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Chapter
[14]

Distillery spent wash treatment technologies: A case study of the comparative efficiency of aerobic and anaerobic treatment processes

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Abstract

Effluent generated from distilleries is known as slop/spent or wash/vinasse/stillage. The present study is carried out with the objective of characterization and treatment of distillery spent wash using aerobic and anaerobic treatment processes on the treatment plant of UP Co-operative distillery Jahangirabad, Anoopsahar (UP) form October 2019 to February 2020. Effluent of the distillery (RAW-DSW) was found highly polluted during all the samplings. Influent was observed highly acidic in nature (pH= 4.1-4.5). After the treatment, effluent becomes near neutral in case aerobic treatment and slightly alkaline in case of anaerobic treatment. For TSS aerobic treatment efficiency is 87.6% while in anaerobic treatment efficiency is 90.4%. In case of BOD, efficiency of aerobic treatment is 36.6% while in anaerobic treatment it is 71.7%. The parameters of outlet from both the treatment processes were found above the standards limits of discharge. Although anaerobic treatment processes improve the quality of outlet, yet the performance is not satisfactory and it requires further attention to improve the quality of effluent to meet the discharge limits.

Keywords Biogas, Ethanol, Distillery spent wash, Molasses, Sugar industry

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Introduction

Effluent generated from distilleries is known as slop/spent wash/vinasse/stillage (Nandy *et al.* 2002; Pathade, 2003; Singh *et al.*, 2004). From one litre of alcohol production approximately 8-15L of effluent is generated, therefore a typical distillery generates over half a million litres of spent wash effluent daily (Saha *et al.*, 2005; Pant and Adholeya, 2007; Mohana *et al.*, 2009). Due to widespread industrial applications of alcohol such as in pharmaceuticals, food, perfumery, etc., the alcohol distilleries are extensively growing. It is also used as an alternate fuel. Until 1931 India had only 29 sugar factories in operation, producing small quantities of molasses which did not cause a serious disposal problem. The number of sugar factories increased dramatically in 1935-36 to about 135 and the production of molasses increased to nearly 0.48 million tons (Singh and Nigam, 1995). A report suggests that there are 325 molasses based distilleries in the country producing 3.25 billion litres/year of alcohol and generating 45.0 billion litres/year of spent wash as waste annually (Ayub *et al.*, 2012; Pant and Adholeya, 2007). As per the Ministry of Environment and Forests, alcohol distilleries are listed at the top in the "Red Category" industries (CPCB, 2003; Chittaragi and Byakodi, 2018). India ranks 4th in the globe and 2nd in Asia in terms of ethanol production. Currently the 5% blending is only applicable in 10 States and three Union Territories and requires about 410 million litres of anhydrous alcohol. Increments in both % blending and geographical spread are anticipated. Feed preparation, fermentation, distillation and packaging are the four main steps in alcohol production in distilleries (Satyawali and Balakrishanan, 2008). Different biomass materials can be used in Ethanol production but the potential for their use as feedstock depends on the cost, availability, carbohydrate contents and the ease by which they can be converted to alcohol (Ogbonna, 2004). Nearly 61% of world's ethanol production is from sugar crops (Berg, 2004). Most Indian distilleries exclusively use cane molasses as raw material for fermentation (Handa and Seth, 1990). Distilleries in India are one of the most pollution creating industries, also consumes high volume of water. The diagrammatic process of ethanol production is presented in Figure 1. The agro based distillery outlet is very complex in nature, caramelized and cumbersome having high temperature (70-80^{0}C), dark brown colour, low pH, and high organic matter. The pollution load of the distillery effluent depends on the quality of molasses and the process operations of processing and recovery used (Pandey *et al.*, 2003) and its contribution is approximately seven times in terms of population in Indian. A good volume of Biogas can be generated form the distillery wastewater. Due to increasing awareness and government policies to check pollution load, different industries along with distilleries have been bounded for sustainable technologies for their waste treatment. To meet the standards and to achieve the zero discharge policy of CPCB (2003) distilleries have to look into their treatment methodologies in terms of their cost and sustainability (Mohana *et al.*, 2007). Approximately 1,200 million cubic meters of bio gas can be produced form 45 billion litres of distillery spent wash (DSW) produced in the country and approximately more than 85,000 tons of bio mass annually.

