Wastewater Management and Treatment Technologies with Recycling and Reuse Issues in India Leading to Zero Liquid Discharge (ZLD)

Ashim Kumar Bhattacharya and S. N. Roy

Abstract Wastewater treatment and its recycling issues are considered to be as one of the greatest challenges in today's perspective leading to sustainable water management practices. Wastewater generated from industrial, municipal and communities is contaminated significantly our available water resources and, in some cases, make it toxic as well. It has been estimated that by 2025 India will face severe water scarcity when the water availability in India will drop below 1,000 m^3 per capita unless adequate and sustainable water management practices are initiated on immediate effect. So, these wastewaters must be treated properly before they are discharged. Currently, a very small percentage of domestic and industrial wastewater is treated in India. All large cities in India together generate over 30 billion litres of sewage of which only 6.2 billion litres is treated. In Class-I cities only 26% of the wastewater is treated while in Class-II cities a mere 4% of the wastewater is treated. In case of Industry, around 60% of wastewater is remaining untreated. Recently the Central and State regulatory bodies has implemented stringent discharge norms for wastewater to protect the quality of Nation's water. Based on the fact, suitable technology solution must be taken into consideration to treat the polluted and sometime toxic wastewater generated from industries and municipalities. At the same time wastewater recycling and reuse issues must be given priority to protect country's freshwater resources. Further, online monitoring of effluent quality standards has also been implemented by Central Board for close monitoring of wastewater related issues which at the same time helps to protect our fresh water resources nationwide. The Indian wastewater Industry presently facing acute problems with respect to treatment with recycling and reuse issues across the country as the existing facilities do not function up to the mark

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as desired in revised regulatory norms. The main reasons for the above problems are (a) selection of incorrect and some time backdated technology, (b) faulty design of the system, (c) poor operation and maintenance and (d) lack of operator training for skills and knowledge development. As per estimation, the metros and the largest cities in India are collectively responsible for producing around 38 billion litters of waste water every day, which will eventually need to be recycled. Treated waste water could be the answer to the future of a secure water source in the country. They can be used for industries like Thermal plants, Coal sector, Mining and Mineral processing which often not required so high purity water and thereby help to meet the other industrial and agricultural needs of the nation. Long term challenges of depleting ground and surface water resources can be addressed if waste water recycling is effectively implemented across the country. In the present paper, wastewater management practices in industrial and municipal sector with treatment methodology and various technological aspects have discussed. Different Biological Treatment technology based on conventional, fixed and fluidized bed using media as a carrier of Biological population have been covered. Advance waste water treatment technology like membrane bioreactor; application of membrane-based separation technology during tertiary treatment for recycle and reuse issues have also been taken into consideration. Comparison of Performance efficiency, space availability and cost economic factor of different technologies during primary, secondary and tertiary/advance treatment have been highlighted. Finally, concept of zero liquid discharge leading to sustainable water management practices has also been incorporated with one or two case study examples.

Keywords Wastewater treatment · Water scarcity · Regulatory discharge limits · Fresh water resources · Online monitoring of effluent quality standards · Wastewater recycling · Membrane based separation technology · Tertiary/Advance treatment · Zero liquid discharge · Sustainable water management

1 Introduction

Due to unprecedented growth of population with rapid urbanization as well as industrialization, the entire world specifically developing countries like India is facing challenges on clean and safe water supply. Wastewater generated from industrial, municipal and communities are increasing day by day. It is contaminated significantly our available surface and ground water resources and, in few cases, make it toxic as well. India accounts for 2.4% of Global land area, contributing 16% of world population but represents only 4% of world fresh water resources.

Total water resource availability in the country estimated to be about 1123 BCM (690 BCM from surface and 433 BCM from ground). Irrigation sector seems to be in the top which consumed around 85% of total water availability (Table 1), which again reported to be increase to 1072 BCM by 2050. Ground water is the major source for irrigation in the country. Annual groundwater recharge is about 433 BCM

Table 1 Water demand (billion cubic meters by sector wise) in India till 2050

Sector	2010	2025	2050
Irrigation	688	910	1,072
Industry	12	23	63
Drinking water	56	73	102
Others	57	87	210
Total	813	1,093	1,447

of which irrigation covered 212.5 BCM and 18.1 BCM covered by domestic and industrial sector [1]. Based on present population growth-rate (1.9% per year), the Indian population is expected to cross the 1.5 billion mark by 2050. Due to increasing population with infrastructural and industrial growth, the per capita average annual freshwater availability of the country has been reducing significantly since 1951 from 5177 m^3 to 1588 m^3 in 2010. India is already declared as a water stressed country being per capita availability falls below 1700 cum per person per day. And it is expected to further reduce to 1341 m^3 in 2025 and 1140 m^3 in 2050. Therefore, there is an urgent need for efficient water resource management through enhanced water use efficiency and waste water recycling [2]. Table 1 depicts the water demand in India till 2050.

During recent years, urban and infrastructure development in India is moving mostly in a unplanned manner. Further, infrastructure needed to cater the development process is being stretched to its breakeven point. This leads to water management to be an inherent part of planning and development. The municipalities and industries are observed to be continuously making substantial investment in water and wastewater treatment sector in the country. And this results in opening wide opportunities for technology and equipment solution providers in the said sector [3].

Currently, a very small percentage of domestic and industrial wastewater is treated in India. All large cities in India together generate over 30 billion litres of sewage of which only 6.2 billion litres is treated. In Class-I cities only 26% of the wastewater is treated while in Class-II cities a mere 4% of the wastewater is treated. In case of Industry around 60% of wastewater is being treated [4]. Further, as per the UNESCO and WWAP (2006) estimates [5], the productivity of industrial water usage for India (IWP, in billion constant 1995 US$ per m^3) is seems to be the lowest reported to be just 3.42 and about 1/30th of that for Japan and Republic of Korea. Further by 2050, it has been reported that about 48.2 BCM per day of wastewaters having potential to meet 4.5% of the total irrigation water demand of the country [6]. So, the wastewaters generated by industrial and municipal sectors must be treated and managed properly to make it suitable for discharge and possible reuse [7].

The reducing per capita availability of water and deteriorating water quality has forced the country to look for sustainable and effective water technologies to meet clean and quality water demand [3]. Wastewater treatment and its recycling issues are considered to be as one of the greatest challenges today in a country like India that will lead to sustainable water management practices.

Recently the Central and State regulatory agencies has implemented stringent discharge norms for wastewater to protect the quality of Nation's water resources. Based on this fact, suitable technology solution must be bringing into the picture to treat the polluted and sometime toxic wastewater generated from industries and municipalities. At the same time wastewater recycling and reuse issues must also be given high priority to meet country's freshwater demand. Further, recently online monitoring of effluent quality standards has also been implemented by Central board for close monitoring of wastewater discharge parameters and compliance issues which ultimately helps to protect our fresh water resources nationwide to a great extent.

1.1 Common Effluent Treatment Plants

The Small-Scale Industries in the country has been reported to be increased to large numbers in recent years which again raise the concern on increased volume of wastewater generation in the country. Further, most of the SSI units due to space constrain, lack of skills and knowledge, and limited financial capacity individually unable to install and operate their own wastewater treatment plant, resulting in inability to meet the regulatory issues. To address the pollution coming out from these categories of industries, Common Effluent Treatment Plants (CETPs) seems to be one of the viable solutions for small and medium scale enterprises for effective wastewater management.

In India, Ministry of Environment and Forest (MoEF) during 1991 initiated an innovative financial support scheme for CETPs to ensure growth of the small and medium entrepreneurs (SMEs) in an environmentally compatible manner. While initially the scheme was launched for first ten years, but based on evaluation of need base demand, it was extended further. Accordingly, the MoEF instructed various State Pollution Control Boards (SPCBs) to examine the possibilities of establishing CETPs in various industrial estates in the respective states. As reported, in India more than 150 CETPs have been set up so far under this scheme. The CETP facilitates in reduction of number of discharge points in an industrial estate for better enforcement by regulatory bodies. The investment of substantial government finances in the CETP scheme was justified on the basis of potential benefits in terms of pollution reduction and environmental improvements by protecting our fresh water resources [8].

1.2 Problem Statement

The Indian wastewater Industry presently facing acute problems with respect to treatment with recycling and reuse issues across the country as the existing facilities do not function up to the mark as desired in revised regulatory norms.

The main reasons for the above problems are (a) selection of incorrect and some time back dated technology, (b) faulty design of system, (c) poor operation and maintenance and (d) lack of operator training for skills and knowledge development.

As per estimation, the metros and the largest cities in India are collectively responsible for producing around 38 billion litters of waste water every day, which will eventually need to be recycled. Treated waste water could be the answer to the future of a secure water source in the country. They can be used for industries like Thermal plants, Coal sector, Mining and Mineral processing which often not required so high purity water and thereby help to meet the other industrial and agricultural needs of the nation. Long term challenges of depleting ground and surface water resources can be addressed if waste water recycling is effectively implemented across the country.

