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THE EFFECTIVENESS OF WASTE STABILIZATION PONDS IN THE TREATMENT OF BREWERY EFFLUENT THE CASE OF META ABO BREWERY WASTE STABILIZATION PONDS, SEBETA, ETHIOPIA

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ABSTRACT

The objective of this paper is to evaluate the efficiency of waste stabilization pond systems owned by Meta Abo Brewery in the treatment of brewery effluent. The wastewater treatment system consists of a preliminary treatment unit, single string of stabilization ponds and a post treatment unit. The waste stabilization pond system collects 2476 m^3 wastewater each day with organic loading rate of 1241.63 kg/ha.day. Wastewater samples were collected at the inlet and outlet of the pond string and analyzed for biochemical oxygen demand (BOD), total suspended solids (TSS), total ammonia nitrogen, sulfide, sulfate, nitrate nitrogen, total nitrogen, turbidity, conductivity, chemical oxygen demand (COD), total phosphorus and orthophosphate between September 2011 and June 2012. Non conservable parameters such as dissolve oxygen (DO), temperature and pH were measured onsite immediately after sampling using handheld portable water quality measuring instrumentation. This was done to determine the efficiency of the waste stabilization pond system so that the final effluent discharged from the system to surface water comply with the Ethiopian Environmental Protection Authority (EEPA) standards. The percentage removal efficiency of the pond system was 84.38, 66.10, 59.64, 56.93, 41.83, 31.47, 19.68, 15.08, 11.56, 7.90 and 0.80 for total nitrogen, orthophosphate, nitrate nitrogen, sulfide, total ammonia, turbidity, total suspended solids, BOD_5, total phosphorus, COD and conductivity respectively in decreasing order.

The results showed that except pH and temperature most of the parameters did not comply with the Ethiopian Environmental Protection Authority (EEPA) standards. COD, BOD_5, TSS, total nitrogen, total ammonia nitrogen, sulfide, turbidity, orthophosphate, specific conductivity and total phosphorus levels were abnormally high, exceeding EEPA's red bands *limits. This implies that the brewery effluent presented a significant risk of water pollution and ecological damages. The results conclusively indicated that the waste stabilization pond system is not efficiently performing in treating brewery effluent. Up grading and management strategies of the system are promptly important in order to achieve effective performance and to meet discharge limits requirements of treated effluent into surface water.*

Keywords: Waste stabilization ponds, Treatment Efficiency, Meta Abo Brewery, Wastewater.

INTRODUCTION

The history of wastewater treatment spins around the development of system to deal with concerns associated with discharge of untreated wastewater. Perhaps one of the most ancient wastewater treatment methods known to humans is the waste stabilization ponds, also known as oxidation ponds. They have been used as a natural process for the treatment of wastewaters for over 3,000 years. The first recorded wastewater treatment pond facility was constructed in USA in San Antonio, Texas, in 1901 (Gloyna, 1971).

Mara (2004) and Hamzeh and Ponce (2007) describes waste stabilization ponds as large shallow man made basins constructed through excavation and compaction of earth to create reservoirs enclosed by embankments in which organic matter found in wastewater is decomposed entirely by natural (biological) processes involving both algae and bacteria. Waste stabilization ponds are suspended growth biochemical treatment process with the common characteristic that do not include downstream clarifiers and associated sludge return (Leslie Grady and. Glen Daigger, 1999).

Waste stabilization ponds can be categorized based on the type of metabolism and mechanism by which the terminal electron acceptors are supplied as anaerobic, facultative and aerobic (maturation) ponds. It is the relative rate of oxygen production and consumption by algae and bacteria that determines the type of pond. If the rate of oxygen production by algae is greater than the rate of oxygen consumption by bacteria, the process is aerobic and the pond is categorized as aerobic pond. If the reverse occurs, anaerobic conditions prevail and the pond becomes anaerobic pond. If both aerobic and anaerobic conditions prevail, the waste stabilization pond termed facultative pond. In a facultative pond, aerobic process occurs in the upper zone where sunlight penetration activates the photosynthetic process to greater completion while anaerobic conditions occur in the lower depths as the result of reduced sunlight penetration which results in an oxygen deficiency. Anaerobic and facultative ponds are designed for BOD removal and maturation ponds are primarily designed for the removal of pathogens, nutrients and possibly algae (Mara, 2008).

