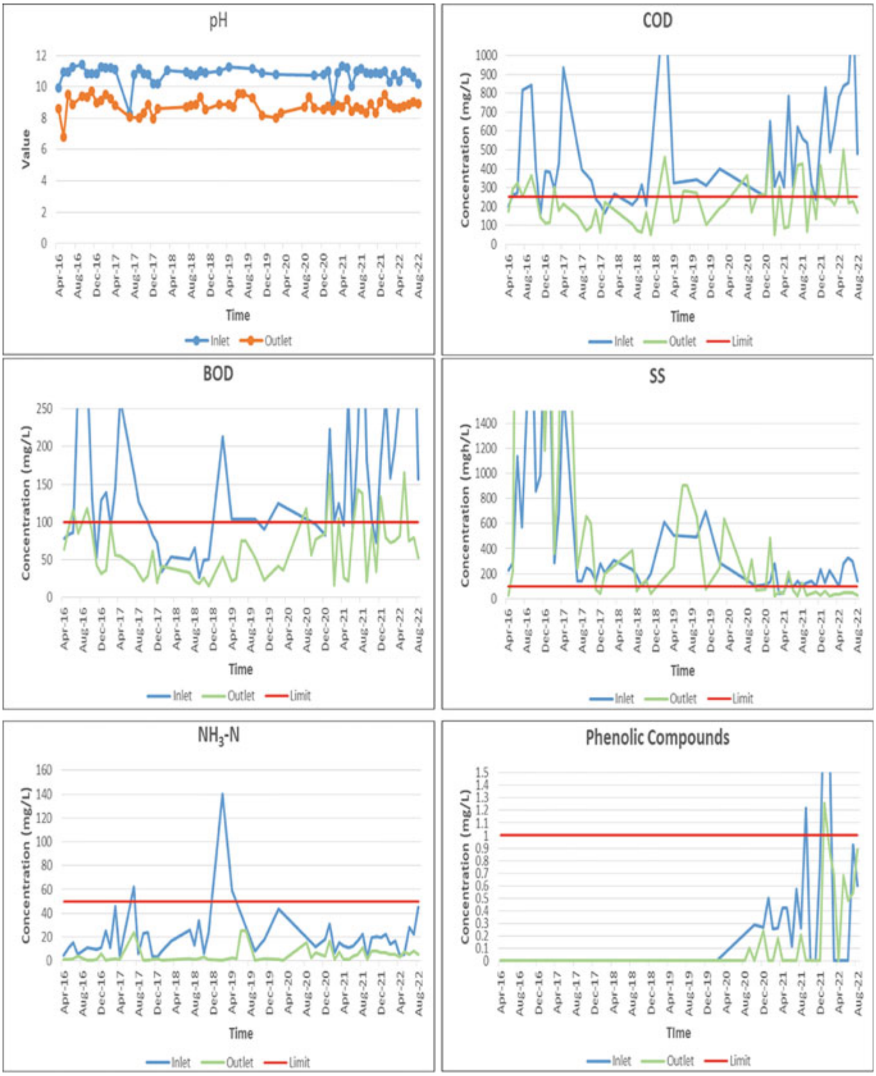

Fig. 4 Observed variation in concentration of pollutants at inlet and outlet

the mean value, resulting in high Cv values for the parameter. Furthermore, it can be seen that CETP is capable of treating COD on a regular basis, as demonstrated by the lower coefficient of variance. Even if the CETP operates at a 60% confidence level, it can still match the discharge limit for the COD parameter. The CETP must operate at a confidence level greater than 80% to ensure maximum compliance with all standards.

Table 3 Required mean concentration to achieve various reliability levels

CETP statistics (%)		COD	BOD	SS	NH_3-N	PC
95	μx	219.313	64.423	629.964	4.778	0.11
	σx	118.786	39.372	1141.409	5.98	0.273
	Cv	0542	0.611	1.812	1.252	2.482
	COR	0.493	0.464	0.285	0.324	0.105
	t	123.25	46.4	28.5	16.2	0.105
90	μx	219.313	64.423	629.964	4.778	0.11
	σx	118.786	39.372	1141.409	5.98	0.273
	Cv	0.542	0.611	1.812	1.252	2.482
	COR	0.593	0.611	0.441	0.461	0.443
	t	148.25	61.1	44.1	23.05	0.443
80	μx	219.313	64.423	629.964	4.778	0.11
	σx	118.786	39.372	1141.409	5.98	0.273
	Cv	0542	0.611	1.812	1.252	2.482
	COR	0.742	0.897	0.75	0.724	0.821
	t	185.5	89.7	75	36.2	0.821
70	μx	219.313	64.423	629.964	4.778	0.11
	σx	118.786	39.372	1141.409	5.98	0.273
	Cv	0542	0.611	1.812	1.252	2.482
	COR	0.871	0.872	1.099	0.962	1.281
	t	217.75	87.2	109	48.1	1.281
60	μx	219.313	64.423	629.964	4.778	0.11
	σx	118.786	39.372	1141.409	5.98	0.273
	Cv	0542	0.611	1.812	1.252	2.482
	COR	1	1.016	1.526	1.253	1.626
	t	250	101.6	152.6	62.65	1.626

3.3 Observed Reliability Level

The CETP showed a mean effluent concentration of 219.313 mg/L for COD, 64 mg/L for BOD, 629.64 mg/L for SS, 4.778 mg/L for NH_3-N, and 0.11 mg/L for PC. This, along with their respective Cv, can be used in Eq. 4 to determine the actual compliance rate for standard limits at which the CETP has functioned over the last 6 years.

