9 Bioremediation and Decolourisation of Biomethanated Distillery Spent Wash

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1 Introduction

With the advent of industrialisation, modern society was blessed with leisure life, but it has also suffered due to rapid pollution being created by a number of these industries, which is currently creating havoc. With increased pollution load, various remedial measures are being planned and executed by the planner, researchers and development agencies. Water, being one of the most important commodities for the survival of humankind, faces a number of problems, threatening it both in quantitative and qualitative terms. Rapid urbanisation, industrialisation and changing consumption pattern have pushed readily available fresh water resources to extinction levels. The reckless disposal of industrial effluents in surface water has converted nearly all the major rivers into wastewater stream. These developments have resulted in severe water crisis in majority of countries worldwide.

Even in India, large volumes of wastewater is being generated, and its safe disposal is posing a great challenge to the researchers and environmentalists. As per UNESCO report, India was under water-rich category up to the 1950s, but currently it has been ranked under water-stressed category. It invites immediate attention towards the conservation of water resources, its harvesting, treatment and recycling to help the nation to come out of this emergent scenario.

To fill the demand and supply gap of alcohols, distillery industry in India is growing at fast rate. These industries can be ranked in the top bracket of most polluting industries as they generate large quantity of wastewater (12–14 L/L alcohol produced) containing excessive COD and BOD. In India currently, approximately 3.0×10^9 liters of alcohol is being produced and it generates 5×10^{10} liter equivalent of wastewater each year (Uppal 2004). The most famous conventional secondary treatment technique for this wastewater is the aerobic treatment using suspended culture. These reactors need larger space and installation cost; with increasing quantities of wastewater, larger space and more monetary investment are required, that is, the biggest roadblock for this technology (Fumi et al. 1995). As distilleries are using molasses as a raw material to produce alcohol, we can find a large number of integrated sugar mills and distilleries in India. Bagasse and pressmud are other two prominent wastes being generated from sugar industries. Bagasse is generally used as the raw material for paper manufacturing or as a fuel for boilers, whereas pressmud has no notable use (Nandy et al. 2002). Recently, pressmud was found to have an interesting application in energy generation; a few of the entrepreneurs are using pressmud for making briquette. The main concern from the environmental point of view is large effluents being generated from molasses-based distilleries known as spent wash (SW). As per the average estimate, molasses-based distillery generates nearly 12–15 L of spent wash per litre of alcohol produced (Beltran et al. 2001). Spent wash having low pH, high temperature (70–80 °C), dark-brown colour, high ash content and high percentage of dissolved organic and inorganic matter is very difficult to dispose as it is very hazardous to surface water (Beltran et al. 1999; Yeoh 1997). As per Nandy et al. (2002), the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the spent wash typically range between 35,000–50,000 and 100,000–150,000 mg/L, respectively. However, it is not easy to predict the exact characteristics and volume of wastewater being generated from distilleries as it heavily depends on the raw material being used and processing technology. Other prominent discharges contributing to the quantity of wastewater being generated from distilleries include washing water used to clean the fermenters, cooling water and boiler water (Pant and Adholeya 2007; Satyawali and Balakrishnan 2007). The intensity of

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potential pollution being created by this distillery wastewater based on BOD can very well be understood by the population equivalent of 1.25 billion for India. It implies that this organic pollution load is approximately seven times more than that of total organic load of municipal and domestic discharges based on the total population of India.

There is a minimum standard to be followed as promulgated by the Central Pollution Control Board (CPCB) as per the regulations of Environment Protection Act, 1986, known as minimal national standards (MINAS) for discharge of distillery wastewater. According to MINAS, only distillery wastewater having BOD < 30 mg L^{-1} and COD < 250 mg L^{-1} can be disposed into inland surface water. Similarly, prior to disposal on land, this wastewater should have BOD < 100 mg L^{-1}, pH of 5.5–9.0 and Total Suspended Solids (TSS) < 100 mg L^{-1}. Effort should also be made to minimise colour to the maximum extent (CPCB 2003).

1.1 Wastewater Generation and Characteristics

As per the CPCB, distilleries fall under the category of most polluting industries in India, ranking among the top 20 most polluting industries. The wastewater being generated at various stages in a typical distillery and their typical composition can be seen from Table 9.1 to Table 9.2. Major contributors are spent wash, fermenter cleaning and cooling steps.