The configuration of waste stabilization ponds comprises a single string of the three ponds in series or several such series in parallel. Usually a waste stabilization pond system consists of anaerobic ponds followed by facultative ponds with aerobic ponds at the end of the configuration. Generally wastewater flows from the anaerobic pond to the facultative pond and finally, if necessary, to the aerobic pond (Mara, 1997).

When land is available, waste stabilization ponds are the most popular biological wastewater treatment systems in developing countries where the climate is most favorable for their operation. They offer considerable economic advantages over other complex electromechanical treatment systems because of low construction and maintenance costs, ability to handle loading shocks, high efficiency, flexibility in handling different types of wastes, entirely natural, highly sustainable, natural disinfection of pathogens, low energy requirements and require little operational skills and technical experiences. Therefore, such systems have gained increasing popularity throughout the world (Safieddine T., 2007). The only energy they use is direct solar energy and they do not need any electromechanical equipment, saving expenditure on electricity and skilled manpower for operation (Mara and Pearson, 1998).

The wastewater treatment system employed at Meta Abo Brewery is a waste stabilization pond system comprising of an anaerobic pond, a facultative pond and a maturation pond, all lined with fine sands. The treated effluent from the pond system is released in to ecologically sensitive water body (Finchewa River) which is located adjacent to it. If there is no net loss in the quantity of incoming wastewater from the treatment system, the total time the wastewater spent in the system is 5.44 days (Table 1). This value indicates that the detention time of the pond system was found to be far less than the typical detention time of a facultative pond (25 to180 days).

A study made by Tesfalem Fikresilasie (2010), indicated that effluent from the waste stabilization ponds system owned by Meta Abo brewery was polluting Fenchewa River but a threat to groundwater zones have not yet been conducted. This researcher in his study “the impacts of brewery effluent on the water quality of Fenchewa River” found out that brewery effluent had poor quality that does not meet the stipulated minimum requirement for discharge into surface water.

In recent decades, the value of the environment has been taken for granted because human activities have extremely damaged the environment and its elements such as water, air, land and others. Thus environmental issues are a critical factor for today’s industry competitiveness. A wastewater treatment plant that maximizes pollutant removal efficiency and minimizes investment and operation costs is a key factor in order to protect and guard natural ecosystems against wastewater pollution (Driessen and Vereijken, 2003).

Brewery is a traditional industry with an important economic value in the agro-food sector. Wastewater is one of the most significant waste products of brewery operations. Brewery consumes large volumes of water and at the same time it also discharges large volumes of effluent throughout the year. Even though substantial technological improvements have been made in the past, it has been estimated that approximately 3 - 10 L of wastewater is generated per liter of beer produced in breweries (Kanagachandran and Jayaratne, 2006).

The production of beer involves the blending of the extracts of malt, hops and sugar with water, followed by its subsequent fermentation with yeast (Wainwright, 1998). The brewing industry employs a number of batch-type operations in processing raw materials to the final beer product. In the process, large quantities of water are used for the production of beer itself, as well as for washing, cleaning and sterilizing of various units after each batch are completed. A large amount of this water is discharged to the drains. The main water use areas of a typical brewery are brew house, cellars, packaging and general water use. Water use attributed to these areas includes all water used in the product, vessel washing, general washing and cleaning in place (CIP); which are of considerable importance both in terms of water intake and effluent produced (Van der Merwe and Friend, 2002).