The CETP demonstrated a 70% reliability for the COD parameter, a very good 86% compliance rate for BOD, 100% for NH_3-N, and 99% for PC, according to the analysis. But as observed in the removal efficiency of all pollutants, the CETP showed a very poor reliability of just 18% for the SS parameter. The fluctuation in influent characteristics and high suspended solid concentration in the inlet can

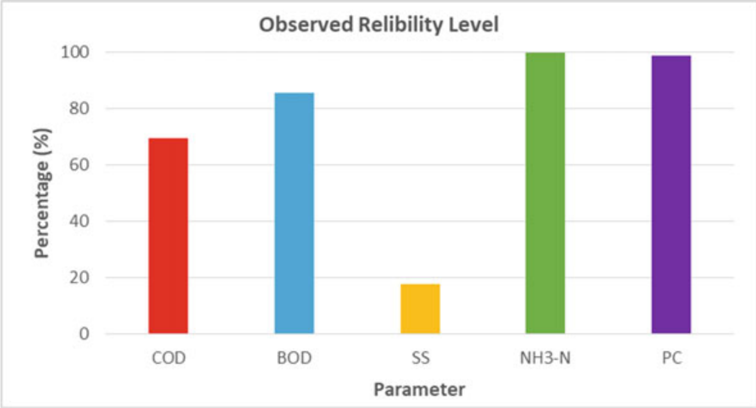

Fig. 5 Observed reliability level

be attributed to the CETP's poor performance in terms of treating suspended solids (Fig. 5).

4 Conclusion

The quality of treated wastewater is the key indicator of a CETP's effectiveness. The CETP showed very good efficiency in terms of COD, BOD, NH_3-N, and PC. The CETP is getting the benefit of under-concentrated pollutant wastewater generated by industries. The lower concentration of all contaminants in influent wastewater makes it easier for the plant to release the wastewater within the discharge limits of GPCB. The CETP is also using the guard pond which helps to prevent the contamination of the near aquifers. This analysis identified the suspended solids (SS) parameter that is not being handled adequately and requires additional attention in accordance with compliance. To achieve a higher SS compliance rate, authorities should properly maintain primary and secondary clarifiers for improvements in floc and sludge removal, which will reduce the rate of SS concentration at the outlet. Overall, the CETP demonstrated excellent treatment capability by decreasing pollutants under discharge limits most of the time. The reliability analysis model used here proved to be an effective tool for assessing the performance of the CETP for compliance with GPCB standards. More stringent discharge limits demand more confidence levels from the CETP, which increases the cost of treatment, require good operation and maintenance, and needs lower variation in influent characteristics received from member industries. The current study proves the significance of statistics provided by regulators for all CETP of Gujarat. Rather than viewing this data as mere information, it should be analyzed and used to improve the CETP's performance.

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An Investigation into the Scale Shift of an Efficient Biodegradation Practice from Batch to Pilot Scale Continuous Feeding Mode

Suryateja Pottipati and Ajay S. Kalamdhad

Abstract A significant challenge for cities is dealing with the increasing amounts of organic waste they produce. Municipal organizations have been compelled to establish innovative and effective systems for managing the enormous amounts of waste produced. The current study studied the effect of scale shift in rotary drum composting using vegetable waste as a feedstock. The process optimization was first investigated in a batch-scale 550-L rotary drum composter, followed by a 3-L vermicomposter inoculated with three different vermicultures. Further, the best combination was run in the pilot-scale reactors. The results of the batch-scale study showed that 7-day rotary drum composting followed by *Eisenia fetida*-based vermicomposting for 20 days was significant in producing nutrient-rich vermicompost. Furthermore, the pilot-scale operation demonstrates the technical feasibility of a pilot-scale operation. The data presented here can be used to produce value-added products on a large scale by the organic waste management sectors.

Keywords *Eisenia fetida* · Organic degradation · Process optimization · Rotary drum composting · Thermophilic-mesophilic degradation

1 Introduction

Composting is the biological decomposition and stabilization of organic substrates under conditions that allow the development of thermophilic temperatures due to biologically produced heat to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land [5]. Because of its adaptable disposal capacity ranging from hundreds to thousands of tons per day, in-vessel

S. Pottipati (✉) · A. S. Kalamdhad
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam 781039, India
e-mail: pottipatisuryateja@iitg.ac.in

A. S. Kalamdhad
e-mail: kajay@iitg.ac.in

K. D. Yadav et al. (eds.), *Recent Advances in Sustainable Waste Management Practices*, Lecture Notes in Civil Engineering 430, https://doi.org/10.1007/978-981-99-4186-5_26

composting became the dominating solution for centralized FW disposal in big cities like Shanghai and Shenzhen, China [25]. In India, traditional windrow composting is still used in all the major cities in biodegrading municipal solid waste, a mixture of organic and inorganic waste produced by the community. The production of city compost from the mechanical composting facilities from the dumpsites has not met the desired standards to be accepted as biofertilizers by the farmers because of the high amount of contaminants in the produce [1].