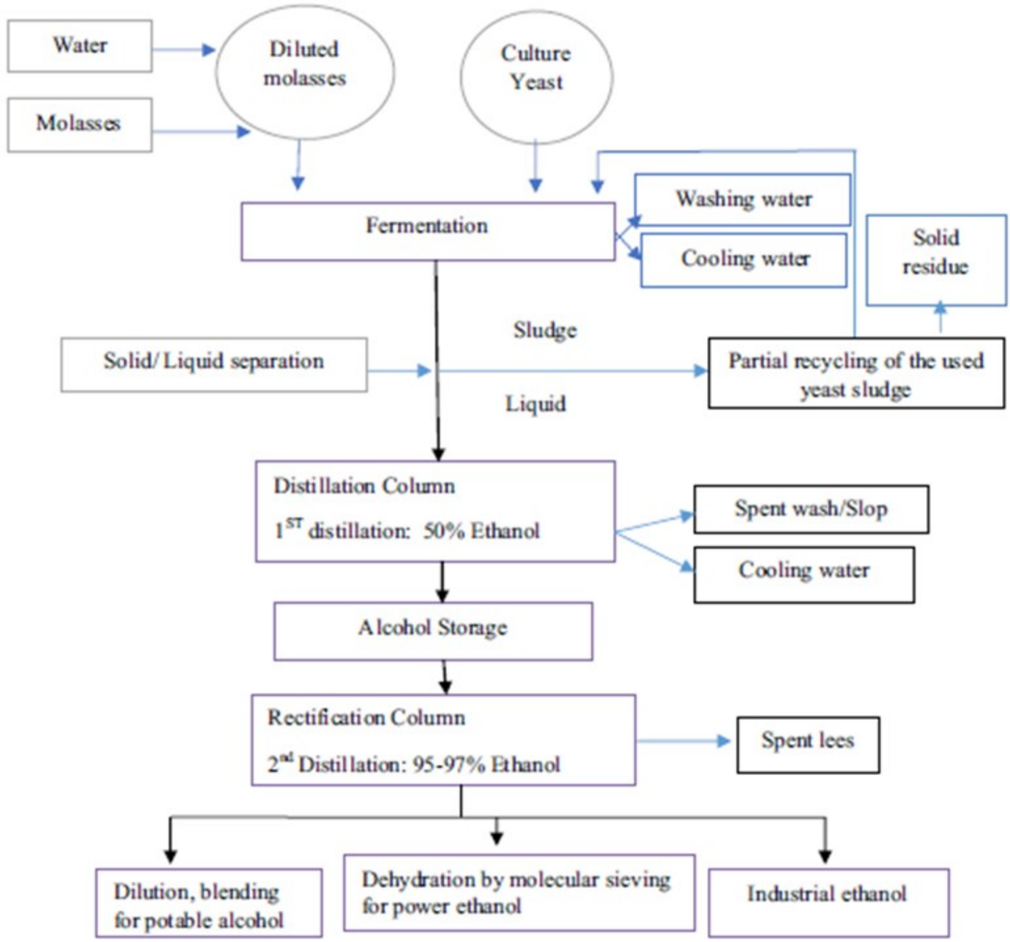


Figure 1. Ethanol distillery manufacturing process (Fito *et al*., 2019; Satyawali and Balakrishanan, 2008)

Environmental impacts of distillery spent wash

Spent wash or effluent generated from distillation process has very high polluting potential. In the areas, where the treated water of distillery is used for irrigation purpose, colour problem in ground water is observed to an extent that the industries have to provide the drinking water to the nearby villages. Different types of physicochemical and biological methods are applicable for the removal of colour from distillery spent wash was tried, but a cost effective and efficient treatment method is still awaited for the better achievement (Ogbonna, 2004). The variation in the quality of DSW is due to different processes and mixing of their wastewater, combination of all these wastewater makes DSW