The wastewater being generated by molasses-based distilleries have dark-brown colour. This colour can primarily be attributed to a dark-brown pigment, melanoidin. The presence of phenolic compounds and caramel is also responsible for this (Kalavathi et al. 2001). Melanoidins are nitrogen-containing natural heterogeneous polymers produced by nonenzymatic browning reaction known as the Maillard reaction. This is a chemical reaction which takes place between the carbonyl groups of reducing sugars and the amino groups of amino acids, peptides or proteins. Temperature at around 50 °C and pH of 4–7 are favourable for melanoidin production through the Maillard reaction, and these are responsible for the the characteristic dark brown colour of spent wash of distilleries (Rivero-Pérez et al. 2002).

As per Martins and Van-Boekel (2004), spent wash contains 2 % melanoidins, which has an empirical formula of $C_{17}H_{26-27}O_{10}N$. The conjugated carbon–carbon double bonds –C = C – in melanoidins are responsible for the brown colour (Kim et al. 1997). The molecular weight of this group lies in the range 5000–40,000. As melanoidins contain recalcitrant compounds, it is very difficult to remove its colour through conventional treatment technique. The colour intensity even increases during anaerobic digestion, due to re-polymerisation (Satyawali and Balakrishnan 2007). Melanoidins are also having antimicrobial properties which are toxic to a number of microorganisms involved in wastewater treatment processes (Sirianuntapiboon et al. 2004).

1.2 Profile of Lords Distillery Ltd., Nandganj, Ghazipur, UP, India

The samples were collected for the study from Lords Distillery Ltd., Nandganj Ghazipur, UP, India. The installed capacity of Lords Distillery Ltd. for manufacturing rectified spirit (RS) is 14,850 KL (94.5 % alcohol) per annum. The molasses is converted into alcohol by fermentation using yeast through a batch fermentation process. The yeast culture used for fermentation converts the sugar present in molasses into alcohol. Alcohol is extracted from the fermenter wash by distillation. The final products are rectified spirit, country liquor and Indian-made foreign liquor (IMFL). The capacity utilisation of the plant in the study period has been almost 41.9 %. The first stage of Effluent Treatment Plant (ETP) is an anaerobic biological digestion. The second stage comprises of a primary clarifier, an anaerobic digester with extended aeration system using diffused aeration mechanism and a secondary clarifier. The third stage comprises of an aerobic digester consisting of a hybrid aerobic biological reactor wherein microorganisms supported by activated carbon particles are kept suspended within the reactor by means of air diffusion and a tertiary clarifier. In addition to the above treatment process, the company has developed a botanical treatment plant using the root zone process. Two lagoons of capacities 1435 and 890 m^3 have also been provided for storage of spent wash in case of emergencies.

Table 9.1 Wastewater generations in different distillery operations

Distillery operations	Average wastewater generation (KLD/distillery)	Specific wastewater KL wastewater/KL alcohol
Spent wash (from distillation)	511.4	11.9
Fermenter cleaning	108.2	2.5
Fermenter cooling	307.7	7.2
Condenser cooling	34.2	0.8
Floor wash	47.6	1.1
Bottling plant	126.9	3.0
Others*	33.3	0.8

Source: The Energy and Resources Institute (CPCB 2003)
* Wastewater generated through other distillary operations

Table 9.2 Typical characteristics of various wastewater streams in distilleries

Parameter	Spent wash	Fermenter cooling	Fermenter cleaning	Condenser cooling	Fermenter wash	Bottling plant
Colour	Dark brown	Colourless	Colourless	Colourless	Faint	Colourless
pH	4.0–4.5	6.25	5.0–5.5	6.8–7.8	6.0	7.45
Alkalinity (mg L^{-1})	3500	300	Nil	_	40	80
Total solids (mg L^{-1})	1,00,000	1000–1300	1000–1500	700–900	550	400
Suspended solids (mg L^{-1})	10,000	220	400–600	180–200	300	100
BOD (mg L^{-1})	45,000–60,000	100–110	500–6000	70–80	15	5
COD (mg L^{-1})	80,000–1,20,000	500–1000	1200–1600	200–300	25	15

Source: TERI (2003)

Table 9.3 Characteristics of distillery spent wash and anaerobically digested distillery effluent (BDE) of Lords Distillery Ltd. Nandganj, Ghazipur