Numerous authors have studied in-vessel rotary drum composting in the Indian waste scenario [16, 19, 20]. The documented studies were majorly on the lab scale. The in-vessel rotary drum composting technique has been explored less as a pilot-scale organic waste management tool. Rotary drum composting can degrade various organic wastes in less than 20 days, according to studies [8]. If this technique is explored on a pilot scale, it has the potential to treat 150–200 kg of organic waste daily using significantly less space and can produce quality compost and also vermicompost if amended with vermiculture, according to [7]. Further, amending vermicomposting as a post-treatment after Rotary drums' thermophilic degradation has shown significant changes in the quality of the end product [10, 21].

Thus the primary objective of the current study is to investigate the feasibility of the combination of rotary drum composting followed by vermicomposting as studied by [10] in batch scale using vegetable waste as feedstock and further study the effect on the scale by using 5000L capacity rotary drum composting followed by bag vermicomposting the partially degraded waste. The study hypothesizes that this approach can decrease the vermicomposting duration and efficiently work on a pilot scale.

2 Materials and Methodologies

2.1 Feedstock Materials

The vegetable marketplace area in the Fancy Bazar area of Guwahati was selected because it serves the city's substantial vegetable demands. Morning (4 to 8 a.m. IST) garbage collection included waste produced during open hours, collected and sent to the IITG composting plant. Before further processing, the trash was thoroughly inspected, and non-biodegradable debris, such as plastic wrappers, was physically removed.

The waste was then mechanically shredded to a maximum size of 2 cm. Throughout the experiment, dry leaves were collected daily at IITG and used as a possible carbon source to reduce the feedstock's moisture content. Additionally, sawdust was used to absorb moisture generated during the shredding process. The sawdust was collected from the nearby hamlet of Ameangaon. In addition, the feedstock was uniformly mixed and introduced into the reactor. Table 1 summarizes the initial characterization of the waste and investigational materials.

Table 1 Initial characterization of the feedstock materials

Parameters	Vegetable waste	Cow dung	Sawdust	Dry leaves
Moisture content (%)	90.10 ± 2.22	85.35 ± 1.90	13.10 ± 1.10	10 ± 0.15
Volatile solids (%)	77.10 ± 3.10	87.50 ± 1.40	85.00 ± 1.30	90.00 ± 1.50
pH	5.60 ± 0.02	6.40 ± 0.01	6.00 ± 0.01	5.50 ± 0.15
EC (mS/cm)	2.30 ± 0.04	3.20 ± 0.02	0.60 ± 0.03	0.85 ± 0.10
Total nitrogen (%)	2.60 ± 0.20	1.70 ± 0.10	0.34 ± 0.10	0.40 ± 1.10
Total organic carbon (%)	65.15 ± 0.50	73.05 ± 1.50	73.58 ± 2.00	75.20 ± 1.50
Total phosphorus (g/kg)	6.58 ± 0.20	5.15 ± 0.30	2.10 ± 0.30	2.60 ± 1.50

2.2 *Reactor Setup*

2.2.1 Thermophilic Biodegradation Through Rotary Drum Composting

The composters were used for active thermophilic breakdown (initial 7 days), as Pottipati et al. [15, 16] suggested. Since the thermophilic phase decomposes substantial amounts of organic waste and concurrently stimulates the indigenous bacterial population to mineralize organic materials at an accelerated pace [11]. Also, Rotary drum in-vessel composting (RDC) is an optimized and expedited composting method [6] that reaches the thermophilic phase in less than 24 h and sustains it for 7–10 days [8].

2.3 *Batch Scale Operation and Optimization*

Principally, a 550 L rotational drum composter was used for composting. 150 kg of biodegradable material was added to the rotating drum composter, and the feedstock mass was aerated by 1 rotation per day during the composting period [16].

2.4 *Continuous Feeding Pilot Scale Operation*

In the solid waste laboratory of IITG, a pilot-scale rotary drum composter (capacity: 5000 L) was built following all safety regulations. The reactor was mounted on an iron frame and rollers for operational comfort. A 7 HP motor was installed to facilitate the drum's rotation. A 2 HP air blower was used in aerating the fed biomass. Figure 1 illustrates the arrangement.

550 L composter **5000 L composter**

Rotary drum composters

Vermicomposters

Fig. 1 Experimental setups

2.4.1 Mesophilic Biodegradation Through Vermicomposting

The partially degraded material from the rotary drum composter was then vermicomposted. Since the thermophilic phase of composting was completed, the temperature trends in vermicomposting were mesophilic throughout the study period.

2.5 Batch Scale

In the current combination approach for vermicomposting (VC), the feedstock, 3 L porous plastic trays, and three distinct vermi-mono cultures (*Eisenia fetida*, *Eudrilus eugeniae*, and *Perionyx excavatus*) were used. Before its use in VC, the earthworms were obtained from Krishi Vigyan Kendra (KVK), Guwahati, and raised in the laboratory. After 7 days of initial RDC operation, 2.5 kg of predegraded waste was extracted and analyzed in the VC. On day 0 and day 20 of VC, the biomass of earthworms was investigated.

In batch studies, the experimented trails are R1: RDC of the substrate, inoculum, and bulking agent in a 5:4:1 (w/w) ratio; R2: RDC followed by VC with *E. eugeniae*; R3: RDC followed by VC with *E. fetida*; R4: RDC followed by VC with *P. excavatus*. Comparatively, the length of biodegradation in RDC was 27 days for R1, 7 days for R2, R3, and R4, and 20 days for VC. The vermicomposting of each of these mixtures was examined in triplicate.