(Tewari *et al.*, 2007). DSW has very high BOD/COD ratio making it unsuitable for biological treatment and showing the non-biodegradable nature of pollutants. The release of this waste into water bodies cause the problem of eutrophication due to high amount of inorganic substances (Kumar *et al.*, 1997; Sharma *et al.*, 2007). The presence of compounds such as melanoidins, anthocyanins, caramel, tannins and different xenobiotic compounds makes it recalcitrant and toxic for many microorganisms. These compounds remain unbreakable and can be found in the out let of treatment plants (Pandey *et al.*, 2003). The presence of compounds such as skatole, indole and other sulphur compounds provides unpleasant odour to the effluent and these compounds also passed out in the outlet without degradation (Acharya *et al.*, 2008; Shivajirao, 2012). DSW is harmful to aquatic life as it reduces the amount of DO due to reduced process of photosynthesis by green plants because it makes the water opaque due to presence of coloured components (Ramakrithnan *et al.*, 2005; Chaudhary and Arora, 2011; Arimi *et al.*, 2014; Farid *et al.*, 2010). Disposal of DSW on land is equally hazardous to the vegetation as it reduces soil alkalinity and availability of manganese, which results in less seed germination (Kumar *et al.*, 1997). Kannan and Upreti (2008) reported high toxic effects of raw distillery effluent on the growth and germination of *Vigna radiata* seeds even at low concentration of 5% (v/v).

Various methods of distillery spent wash treatment

A number of technologies have been discussed in the literature for reducing the pollution load of distillery effluent. Based on the literature, different treatment methodologies and their sub methodologies available for the treatment of distillery spent wash (DSW) are presented in Figure 2. Ministry of Environment, Forest and Climate Change (MOEFCC), recommended the Reboiler, Bio-methanation, Reverse Osmosis (RO) System, Multi Effect Evaporator (MEE), Bio-composting and one time controlled land application, Ferti-irrigation, Turbo Mist Evaporation, and Concentration and Incineration technologies/processes for spent wash treatment.

Biological treatment

Biological treatment is considered as simple, inexpensive and environmental friendly for the degradation of wastes. Certain factors such as temperature, aeration rate, pH, and nutrients affect the performance of biological treatment (Ali *et al.*, 2015). In biological processes, microbes used oxidize and degrade the organic materials and utilise the carbon and energy for their growth. The drawbacks of biological methods are its slow speeds and more uncertainty. Biological methods are of two types:

1. Anaerobic treatment

Anaerobic processes produces small amount of sludge and consumes less amount of energy and also generate useful biogas which makes it a profitable process (Mailleret *et al.*, 2003). Organic shock