Due to improper design, poor maintenance, frequent breakdown of electricity and lack of availability technical man power, the wastewater treatment facilities do not function properly, in fact, often remain closed for most of the time [9]. One of the major problems with many waste water treatment facilities is that none of the implemented technologies has been assessed by cost benefit analysis with payback period. Due to this, most of the local authorities are often became less interested in smooth running of waste water treatment plants. Based on a performance evaluation studies of STPs in some selected Indian cities carried out by CPCB, it has been reported that though the waste water treatment capacity in the country has increased by about 2.5 times during last three decades, still hardly 10% of the sewage generated has been reported to be treated properly and effectively. The rest finds its own way to contaminate the rivers and ground water resources in the country and thereby disturbing the natural dynamic equilibrium of our ecosystems [7, 10].

1.3 Technology Trends

The knowledge on wastewater treatment for reuse has evolved quite a long time before and it has been advanced with human history [11]. Reuse of untreated municipal wastewater has been practiced for many centuries to divert the human waste outside of urban settlements. Likewise, use of domestic wastewater for land application is an old and common practice. This under different stages of development has led to better understanding of process, treatment technology with simultaneous development of water quality standards. In countries like Europe and United States of America wastewater treatment and it's recycling and reuse has been reported to be practised for quite some time. However, in recent years, with enhance demand for drinking water resources; the rate of water reuse is becoming a priority issue in the Asia Pacific regions as well, specifically in a country like India [3].

Majority of the Sewage Water Treatment plants (STPs) in India were developed under various river action plans (from 1978–79 onwards) and are located in Class-I and class II cities/towns along the banks of major rivers [12]. Oxidation Pond and activated sludge process reported to be the mostly commonly employed technology followed by Up-flow Anaerobic Sludge Blanket technology. Later quite a number of Waste Stabilization Ponds Technology has also been reported to be implemented successfully. A World Bank Report [13] came out strongly in favour of stabilization ponds as the most suitable wastewater treatment system for municipal sewage treatment plants in developing countries like India, where land is often available at reasonable opportunity cost and skilled labour is in short supply. But with recent trends of urbanization with infrastructural growth in the country together with land availability plays one of the pivotal roles for shifting from selection and implementation of aforesaid land-based technology. Technology trends from then onwards focused move towards more space saving technology, lower installation and commissioning time with performance oriented improved effluent quality suitable for recycle and reuse.

Wastewater treatment technology mainly involve a preliminary treatment in the initial stage to remove coarse /bulk materials with substances like oil and grease and then follows three stage of treatment process namely Primary, Secondary and Tertiary Treatment process. Primary and Tertiary treatment process are mostly based on physico-chemical treatment. Different technologies involve in the process includes coagulation-flocculation, de-emulsification for treatment of oily wastewater, sedimentation/clarification, dissolve air flotation, flash mixer, clariflocculator, dual media filter, activated carbon filter, pressure sand filtration and tank stabilization etc. Secondary treatment process mainly known as biological treatment process is responsible for degradation of organic matter relying on bacterial population. The dominating technologies in the biological treatment process are mainly based on mechanism of suspended and attached growth process. More details of the aforesaid technologies have been discussed in the later sections.

With increasing water scarcity and demand along with stringent regulatory norms forced Industries to search more on wastewater recycling technologies for sustainable growth. Recycling of wastewater involves a combination of technologies to treat the wastewater and make it reusable with attainment of safe disposal standards. As energy-efficient cost effective processes are need of the hour membrane based separation technologies, hybrid/solar desalination and advance oxidation technologies will gain importance during the years to come.

1.4 Regulatory Trends

With the increase of urbanization and industrial activity, availability of fresh water resources in the country is in declining trend. The regulatory and compliance issue as set by the government authority become more stringent to maintain the wastewater discharge quality requirements. There are total 46 categories of industry have been identified specific to each industry segments in India which includes industry like distilleries, pulp and paper, power sector, refineries etc. Recently, based on the trend of water resource scenario in the country, the policy on Zero Liquid Discharge (ZLD) has been drafted by Ministry of Environment and Forests (MoEF) which strives the industry for gradual move to ZLD status specifically water intensive industries like

Textile, Pulp and paper, Steel and Power etc. The implementation part of the policy will be governed by individual State Pollution Control Boards. Presently, only a few states in the country have been advised to specific industry end users like Textile, Paint, Pulp and Paper, Pharma, Automobile manufacturer, Breweries to achieve the ZLD status as a mandatory requirement. In fact, this is expected to be implemented thorough out the country during the coming years [3].

In the present paper, wastewater management practices in industrial and municipal sector with treatment methodology and various technological aspects will be discussed. Different Biological Treatment technology based on conventional, fixed and fluidized bed using media as a carrier of biological population have been covered. Advance waste water treatment technology like membrane bioreactor; application of membrane-based separation technology during tertiary treatment for recycle and reuse issues have also been taken into consideration. Comparison of Performance efficiency, space availability and cost economic factor of different technologies during primary, secondary and tertiary/advance treatment have highlighted. Finally, concept of zero liquid discharge leading to sustainable water management practices has also been incorporated with one or two case study with examples.

2 Wastewater Management and Treatment Practices in India in Industrial and Municipal Sector

2.1 Treatment Methodology

Wastewater depending on its source and characteristics may subject to different treatment options. The wastewater management and treatment practices followed by industrial and municipal sector as discussed in the previous Sect. 1.3 are based on collection and preliminary treatment followed by primary and secondary treatment process. Finally wastewater is allowed to pass through tertiary and advance treatment process to remove residual solids (mostly suspended), organic matters and sometimes nutrients as well. Advance treatment process and operation often makes it suitable for recycle and reuse meeting the regulatory norms set by central and state authorities (Fig. 1). Clear understanding, in-depth knowledge of all these treatment methodologies, technological aspects, selection process and factors regulating the treatment mechanism is very important for better management of wastewater treatment plants (ETPs/STPs/CETPs).

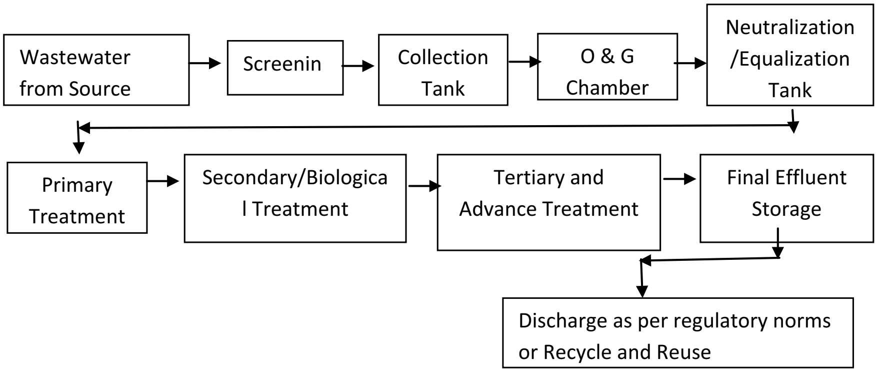

Fig. 1 Treatment methodologies for wastewater treatment

2.2 Technological Aspects

Based on treatment methodology, the availability of different types of technologies and their applicability to Indian wastewater sectors are discussed in detail in the following sections:

2.2.1 Primary Treatment Technologies (Physico-chemical Treatment of Wastewater)

Primary Treatment Methodology is considered as the 1st stage of wastewater treatment process. It is mostly based on physico-chemical unit operations. The treatment process followed largely depends on the operations being carried out in the production/utility process in the plant. Physical operations such as screening, sedimentation, skimming and flotation are used. The steps involved screening, removal of oil and grease by skimming mechanism or by application of de-emulsification process prior to skimming in case of emulsified oily waste treatment. Next process involves equalization/neutralization processes followed by sedimentation/clarification with or without coagulation-flocculation. It has been observed that in many of the industry sectors like Pharmaceutical, Food processing, Paints, Dairies the removal of oil and grease is carried out manually which seems to be ineffective and there is every possibility of carryover of oil and grease in next stage of treatment process. As a result, post treatment performance got affected. Installation of proper skimming mechanism with belt type skimmer as shown in Fig. 2 may strongly be recommend for solving the issue in an effective manner.

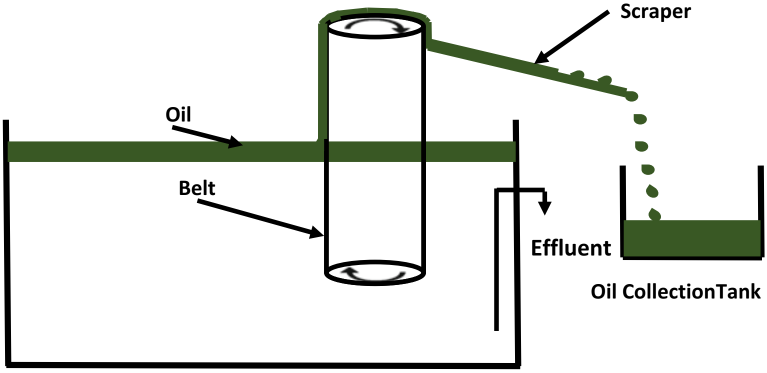

Fig. 2 Belt type skimmer for removing oil and grease from wastewater

2.2.2 Coagulation-Flocculation Technology

For removal of suspended solids, coagulation–flocculation technology (Fig. 3) is the most dominating one in globally and also in Indian Industry sector. Here selection of chemicals specifically polymers plays a most crucial role for obtaining optimum removal efficiency of the suspended solids. It's a three-stage treatment process i.e. rapid mixing (1st stage) followed by slow speed mixing (2nd stage) and lastly sedimentation/clarification process (3rd stage).