The quantity of brewery wastewater will depend on the production and the specific water usage. Brewery wastewater has high organic matter content, not toxic, does not usually contain appreciable quantities of heavy metals (possibly originate from label inks, labels, herbicides) and is easily biodegradable (Brewers of Europe, 2002). Wastewater from breweries is divided into three types namely industrial process wastewater, sanitary wastewater from toilets and kitchens and rain water. Due to high organic content and acidic nature, brewery effluent has the potential to cause considerable ecological damages in the receiving water bodies (Olajire, 2012).

Similarly, effluent to beer ratio is correlated to beer production. It has been shown that the effluent load is very similar to the water load since none of this water is used to brew beer and most of it ends up as effluent (Perry and De Villiers (2003) as cited in Olajire, 2012).

Table 1. Dimension of waste stabilization ponds, Meta Abo Brewery private company

Pond type	**Average surface area (m^2)**	**Depth (m)**	**Volume (m^3)**	**Retention time (day)**
Anaerobic pond	860.52	4.70	4044.44	1.61
Facultative pond	860.52	4.7 0	2684.82	1.61
Aerobic pond	1183.21	4.7 0	2792.38	2.22

Waste stabilization ponds are used to treat a variety of wastewaters, ranging from domestic wastewater to complex industrial effluents as well as combination of both provided that the wastewater is able to be treated biologically and they function under a wide range of climatic conditions, from tropical to arctic (Shilton and Harrison, 2003).

Several treatment options have been used to treat brewery effluent including aerobic treatment. However, brewery effluent is categorized as medium to high strength organic wastewater and needs an intensive amount of energy for aeration. The other disadvantage of aerobic treatment is the large amount of waste sludge produced during aerobic treatment which will increase the cost of operation for the treatment system in handling and disposal of the sludge. Thus driven by implementation of ISO 14001 certification and more stringent environmental legislation the brewing industry has shown increasing awareness for environmental protection and the need of sustainable production processes to invest in biological effluent treatment such as the use of waste stabilization ponds (Driessen and Vereijken, 2003).

However, researches on the treatment of brewery wastewater using oxidation ponds and their performance to remove pollutants are limited. Therefore, the primarily goal of this paper is to critically evaluate the suitability of a series of an anaerobic, a facultative and a maturation ponds whose bottom lined by fine sands for the treatment of brewery wastewater by determining the treatment efficiency of the system. In addition, drawing from the available literature, it suggests better treatment options for the wastewater from the brewery industry. The results obtained will serve to identify areas where control measures are necessary, enhance decision making tools for management, to identify opportunities for reducing waste and would be applicable to other breweries operating in the country.

MATERIALS AND METHODS

Description of the study area

The study was conducted from September 2011 to June 2012 in Meta Abo Brewery, Sebeta Ethiopia. Meta Abo Brewery is one of the currently existing eight breweries in Ethiopian brewing industry. It is located in the town of Sebeta, 27 kilometers from the capital, Addis Ababa to the South West, in the Oromia National Regional State. Geographically, the company is located at an average altitude of 2182 meters above sea level to the south of mount Mogle and at the coordinates of 8° 54.68' North latitude and 38° 55.72' East longitude. The coordinates of the study area were fixed using Global Positioning System Unit (GPSMAP76, Garmin OLATHE®, KS, USA 2009). The map of the study area was developed using ArcGIS 9.1 software.