Parameters	Distillery spent wash	Anaerobically biodigested distillery effluent (ABDE)
pH	4.5–5.4	7.5–8
BOD5	55,000–65,000	5000–8000
COD	110,000–130,000	40,000–52,000
Total solid (TS)	130,000–160,000	70,000–75,000
Total volatile solid (TVS)	60,000–75,000	48,000–60,000
Total dissolved solids (TDS)	90,000–120,000	35,000–50,000
Chlorides	6000–8500	5000–5500
Phenols	8000–10,000	7000–8000
Sulphate	7500–9000	3000–5000
Phosphate	2500–2700	1500–1700
Total nitrogen	5000–7000	4000–4200

Unit of all the parameters is mg L^{-1} except pH

Effluent from the ETP is diluted, if required, and subsequently discharged onto the neighbouring agricultural land. The characteristics of spent wash and anaerobically biodigested distillery effluent (ABDE) of Lords Distillery Ltd. are given in Table 9.3, along with the detailed flow sheet of effluent treatment plant used in Lords Distillery Ltd., Nandganj, shown in Fig. 9.1.

1.3 Challenges and R&D Focus Areas in Distillery Effluent Treatment

Anaerobic treatment yielding methane is a key secondary treatment being applied to the treatment of the spent wash, and these processes result in the generation of energy in addition to considerable reduction of pollution load. Majority of ETPs in distilleries are using aerobic digestion of post-biomethanated effluent, but it does not give the desired yield of methane in spite of considerable energy consumption in aeration. The two-stage aerobic digestion currently being used reduces COD considerably but it is nearly ineffective in colour removal. Decolourisation of distillery effluent is a challenge to R&D effort, and it also needs complete knowledge of colour-causing compounds and its characteristics prior to designing any such process. Numerous efforts to test the efficacy of conventional physical, chemical and biological treatment for this purpose have been reported with little success (Satyawali and Balakrishnan 2007; Pant and Adholeya 2007). The main disadvantage associated with physicochemical processes such as adsorption, flocculation, oxidation and coagulation is sludge handling in addition to the economy of the process (Rajor et al. 2002). Adsorption still attracts attention, but focus should be on the selection of any prominent solid waste being generated by industries as it will potentially reduce the process cost. To reach to zero discharge goals, the industries are currently forced to use highly expensive technologies like reverse osmosis (RO). Although the superiority of biodegradation processes for the treatment of distillery effluent cannot be questioned due to the large amount of wastewater being generated by these industries, efforts are certainly required for an integrated approach to deal with the problem and minimise the wastage of freshwater being currently used for dilution purposes.

1.4 Treatment Processes Employed in Distilleries

The removal of BOD, COD, Suspended Solid (SS), nutrients (nitrate, phosphate and potash), colourants, pathogens and