2.6 Continuous Feeding Pilot Scale Operation

This investigation used widely available bag vermicomposter's purchased from Fancy Bajar market area of Guwahati city. On day 1, feeding started in one corner, and on day 2, the same quantity of feed was provided adjacent to the herd as on day 1. This procedure was continued to the other corner, at which point a second bag was used. One of the four bags used for the investigation has a capacity of 1,000 kg. *Eisenia fetida* vermiculture was procured for the research from the Guwahati Krishi Vigyan Kendra (KVK). Throughout the investigation, 10 adult earthworms per kilogram of substrate were used. Also, on the 10th and 20th day of vermicomposting, the growth of earthworms was evaluated. The number of earthworms, their weight, and the number of cocoons were examined as variables.

In the experimented trial in a pilot scale, the analysis results of samples collected at the inlet zone, outlet zone of the pilot scale rotary drum composter, and final vermicompost produced in vermibags were recorded and presented in the article.

2.7 Process Operation and Monitoring Parameters Evaluation

The temperature was measured with a digital temperature gauge, and the material's moisture content (MC) was calculated after 24 h of oven drying at 105 °C [8]. A muffle furnace was used to evaluate the losing weight on ignition of volatile solids (VS) at 550 °C in 2 h. Powdered samples were blended with distilled water in a 1:10 (w/v) ratio for 2 h and centrifuged to get a clear extract, which was then used to calculate pH and electrical conductivity (EC).

2.8 Evaluation of NPK

Total Kjeldahl Nitrogen (TKN) and total phosphorus (TP) were calculated using the Kjeldahl (acid digestion) technique and the stannous chloride procedure, correspondingly. Total potassium (TK) was measured using a flame photometer after digesting a 0.2 g oven-dried 212-sieved powder sample with 10 ml of $HClO_4$ and H_2SO_4 (1:5) for 2 h at 300 °C.

2.9 Statistical Analysis

The mean and standard deviations of three independent samples were provided in this research. SPSS-20 was used for statistical analysis, and $P < 0.05$ (significant) was plotted. The OriginPro-22 software was used to generate all of the figures.

3 Results and Discussions

3.1 Batch Scale Operation

3.1.1 Effect on Temperature and Moisture Content Profile in Feedstock

In composting processes, the thermophilic conditions in feedstock were seen for a prolonged duration, but in rotary drum composting, the thermophilic conditions prevail with the highest degree only in the initial 7–10 days and immediately followed by mesophilic stage, gradually ambient temperatures are obtained [9]. In the present study, during the first 24 h of composting, the feedstock temperature rose from 37 to 51.5 °C. Because no additional heat source was given for the reactor, this rise is entirely due to microbial activity and the efficient functioning of the rotary drum composter. For 7 days, the reactor volume stayed in the thermophilic range before progressively dropping to the mesophilic zone. Composting causes a temperature change owing to the fast breakdown of readily accessible biodegradable organic components by microbial activity [23].

The role of MC in the composting process is critical. Organic waste having a higher moisture content must be supplemented with bulking materials such as sawdust, wood chips, dry leaves, or grass clippings to minimize leachate generation. Because of the high warmth and aeration during the composting process, the material may lose moisture. During composting, optimal water content enhances the microbial activity and organic matter breakdown [22]. The moisture content of RDC was lowered from 77 to 67% in this research (Fig. 2). The first 7 days of RDC saw a significant drop (4% out of 12%). Since water must be sprayed over the material for the proper development of earthworms, a moisture level of 70% was maintained. Because lower MC is typically accepted in mature compost to enhance workability and handling, controlled drying is critical for the final vermicompost [13].

3.1.2 Changes in Volatile Solids Fraction of Feedstock

VS is a measure of a substance's organic content. The conversion of organic matter to humid chemicals during the degradation process, notably ammonia gas volatilization, reduced the VS of all combinations [22]. The present investigation found an average VS drop of 38–40%, with a maximum decrease of 42% in *E. fetida* (R3).

3.1.3 Shift in pH and Electrical Conductivity of Feedstock

The resulting compost has an alkaline pH range (of 6.5–8.2). The *E. fetida* earthworm culture yielded a very basic-natured final product in all studies. pH changes are linked to the generation of organic acids by bacteria, nitrification, and ammonification activities throughout the composting process. Ammonia release and buildup in composting piles are attributed to the decomposition of nitrogen-containing molecules, which causes the pH to increase [22]. Furthermore, during the vermicomposting conversion process, earthworms may neutralize pH in their gut by creating calcium and ammonia, which limit humic acid production (especially carboxylic and phenolic groups) [3]. The final products are adequately stable if the pH values stay between 6.5 and 8 [4].

In all three experiments, the combined composting process dramatically decreased the EC value or salt concentration from 8.2 to 2 1 mS/cm on average; the *E. fetida* culture in the reactor (R3) demonstrated a notable 50% reduction in EC. Because the finished product showed no inhibition, the EC value was suitable for plant development. It has been found that a high concentration of soluble salts in the compost product inhibits seed germination [23].