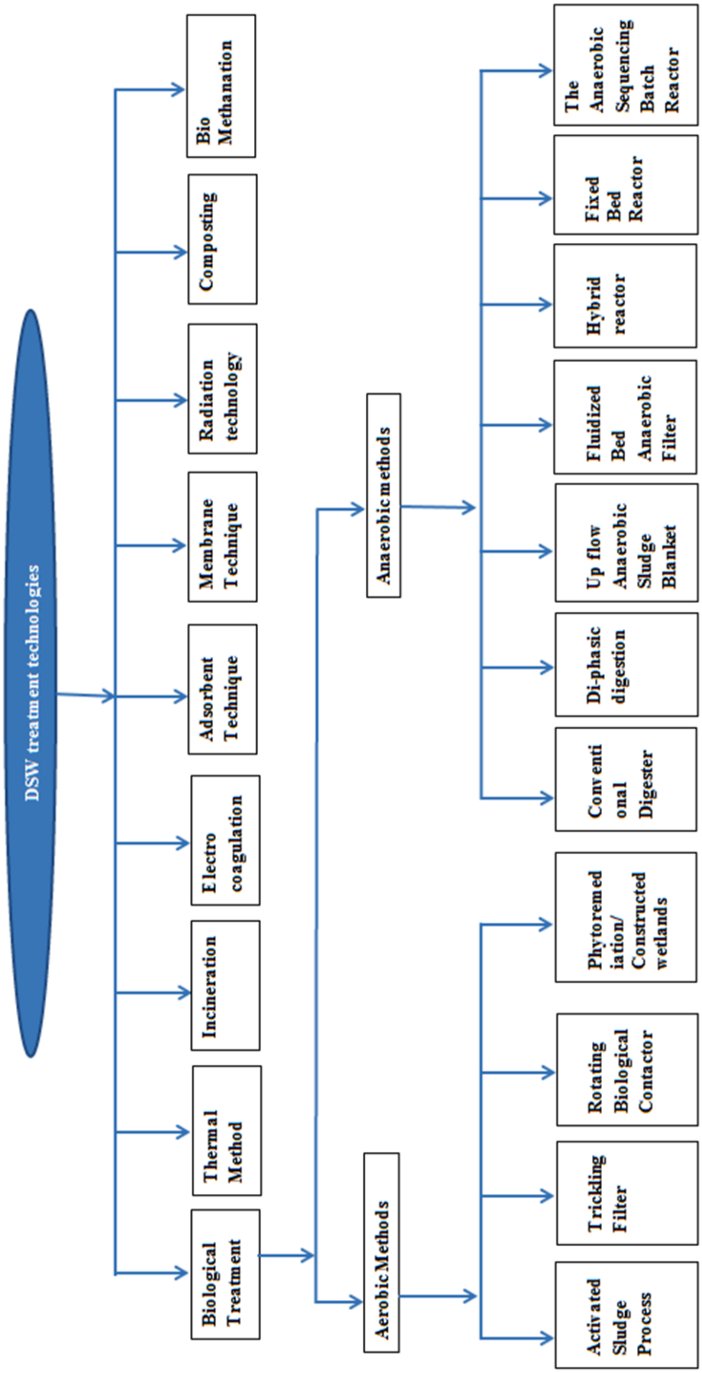


Figure 2. Different methodologies of distillery spent wash (Adopted from Bhardwaj *et al*., 2019).

loadings, low pH and show slow degradation, and longer hydraulic retention times (HRT) are some of the factors or drawbacks which affect the performance of anaerobic treatment processes. These entire drawbacks are continuously eliminated in different upgraded anaerobic treatment process.

***Conventional digester*:** In this process the wastewater is treated in a single tank using acidification, methane fermentation and sludge thickening processes without any heat and mixing (Bhardwaj *et al.*, 2019).

***Phasic digestion*:** In single phasic system, there is only one reactor while in biphasic system, there are two reactors. In biphasic system acidogenic and methanogenic reactions occur in separate reactors. The end products of acidogenesis phase are formate, acetate, lactate, ethanol, carbon dioxide, hydrogen and C3 and higher volatile fatty acids while the end products of methanogenesis phase are methane and carbon dioxide (Gosh, 1990; Seth *et al.*, 1995). A three phase fluidised bed biofilm reactor was also used for distillery effluent treatment (Kumaresan *et al.,* 2009; Lakshmikanth and Virupakshi, 2012)

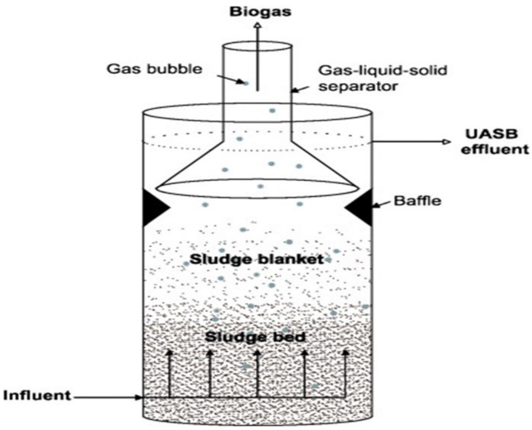
***Upflow Anaerobic Sludge Blanket (UASB)*:** This is high rate anaerobic, well-established wastewater treatment method applied for treatment of food industry, distilleries, tanneries and municipalities wastewaters. Three phase separators, sludge bed, and sludge blanket are the different components of the reactor (gas-liquid solid, GLS separator). Continuous recirculation process is used to kept the micro-organisms in the suspension form and for that an internal settler was used at the top of the reactor (Patyal, 2015). Treatment occurs as the wastewater comes in contact with the granules and/or thick flocculent sludge. This type of reactor treatment was studied by several researchers (Kansal *et al.*, 1998; Goodwin and Stuart, 1994; Florencio *et al.*, 1997; Harada *et al.*, 1996).

***Fluidized Bed Anaerobic Filter (FBR)*:** In this technology, the carriers for the biofilm are fluidised bed. The media used are small particle size sand, activated carbon and inert materials. In the fluidized state, each medium provides a large surface area for biofilm formation and growth. The energy demand in technology is very high.

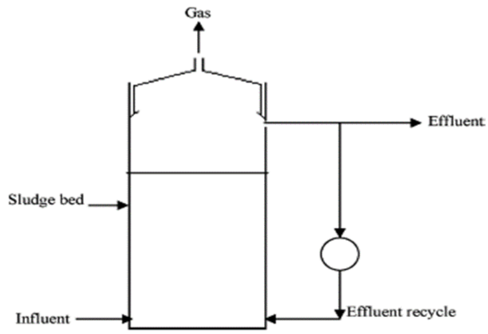
***Hybrid reactor*:** Hybrid, an anaerobic digester, filled with sludge bed at the bottom can be used for treatment of wastewaters of both high and low strength. Hybrid reactor is taller than the UASB reactor (Patyal, 2015).