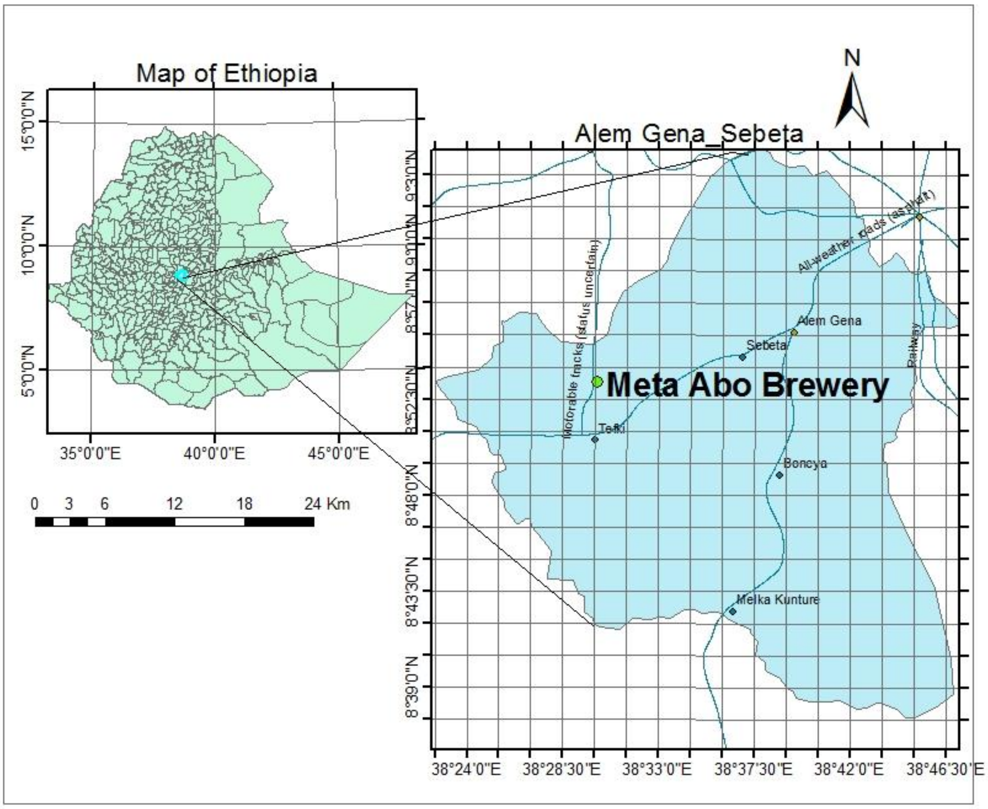

Figure 1. Map of the study area and location of Meta Abo Brewery (Map source: EMA, 2012)

The study area is characterized by biannual rainy seasons: summer rainy season which occurs between mid June and mid September is responsible for 70% of the annual average rainfall and spring rainy season which covers the period from February to April. The remaining months of the year are generally characterized by having little or no rainfall. The maximum and minimum annual temperature varies from 9 ^{0}C to 30 ^{0}C (ENMA, 2012).

Meta Abo brewery was established in 1963 by the Ethiopian Government and Ethiopian private Nationals with an initial production capacity of 50,000 hectoliters per annum and 128 permanent employees (ECPC, 2005). It has undergone expansion programs in 1970's, 1980's, 2005 and 2011 with several folds of increasing annual production capacity and raising number of permanent employees. The company adopted ISO based EMS in 2005 for the first time. Following an International bid by the Ethiopian Privatisation and Public Enterprises Supervising Agency (EPPESA), the company has sold to Diageo, a UK based international liquor firm that operates in many countries of the world.

Figure 2. Partial view of Meta Abo Brewery waste stabilization pond system

The total land holding of the brewery is 369,000 square meter of which 25,000 square meter is a built up area. A car park, recreation and horticultural farms occupy the major part of the brewery's premises. **Meta Abo Brewery** is the only brewery industry in the country which gets water from a big reserve of soft spring water (locally known as Holy Water of St. Abo). The spring water meets the international brew standard to be used without any form of treatment.