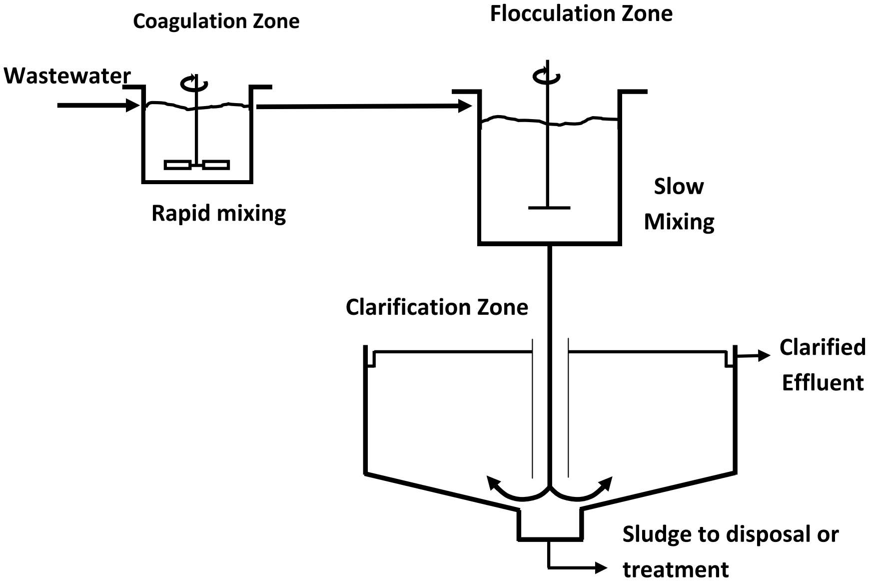

Fig. 3 Chemical coagulation-flocculation process in wastewater treatment

The equipment used in the 1st stage of the treatment process is known as Flash Mixer which involve high speed mixing (150–200 rpm) of influent with the chemicals commonly termed as coagulant. The examples are Alum, Poly Aluminium Chloride (PAC), Lime, Ferric Alum etc. In this stage agglomeration of suspended solids and colloidal impurities occurred by charge neutralization process. Retention time provided here typically vary from 30 s to 2 min.

2nd stage is the floc building stage where after agglomeration. Here, flocculants are added in the flocculation tank with a stirring arrangement with a speed of 30–50 rpm and retention time of 20–45 min. Here the particles come closer together to build large size heavier particles commonly known as floc having very high settling rate.

3rd stage is the sedimentation or say clarification process where the suspended/colloidal impurities settle down after floc building stage and effluent got clarified in the sedimentation tank or clarifier. In this zone, 1–3 h retention time is provided. The clarified effluent then allows passing to the next stage of treatment process namely Biological Treatment process.

Some design considers coagulation, flocculation and sedimentation in a single unit often termed as Mixing-Flocculation-Sedimentation (MFS) Unit.

During primary treatment process, selection of coagulant plays a crucial role to obtain system efficacy and it depends upon the nature of suspended solid to be removed, wastewater matrix, design facility, and chemicals cost. Quantity required depend wastewater flow and suspended solids loading rate. However, final selection of coagulant (or coagulants) should be made with jar testing experiments at lab level first followed by plant scale evaluation. Consideration must be given to required treated effluent quality, effect upon downstream treatment process performance, cost factor and sludge generation/handling cost and its disposal through effective treatment [14].

In coagulation–flocculation process during clarification stage clarifier generally chosen circular type of clarifier where retention time provided is 2–3 h. But sometimes the clarifier has been found to replaced by tube settler or say plate separator type of mechanism which requires much less space, lower installation commissioning time and faster settling time as well with retention time varies from 1 to 2 h maximum.

2.2.3 Advantages of Tube Settler

Tube settlers offer a cost-effective approach for upgrading existing wastewater treatment plant clarifiers and sedimentation basins to obtain enhanced performance with energy efficient manner. It often helps to reduce the tank age/footprint required in new installations or improve the performance of existing settling basins by reducing the solids loading on downstream filters. Tube settlers generally made of light weight PVC and can be easily supported with minimum structures that often incorporate the effluent trough supports [15].

One great advantage of tube settlers is that they are often available in a variety of module sizes and tube lengths to fit any tank geometry, with customised design and engineering offered by the manufacturer.

It uses multiple tubular channels placed at an angle of 60° and adjacent to each other, which combine to form an increased effective settling area. This provides for a particle settling depth which is significantly less than the settling depth of a conventional clarifier, reducing settling times. The channel collects solids into a thickened mass which promotes the solids to slide down along the tube channel. It can be installed as needed to fit in a new or existing clarifiers/basin of any size [15].

Only in case of high TSS loading and large capacity wastewater treatment plant, tube settler type of mechanism often lead to chocking problems which required frequent cleaning-making it operation/maintenance intensive. In that case circular clarifier may be looked for a better choice.

2.2.4 Dissolve Air Flotation Technique

Flotation is a unit operation that separate simultaneously oil and grease with suspended solids from the wastewater stream. Separation is carried out by introducing fine gas (usually air) bubbles into the liquid phase. In this section it has been discussed in detail considering it as one of the most effective treatment systems for wastewater containing suspended solids with oil and grease. The most common technique is that of dissolved air flotation (DAF), in which the waste stream is first pressurized with air in a closed tank. Then it is allowed to pass through a pressure-reduction valve, after that wastewater enters the flotation tank (Fig. 4) where, due to the sudden reduction in pressure, minute air bubbles in the order of 50–100 microns in diameter are formed. As the bubbles rise to the surface, the suspended solids and oil or grease materials adhere to them and are carried upwards. Most of the cases, chemicals are used to enhance flotation performance with coagulants, flocculating agents, emulsion breaking agents etc. [16].

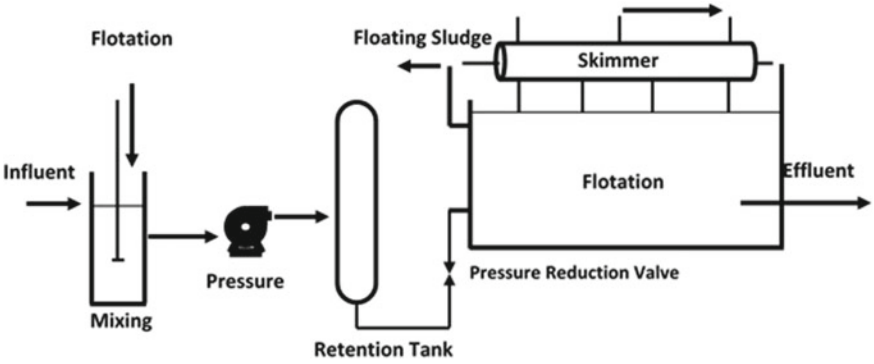

Fig. 4 Process design of a dissolved air flotation system

The main advantage claimed for a DAF system is the faster rate at which very small or light suspended solids can be removed in comparison with settling [16].

Performance of DAF system has been reported to be dependent on several factors like inlet solids concentration and air to solid ratio, maintenance of pH of the system.

Also proper flow rates and the continuous presence of trained/skilled operators are found to be key performance criteria for any DAF system. The principal advantages of this dissolve air flotation technique over sedimentation are that very minute or light particles that settles very slowly in sedimentation process can be removed almost completely and also in a less time. Once the particles floated in the surface, can be removed by skimming operation [17].

In one study, oil removal was reported to be 90% [18]. Another study, in first case a unit of tuna processing wastewaters, the DAF able to removed 80% of oil and grease and 74.8% of suspended solids in one case and a second case showed removal efficiencies of 64.3% for oil and grease and 48.2% of suspended solids. The main difference between these last two effluents was the lower solids usually content of the second [19]. Although considered very effective, DAF systems are not generally recommended for treating oily wastewater from small scale industrial units due to its high cost [20] and also requirement of skilled/trained operators [14].

2.2.5 Biological Treatment Technologies

Biological treatment is considered as an essential and integral part of any wastewater generated from industrial or municipal source. The wastewater generally contains soluble organic impurities or a mix of the both types of wastewater sources. The obvious treatment performance with cost benefits, both in terms of capital investment and operation/maintenance costs of biological treatment, over other treatment processes seems to be quite significant in any integrated wastewater treatment plant.

