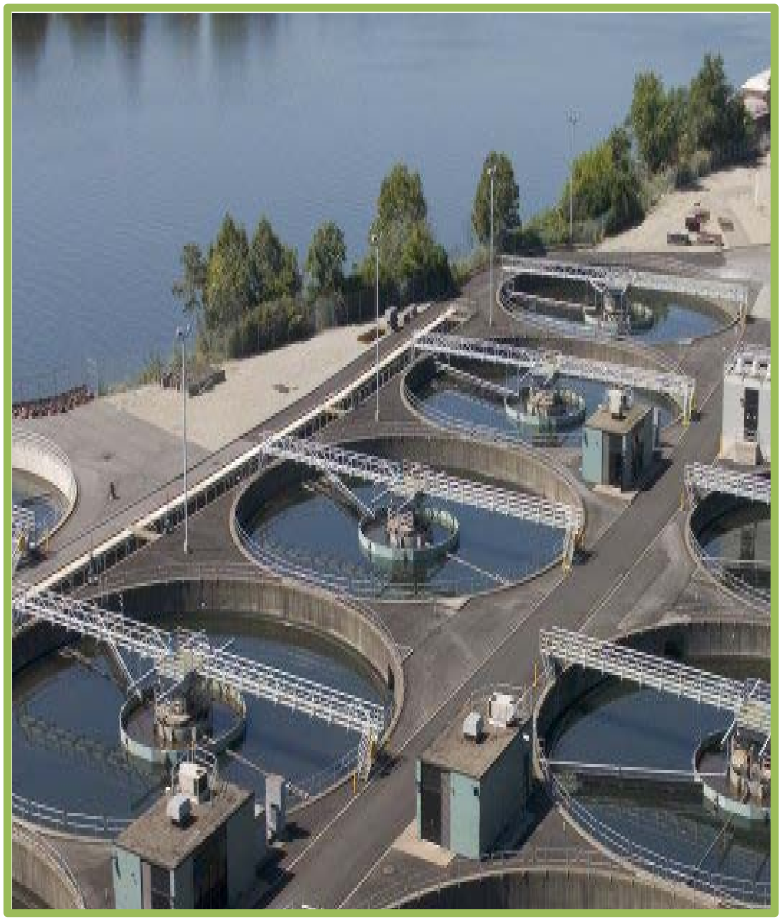

Wastewater Treatment Design for a Brewery

Myles McManus

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Wastewater constituents and average values at a typical brewery

The brewing process generates a unique, high-strength wastewater as a by-product. The wastewater typically has a high concentration of biochemical oxygen demand (BOD) from the carbohydrates and protein used in brewing beer. Brewery wastewater usually has a warm temperature (greater than 100°F). The high level of soluble BOD and the warm temperature make brewery wastewater an ideal substrate for anaerobic treatment. Anaerobic treatment of brewery wastewater is a proven process. More than 250 full-scale systems are operational worldwide.

Wastewater quality may be defined by its physical and chemical characteristics. Physical parameters include color, odor, temperature, and turbidity. Insoluble contents such as total solids (TS), oil and grease also fall into this category. Chemical parameters associated with the organic content of waste-water include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total oxygen demand.

Physical treatment is for removing coarse solids and other large materials, rather than dissolved pollutants. It may be a passive process, such as sedimentation to allow suspended pollutants to settle out or float to the top naturally.

The most cost-effective method for significantly reducing effluent load of brewery wastewater is to separate the solid wastes from the wastewater itself. The equipment necessary includes holding vessels, tanker trucks that can haul away the material, pumps, and dedicated piping or hoses for transfer. Typical solid wastes include spent grains, trub, spent yeast, diatomaceous earth slurry from filtration, and packing materials.

Beer production results in a variety of residues, such as spent grains, which have a commercial value and can be sold as byproducts for livestock feed. The nutritional value of spent grain is much less than that of the same amount of dried barley, but the moisture makes it easily digestible by livestock. Trub is slurry consisting of wort, hop particles, and unstable colloidal proteins coagulated during the wort boiling. In brewing, surplus yeast is recovered by natural sedimentation at the end of the fermentation and conditioning. Only part of the yeast can be reused as new production yeast. Spent yeast is very high in protein and B vitamins, and may be given to livestock as a feeding supplement. Diatomaceous earth slurry from the filtration of beer also constitutes a very large category high in SS and BOD/COD. Different methods for regeneration are under development, but presently they are not capable of totally replacing new diatomaceous earth.