***Fixed bed reactor*:** In this reactor, an inert plastic material is used as filter medium of high specific surface for the growth of biomass are used with external separation and recirculation of sludge.

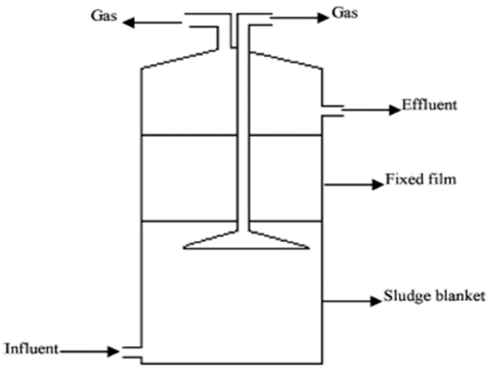
***Anaerobic Sequencing Batch Reactor (ASBR)*:** The main steps in anaerobic sequencing batch reactors (ASBRs) are feed, reaction, settling and decantation. The reaction and solid-liquid separation occurs in the same vessel. The first step involves the addition of substrate to the reactor where the contents are continuously mixed. The volume of substrate fed depends on a number of factors, including the desired hydraulic retention time (HRT), organic loading, and expected settling characteristics. The conversion of biodegradable organic matter to biogas is achieved. Banerjee and Biswas (2004) worked on these types of reactors.



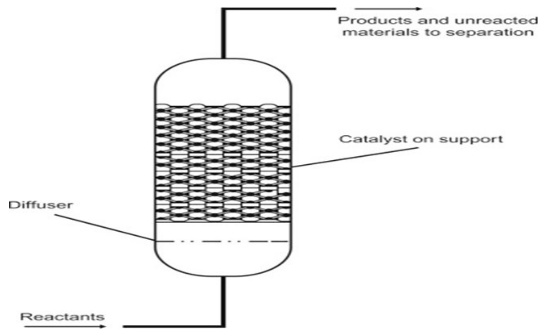
Upflow anaerobic sludge blanket (UASB)



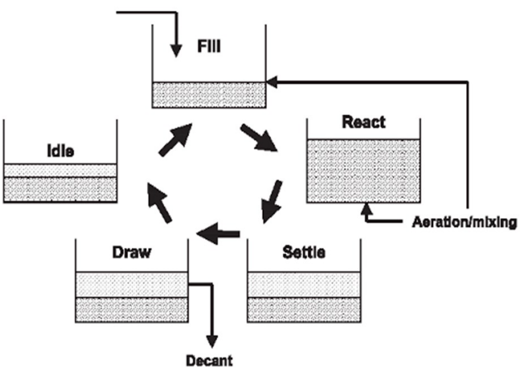
Anaerobic fluidized bed reactor



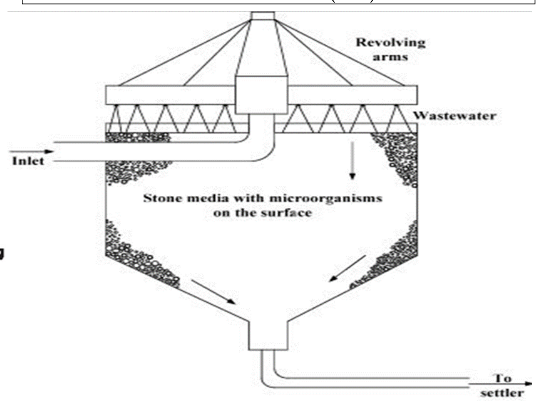
Anaerobic hybrid reactor



Fixed bed reactor (FBR)



Anaerobic sequencing batch reactor (ASBR)



Trickling filter

Figure 3. Various methods and reactors used for the treatment of distillery spent wash.

2. Aerobic treatment

After the treatment with anaerobic process, the treated water still contains the undesirable concentration of pollutants. The most important pollutant remains after the anaerobic treatment is colourant compound. After anaerobic treatment, aerobic treatment of distillery spent wash is performed for the decolourization of the major colourant compounds and for the reduction of the COD and BOD (Mohana *et al.,* 2009).

Activated Sludge Process (ASP)**:** Most common biological method for the treatment of industrial and municipal wastewater. Aeration of incoming wastewater is performed with intermittent supply of micro-organism in an aeration tank. Aeration tank (reactor), clarifier, and recirculation system are the essential steps of ASP. Organic materials are biodegraded by being in contact with micro-organisms within an aerobic environment. Activated sludge treatment is regarded as a suspended growth process due to microbes being suspended in the water.