Biological treatment process often referred to as secondary treatment process where the microorganisms used are responsible for the degradation of the organic matter with the stabilization of organic wastes. The biological treatment processes are broadly classified as aerobic (in which aerobic and facultative micro-organisms predominate) or anaerobic (which use anaerobic micro-organism. Further, if the micro-organisms are suspended in the wastewater during biological operation, the operations are "called suspended growth processes", while the micro-organisms that are attached to a surface act as a carrier over which they grow are called "attached growth processes".

In most of the cases aerobic treatment process is followed. In case of effluent with high organic load e.g. in distillery, dairies, food processing, slaughter house effluent—the biological treatment process carried out first by anaerobic treatment followed by aerobic treatment to reduce the load to aerobic process and also to achieve the desired output in terms of BOD removal efficiency. The end product is methane in case of anaerobic process while in aerobic treatment the end product is carbon dioxide and water.

The low biomass yield does mean the nutrients requirement of an anaerobic process is lower than that of the aerobic process. In terms of BOD:N:P, the aerobic process would have required 100:5:1 while the anaerobic process only require 100:3.5:0.5. Notwithstanding this lower requirement, nutrients supplementation may still be considered in many industrial wastewaters treatment where wastewater are seems to be nutrients deficient even for anaerobic processes [21].

The conventional sewage treatment technologies such as Activated Sludge Process (ASP), Waste Stabilization pond (WSP) [22] up flow Anaerobic Sludge Blanket (UASB) Reactor etc., are commonly adopted in sewerage system to treat wastewater up to secondary level as per the effluent standards.

Biological treatment using aerobic activated sludge process has been followed widely well over a century both in municipal and industrial wastewater treatment. However, in recent years due to stringent regulatory norms forced the industry and municipal sector to follow various advance biological treatment technologies based on suspended and attached growth process.

Different dominating technologies in the Biological Treatment field in the country as per present practices applicable to industrial and municipal wastewater treatment are mentioned below.

2.2.6 Conventional Activated Sludge Process (ASP)

This is the most common and widely used aerobic biological treatment process to treat the wastewater generated from Industrial and Municipal services. The process is based on suspended growth of bacterial population where effluent after removal of suspended solids in primary treatment enter into the system comprising of a Aeration tanks and a secondary clarifier (Fig. 5). Diffused aeration technique is now followed to maintain Dissolve Oxygen level typically in the range of 2 mg/l. Biological growth is monitored by measuring Mixed Liquor Suspended Solids (MLSS) in the range of 1800- –4,500 mg/l typically or Mixed Liquor Volatile Suspended Solids (MLVSS)

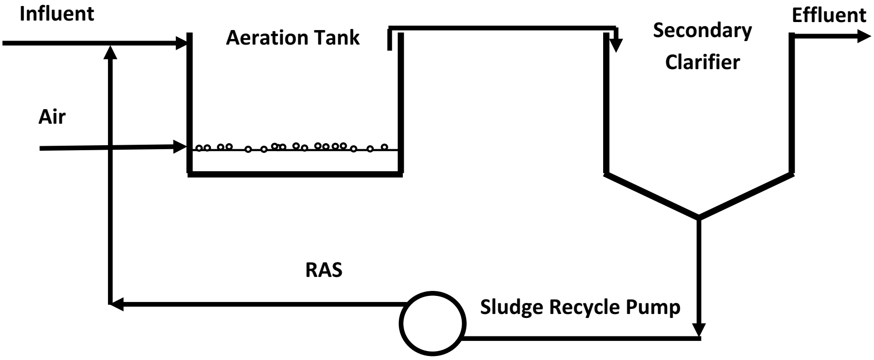

Fig. 5 Schematic of conventional activated sludge process

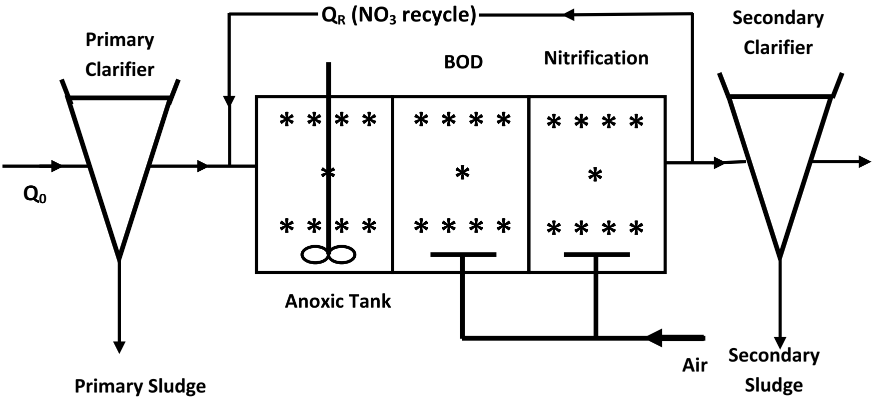

Fig. 6 Schematic of fluidized bed bio-reactor (FAB)/moving bed bio-reactor (MBBR) process

which should be 70% of the MLSS value for effective degradation of COD and BOD of the wastewater by removing soluble organics present.

2.2.7 Fluidized Aerobic Bio-reactor (FAB) More Popularly Known as Moving Bed Bio-reactor (MBBR)

This technology is based on the attached growth process. Here bacteriological growth is higher compare to conventional activated sludge process due to additional surface area availability provided by the media. Diffused aeration is essential and the reactor carrying the media acts as a fluidized bed. Thus, the process often referred to as Fluidized Aerobic Bioreactor (FAB) or also termed as Moving Bed Bioreactor (MBBR) as well. Schematic flow diagram of the process is presented in Fig. 6. This technology seems to be preferable option than the conventional activated sludge process due to higher surface area availability resulting in enhanced organic load reduction in the wastewater [22].

2.2.8 Submerged Aerobic Fixed Film Bio-Reactor (SAFE)

The key features of this process are in the following which represents in Fig. 7.

- Tube settlers inside aeration tank offer space economy
- Essentially a fixed film media as the name suggest with enhanced oxygen supply through submerged aeration
- Reactors up to 6 m deep enabling low land requirements
- Large biomass and long solid retention time in the reactor leading to low ‘food to micro-organism ratio and higher organic removal based two stage biological oxidation

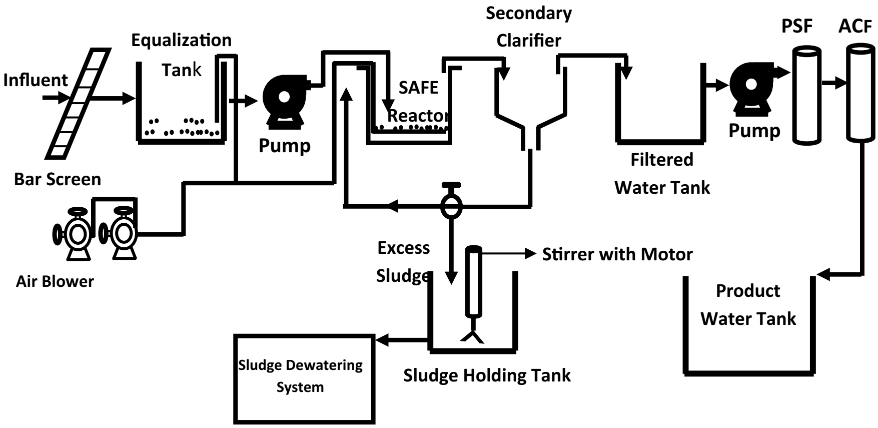

Fig. 7 Schematic of submerged aerobic fixed film bio-reactor (SAFE) process

- Many Pharmaceutical, food processing plants based on such technology are functioning in industrial wastewater application in India.

2.2.9 Sequential Batch Reactor also Known as Cyclic Activated Sludge System (SBR/CASS)

This is one of the newer technologies recently using in Indian industrial and municipal wastewater treatment sector. The treatment methodology of this technology may be looked as a variation of ASP technology which is essentially a batch treatment by combining, primary settling, aeration, secondary settling and decanting the treated effluent in a series of sequenced and or simultaneous reactions in the same basin on a time deferred cycle. Thus, multiple basins are considered for the design basis whereby when one tank is in one part of the cycle such as aeration, another tank will be settling and discharging the treated effluent in a cyclically repeated operation. For the aeration purpose high efficiency fine bubble non-clog membrane type diffusers are preferred. The rate kinetics for the bio reaction in this process is non steady type, not like conventional activated sludge process where reaction kinetics is based on continuous flow steady state. Close monitoring and optimization is essential for achieving the higher rate. Schematic diagram of Sequencing Batch Reactor process is presented in Fig. 8.

The process has the ability to remove simultaneously BOD with N and P from the wastewater. The technology got popularized and seems to produce very effective results in India in municipal sewage treatment. The consideration of this technology for industrial wastewater treatment specifically for Distillery, Dairy, Slaughter House, Textile, Tannery wastewater is yet to be established.