Sampling Methodology, Sample Preservation and Analysis

During the study period composite wastewater samples were collected in 1L polypropylene bottles in five rounds between September 2011and June 20112 at the inlet (before the wastewater enters the ponds) of the pond system. Similarly grab samples were collected at the outlet (at the points where the wastewater leaves the pond system) of the pond system. Prior to sampling the polyethylene bottles were cleaned by incubating them with 10 % (V/V) nitric acid (analytical, Merck) solution for 48 hours in a hot water bath and then washed and rinsed with distilled and de-ionized water. The polyethylene bottles were thoroughly rinsed with the wastewater from the sampling points before taking samples. The wastewater samples were brought to Addis Ababa City Administration Environmental Protection Authority (AAEPA) water and wastewater laboratory in ice kits and analyzed for physicochemical parameters according to the analytical methods described in Standard Methods for the Examination of Water and Wastewater (APHA, 2005) using graded laboratory reagents. The samples were kept in a refrigerator at 4 ^{0}C until analyzed for the parameters.

Non conservable parameters such dissolved oxygen (DO), pH, electrical conductivity and temperature were measured onsite immediately after sampling with the help of portable water quality measuring instrumentation (Cyberscan Series 600, EUTECH PCD 650, Singapore) at the inlet and outlet of the pond system.

Round averages were calculated for all parameters, from which average performance values have been obtained for the whole study period. The study was limited to the ending of rainy season period in Ethiopia in order to avoid the possible effects of rain water on the results obtained.

A HACH DR/2010 (HACH Company, Loveland, CO, USA) spectrophotometer was used to measure total ammonia-nitrogen, total nitrogen, chemical oxygen demand, sulfide and phosphate according to HACH instructions. BOD_5 was measured according to the methods described Standard Methods for the Examination of Water and Wastewater (APHA, 2005) using graded laboratory reagents. Gravimetric method was used to determine the total suspended solids (TSS) of the wastewater samples at temperature of 103 - 105 °C (APHA, 2005). Nitrate-nitrogen was determined by Cadmium reduction method using powder pillow or accuVac® ampoules spectrophotometer. Total Phosphorous (TP) was measured by the persulfate digestion procedure.

Data Analysis

The data obtained from the study were analyzed using descriptive statistics in Microsoft Excel and SPSS version 16.0 software packages. The results were expressed in terms of mean and standard deviation. The results were also compared with standard water quality guidelines. A one-way analysis of variance test was used to compare the difference between means.

RESULTS AND DISCUSSION

Determination of wastewater flow rate: wastewater is one of the most significant waste products of brewery operations. The quantity of brewery wastewater will depend on the production and the specific water usage (Olajire, 2012).

The main water source of the brewery was a big reserve of soft spring water (locally known as Holy Water of St. Abo) which meets the international brew standard without any form of treatment. The current annual production capacity of the brewery is 1, 200000 hectoliters. The mean wastewater flow rate was carefully estimated by means of fill Bucket and Stop Watch (fill and empty) method for about 16 days at different time of the day. This simplest method was chosen due to its simplicity and it also does not require any special equipment. The time needed to fill the bucket (plastic bucket of 20 ml) was recorded in situ and wastewater flow was estimated using the following formula was found to be 2476 m^3/d.

$$\text{Flow rate } (m^3/d) = \frac{\text{Volume}}{\text{Time}}$$

Even though substantial technological improvements have been made in the past, it has been estimated that approximately 3 - 10 liters of wastewater is generated per liter of beer produced in breweries (Kanagachandran and Jayaratne, 2006). Based on this estimation, Meta Abo brewery generates approximately 986.30 – 3287.60 liters of wastewater each day. Thus the quantity of wastewater discharged by the Meta Abo brewery obtained by means of fill Bucket and Stop Watch method falls within this range.

Treatment efficiency of the pond system: Table 2 shows the results of the analysis of the various physicochemical parameters. The mean DO concentrations (0.22 ± 0.06 mg/L) of the treated wastewater indicate that anaerobic condition prevailed in the treatment system where oxygen unable to enter into the system through direct diffusion across air-liquid interface or the rate of oxygen production through photosynthesis were lower than the rate of oxygen consumption through respiration and decomposition of organic matter. This might be attributed to a reduced algal activity. This fall in DO concentration over the monitoring period indicates that the pond is becoming anoxic and some management strategy such as aeration with surface mechanical aerators and mixers, or by various forms of diffusers supplied with compressed air from mechanical blowers or compressors must be implemented.