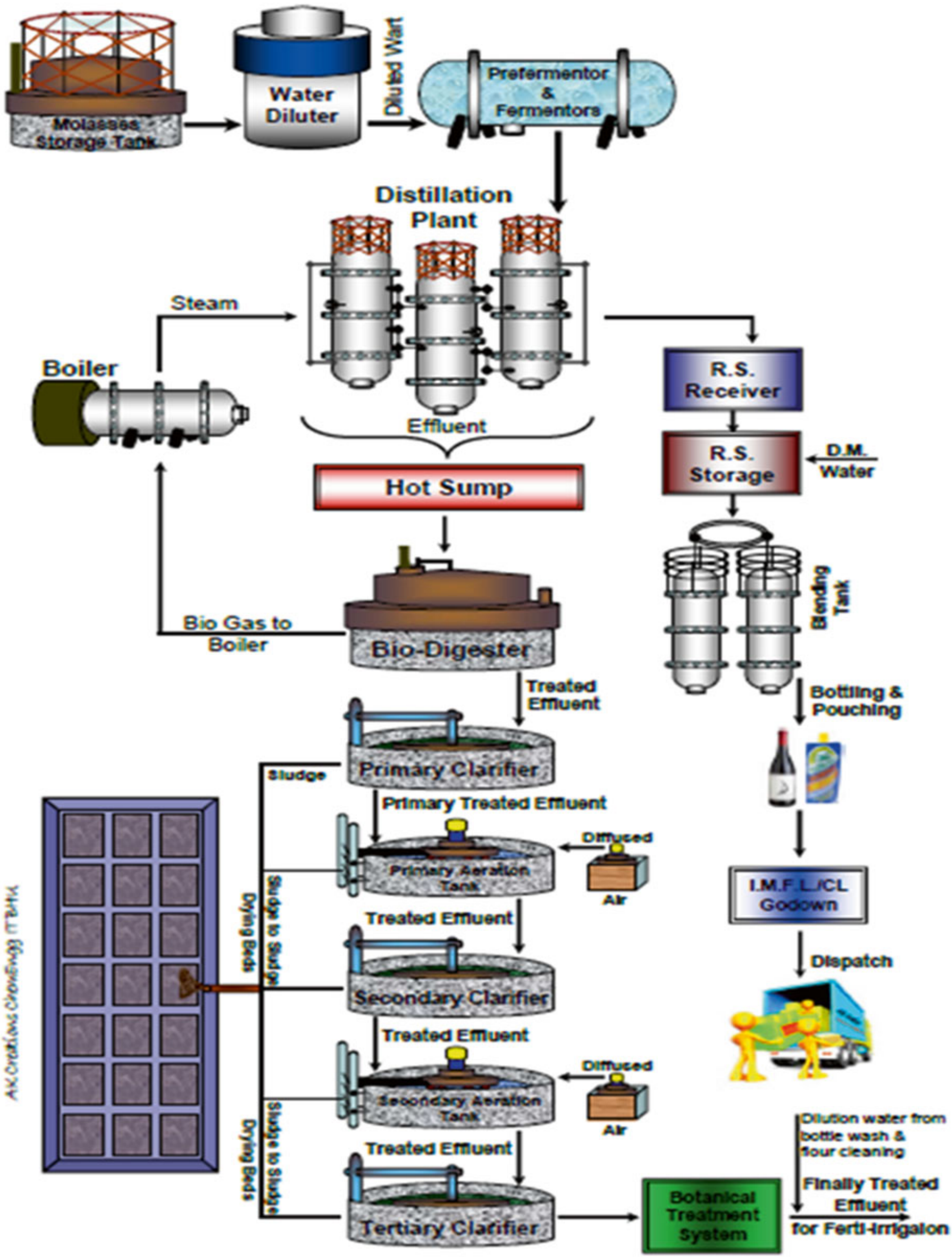

Fig. 9.1 Effluent treatment plant used in Lords Distillery Ltd., Nandganj

toxicity is required to make wastewater fit for disposal into the environment. The organics present in water primarily consume dissolved oxygen (DO) present in water to facilitate degradation, resulting in depletion of DO level in any surface stream leading to death of aquatic animals. The suspended particulate matters are primarily removed through sedimentation or filtration, and when required, some chemical aids can also be used for this purpose. The excessive release of nutrients leads to eutrophication resulting in the growth of unwanted plants such as algae and aquatic macrophytes. The excessive nitrate concentration above 45 g m^{-3} in drinking water has been reported to lead to blue baby syndrome (Lincolin and Earle 1990).

Certain investigations have revealed the positive impact of the spent wash on certain crops that is why till the 1970s it was disposed on the land. Due to its high nitrogen, phosphorus and organic content even in Brazil, *vinasse* produced during the fermentation of sugarcane juice is being used as fertiliser. As per Rodríguez (2000), this can be used as fertiliser under controlled conditions. The main drawback associated with land disposal of the spent wash is its strong colour and odour in addition to some toxic effects. In addition to this, it requires a large area preferably in the vicinity of distilleries, and in order to avoid its transport into the surface or groundwater, the disposal site should lie in low and medium rainfall area (Sheehan and Greenfield 1980). Groundwater contamination is the most potent danger in this practice (Jain et al. 2002). Animal feed and potash production through evaporation and incineration, respectively, are other two important options validated by researchers (Sheehan and Greenfield 1980; Wilkie et al. 2000).

The physical, chemical and biological treatments either in isolation or in combination can be used to make wastewater safe for disposal. Suspended pollutants are mostly removed through physical treatment, whereas colloids and dissolved contaminants can be removed through chemical treatments (Stumm and Morgan 1962).

A critical review of existing literature in the field of distillery wastewater treatment reveals that still there is a scope of improvement and various microbes and algae should be examined for their efficacy. In addition to this, attempt should also be made to investigate the hybrid processes suitable for this treatment scheme.

1.4.1 Biological Treatment Processes

In recent years, a number of studies have focused on microorganisms, which are able to biodegrade and bioasorb colouring compounds present in wastewater. With increasing consciousness about pollution control, biological decolourisation is receiving prime attention for effluent treatment. With economic constraints on pollution control process, affordable and effective methods have become a necessity. Since spent wash is a high-strength wastewater, it is generally subjected to anaerobic digestion in huge methane reactors to convert organics into methane, which is used as a fuel. The ABDE is, then, treated aerobically in activated sludge treatment plants to further reduce BOD/COD and used for composting pressmud, a by-product of sugar mills. The colour of spent wash persists even after bio-methanation. A number of microorganisms have been evaluated in recent years to either biodegrade or bio-sorb the colour-causing components; still a lot more has to be done to make these processes economically viable.