Unit Operations

Typically, the wastewater is first screened to remove glass, labels, and bottle caps, floating plastic items and spent grains. After the wastewater has been screened, it may flow into a grit chamber where sand, grit, and small stones settle to the bottom. With the screening completed and the grit removed, wastewater still contains dissolved organic and inorganic constituents along with suspended solids. The suspended solids consist of minute particles of matter that can be removed from the wastewater with further treatment such as sedimentation or chemical flocculation. Among the chemical treatment methods, pH adjustment and flocculation are some of the most commonly used at breweries in removing toxic materials and colloidal impurities. The acidity or alkalinity of wastewater affects both wastewater treatment and the environment. Low pH indicates increasing acidity while a high pH indicates increasing alkalinity (a pH of 7 is neutral). The pH of wastewater needs to remain between 6 and 9 to protect microorganisms used in the treatment process. Flocculation is the stirring or agitation of chemically-treated water to induce coagulation. Flocculation enhances sedimentation performance by increasing particle size resulting in increased settling rates. After the brewery wastewater has undergone physical and chemical treatments, the wastewater can then undergo an additional biological treatment. Biological treatment of wastewater can be either aerobic (with air/oxygen supply) or anaerobic (without oxygen), which are discussed in more detail in the following sections. Generally, aerobic treatment has been applied for the treatment of brewery wastewater and recently anaerobic systems have become an attractive option.

A brewery's wastewater effluent contains high concentration of organics, so a large amount of aeration is required. Also, sludge disposal also needs proper handling. Due to this anaerobic processes are preferred for wastewater treatment in brewery industry as this not only saves energy but also minimizes sludge disposal costs.

The Brewery waste water treatment process has two significant steps- Biomethanation and Aeration. The two methods have a low energy requirement, generate less sludge, and have advantages of easy start up and operation. A biomethanation process reactor, called a biodigester, is usually used for converting organic matter into useful energy in the form of biogas. The whole biological process of conversion takes place in a controlled atmosphere and temperature which results in effective conversion and generates good amount of biogas. There are many applications for utilizing biogas instead of disposing of it with a flare. One of the most common applications of biogas use is as a fuel in boilers. Since anaerobic digestion systems require a heat source, biogas can be a free fuel. Biogas can also be blended with natural gas for use in production plant boilers. Heating equipment variations will be presented and discussed. Biogas can also be used to generate electricity. With energy costs at an all-time high, alternative fuel sources, especially "green power", are in demand. Equipment such as internal combustion engines, micro turbines, Stirling Cycle engines, fuel cells, and absorption chillers are specifically designed to transform biogas into power. Biogas handling and utilization equipment can be expensive. The interest in the utilization of biogas is evident by the increasing sources of funding available for private and public projects of this nature. Major sources of funding will be listed for interested parties. With funding assistance and proper equipment selection and engineering, biogas utilization can be a cost-effective means of developing green energy.

The aeration system receives the wastewater from the biomethanation plant. The plant also receives the brewery wastewater from other sources like condensate water and floor washings. The brewery wastewater in aeration system undergoes two types of treatment-Conventional Activated Sludge System followed by Extended Aeration System. The discharged wastewater can be further treated and recycled by employing activated charcoal and chlorination techniques. Reverse osmosis methods can also be employed for recovering and recycling water.

Brewery wastewater poses a problem of fluctuating loads hence the treatment process should be designed to address such fluctuations without affecting the output parameters of the wastewater treatment system. Flow equalization is a technique used to consolidate wastewater effluent in holding tanks for "equalizing" before introducing wastewater into downstream brewery treatment processes or for that matter directly into the municipal sewage system and addresses fluctuating loads in the system.

Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally CO2, NH3, and H2O).

Aerobic treatment utilizes biological treatment processes, in which microorganisms convert nonsettleable solids to settleable solids. Sedimentation typically follows, allowing the settleable solids to settle out. Three options include: activated sludge, attached growth (biofilm), and trickling filter processes.

In the activated sludge process, the wastewater flows into an aerated and agitated tank that is primed with activated sludge. This complex mixture containing bacteria, fungi, protozoans, and other microorganisms is referred to collectively as the biomass. In this process, the suspension of aerobic microorganisms in the aeration tank, are mixed vigorously by aeration devices which also supply oxygen to the biological suspension.

The second type of aerobic biological treatment system is called "Attached Growth (Biofilm) Process" and deals with microorganisms that are fixed in place on a solid surface. This "attached growth type" aerobic biological treatment process creates an environment that supports the growth of microorganisms that prefer to remain attached to a solid material.