Trickling Filter (TF)**:** Trickling filters also called attached-growth processes are used to the biological treatment of municipal and industrial wastewater for approximately 100 years. The fixed or rotating arms distribute or spray the wastewater over media or rocks that are covered with a biological layer of slime and provide the oxygenation to the water. Microbes present in slime layer (mainly bacteria and algae and various other organisms such as protozoa and metazoa), break down the organic matter. This system also requires a lot of energy and man power so considered as unsustainable.

Rotating Biological Contactor (RBC)**:** Used for the treatment of carbon-based wastewater. Closely spaced circular plastic disks partly submerged into a tank moved through untreated wastewater. Microbial films developed on the surface of the circular disks degrade the organic material in the presence of air. Although, RBC, activated sludge process and trickling filter treatments are mostly similar to each other but the formation of biofilm on the disk process is the principal feature of RBC. RBC requires less land area, and has high removal rates of BOD. It is also an energy intensive process.

Phytoremediation /constructed wetlands**:** Phytoremediation, an emerging low-cost is the process of treating the effluent with the help of plants. Aquatic plants reduce the level of BOD, toxic metals, and solids from the wastewaters excellently (Kumar and Chandra, 2004). Billore *et al.* (2001) studies the potential of *Typha latipholia* and *Phragmites karka* for the treatment of distillery effluent in constructed wetlands. Kumar and Chandra (2004) successfully treated distillery effluent in a two-stage process using a bacterium *Bacillus thuringienesis* and a macrophytes *Spirodela polyrrhiza*. A similar biphasic treatment was also performed with *B. thuringienesis* and *Typha angustata* by Chandra *et al.* (2008). Similar works were performed by Bama *et al.* (2013) and Bhardwaj and Bhasin (2012). Distillery spent was also treated using nanofiltration (Dave *et al.,* 2013), Electrocoagulation (Wagh and Nemade, 2015; Vijaya *et al.,* 2013), Adsorption (Kulkarni, 2013), and Fungal treatment (Tripathi *et al.,* 2007).

Need of the present study

In highly growing population, industrialization, and energy consumption, coupled with an increasing on fossil fuels, the energy security needs of the world continue to escalate. Till date Indian government was not permitted the alcohol blending in motor fuels, due to which the use of alcohol is less but if the government will permit, there will be drastic increase in the demand of alcohol which results in the production of huge amount of DSW. Treatment and safe disposal of the raw spent wash has been a big challenge for a long time (Balasubramanian and Kannan, 2016). The present study was performed on the water treatment plant of UP Co-operative distillery Jahangirabad, Anoopsahar (UP). The plant is continuously struggling to improve the quality of the effluent. Therefore the plant started both the process (aerobic and anaerobic) but running them separately. Thus the present study was carried out to characterize the raw distillery effluent (DSW) and compare the efficiency of aerobic and anaerobic process for the remediation of selected physicochemical parameters.

For the present study UP Co-operative distillery Jahangirabad, Anoopsahar (UP) was selected. In the plant, the DSW was treated with both aerobic and anaerobic treatment processes. For the present study raw distillery effluent, outlet of aerobic and anaerobic treatment process was collected twice in a month in morning hours (7 am-10 am) from UP Co-operative distillery Jahangirabad, Anoopsahar (UP) for a period of five months (From October 2019 to February 2020). A total of ten sampling were performed and named as sampling number 1 to 10 (SN-1 to SN 10). Grab water samples from all the sites were collected in plastic jerry cans keeping and opening Jerri cans below the water surface. Caps of cans were removed and closed after filling up inside the water and then the water samples were transported to the laboratory directly and analysis were performed for following physicochemical parameters *viz*. Colour, Temperature, Total Suspended Solids (TSS), pH, Acidity, Dissolved Oxygen (Winkler method), Biochemical Oxygen Demand (BOD), chemical oxygen demand (COD), Total Kjeldahl Nitrogen (TKN) and Volatile Fatty Acids (VFA). All the analysis was performed within 24 hour of sampling. Analysis of water was done according to standard methods as prescribed by APHA (2012), Trivedy and Goel (1986) and Khanna and Bhutiani (2008) for the examination of the water and waste water.