3.1.4 NPK Dynamics in Feedstock

In this research, the nitrogen concentration of vermicompost was much higher than that of RDC compost. The existence of nitrogen-fixing microorganisms in the worm intestine might be the primary cause. The *E. fetida* culture grew quicker than other cultures, which might explain why the *E. fetida* reactor accumulated more nitrogen. The nitrogen content in R3 grew from 1.8 to 4.15%, whereas it increased from 1.8 to 2.3% in R1, demonstrating that combined composting is more effective than RDC.

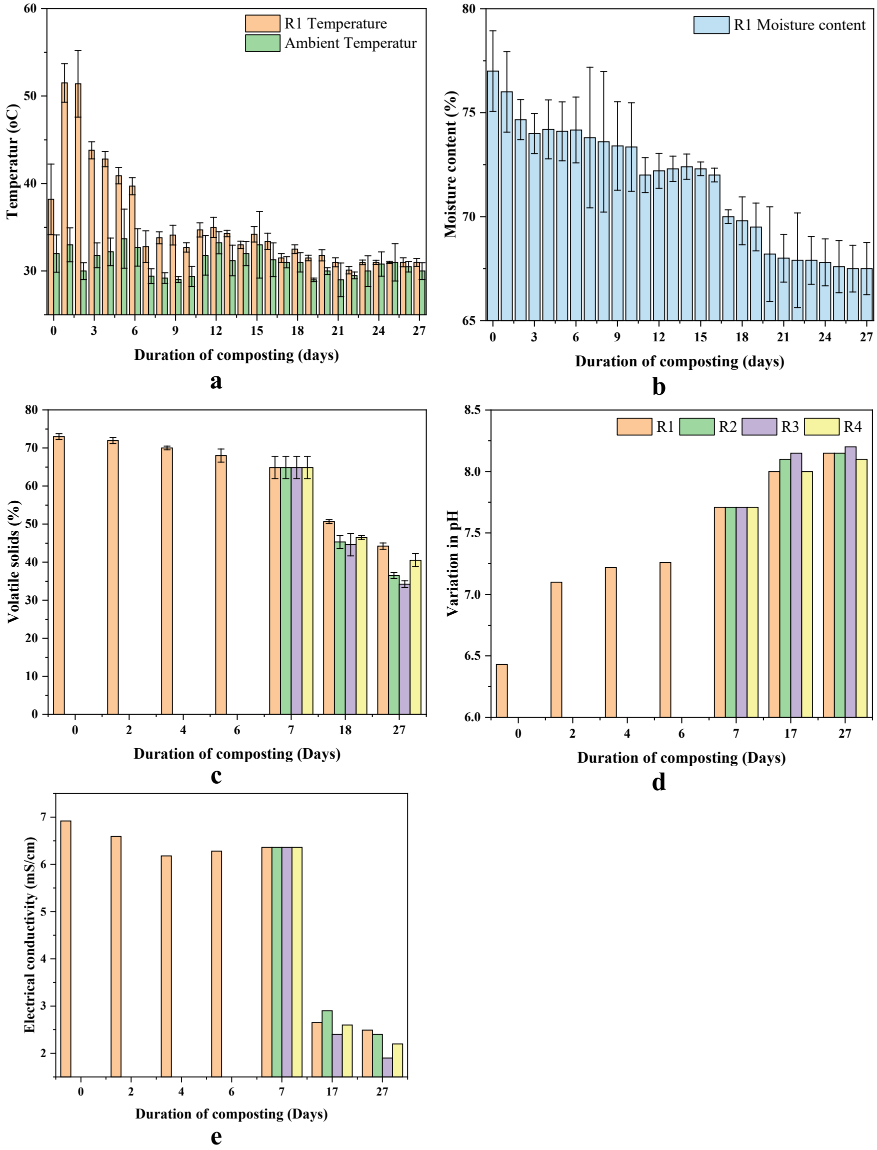

Fig. 2 Variation in **a** Temperature, **b** Moisture content, **c** Volatile solids, **d** pH, and **e** Electrical conductivity during two-stage biodegradation

The nutrient TP is necessary for crop growth and development. As a result, several P-containing fertilizers are used in agriculture to make up for soil P deficiencies [24] TP was raised in the current research. The *E. fetida* culture considerably elevated R3 TP from 3.25 to 15.1 g kg^{-1}. In R1, the TP rise was substantially smaller, at 6.5 from 3.25 g kg^{-1}. The rise in TP in R2 and R4 was considerably compared to R1, although their levels were much lower than R3 by 27 days.

Potassium and nitrogen, and phosphorus constitute the crucial plant nutritional triad. The rise in Na, Ca, and K during 27 days of composting was shown by time-bound patterns, as shown in Fig. 3. TK levels increased by double in R1, from 12 to 25.6 g kg^{-1}, and even more in R3, from 12 to 30.5 g kg^{-1}. Compared to R1, R2, and R3, the more excellent value of R3 may be ascribed to the robust development of *E. fetida*, which contributes to a dense population of earthworms and more significant mineralization of the nutritional content of the feedstock.