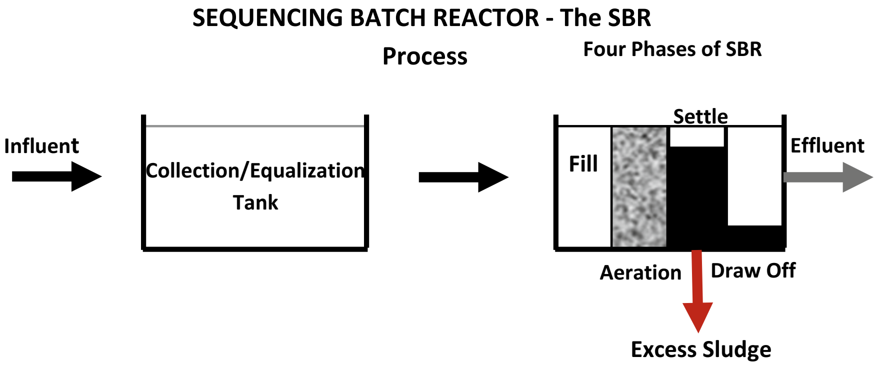

Fig. 8 Schematic of sequential batch reactor (SBR) also known as cyclic activated sludge system (CASS)

2.2.10 Integrated Fixed Film Activated Sludge System (IFAS)

During the initial stage of wastewater treatment plant installations where two stage biological treatment is followed-comprising trickling filter containing mostly stone or sometime plastic media as biological growth carrier (often referred to as packed bio-tower) [23]. The process is then followed by activated sludge process based on suspended growth, followed by secondary clarifier. But with technological advancements, space constraints, stringent regulatory norms this technology is presently rarely followed in Indian Industrial and Municipal wastewater treatment.

The improved and advance version of above configuration has been developed now for implementing in newer industrial as well municipal wastewater treatment systems. The process consists of fluidized aerobic bioreactor often termed as moving bed bioreactor (MBBR) instead of bio-tower followed by activated sludge process. This process has been reported to be produce very successful results in some of the industries like refineries and petrochemical, where the existing wastewater treatment system based on single stage conventional activated sludge process followed by secondary clarification tank is undergoing a capacity expansion plan or forced to meet stringent discharge norms. This hybrid process comprising of fluidized/moving media and activated sludge process is known as Integrated Fixed Film Activated Sludge (IFAS) process [23].

Some major advantages of the aforesaid process are providing below:

- The IFAS system provides enhanced surface area for biomass to grow and degrade the organic contaminants that are reluctant to biodegradation or also may sometime toxic to the environment as well.
- The overall efficiency of IFAS process is higher and more effective in nitrification of wastewater than conventional activated sludge process alone.
- Due to less wastage of sludge, the IFAS process provides much improved sludge management and dewatering facility as compared to the activated sludge process [23].

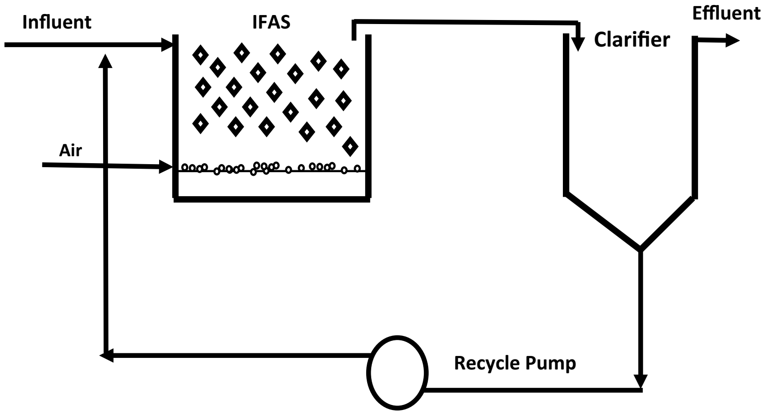

Fig. 9 Schematic for integrated fixed film activated sludge (IFAS) system

The sequences are shown in Fig. 9.

- It can be easily incorporated in the existing activated sludge system to meet additional load due to increased production and process capacity requirement and/or stricter regulations without the need of constructing additional concrete tanks.
- Foot-print of IFAS has a smaller with lower capital and operating cost.

2.2.11 Membrane Bioreactor (MBR)

Membrane Bioreactor technology is now considered to be the most advance technology producing high quality water almost ready for recycle and reuse. This technology combines the aeration and secondary clarifier in one and the same tank by sucking out the aerated mixed liquor through membranes instead of settling in a separate downstream tank. Thus, it yields a treated sewage with practically almost no BOD and suspended solids. Virtually clear and transparent treated liquid obtained from the treatment. The membrane is a matter of proprietorship and the throughput per membrane module offered by various companies are different and also each one advocates different shapes of the membranes like flat sheet, cross flow, dead end flow etc., which makes it difficult for common validated standard design criteria.

MBR technology has been in extensive usage for treatment of domestic sewage, but for industrial waste treatment applications, its use has been somewhat limited or selective. Recently as the wastewater recycling scenario growing in a faster rate the industries are become more prone to this technology. Figure 10 showed the difference in the two processes lies in the method of separation of bio-solids [23].

In the MBR process, the bio-solids are separated by means of a polymeric membrane based on microfiltration or ultra filtration unit, as against the gravity clarification process in the secondary clarifier in conventional activated sludge process.

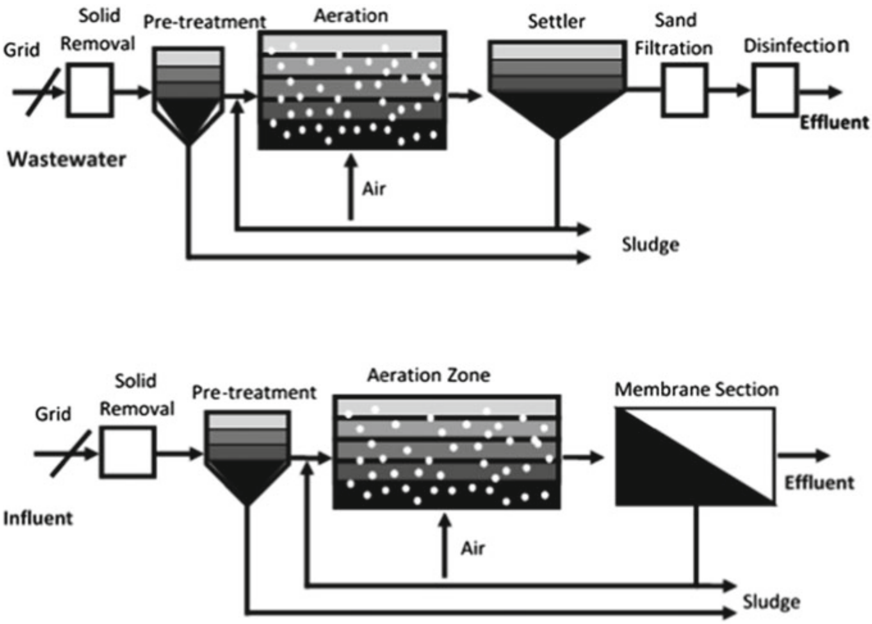

Fig. 10 Schematic of conventional activated sludge process (top) and external (side stream) membrane bio-reactor (bottom)

Therefore, the advantages of MBR system over conventional activated sludge system are obvious as listed below:

- Membrane filtration provides a positive barrier to suspended bio-mass that they cannot escape the system unlike gravity settling in activated sludge process, where the bio-mass continuously leaving the system along with clarified effluent and sometimes a total loss of solids is also occurred due to process upsets and sludge-bulking in the secondary clarifier. As a result, much higher bio-solids concentration measured as MLSS/MLVSS can be maintained (around 3 to 4 times) in a MBR process (around 10,000–12,000 mg/l) in comparison to the activated sludge process (around 2500–4,500 mg/l).
- Due to the above aspect of MBR, aeration tank volume in the MBR process can be one-third to one-fourth the volume of the aeration tank in an activated sludge system. Further, instead of gravity settling based clarifier, a much more compact tank is needed to house the membrane cassettes in case of submerged MBR and skid mounted membrane modules in case of non-submerged, external MBR system.
- In fact, in MBR system requires 40–60% less space as required for activated sludge system. The scope of civil work and overall foot-print as a result reduced to a great extent.

- Due to membrane filtration (micro/ultra filtration), the treated effluent in case of MBR process is much higher quality compared to conventional activated sludge process. Further it avoid the installation of tertiary filtration systems like sand filter and carbon filter which seems to be very common in activated sludge process after secondary clarification. The treated effluent produce is almost ready for reuse like cooling tower make-up, floor washing or for gardening/horticultural use etc. [23].

  Typical treated water quality from MBR system is:

- BOD_5 <5 mg/L
- Turbidity <0.2 NTU
- TSS levels: <0.5 mg/l.

Such high-quality effluent is considered to be an important factor for recycle and re-use based on present scenario of fresh water availability.