1.4.1.1 Anaerobic Biodegradation

Anaerobic biodegradation is certainly the most important biological treatment as far as spent wash is concerned and it is capable of converting substantial portion of COD (more than 50 %) to biogas (Wilkie et al. 2000). The fuel generated can be used for electricity generation. This step reduces COD by 90 % and BOD by 80–90 %, and 85–90 % of biochemical energy is recovered as fuel (Wolmarans and de Villiers 2002). There are various types of reactors used in anaerobic treatment such as downflow fixed film reactor, granular bed anaerobic baffled reactor (GRABR), upflow anaerobic sludge blanket (UASB) reactor, anaerobic contact filter, etc. Out of these reactors, upflow anaerobic sludge blanket (UASB) reactors are commonly used reactors in distilleries (Bories and Ranyal 1988; Akunna and Clark 2000; Harada et al. 1996; Vijayaraghavan and Ramanujam 2000).

Toxicity, pH, temperature and nutrient concentrations are the most important factors in determining the success of biological treatments. To get the influent at required condition before biological reactors, the spent wash is heavily diluted to maintain its pH and toxicity within permissible range. As per Asthana et al. (2001), the effluent of anaerobic digester does not meet surface discharge standards due to excessive organic loading of spent wash. Effluents obtained after anaerobic digestion are called anaerobically biodigested distillery effluent (ABDE), which is characterised by dark-brown colour with high organic load. Therefore, aerobic treatment is considered essential and effective for anaerobically treated final effluent before discharging (Kim et al. 1997).

1.4.1.2 Aerobic Biodegradation

Anaerobically biodigested distillery effluent (ABDE) is treated aerobically in a two-step process with aerator in activated sludge-type (using mixed or pure culture) reactors or other advanced bioreactors. The following sections discuss the utilisation and prospects of pure cultures including bacterial, fungal, algal strain and mixed consortium in aerobic biodegradation of distillery effluent. Several workers have been using pure aerobic bacterial cultures for the treatment of distillery effluent in their studies (Mohana et al. 2007; Chavan et al. 2006; Dahiya et al. 2001a, b; Kumar and Chandra 2006).

Nowadays, various fungal spp. (viz. basidiomycetes and ascomycetes) are utilised to decolourise the characteristic dark brownish colour caused by natural and synthetic melanoidin in distillery wastewater. Fungal treatment is more effective than bacterial treatment due to the presence of pallets in fungi which provide a large surface area for the absorption in treatment of melanoidin and also reduces BOD/COD to a large extent. Beside this, filamentous fungi are least affected by the variation in process parameters such as nutrients (C, H, N and trace metals), pH, temperature and aeration. Fungal spp. have been found to a potential agent for the treatment of distillery wastewater (Shukla et al. 2010; Pant and Adholeya 2009; Shayegan et al. 2004; Rajor et al. 2002).

The application of microalgae in wastewater treatment is an attractive and useful option when compared to other biotreatments because it synthesises carbohydrates by photosynthesis utilising CO_2 which is produced during aerobic degradation of organic compound by fungi and bacteria and also removes nitrogen and phosphorus from the environment (De la Noüe and De Pauw 1988; Goldman 1979; Shelef et al. 1980; Soeder et al. 1978; De Pauw and Van Vaerenbergh 1983; Oswald and Gotaas 1957).

The microalgal genera such as *Chlorella*, *Ankistrodesmus*, *Scenedesmus*, *Euglena*, *Chlamydomonas*, *Oscillatoria*, *Micractinium* and *Golenkinia*, belonging to various classes like Chlorophyta, Cyanophyta, Bacillariophyta and Euglenophyta, are frequently used in waste oxidation ponds and lagoons (Palmer 1969, 1974). Various algal spp. such as *Euglena*, *Oscillatoria*, *Chlamydomonas*, *Scenedesmus*, *Chlorella*, *Nitzschia*, *Navicula* and *Stigeoclonium* are also able to grow in adverse condition (Ramachandra 1993).

Various researchers reported the efficiency of algal spp. in different industries such as sewage treatment, distilleries, tanneries, heavy metals, etc. (Shelef et al. 1980; Mohamed 1994; Ibraheem 1998; De Pauw and Van Vaerenbergh 1983; Zaid-Iso 1990; Ma et al. 1990; Phang 1990, 1991; Kaplan et al. 1988; Soeder et al. 1978; Gerhardt et al. 1991; Hammouda et al. 1995; Cai-XiaoHua et al. 1995).