In the trickling filter process, the wastewater is sprayed over the surface of a bed of rough solids (such as gravel, rock, or plastic) and is allowed to "trickle down" through the microorganism-covered media. A variation of a trickling filtration process is the biofiltration tower or otherwise known as the biotower. The biotower is packed with plastic or redwood media containing the attached microbial growth.

In general, aerobic treatment systems like the activated sludge system produce relatively large quantities of sludge which requires disposal. The sludge can undergo a dewatering treatment either by reconsolidated centrifugation, vacuum filtration or in a pressure filter.

Anaerobic wastewater treatment is the biological treatment of wastewater without the use of air or elemental oxygen. Anaerobic treatment is characterized by biological conversion of organic compounds by anaerobic microorganisms into biogas which can be used as a fuel-mainly methane 55-75 vol% and carbon dioxide 25-40 vol% with traces of hydrogen sulfide (3).

In the Upflow Anaerobic Sludge Blanket (UASB) reactor, the wastewater flows in an upward mode through a dense bed of anaerobic sludge. This sludge is mostly of a granular nature (1-4 mm) having superior settling characteristics (> 50 m/h). The organic materials in solution are attacked by the microbes, which release biogas. The biogas rises, carrying some of the granular microbial blanket.

In a Fludized Bed Reactor (FBR), wastewater flows in through the bottom of the reactor, and up through a media (usually sand or activated carbon) that is colonized by active bacterial biomass. The media provides a growth area for the biofilm. This media is "fluidized" by the upward flow of wastewater into the vessel, with the lowest density particles (those with highest biomass) moving to the top.

Allowable NPDES discharge limits

The following table illustrates the average values of the raw wastewater of a brewery for volume, BOD, and suspended solids set by the EPA's Capsule Report 6: Pollution Abatement in a Brewing Facility.

TABLE 1. TYPICAL RAW WASTE CHARACTERISTICS FROM MALT BEVERAGE PRODUCTION

	Average Range	Brewing Industry Mean Raw Waste Loads per Bbl of Beer[c]
Raw Waste Volume	2649.5-30280 m^3	971.46ℓ/bbl beer[b]
Raw Waste BOD	1400-2000 mg/l[a]	1.37 kg/bbl beer[b] (1622 mg/l)
Raw Waste Suspended Solids	500-700 mg/l[a]	.56 kg/bbl beer[b] (772 mg/l)

[a]Federal Guidelines, State and Local Pretreatment Guidelines, Construction Grants Program Information, EPA-430/9-76-017c, January 1977.

[b]EPA Technology Transfer Series, Capsule Report 6, Pollution Abatement in a Brewing Facility. Prepared by U.S. EPA.

[c]One barrel contains 117.18 liters.

[1]

1 MGD Treatment Plant Design

Using Table 1 as a guide, a 1 MGD flow rate of effluent would be equivalent to 3,785 m^3/day. Linear interpolation was used on Table 1 to approximate the BOD and Suspended Solids concentrations for a volume of 1 MGD. Using this method, the expected BOD concentration is equal to 1,425 mg/L. The expected SS concentration is equal to 508 mg/L. The plant would require a mechanical bar screen to remove any large items in the waste water, an activated sludge aeration tank, and a final clarifier and to reduce the 5-day BOD concentration to below 350 mg/L and settle the suspended solids to a concentration below 600 mg/L.

For the mechanical bar screen, the dimensions will be assumed to have bars of 3/8” thickness with a 1 ¼” clear spacing between the bars. The design velocity through the bars will be 5 ft. per second. The area of the bars for the bar screen is equal to the following equation:

$$A_b = W * D * \left(\frac{1.25"}{1.25" + 3/8"}\right)$$

Where:

A_b= area of the bars (in.^{2})

W= width of the entire bar screen (ft.)

D = depth of the entire bar screen (ft.)

The approach velocity was determined to be 3.85 ft. /s using the following equation:

$$V_a = \frac{V_b * A_b}{A_a}$$

Where:

V_a = the approach velocity (ft./s)

V_b = the velocity through the bars = 5 ft. /s

A_a = W*D = the entire area of the bar screen (ft.^{2})

The width and depth of the bar screen are determined based on the flow. At, an approach velocity of 3.85 ft. /s, and a flow 1 MGD, the area of the bar screen needs to be equal to the flow divided by the velocity. Assuming that the bar screen is square, the required area is equal to:

$$A_a = \frac{(1 * (10^6) gal/day) * (7.481\ ft.^3/gal) * (\frac{day}{86{,}400s})}{3.85\ ft./s} = 22.49\ \text{ft.}^2$$

Since the square root of this area is equal to 4.74 ft., The corresponding mechanical bar screen design width and depth is 4’9” each. After passing the bar screen to remove the larger solids, a smaller screen will be used to remove smaller solids such as pebbled, bottle caps, or grains.