2.2.12 Comparison of Different Biological Treatment Technologies Based on Performance with Cost Benefit Analysis

Table 2 Illustrate the comparison of Fluidized bed bioreactor (MBBR) process with Membrane Bioreactor process (MBR) for biological treatment of wastewater.

The performance of a biological treatment technology plays a very significant role with respect to effluent quality achievable for possible recycle and reuse. Tables 3 and 4 provide a technological summary with respect to some effluent quality parameters as mentioned therein.

Table 2 Comparison of MBR and MBBR technology

Sl No	Parameters	MBBR	MBR
1	Type of process	Aerobic fixed film continuous-attached growth	Aerobic continuous
2	Operating parameters	Automatic-PLC based	Automatic PLS based
3	Odour	Odour possibility-as Sludge not fully stabilized	Sludge fully stabilized-no odor
4	Treatment efficiency achievable	90–95% removal of BOD	95% removal of BOD
5	Post treatment requirement for industrial or indirect potable reuse	Filtration-preferable ultrafiltration followed by disinfection, If TDS is not an issue	Only minimal disinfection; If TDS is not an issue
6	Ease of operation during shutdown/maintenance	Maintenance of media is difficult	Membrane cassette can be isolated even treating the full flow
7	Level of operator attention	Medium	Low

Table 3 Different biological treatment technologies comparison summary

Parameters	SBR	MBBR	MBR
BOD in mg/l	10–20	10–20	3–5
TSS in mg/l	<30	<30	<5
Nh3-N in mg/l	2–5	2–5	<1
TP in mg/l	<0.5	<0.5	<0.5
TN in mg/l	<10	<10	<10
Direct use application	Only for landscaping	Only for landscaping	Possible

2.2.13 Tertiary Treatment Technologies

Tertiary Treatment generally includes physical and chemical treatment process followed after secondary treatment to meet the desired treatment objective. Here, final polish is provided to the effluent that improves wastewater quality before it is reused, recycled or discharged to the environment to meet regulatory norms as defined by Central or State Pollution Control Boards.

The major treatment technologies follow in Indian industrial and municipal sector are based on flocculation/sedimentation, pressure sand filtration, activated carbon adsorption, membranes filtration, ion exchange, de-chlorination and reverse osmosis.

Pressure Sand filtration and Activated Carbon Filtration are mostly used during tertiary treatment after secondary clarification mainly to remove fine residual insoluble impurities including trace organics, colour, odor etc.

Depending on financial criteria and effluent quality requirements sometimes Dual Media Filter, Multigrade filter is also provided after secondary clarification. These types of filters contain sand, gravels and Anthracite based media in a single unit and often plays the role of both sand and carbon filter in a single unit operation reducing operation, maintenance cost, backwash frequency etc. to a great extent.

Adsorption

Globally carbon has been recognised as an adsorbent for centuries. Recent changes in wastewater discharge standards regarding toxic pollutants have placed additional emphasis on this technology. Adsorption is particularly effective during tertiary treatment process for treating low concentration waste streams. After secondary treatment process it acts as a polisher in meeting stringent regulatory norms. The adsorption process utilized to remove colour, odour and other soluble organic pollutants from wastewater [24].

The activated carbon adsorption also helps to removes toxic chemicals such as insecticides, pesticides, phenols and its related compounds, cyanides and organic dyes which are difficult to treat by conventional treatment methods. Dissolved organics are adsorbed on carbon surface as waste water containing contaminants is allowed to pass through the adsorbent. Granular activated carbon is reported to be a very good adsorbent compare to powder activated carbon due to its high surface area to volume ratio [23].

Table 4 Comparison of different biological technologies with respect to cost (capital and operational), treated effluent quality and space requirement

Parameters	Conventional ASP	SBR	MBBR	IFAS	MBR
Treated effluent quality	Meets specified discharge standards with additional filtration step	Meets/exceeds specified discharge standards without additional filtration step	Meets/exceeds specified discharge standards with additional filtration etc	Meets/exceeds specified discharge standards with additional filtration etc	Exceeds specified discharge standards without additional filtration step. Very good for recycle provided TDS level permits
Ability to adjust to variable hydraulic and pollutant loading	Average	Very good	Very good	Very good	Very good
Pre-treatment requirement	Suspended impurities e.g. oil and grease and TSS removal	Suspended impurities e.g. oil and grease and TSS removal	Suspended impurities e.g. oil and grease and TSS removal	Suspended impurities e.g. oil and grease and TSS removal	Suspended impurities e.g. oil and grease and TSS removal with fine screening
Secondary clarifier requirement	Needed	Aeration Basin acts as clarifier	Needed	Needed	Clarifier is replaced by membrane filtration
Complexity to operate and control	Simple, but not operator friendly	Operator friendly	Operator Friendly	Operator friendly	Skilled manpower required
Capital investment	Low	Low	Medium	High	Very High
Operating cost	Low	Low	Medium	High	Very High
Space requirement	High	Low	Average	Average	Low

For many water treatment applications it has been proved to be the least expensive treatment option to remove wide variety trace organic contaminates during tertiary treatment process. Its suitability on any specific application will found to be depending on type of contaminants and costs as they directly relate to the quantity of carbon consumed.

Bio-physical Process of Adsorption

The biophysical process is considered as an augmentation and modification of Activated Sludge Process. In this process, powdered activated carbon is added in activated sludge process. Adsorption and Bio degradation take place as a combined process in a single tank, resulting in synergistic effects. The process has been developed in early seventies named as PACT$^{(R)}$ process and widely applied in USA. Later it spread in Europe and other parts of the world. In this process powdered activated carbon is encapsulated in the biological flocs and two different mechanisms takes place. One is adsorption in to powder activated carbon and next is biological removal-both are being complementary to each other. It helps to tackle specifically reluctant, poorly and sometimes non biodegradable organic compounds. Advantages are better sludge sedimentation and dewatering ability, less foaming, increased nitrification, enhanced removal efficiency with improved process stability [25]. Finally, in many cases disinfection process is often applied to make it suitable for further advance treatment with an objective to recycle and reuse.

2.2.14 Disinfection Process

Disinfection refers to the destruction of mainly pathogenic or say disease causing organisms from waste water. In the field of wastewater treatment, the categories of microorganisms which are human centric and responsible for the disease are bacteria, protozoa, cysts, helminths and viruses. The three-disinfection processes which are popular and widely followed in industrial and municipal applications namely chlorination, ozonation and UV disinfection are discussed in the following section.

Chlorination

Chlorination is a process of disinfection most widely used in treatment of both industrial and domestic wastewaters. Other kinds of use reported in wastewater treatment as advance oxidation process e.g. cyanide oxidation. Usually the effluents are treated with chlorine just before their final discharge to the receiving streams or water bodies. Chlorine gas or hypochlorite solutions found to be used the latter being easier to handle [16]. Chlorine forms hypochlorous acid which in turn forms hypochlorite in water solutions.

$$Cl_2 + H_2O \rightarrow HOCI + H^+ + Cl^-; HOCI \rightarrow H^+ + OCl^-$$

During chlorination process often wastewaters may contain considerable amounts of ammonia or volatile amines resulting in an increased demand of chlorine to achieve a desired degree of disinfection as they react with chlorine to produce chloramines. The amount of products depends on the factors like pH, ammonia concentration and the concentration of organic amines present in the wastewater.

The degree of disinfection is attributed to the residual chlorine present in treated water. During initial phase of chlorine dosing residual chlorine is negligible due to presence of reducing agents in the wastewater. With further addition of chlorine residual will appear as combined chlorine residual due to formation of chloramines. A decreasing phase of chlorine residual then observed due to complete reaction of ammonia and amines present with the added chlorine with disappearance of chloramines. Free residual chlorine will then appear on further addition of chlorine which is also referred to as "breakpoint chlorination". The main objective of obtaining some free chlorine residual is to ensure complete disinfection [16].

Chlorination units are generally simple, consisting of a vessel in which the wastewater and the chlorine are brought into contact to produce a good mixing condition. Residence time recommended not less than 30 s. Prior to final discharge, sufficient time (about 15 min) must be provided for the chlorine to react to meet the objective. This may be done in the ducts which carry the wastewater to the discharge point, provided the residence time exceeds 15 min. A typical configuration is shown in Fig. 11 [16].

The levels of free available chlorine should comply with the local regulations that usually vary between 0.2 and 1 mg/l. Some cases excess chlorine as residual in wastewater effluents was identified as the main toxicant suppressing the diversity, size, and quantity of fish in receiving streams or ecosystems [26]. To achieve effective disinfection, although 15 min is very common, retention times of up to 30 min are also used. The chlorine dosage needed to achieve the residuals will vary with the wastewater considered: 2–8 mg/l is common for an effluent from activated sludge plant, and can be as high as 40 mg/l in the case of septic wastewater [16, 17, 27].