1.4.2 Treatment of Distillery Effluent by Coagulation

Aerobic biological treatment is only effective at higher dilution because melanoidin retards the activity of conventional micro- and macroorganisms due to its recalcitrant nature. So, coagulation seems to be an effective alternative pretreatment process in biological aerobic treatment in order to avoid heavy use of water for dilution, making the process cost-effective and efficient. The coagulants or flocculants are cheaper, accessible and have been used extensively in wastewater treatment. Sufficient literature are available (Dilek and Gokcay 1994; Al-Malack et al. 1999; Sundin and Hartler 2000a, b; Dilek and Bose 2001; Georgiou et al. 2003; Dugal et al. 1976, Lathia and Joyce 1978; Joyse et al. 1979; Srivastava and Jalan 1994, Srivastava et al. 2005; Beulker and Jekel 1993; Stephenson and Duff 1993, 1996a, b; Garg 1996) on the use of coagulants for the treatment of wastewater specifically, being disposed from textile, pulp and paper and allied industries. However, various researchers have also been investigating the efficacy of coagulation for the treatment of distillery effluent (Singh and Dikshit 2010; Chaudhari et al. 2007; Mishra and Chaudhary 2007; Pandey et al. 2003; Migo et al. 1997; Ramachandra and Singh 1999; Olthof and Eckenfelder 1975; Hayase et al. 1984; Mandal et al. 2003).

The coagulation with alum (Kawamura 1987), $FeCl_3$ (Olthof and Eckenfelder 1975) and $MgSO_4$, (Serger 1977) physically removed the colour of spent wash, but the voluminous sludge generated posed disposal problems. In the case of $FeCl_3$, ferric ions further imparted colour. Ramachandra and Singh (1999) attempted decolourisation of anaerobically biodigested distillery effluent by precipitation with aluminium sulphate and bleaching powder.

1.5 Objective of Present Investigation

Several reports on treatment techniques are available in the field of distilleries. A combination of physicochemical and biological methods is required to obtain a stream which can be recycled and reused to attain zero discharge status. One of the major drawbacks dealing with biological treatments, particularly aerobic biodegradation, is requirement of higher degree of dilution. The anaerobic digestion of spent wash is undoubtedly attractive and viable as it renders considerable decrease in COD and BOD loads besides generating methane, which is also considered a potential source of energy. To overcome the problem faced by excessive dilution before aerobic digestion, coagulation is supposed to have tremendous potential in treating the anaerobically biodigested distillery effluent and making it viable for supplementary aerobic degradation. Appropriate polymeric flocculants may be used for coagulation to reduce the amount of coagulant required. The use of fungal spp. and microalgae in treatment of distillery wastewater has been regarded as a cost-effective approach in removing refractory organic compounds along with nutrient elimination by maintaining aerobic conditions.

In light of the above discussion, the present investigation has been planned to study the treatability of anaerobically biodigested distillery effluent (ABDE) purchased from Lords Distillery Ltd., Nandganj, Ghazipur, UP, India. An integrated treatment approach combining coagulation-aerobic fungal degradation has been tested.

2 Materials and Methods

2.1 Wastewater

The sample (distillery spent wash and ABDE) for the decolourisation study was taken from cane molasses-based Lords Distillery Ltd., Nandganj, Ghazipur, UP, India, and kept in deep freezer at low temperature (3–4 ± 2 °C). The physicochemical analysis of samples was carried out in the laboratory based on the Standard Methods for the Examination of Water and Wastewater, APHA (1985, 1989), as shown in Table 9.4.

2.2 Coagulant Treatment

Anaerobically biodigested distillery effluent was pretreated with coagulants such as aluminium chloride ($AlCl_3$), ferric chloride ($FeCl_3.6H_2O$) and potash alum ($K_2SO_4.Al_2(SO_4)_3.24H_2O$) which were LR grade (commercial), procured from M/S Merck Specialities Pvt. Ltd., Mumbai, and optimized dose and temperature for maximum decolourisation were decided by a jar test (VELP Scientifica, Model JLT 6, France).

2.3 Microorganism and Inoculums

Pure culture of *Aspergillus niger* ATCC No. 26550 and NCIM No. 684 was procured from National Chemical Laboratory (NCL), Pune, and maintained on Potato Dextrose Agar (PDA) under incubattion at 30 °C (Miranda et al. 1997). The maintenance and growth medium were the same and showed maximum activity in 72–96 h.