The average pH value of the influent wastewater has shown acidic character. The anaerobic bacteria are usually sensitive to pH value less than 6.2. Thus, this acidic wastewater must have been neutralized prior to its treatment in anaerobic ponds. pH values increased slightly from 5.58 in the influent to 6.19 in the effluent of the treatment plant. This might be attributed to increasing algal activity in facultative and aerobic ponds as CO_2 is consumed during photosynthesis by algae. The increment in pH could also be due to high ammonia concentrations in the effluent.

The percentage treatment efficiency of the pond system was 84.38, 66.10, 59.64, 56.93, 41.83, 31.47, 19.68, 15.08, 11.56, 7.90 and 0.80 for total nitrogen, phosphate, nitrate nitrogen, sulfide, total ammonia, turbidity, total suspended solids, BOD5, total phosphorus, COD and conductivity respectively in decreasing order.

The mean BOD (431.80 mg/L) and COD (2232.60 mg/L) concentrations of the brewery wastewater were similar to values indicated in the literature. With this BOD value of the influent wastewater, the calculated organic loading rate on the anaerobic pond was 1241.63 kg per hectare per day, which is much lower than the typical organic loading rates of $\geq$3000 kg BOD per hectare per day for the given depth (Hamzeh and Ponce, 2007). The effluent BOD and TSS concentrations were higher than that set by the U.S. standards for secondary effluent and the European Community Commission for Environmental Protection minimum effluent standards. This higher value indicated that the pond system was poorly performing because an environmental condition in the pond particularly pH, is not suitable for the anaerobic microorganisms to bring about the breakdown of organic matter of the brewery wastewater.

The TSS concentration (1809.20 mg/L) of the raw wastewater of the brewery wastewater was much higher than the average TSS concentration of domestic wastewater. This might be attributed to the short retention periods and the presence of large amount of waste grains that should be removed at preliminary treatment unit.

Various species of nitrogen and phosphorus were analyzed in the wastewater stream in order to determine the nutrient load on the pond and the receiving water body. There has been a 59.64% reduction of nitrate nitrogen by the pond system. Abnormally high levels of total nitrogen were found in effluent wastewater. This might be attributed to the conversion of nitrogen locked up in the organic material to inorganic nitrogen forms. EEPA standards require total nitrogen to be ≤ 10mg/L. These high values of nitrogen in the wastewater imply that the effluent wastewater can cause significant pollution in the receiving water and other forms of environmental damage.

Table 2: characteristics of physicochemical parameters at the inlet and outlet of the treatment system

Parameters analyzed	Inlet (Influent) Mean ± STD	Outlet (Effluent) Mean ± STD	Limits (EEPA, 2003)	Efficiency (%)
pH	5.58 ± 0.11	6.19 ± 0.18	6 - 9	-
Conductivity ($\mu S/cm$)	1255.54 ± 25.71	1245.51 ± 24.98	≤ 1000 µs/cm	0.80
DO (mg/L)	0.28 ± 0.09	0.22 ± 0.06	-	-
Temperature (℃)	29.35 ± 1.28	26.93 ± 1.33	20 – 40 ℃	-
Total NH_3-N (mg/L)	48.20 ± 17.81	28.04 ± 18.82	≤ 20 mg/L	41.83
Sulfide (mg/L)	2.64.00 ± 3.54	6.13 ± 2.98	≤ 1mg/L	-132.20
Sulfate (mg/L)	344.80 ± 94.46	300.00 ± 86.60	≤ 250 mg/L	12.99
COD (mg/L)	2232.60 ± 390.75	2056.30 ± 309.44	≤ 125 mg/L	07.90
BOD_5 (mg/L)	431.80 ± 79.87	369.67 ± 149.15	≤ 25 mg/L	15.08
Total phosphorus (mg/L)	139.64 ± 28.78	123.50 ± 72.07	≤ 1 mg/L	11.56
Total nitrogen (mg/L)	68.96 ± 27.38	10.77 ± 6.29	≤ 20 mg/L	84.38
Nitrate nitrogen (mg/L)	35.83 ± 15.83	14.46 ± 5.02	≤ 10 mg/L	59.64
TSS (mg/L)	1809.20 ± 324.63	1453.00 ± 356.83	≤ 35 mg/L	19.68
Turbidity (NTU)	2896.80 ± 1300.64	1985.00 ± 635.96	≤ 300 NTU	31.47
Ortho phosphate (mg/L)	75.72 ± 24.74	25.67 ± 24.66	≤ 0.5 mg/L	66.10