Ozonation

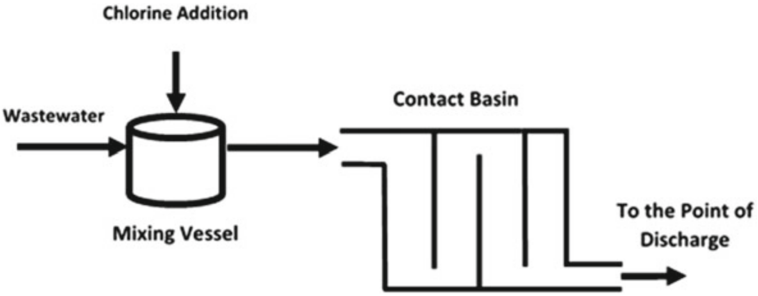

Fig. 11 A typical configuration of chlorination system

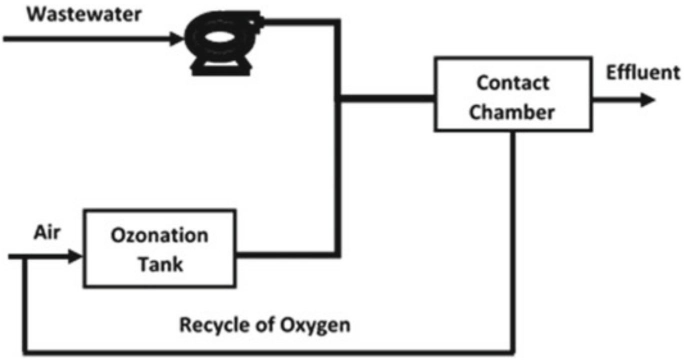

Fig. 12 Schematic diagram of an ozonation system

Ozonation is considered to be a very effective disinfection process applicable to water and wastewater treatment plant operation. It is a unit operation applied at the end of the treatment similar to chlorine or uv disinfection. Ozone seems to be as a very effective oxidizing agent useful for disinfection purpose to kill the bacteria and viruses from the wastewater. Ozone (O_3) is produced when a high voltage is discharged across a narrow gap in the presence of air or oxygen. Ozonation systems in situ generate O_3. From safety point of view ozonation is a much better choice than chlorination. Figure 12 represents a schematic diagram of an ozonation system.

Once ozone has been added and reacted, it enhances the dissolved oxygen level of the effluent to be discharged, which often beneficial to the receiving water stream. Also, as an advance treatment process it often helps to remove traces of any oxidizable impurities present in the wastewater in terms of COD and BOD as well. Contact tanks are usually closed to recirculate the oxygen-enriched air to the ozonation unit. Advantages over chlorination are that it does not produce dissolved solids and is affected neither by ammonia compounds present nor by the pH value of the effluent. It is also reported to be used to oxidize ammonia and nitrites present specifically in fish culture facilities [16, 28].

Ultraviolet (UV) Disinfection

This technique is primarily employed as a disinfection process that inactivates waterborne pathogens without use of chemicals. Additionally, UV is also effective for residual TOC removal, destruction of chloramines and ozone. The process is not considered as a popular one during industrial and municipal wastewater treatment plant application for disinfection purpose like chlorine and ozone.

In Indian wastewater sector the use of disinfection process follows the sequence:

Chlorination > Ozonation > UV disinfection. Considering cost as another factor which follow the sequence Ozonation > UV > Chlorination.

2.2.15 Advance Treatment Technologies for Recycle and Reuse

After tertiary treatment the requirement of advance treatment technology arises especially when the objective is to recycle and reuse. Advance treatment often may be considered to further stabilize chemical and biological oxygen demand in wastewater including removal of nitrogen and phosphorus. Sometimes the wastewater is also treated with substances like ozone or hydrogen peroxide as an advance oxidation process to destroy many trace and harmful contaminants that may contribute to compliance issue in the treated water to be discharged.

While considering the objective of recycle and reuse, advance treatment mainly focused on application of membrane-based separation technologies.

Based on the effluent quality obtained after tertiary treatment, selection of membrane-based technologies has been taken into consideration. Further purification of organics and dissolved salts in tertiary treated wastewater is achieved by use of reverse osmosis. The reverse osmosis is based on the certain specific polymeric membranes, usually cellulose acetate, polyamide or nylon to pass clean and pure water at fairly high rates and salts are rejected by the membranes.

RO membranes are very often susceptible to fouling due to presence of organics, colloidal impurities and microorganisms. A selection of proper pre-treatment systems like Sand filtration, Carbon filtration, Micro filtration and Ultra filtration systems often found suitable to get rid of this fouling issues.

Ultrafiltration (UF)

Ultrafiltration membrane often considered as an important pre-treatment process before reverse osmosis. Also it has been now widely applied during wastewater recycling as an advance treatment process when total dissolve solids in final treated water is not an issue.

It is responsible for retaining only macro molecules, viruses, traces of oily substances, colloidal silica and suspended solids. Thus, components like salts, solvents and low molecular weight organic solutes pass through ultrafiltration membrane with the permeate water [24]. The pressure differences across UF membrane are considered to be negligible due to non-retaining the salts by the membrane. But flux rates through the membranes are seems to be quite high allowing the use of lower pressures.

Nanofiltration (NF)

In the membrane spectrum Nanofiltration is positioned after Ultrafiltration but before Reverse Osmosis with a typical operating range of 0.001–0.01 μm [29]. This is essentially a lower pressure version of membrane capable of removing bivalent hardness causing ions such as calcium or magnesium together with bacteria, viruses, and colour. The treatment cost of nanofiltration is generally lower than reverse osmosis treatment including operational cost. Nanofiltration is preferentially recommended when permeate with some residual TDS but without colour, COD and hardness is acceptable. Feed water system needs to be maintained similar to reverse osmosis. Turbidity and colloidal impurities need to be maintained at minimum level. In case of high turbidity specifically when colloidal silica is present, pre-treatment through Microfiltration and Ultrafiltration is needed to be included in the treatment scheme. Disinfection of feed will be necessary to remove micro-organism from permeate.

3 Zero Liquid Discharge Concept and Case Study Example

Zero liquid discharge (ZLD) is a process developed to provide beneficial effects to industrial and municipal organizations for tackling the stringent environmental norms applicable to liquid and solid waste management. The process enables to protect our environment to its highest level with no effluent discharge or say left over leading to sustainable environmental practices. ZLD systems employ the implementation of advanced wastewater treatment technologies to recover and recycle virtually all of the wastewater produced.

Some of the salient features of a ZLD systems:

- A Zero liquid discharge facility (ZLD), is an industrial or municipal plant means without discharge of any wastewaters.
- Target ZLD is normally achieved by maximum waste water recovery
- Separation achieve by evaporation or boiling of water or part of waste water not reusable after passing through membrane process, in evaporators, crystallizers and recovery. The process produces solid waste and high purity water ready for reuse.
- Finally, ZLD facility enhances corporate image of an organization with a improved marketing image by providing better water resource optimization on sustainable basis.

Presently the major drivers of ZLD in the country are

(i) Water scarcity with growing fresh water demand along with still negligible rate of waste water recycling and water conservation practices following by the industries
(ii) Economics: recycled water becomes more affordable as the usable water supply from conventional sources becomes more expensive in many cases especially coastal and water stress areas.
(iii) Growing social responsibility and as an education towards awareness of environmental issues
(iv) ZLD cost is generally high in most cases but it might be a more economic solution when waste needs to be arranged and transported in large volumes over long distances on daily basis [30].

3.1 *Process Schematic (in General) for a ZLD Project*

Phase-I

Influent → ETP → Treated water from ETP → Ultrafiltration → Reverse Osmosis → Permeate Water → Recycle/Reuse.

Phase-II

Reject from Reverse Osmosis systems → Evaporation/Crystallization → Solid Waste.

Some major components of ZLD Systems

- Ultrafiltration Systems
- Reverse Osmosis (RO) mostly are of two stages
- Mechanical/Multi-effect Evaporators (MEE)
- Agitating Thin Film Digester (ATFD), etc.

3.1.1 Multi-effect Evaporators

This is the most popular and widely accepted unit operation when the desired objective is to achieve a zero liquid discharge facility to meet the stringent regulatory norms in wastewater treatment for an industry (Fig. 13).

The following points seem to be important while considering a Multi-Effect Evaporator system:

- For optimizing the design of an evaporator, one of the most significant consideration is the steam economy (kg of liquid evaporated per kilogram of steam used). In fact steam economy ultimately governs the successful implementation of the process.