2.3.1 Flask Cultures

The aerobic treatment of coagulated ABDE was carried out in 250 mL Erlenmeyer shake flasks with 100 mL sample in nutrient broth. Various process parameters such as nutrient concentration, temperature of the solution, pH, inoculum volume and shaking speed were optimized for maximum decolourisation of ABDE. Samples were collected at the end of every 24 h for observing maximum decolourisation at various operating conditions.

Table 9.4 Composition of anaerobically biodigested distillery effluent (ABDE) obtained from Lords Distillery Ltd., Nandganj, Ghazipur, UP

Parameter	ABDE
COD	42500.0
BOD	6200.0
Colour	Blackish brown
pH	7.6
Ca	175.9
K	930.0
Total N	3900.0
SO_4	3200
Fe	18.0
PO_4	1650

Note: All values are in mg/L except colour and pH

2.4 Decolourisation Assay

During aerobic reaction, the sample collected after every 24 h interval was centrifuged at 10,000 rpm for 10 min prior to optical density measurement of the supernatant with Systronics double beam spectrophotometer (2202) at 475 nm. Decolourisation of effluent was measured in percentage as given below:

$$\% \text{decolourisation} = [(\text{initial OD} \;\; \text{final OD}) / \text{initial OD}]\, 100$$

3 Results and Discussion

Batch studies were performed in 250 ml Erlenmeyer flask using *Aspergillus niger* inoculums for biodegradation of anaerobically biodigested distillery effluent (ABDE) procured from Lords Distillery Ltd., Nandganj, Ghazipur. The primary investigation revealed the requirement of excessive dilution resulting in additional wastage of water. The maximum percentage of decolourisation obtained from *Aspergillus niger* was 63.5 % at excessive dilution of 100 %. Depending upon its cost-effectiveness and degradation ability, potash alum was selected as the best coagulant among the three as shown in Table 9.5. The cost-effectiveness of aerobic treatment was enhanced by coagulation as a pretreatment step. Coagulation reduced the dilution of ABDE up to 90 % in aerobic treatment. The typical characteristics of ABDE before and after treatment by coagulants are shown in Table 9.6 and it was observed that the maximum colour and COD reduction was achieved by treatment with potash alum, i.e. 92.45 % and 78.5 %, respectively, among the three coagulants. The organic content and dissolved solids were precipitated due to coagulation and flocculation processes, resulting in removal of colour and COD reduction.

3.1 Biodegradation of Coagulated ABDE

In aerobic biodegradation, coagulated ABDE filtrate was used and various process parameters like nutrient concentration, pH, temperature, stirring speed and inoculation volume were optimized for maximum decolourisation and COD reduction by *Aspergillus niger*. This fungus was characterised by growth of small, compact and uniform pallets (2–6 mm diameter) in 72–96 h.

3.2 Benefits of Algae Wastewater Treatment Processes

Microalgae have several properties by which they can play an important role in the field of wastewater treatment partic-

Table 9.5 % colour, COD and pH reduction of ABDE at optimum doses of coagulants

Particulars	Optimum dose (g/L)	% Colour removal	% COD reduction	pH reduction of ABDE
Alum	80	92.45	78.5	4.8
Aluminium chloride	35	74.6	66.8	3.9
Ferric sulphate	30	67.0	59.4	4.2

Table 9.6 Characteristics of ABDE before and after coagulation

Parameters	ABDE	Treated ABDE with		
		Alum	$AlCl_3$	$FeCl_3$
COD	42500.0	9450.0	14110.0	17425.0
BOD	6200.0	1705.0	2790.0	3410.0
Colour	Blackish brown	Light yellow	Light brown	Greenish brown
pH	7.6	4.8	3.9	4.2
Ca	175.9	38.8	27.28	58.6
K	930.0	860.0	86.0	820.0
Total N	3900.0	1390	2118.0	2245.0
SO_4	3200	1232.0	1650.0	1834.0
Fe	18.0	67.86	8.92	1035.7
PO_4	1650	1043.0	1254.0	1287

Note: All values are in mg/L except colour and pH

ularly for organic-rich effluents. Distillery industries employ various treatment techniques to treat effluent, but the most effective technique is anaerobic digestion followed by two-stage aerobic treatment by activated sludge processes. Aerobic treatment requires an aerator which maintains oxygen concentration in reactor, triggering the degradation processes by aerobic microorganism present in activated sludge. This process requires huge amount of energy to maintain oxygen concentration. The effluent after aerobic treatment contains large amounts of organic load along with high nitrogen and phosphorus concentration which are produced as stable products in aerobic biodegradation process and the effluent can not be disposed off as such because of strict environmental legislation.