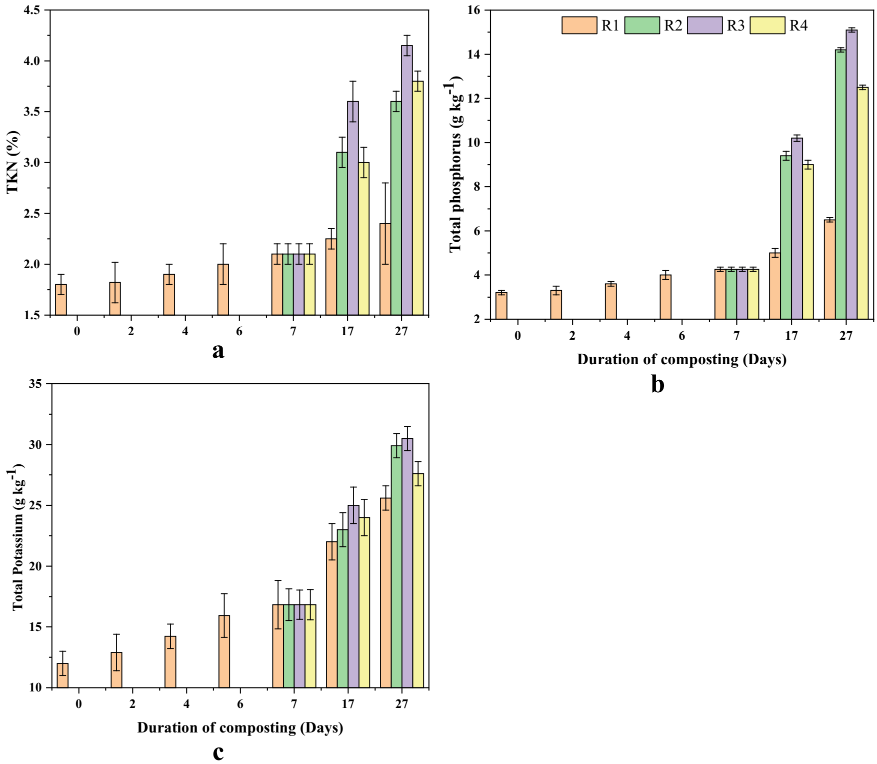

Fig. 3 Variation in **a** TKN, **b** Total phosphorus, and **c** Total potassium

Table 2 Vermiculture growth in the batch scale vermicomposting

Day	R2 (*Eudrillus euginae)*		R3 (*Eisenia fetida*)		R4 (*Perionyx excavates*)	
	Earthworms	Cocoons (no's per 100 g)	Adults	Cocoons (no's per 100 g)	Adults	Cocoons (no's per 100 g)
7	120	0	120	0	120	0
17	133	5	142	3	128	6
27	159	15	153	25	143	11

3.1.5 Vermiculture Growth in Partially Degraded Feedstock

The earthworm population is an essential indication of vermicomposting [2]. The experimental earthworm's average biomass increased by 2.5 times that at the study's beginning (Table 2). Compared to all other vermicultures, the number of cocoons in the *E. fetida* culture was also significant, which was possible by feeding the earthworms on deteriorated material. The 7-day RDC time before vermicomposting served as a preprocessing for the feedstock's vermicomposting.

3.2 Continuous Feeding Pilot-Scale Operation

3.2.1 Reactor Seeding

It uses the feed-to-microbial inoculant ratio suggested by the procedures of Pottipati et al. [15, 16], the reactor got primarily commissioned for 1 week (2:1 ratio). In the first 7 days, the reactor was fed a mixture of vegetable waste, cow manure, sawdust, and dry leaves until it was half-filled. After that, it was fed a mixture of vegetable waste with dry leaves at a ratio of 5:1 until it reached 250 kg.

3.2.2 Effect on Temperature Profile in Feedstock

Temperature distribution throughout the current investigation is depicted in Fig. 2a. It took 24 h for the intake zone temperature profile to rise from atmospheric to thermophilic during commissioning, and this tendency persisted throughout the research. As seen in the graph, rising ambient temperatures affect the thermophilic temperature but less affect the emergence of thermophilic conditions. Early on, while the atmospheric temperature was just 20 °C, thermophilic temperatures reached well over 50 °C, showing that the spinning drum composter can create a thermophilic phase inside the feedstock independent of the outside temperature. After 7–10 days, when the feed temperature was suitable for vermicomposting (35 °C), the process was started. The material then matched the surrounding mesophilic temperature profile.

3.2.3 Changes in Volatile Solids Fraction of Feedstock

Understanding bacterial growth and the development of compost products requires an appreciation of the role played by organic matter [16]. The present study found that the volatile solid percentage varied with seasonality, the supply of vegetables varied with the seasons, and the volatile matter in the feedstock varied from 45 to 57% across the reactor loading. The typical VS dropped by 17% in the first week and another 53% after the study period. Organic matter mineralization causes rapid VS decreases early in the composting process, indicating vigorous early microbial activity; this is consistent with the wide physiological thermophilic range that develops in the rotating drum reactor [10].

3.2.4 Shift in pH and Electrical Conductivity of Feedstock

A more excellent pH range during composting indicates more rapid biodegradation of organic matter. The end compounds are stable in the range of around 8 on the pH scale. In the present study, the intake pH rose from 5.6 to 8, indicating that RDC was successful. Furthermore, after vermicomposting, the highest pH of the material reached 8.5, indicating a less drastic alteration. Temperature-driven decomposition of RDCs significantly impacts pH changes. Among the byproducts of nitrogen-containing chemical degradation is ammonia, which is released and accumulates in compost material, leading to a rise in pH [22].