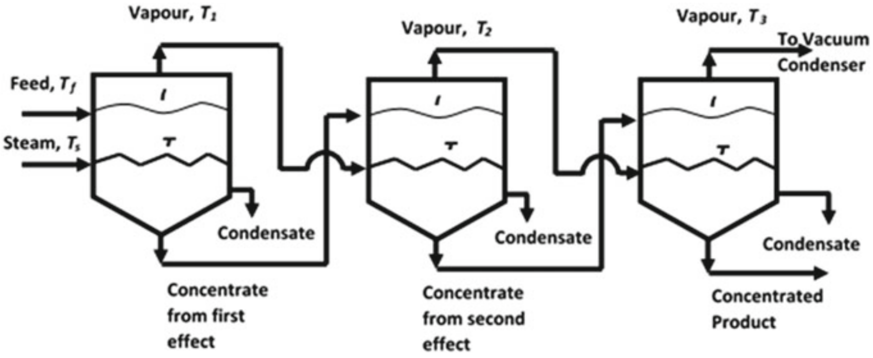

Fig. 13 Multi-effect evaporators for zero liquid discharge facility

- The most effective way to obtain high economies is to use a **Multiple Effect Evaporator**, whereby the vapor from one effect—is used to heat the feed in the next effect, where boiling occurs at lower pressure [31].
- Further, by thermo-compression the vapors will condensate at a temperature high enough to be reused for the next effect through compression, will always help to enhance efficiency of the evaporator.

3.1.2 Agitating Thin Film Digester (ATFD)

This is another unit operation/equipment which often considered during designing a zero liquid discharge system.

Operating Principle

- ATFD stands for evaporation of water/solvents to convert concentrated liquid to dry powder or flakes. Selection is important based on application -either recovered solvent or dry product or dry sludge.
- Agitated Thin Film Dryer is considered to be the ideal equipment for continuous processing of concentrated liquid for drying. The design basis consists of cylindrical, vertical body with heating jacket and a rotor inside of the shell which is equipped with rows of pendulum blades all over the length of the dryer.
- Here, heat will transfer from jacket to main shell by smooth agitation while water/solvent will evaporate and liquid will convert gradually to slurry, to cake and finally to either dry powder or flakes [32].

3.2 Solar Based Application in ZLD

This application is possible where land is not an issue and easily available. The reject from RO systems is directly sent to solar based evaporation pond where under sunlight evaporation take place with subsequent crystallization of the solid. The dry solid is taken out and stored for safe disposal as per solid waste management rules/guidelines. This is seems to be quite effective with respect to energy savings point of view and also significantly low treatment cost with minimum manpower requirement. Considering the climate scenario in India this type of project may be looked for southern and western states of the country.

3.3 Application Areas

- *Pharmaceutical Industries*
  - Drying of API and its intermediates to eliminate product the conventional process of drying.

  - Recovery of important solvents from the feed.
- *Textile Industries*
  - Drying of concentrated liquid for s recovery.
- *Agro Chemicals-Dyers and Pigment Industries*
  - Drying of product for recovery of inorganic product, to eliminate other conventional systems
- *Chemical and Petro-Chemical Industries*
  - Drying of Chemical and petro-chemical products to recover the powder or cakes.
- *Sugar Industries and Distilleries*
  - Drying of concentrated effluent to make the Zero Liquid Discharge System.
- *Effluent Treatment Plants*
  - One stop solution for drying of effluent to make Zero Liquid Discharge.

4 Case Study of Recycle and Reuse Leading to Zero Liquid Discharge

Case Study-1

A pharmaceutical industry manufacturing formulation-based product generates waste water at a capacity of 100 KLD. The influent sources are from (i) Utility, process and kitchen waste and (ii) another source is from sewage water from sanitation activities with a capacity of 10 kl per day. The effluent characteristics from the two sources are provided below:

Influent Characteristics:

(i) pH—6.2–7.2, TSS—145–240 mg/L COD: 750–1300 mg/l, BOD: 630–850 mg/l, Oil and Grease: 45–60 mg/l; TDS: 350–430 mg/L

(ii) pH: 6.5–7.8, TSS: 130–280 mg/l, Oil and Grease: 25–40 mg/L, COD: 450–550 mg/L, BOD 260–300 mg/l.

Desired Treated water quality for recycling and reuse:

The process design has been carried out based on following Treated water quality for possible recycle and reuse as secondary purpose (non potable use):

pH: 7.0-8.0, TSS: <5 mg/L, BOD: <10 mg/l; COD: 50 mg/L (max), O&G: BDL, TDS: <500 mg/L.

Process schematic

Influent → Bar screen → Collection Chamber → Oil and Grease Chamber → Equalization Tank → Flash Mixer → Flocculator → Primary Clarifier → Aerobic

Treatment (ASP) → Secondary Clarifier → Filter Feed Tank with Chlorine Dosing System → Pressure Sand filter → Activated Carbon Filter → Treated Water Tank → Ultrafiltration Membrane → Final Treated water Storage → CT Make UP and Gardening use.

STP Process Design: Influent → Bar screen → Collection Chamber → Oil and Grease Chamber → Equalization Tank → Aerobic Treatment → Secondary Clarifier → Treated water with Chlorine Disinfection → Send to ETP Treated water storage for Ultrafiltration Treatment Plant.

Sludge from the secondary clarifier returns back to aeration tank to maintained Active Biomass as Mixed Liquid Suspended Solids (MLSS).

Final treated water parameters

pH—7.3-7.8; TSS <3mg/L, Oil and grease—BDL; COD—30-40 mg/l ; BOD—6-8 mg/l, TDS—<400 mg/L; Total Bacteriological Count-Nil.

As Total Dissolve Solids are well within regulatory limits (below 2,000 mg/l) the Reverse osmosis systems are not considered in the treatment scheme and thereby minimizing the treatment as well as operation and maintenance cost.

The treated water is recycling reuse for cooling water make up, gardening; road /pavement washing, fire fighting storage. No water is discharging to any streams or river leading to zero-discharge facility and thereby meeting successfully the regulatory board requirements.

Case Study-2

Textile Mill Wastewater Treatment with recycle and reuse:

Typical influent characteristics: pH: 10.5–11.5, Temp: 55–60 °C; TSS: 230–285 mg/L, COD: 750–930 mg/L, BOD: 380–470 mg/L, Pt Co Color: 1200–2200, Flow: >300 KLD.

Process schematic: Influent → Influent → Bar screen → Collection Chamber → Cooling Tower system → Equalization Tank → Flash Mixer → Flocculator → Primary Clarifier → Aerobic Treatment (ASP) → Secondary Clarifier → Filter Feed Tank with Chlorine Dosing System → Pressure Sand filter → Activated carbon Filter—Treated water Tank → Feed to two stage RO systems.

1st stage:

Treated water → Microfiltration → Ultrafiltration Membrane →RO Membrane →Permeate (60% Recovery) → Final Treated water → storage for Recycle and Reuse.

Reject (40%) from the 1st stage →

2nd Stage RO Membrane system → Permeate for recycle and reuse (20% Recovery),

Overall recovery combining 1st and 2nd stage: 80% (60% from 1st stage plus 20% from 2nd stage).

Reject from the 2nd stage: Multi-effect Evaporator → Vapour → Condenser → Condensate → Treated water storage.

Solid from MEE: Crystallization, Collection and Storage and disposal as per solid handling rules.

Final Treated Water Quality: pH: 6.7-7.5, TDS: <10 mg/L, BOD: <15 mg/L, COD: <50 mg/l, TSS: <1 mg/L, O&G: Nil.

The final treated water used in process side application and feed to DM (demineralised) plant for boiler application.

5 Conclusion

Every one of us must accept the fact that water is a basic necessity for the survival of humans. There is interplay of various factors that govern access and utilisation of water resources and in light of the increasing water demand it becomes important to look for holistic, people centred and industry specific approaches for water and wastewater management. It needs the combined initiative and action of all levels, for the socioeconomic development of the country. Wastewater Management with recycle and reuse must be taken as a key performance indicator to protect our fresh water resources. Looking into Industry, it is the second largest user of water after agriculture. The amount of water used varies widely from one industry type to another. Many businesses, notably the textile, food, beverages, and pharmaceutical sectors are highly water intensive and consume water by using it as an ingredient in processing finished products. Many businesses discharge of wastewater or wash water into natural fresh water ecosystems. Each litre of water moving through a system represents a significant energy cost. Water losses in the form of inefficient treatment, delivery leakages, theft, and consumer waste all directly affect the amount of energy required to deliver water for its proper use. Wastage of water directly leads to a waste of energy. Industries and municipalities must focus on effective water uses by reducing demand, maximizing recycling opportunities; minimizing water losses due to breakdowns and leakages; and investing in new water storage infrastructure. For Sustainable development optimal management of water and wastewater leading to zero discharge is now another challenge before the industry. Finally, in terms of working methodology, it may be looked as a systematic approach of Identifying, Measuring, Monitoring and Reducing the Water Consumption by different activities by Industries and municipalities. It should be an exercise of stewardship of water resources through deployment of cost effective, performance oriented appropriate/advance technology focusing on recycle and reusing the wastewater for the greatest good of society and the environment on sustainable basis.

6 Recommendations

(i) Development of strategy for systematic utilization of water resources in various industrial processes reducing water demand and losses.

(ii) Implementation of energy efficient, performance oriented and cost-effective technologies that helps to achieve sustainable environmental practices with opportunities for recycle and reuse.
(iii) Conducting water balance study in a regular interval to understand the water consumption pattern and improvement needs.
(iv) Any better approach and improved technology solution may give a new pathway to the wastewater management in industrial and municipal sector in India.

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