So, the future application of microalgae in aerobic biodegradation process along with fungi seems to be a viable cost-effective and ecofriendly technique when compared to conventional treatment processes as discussed below:

(a) Microalgae absorb CO_2 in the presence of sunlight and produces useful biomass along with oxygen by the process of photosynthesis (Greeno et al. 1996). These properties of microalgae reduces the cost of conventional treatment in which mechanical aerator is required to maintain oxygen concentration in the reactor. It has been estimated that 1 Kw of electricity is required to maintain oxygen concentration in the reactor which is sufficient to remove approximately 1 kg f BOD from the reactor. The production of 1 Kw of electricity is achieved by burning of fossil fuel which emits almost 1 kg of CO_2 in the atmosphere. So the conventional aerator system is neither cost-effective nor ecofriendly (Oswald 1988a, b).
(b) Sludge management is an important step in conventional treatment process. Nowadays, lots of new techniques are being employed in industries for the treatment and reuse of sludge. By this activity, industries are trying to reduce the cost of treatment and the pressure on natural resources. The application of microalgae also reduces the sludge problem because it utilises the by-product of aerobic degradation in photosynthesis and other metabolic activities and produced biomass can be used to produce valuable products for humankind like biofuel, edible products, raw materials for industries, etc.
(c) Greenhouse gas (GHG) emission is a major problem of conventional wastewater treatment. The algal-based wastewater treatment process emits very less amount of GHG in the atmosphere because most of the CO_2 and other important gases are utilised by algae in photosynthesis and metabolic activity.
(d) Microalgae have excellent carbon dioxide sequestration potential because it absorb huge amount of CO_2 and produces useful biomass. According to the National Renewable Energy Laboratory (NREL), under controlled environment, algae can produce up to 40 times more biodiesel when compared to terrestrial oil plant (Sheehan et al. 1998; Wald 1988). So, wastewater treatment with algae will be a cost-effective, ecofriendly and sustainable technique along with production of some useful by-products.
(e) Algal wastewater treatment also reduces the cost of disinfectant which is commonly used in conventional treat-

ment for harmful pathogens. In carbon-limited condition, microalgae can utilise carbonate as a carbon source and liberate hydroxide ions in the solution which increases the pH of the solution up to 9–10. At this pH most of the pathogens are killed, so the water obtained after this treatment is free of pathogens when compared to conventional treatment (Watanabe and Hall 1996; Zhu et al. 2008).

4 Conclusions

Nowadays, distilleries are considered as one of the most polluting and growth-oriented industries in the world. Distilleries consume huge amount of water in the manufacturing of alcohol and produce large amount of wastewater containing high organic load, acidic nature and are usually dark brown in color. This wastewater alters the physical, chemical and biological characteristics of receiving waterbody and soil if discharged directly into the environment without any treatment. Water is one of the most important natural resources for the survival of the living being on this planet Earth.

So, the development of effective treatment plan for distilleries is one of the challenges to environmental engineers. Taking this in consideration, developing effective treatment plan for distilleries, i.e. coagulation followed by mixed culture aerobic treatment (fungal and algal), seems to be a viable cost-effective and ecofriendly technique in future.

Keeping these in mind, a case study of the distillery effluent from Lords Distillery Ltd., Nandganj, Ghazipur, UP, India, has been discussed to evaluate an integrated approach combining coagulation + aerobic degradation (fungal) for a high removal of the contaminants from anaerobically biodigested distillery effluent (ABDE) and reduction of the cost of treatment.

This work on bioremediation and decolourisation of anaerobically biodigested distillery effluent (ABDE) shows that an incorporated planning approach, considering cost–benefit analysis of conventional treatment vs fungal treatment, is a more economical and viable option of treatment as compared to conventional treatment with following advantages :

(a) Reduces the cost of treatment by absorbing raw material of aerobic biodegradation and maintaines oxygen by photosynthesis even in extreme growth conditions (extreme pH, high salinity, etc.).
(b) It produces useful biomass which can act as raw material for industries and reduces the pressure on fossil fuel by producing biofuel.
(c) It acts as natural disinfectant and removes heavy metal from effluents.

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