For the clarifier, I have decided to use a rectangular shaped tank because of the ease in which it is designed and constructed. I have designed the detention time to be such that the waste water can be accumulated, treated, and sent out as effluent within a single work day. So, the design detention time I will use is 3 hours to allow time to start up the brewery, create wastewater, aerate the wastewater, clarify the wastewater, and then remove the wastewater as effluent. The following equation was used to determine the dimensions:

$$t = \frac{7.481 * W}{\left(\frac{V}{24 * H * L *}\right)} = 3\ hours$$

Where:

t = detention time (hours)

W = Width (ft.)

7.4181 = gallons per ft.^{3}

V = flow rate (gallons per day)

24 = hours per day

H = height (ft.)

L = Length (ft.)

Assume: Length is equal to twice the width and height is equal to 2/3 the width.

Using this equation with a known detention time along with the assumptions about the dimensions, the dimensions become:

W = 42.33 ft. = 42’4” H = 28.22 ft. = 28’ 3” L = 84.66 = 84’8”

The reduction of suspended solids is dependent on the settling velocity of particles being significantly greater than the upward fluid velocity. For type II flocculent sedimentation behavior, it would be required to perform a laboratory settling analysis using a column of sample water with multiple withdrawal ports along the vertical shaft of said column. This analysis would be used to determine the SS removed versus time by checking the SS concentration at various times at each of the ports on the column of sample water. The percentage of overall removal of SS versus detention time could then determined by using isoremoval curves on a depth versus settling time chart, and estimating the percentage removed at a given time. The percentage of SS overall removed versus the surface overflow rate can then be calculated by first, determining the overflow rate, which is equal to the column length divided by a settling time, and then comparing the overflow rate a given time to the percent of overall removal of SS at the same time. The overflow rate will then be equal to:

$$v_0 = \frac{V}{A} = \left(\frac{1 * 10^6 gal/day}{(84'8") * (42"4")}\right) * \left(\frac{1\ ft.^3}{7.481\ gal}\right) = \frac{37.29\ ft.}{day}$$

Where:

V_0 = Overflow rate (ft. /day)

V = flow rate (gallons/day)

A = surface area of aeration tank (Length times Width, ft.^{2})

Typically clarifiers are scaled up in size by a factor of about 1.5 as a means of implementing a safety factor for higher than normal flow rates into the treatment plant such that we can assured that the effluent suspended solids concentration will be less than 600 mg/L.

For the aeration tank, I have decided to use a rectangular tank with the assumption that length will be twice the width, the height will be 2/3 of the width, and that the detention time will be 3 hours. The overflow rate must be determined using the flow and the surface area. Using the same equation used in the design of the clarifier, and given the assumptions about the dimension ratios and detention times are equivalent, the dimensions will also be equivalent. In order to determine the amount of BOD decreased in the aeration tank, 5-day BOD tests would be done using 300 mL test bottles with 8 mL of sample and the rest of the bottle filled with deionized water. The DO for the bottle would be measured. The dilution factor is equal to 8 mL/300 mL, which is equal to 0.0267. The BOD was determined by taking the 5 day incubation period bottle and dividing the difference of the DO before and after the incubation period by the dilution factor. Typically two bottles with the same DO and dilution factor are tested and the average BOD value is considered to be the actual 5-day BOD concentration for the wastewater. Depending on the results the aeration tank may need additional brushes added, in order to increase the amount of aeration in order to further increase the aerobic digestion of the BOD in the waste water at the plant. The 5-day BOD concentration needs to be reduced to below 350 mg/L to be similar to sewage waste water BOD concentrations, such that the municipal treatment plant will not have to take extra measures to treat the water coming from the brewery.

Ethical Considerations

When dealing with the operation of a brewery, the most important ethical issue to consider is the effects of the finished product, drunkenness. All breweries should consider contributing to educational resources focused on the safe consumption of alcohol such that the business is model does not become a revisit to the 1920's prohibition era, moonshine bootlegging model. As far as the waste water of a brewery is concerned, the wastewater must be pretreated for BOD and suspended solids so that the municipal waste water system is not responsible for the treatment of this water. Otherwise there could be a cost increase at the municipal treatment plant which is passed on to the tax payers of the community.

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