Indicative of possible phytotoxic inhibitory effects, EC dynamics are strongly influenced by the degree to which organic components are mineralized during the process [14]. There was a general downward trend in EC values, with a 46% drop occurring during the operation. Extensive research has shown that a compost product rich in soluble salts harms germinating seeds [23]. The present study's final product had a safe value of 2.43 mS/cm when applied to the soil. Previous research on vegetable waste using batch operation has also shown similar tendencies [15] (Fig. 4).

3.2.5 NPK Dynamics in Feedstock

According to the research, both composting and vermicomposting lead to an increase in total nitrogen concentration. Composting and vermicomposting, where the earthworm's gut microbial effects were added to the process, generate nitrogen-rich vermicomposting, which are the primary drivers of this impact. Both processes decompose organic waste, which produces accessible nitrogen and lowers material moisture [18]. Both procedures were used in the present research, leading to more significant nitrogen in the final product. As shown in Fig. 5, the process produced 3.5% TN in the winter and 4.2% TN when the thermophilic range of the reactor was raised above 70 °C in the spring. Vermicompost with a high nitrogen content is a testament to the success of a two-stage composting process.

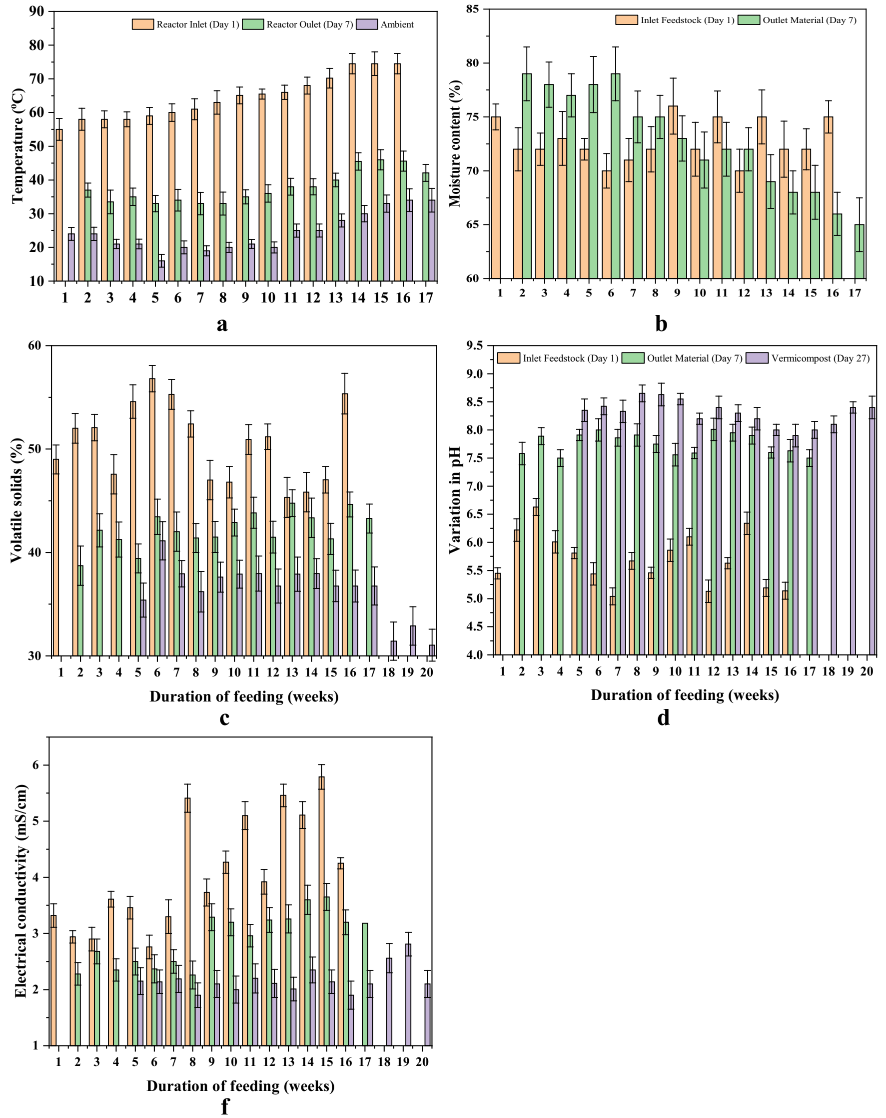

Fig. 4 Variation in **a** Temperature, **b** Moisture content, **c** Volatile solids, **d** pH, and **e** Electrical conductivity during two-stage biodegradation in pilot scale

Effective fertilizer and reasonably high phosphorus levels may be produced from composting organic waste [17]. During the current study's two-stage procedure, the TP content rose by a statistically significant 40% in RDC and by 50% overall. Thermophilic breakdown in the first week of composting is also responsible for the rapid increase in TP.