Aerobic treatment processes of DSW are those processes which are operated in the presence of oxygen while anaerobic treatment processes are those which are operated in the absence of oxygen. The results of aerobic treatment and anaerobic treatment are presented in Table 1 and Figure 4. The minimum, maximum and average temperature was observed 68.0^{0}C, 76.0^{0}C and 71.3^{0}C±2.6 in RAW-DSW while 28.0^{0}C, 33.0^{0}C and 30.4^{0}C±1.6 with aerobic treatment and 29.0^{0}C, 36.0^{0}C and 32.1^{0}C±2.0 with anaerobic treatment. The minimum, maximum and average temperature removal was observed 54.3%, 60.0% and 57.3% in aerobic treatment while 49.3%, 58.7% and 54.9% in anaerobic treatment.

The minimum, maximum and average TSS was observed 1380mg/L, 1560mg/L and 1496.6mg/L±56.0 in RAW-DSW while 160mg/L, 220mg/L and 186.0mg/L±17.0 with aerobic treatment and 80mg/L, 210mg/L and 143.6mg/L±48.5 with anaerobic treatment. The minimum, maximum and average TSS removal was observed 85.5%, 89.7% and 87.5% in aerobic treatment while 86.1%, 94.9% and 90.4% in anaerobic treatment. The minimum, maximum and average pH was observed 4.2, 4.5 and 4.1±0.1 RAW-DSW while 7.2, 7.8 and 7.5±0.1with aerobic treatment and 7.8, 8.5 and 8.1±0.2 with anaerobic treatment. The minimum, maximum and average pH gain was observed 60.0%, 78.6% and 70.7% respectively in aerobic treatment while 73.3%, 95.2% and 85.2% in anaerobic treatment. In most of the research an increase in the pH was observed (Banu *et al.*, 2007; Mohana *et al.*, 2009; Mise *et al.*, 2013).

BOD removal is indicative of the efficiency of biological treatment processes and is the most widely used parameter to measure wastewater quality. The minimum, maximum and average BOD was observed 31876mg/L, 34145mg/L and 32869.2mg/L±835.5 in RAW-DSW while 20032mg/L, 22012mg/L and 20848.7mg/L±581.8 with aerobic treatment and 8509mg/L, 10000mg/L and 9316.8mg/L±487.9 with anaerobic treatment. The minimum, maximum and average BOD removal was observed 34.2%, 38.7% and 36.6% respectively in aerobic treatment while 68.9%, 74.5% and 71.6% in anaerobic treatment. Results are in accordance with that of Mallick *et al*. (2010). COD is the amount of oxygen required for the breakdown of organic and inorganic matter chemically (Akan *et al.*, 2008). The minimum, maximum and average COD was observed 82000mg/L, 86198mg/L and 85010.2mg/L±1548.1 in RAW-DSW while 48087mg/L, 51134mg/L and 49180.9mg/L±1054.5 with aerobic treatment and 36056mg/L, 37900mg/L and 36871.0mg/L±628.4 with anaerobic treatment. The minimum, maximum and average COD removal was observed 38.9%, 44.2% and 42.1% respectively in aerobic treatment while 54.9%, 58.1% and 56.6% in anaerobic treatment. Our results are in accordance with that of Kumar *et al*. (2006), Kumar *et al.* (2020) and Mise *et al.* (2013)

The Kjeldahl method consisting of three steps *viz.* digestion, distillation and titration is a method of quantification of the nitrogen content in different soil and water samples. The minimum, maximum and average TKN was observed 900mg/L, 1040mg/L and 960.0mg/L±52.5 in RAW-DSW while 240mg/L, 288mg/L and 266.7mg/L±14.6 with aerobic treatment and 231mg/L, 270mg/L and 251.9mg/L±13.2 with anaerobic treatment. The minimum, maximum and average TKN removal was observed 70.4%, 74.5% and 72.2% respectively in aerobic treatment while 71.7%, 75.9% and 73.7% in anaerobic treatment. More or less similar results were obtained by Banu *et al*. (2007) and Kumar *et al*. (2006). The minimum, maximum and average acidity was observed 1650mg/L, 2220mg/L and 2027.0mg/L±165.0 in RAW-DSW while 695mg/L, 867mg/L and 754.4mg/L±52.0 with aerobic treatment and 80mg/L, 760mg/L and 577.0mg/L±121.1 with anaerobic treatment. The minimum, maximum and average acidity removal was observed 55.5%, 65.6% and 62.6% respectively in aerobic treatment while 59.6%, 79.4% and 71.6% in anaerobic treatment. Our results are in accordance with that of Shivayogimath and Ramanujam (1999). The minimum, maximum and average VFA was observed 4856mg/L, 5876mg/L and 5181.2mg/L±311.8 in RAW-DSW while 3102mg/L, 4988mg/L and 4065.7mg/L±626.6 with aerobic treatment and 2474mg/L, 3015mg/L and 2724.8mg/L±158.3 with anaerobic treatment. The minimum, maximum and average VFA

Table 1. Average values of all the parameters and their average removal through aerobic and anaerobic treatment process during the study period.