Although the pond system reduced 41.83% of influent ammonia concentration that entered the system the effluent concentration was greater than the value recommended by EEPA.

The concentration of total phosphorus was abnormally high in effluent of the pond system. This is a good indication that the pond system is poorly performing to remove phosphorus from the wastewater. EEPA standards require the effluent wastewater to have a phosphorus concentration ≤ 0.5mg/L. This phosphorus content of pond effluent compounded with nitrate concentration can cause eutrophication in the receiving water body.

The Brewery effluent had a mean temperature 26.93 °C which was within the limits set by Ethiopian Environmental Protection Authority (EEPA, 2003). The average electrical conductivity of the pond effluent (1245.51mg/L) was above the normal limits set by EEPA. High electrical conductivity in the pond effluent may be due to presence of ionized species. Many fold increase in the concentration of sulfide as the wastewater flows from inlet to the outlet might be due to the sulfate-reducing bacteria oxidized the organic compounds and reduce the sulfates to form sulfides.

In general, the percentage treatment efficiency of the pond for BOD, Sulfide, Total Suspended solids, COD, nitrate, and total nitrogen were satisfactory. However, the effluent BOD_5, COD and TSS concentrations were higher than standard set by the U.S. federal standards for secondary effluents.

CONCLUSIONS AND RECOMMENDATIONS

The brewing process uses large volumes of water mostly for the brewing, rinsing and cooling purposes. At same time it also generates large amounts of wastewater effluent and solid wastes that must be disposed off or safely treated in the least costly and safest way so as to meet the strict discharge regulations set by EEPA to avoid damages caused to aquatic life and the environment. As a result, many brewers are today searching for ways to cut down on their water usage during the beer brewing process and/or means to cost effectively and safely treat the brewery wastewater for reuse (Simate et al., 2011).

The often various literatures were reviewed in order to identify the best treatment methods for brewery wastewater and wastewaters having similar characteristics. Accordingly, aerobic and anaerobic biological treatment methods have been suggested. However, brewery effluent is categorized as medium to high strength organic wastewater and needs an intensive amount of energy for aeration. The other disadvantage of aerobic treatment is the large amount of sludge that has been produced during aerobic treatment process which will increase the cost of operation for the treatment system in handling and disposal of the sludge. In recent years, there has been increasing interest to use of waste stabilization ponds to treat the brewery wastewater.

Austermann Haun and Seyfried (1994) suggested that waste stabilization pond system is proved to be the ideal treatment method to treat brewery effluent. It is environmentally safer, achieve greater treatment efficiency, more economical and use natural energy sources. However, it has its own disadvantages such as problem related to the local climatic conditions, design and operation. Also the waste stabilization ponds of many industrial wastes with low pH and high organic load have always been problematic as compared to other wastes of different origin.

Another method highly recommended for the effective treatment of brewery effluent is the use of constructed wetlands. It is effective in the treatment of the wastewater and it is not expensive for construction, operation and maintenance. Land will not be a problem too.

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