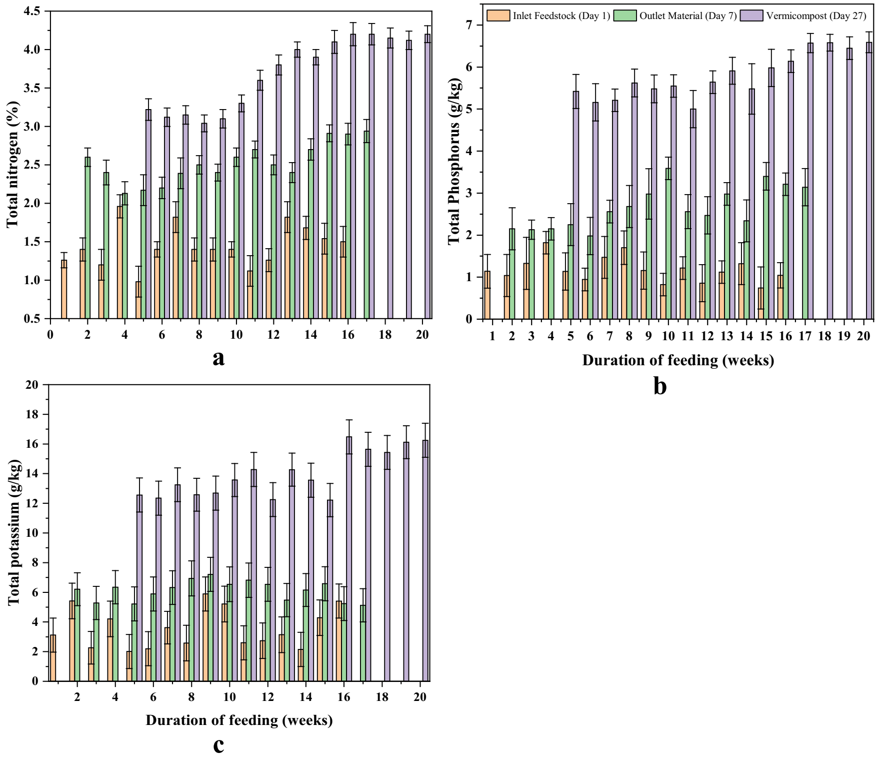

Fig. 5 Variation in **a** TKN, **b** Total phosphorus, and **c** Total potassium

There was a rise in TK, TN, and TP throughout the procedure, a significant increase in RDC (constituting 90% of the gain in value) and an overall increase of 38%. Mineralization and reduction in bulk during microbial degradation are to account for this phenomenon. Additional vermicomposting of the feedstock is accompanied by an increased activity of earthworms, which hastens the mineralization phase and changes the potassium distribution [12].

3.2.6 Vermiculture Growth in Bag Vermicomposters

In this study, *E. fetida* was used, and it performed well in breaking down the feedstock in a batch-scale study. On day 1, 2,000 earthworms were introduced into 1,000 kg of partly decomposed material (via rotary drum composting) for a worm density of 2%. In only 20 days, the worm population skyrocketed from 2 to 8 per kilogram. Additionally, the average number of juveniles and cocoons per kilogram was observed to be 15 and 32, respectively (Table 3). The viability of using *E. fetida* growth vitality and increased cocoon output are signs of early adaption and substrate bioconversion.

Table 3 Vermiculture growth in the pilot-scale vermicomposting

Earthworms	Initial day (day 7)		The final day (day 27)	
	Numbers (per kg)	Biomass (in g)	Numbers (per kg)	Biomass (in g)
Adults	2	0.5	9	6.6
Juveniles	0	0	17	9.8
Cocoons	0	0	37	4.0

This research also suggests that fed-batch feeding may facilitate commercial-scale vermicomposting operations.

3.3 Troubleshooting the Issues Linked with Scale Shift

Preliminary analysis in batch-scale reactors was solid enough to know the fate of the organic waste through a two-stage biodegradation technique. However, in the same study, if we wanted to replicate it pilot scale, various issues needed to address.

1. Seeding the reactor prior to use.
2. Bulking agent availability.
3. Controlling the leachate formation during the process.
4. Duration of aeration.
5. Number of rotations during the biodegradation.
6. Vermiculture availability.
7. Economic potential.

The operational aspects suggested that adding 20% bulking agent and vegetable waste can reduce moisture-related issues during the process. As the literature suggested, two turns, one at the time of feeding and one after feeding, will provide proper mixing of the feed material with existing material will be sufficient. Further, if the waste of higher moisture content (>90%) is meant to manage through the process, it is suggested to maintain the moisture of the material feeding at 60% can reduce the associated problems.

3.4 Practical Implication of the Study

The study's focus on optimizing composting as a waste management strategy reveals that this approach has significant potential as a decentralized waste management tool. Trash that biological processes can break down has always been an inherent component of municipal solid waste. Daily production might be regarded as a possible source of organic waste. The organic waste generated in metropolitan areas often finds its way into landfills; this trash is also one of the factors contributing to the production of leachate and greenhouse gases by landfills. The method that has been mentioned has the potential to lessen the strain that the community feels as a result of its organic waste, and if it is put into practice on a community scale, it has the potential to create manure that the community may put to a wide range of uses. The organic waste generated in urban areas has a new opportunity to be repurposed into manure thanks to recent developments.

4 Conclusions

The study references the use of a reactor-based biodegradation process on a pilot scale and continuous feeding up to 250 kg per day using the 5000 l capacity rotary drum composter in combination with vermicomposting using vermi bags. The temperature profile of the pilot scale reactor signifies the efficiency of the in-vessel reactor in developing rapid biodegrading conditions in biomass. The resulting vermicomposting exhibited the desired NPK values to be used as a soil conditioner.

Acknowledgements The author would like to express his gratitude to the Department of Science and Technology, Government of India, New Delhi (File Number—DST/TDT/WMT/2017/153 (G)).

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