Parameters/treatment	RAW-DSW	Aerobic	% removal	Anaerobic	% removal
Temperature	71.3	30.4	-57.4	32.1	-55.0
TSS	1496.6	186.0	-87.6	143.6	-90.4
pH	4.38	7.5	+70.5	8.1	+85.2
BOD	32869.2	20848.7	-36.6	9316.8	-71.7
COD	85010.2	49180.9	-42.1	36871.0	-56.6
TKN	960	266.7	-72.2	251.9	-73.8
Acidity	2027	754.4	-62.8	577.0	-71.5
VFA	9681.2	4065.7	-58.0	2724.8	-71.9

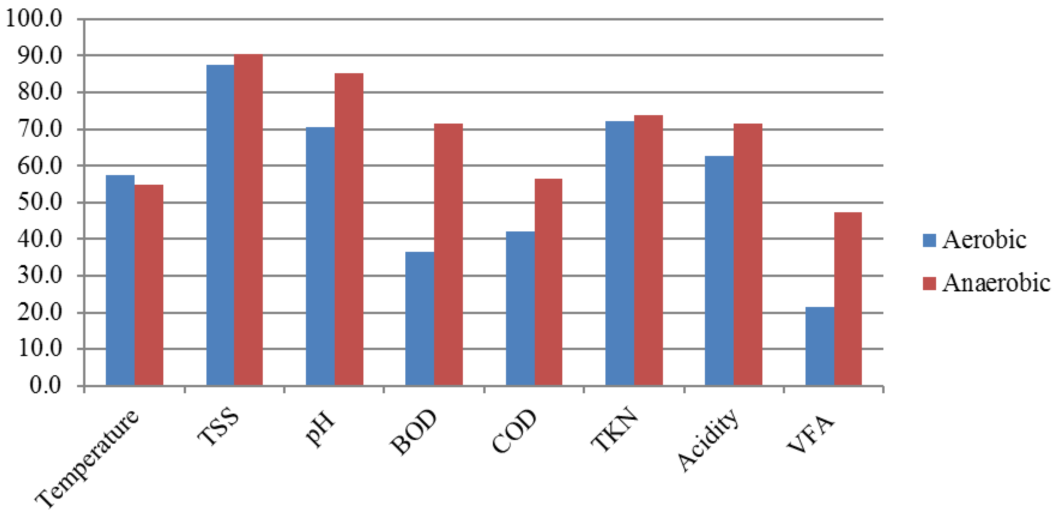


Figure 4. Percent efficiency of aerobic and anaerobic treatment process for all the studied parameters.

removal was observed 0.6%, 39.4% and 21.4% respectively in aerobic treatment while 44.6%, 54.7% and 47.3% in anaerobic treatment. Our results are in accordance with that of Banu *et al.* (2007).

Conclusion

The objective of the present study is the comparative assessment of treatment efficiency of aerobic and anaerobic treatment processes treating the effluent of a distillery plant. The raw effluent of the distillery (RAW-DSW) was found highly polluted during all the samplings. Influent was observed highly acidic in nature. After the treatment aerobic and anaerobic treatment, pH was increased and the effluent becomes near neutral in case aerobic treatment and slightly alkaline in case of anaerobic treatment. When overall efficiency of both the treatment processes was compared, it was observed that anaerobic treatment processes are much effective for the treatment of distillery effluent. The concentration of parameters of outlet from both the treatment processes was found above the standards limits of discharge. Although anaerobic treatment processes improve the quality of outlet, yet the performance is not satisfactory and it requires further attention to improve the quality of effluent to meet the discharge limits. Our recommendation for the distillery industry wastewater treatment is the use of both anaerobic and aerobic treatment process in combination one after the other to achieve the desirable water quality.

Conflict of interest: The author declares that there is no conflict of interest.

Acknowledgments

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