TREATMENT OF BREWERY EFFLUENT BY UASB PROCESS

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ABSTRACT: A five-month pilot study was conducted to examine the effectiveness of the upflow anaerobic sludge blanket (UASB) process for the treatment of effluent from a brewery in rural China. Results indicate that the process operated at 26° C could reduce over 89% of chemical oxygen demand (COD) and 92% of five-day biochemical oxygen demand (BOD_5) from the brewery effluent, with a hydraulic retention time (HRT) of 13.3 hr and a COD loading rate of 4.9 kg COD/m^3/day. The brewery effluent in this study on average contained 2,692 ppm COD and 1,407 ppm BOD_5. The treated effluent on the other hand contained 295 ppm COD and 122 ppm BOD_5; both of which could be further reduced should the suspended solids be more effectively removed. Overall, this process was operated satisfactorily and smoothly, as reflected by the constant effluent pH and gas production rate, as well as the consistently high degrees of reduction of COD and BOD_5. Parameters such as sludge density, distribution of volatile suspended solids (VSS) and soluble COD in sludge bed, gas production rate, and nutrient levels are discussed.

INTRODUCTION

As the standard of living has improved in the last 10 years, beer, a western beverage, has become very popular in China. With an estimated annual production of 6,000,000 m^3, China has become the fifth-largest beer-consuming nation in the world, after the United States, West Germany, United Kingdom, and Russia. Of the thousands of breweries in China, most are located in rural areas, use outdated technology, and, until recently, have little concern of pollution. For each cubic meter of beer produced, these plants in general generate 20–30 m^3 of effluent, much higher than the reported 5–9 m^3 from modern plants in the western nations (Rüffer and Rosenwinkel 1984). The effluent has an organic strength of about 2,500–3,000 ppm COD or 1,400–1,800 ppm BOD_5, comparable to those from western plants.

Consequently, the brewery industry has become one of the major polluters in China. As the country has recently decided to attack her industrial wastewater pollution problem, treatment of brewery effluent has received top priority. Many breweries have already used the more familiar aerobic processes, such as activated sludge, oxidation ditch, and rotating biological contactor. However, brewery effluent has high levels of organics and requires an intensive

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amount of energy for aeration, causing practical difficulties when using aerobic processes in rural China, where electricity supply is short and often unreliable. Thus, anaerobic processes are the logical alternative. This paper summarizes a pilot study using the upflow anaerobic sludge blanket (UASB) process to treat the effluent at a brewery located in the mountainous region of the rural Zhejiang province, about 400 km, or 10 hr by car, from Shanghai. This brewery has an annual beer production capacity of 15,000 m^3, generating 1,200 m^3 effluent daily.

The UASB design was developed by Lettinga et al. (1980) and has attracted much research and development efforts. It has been applied effectively to a variety of industrial wastewaters, such as those from potato processing (Lettinga and Pol 1986), starch, paper mill, alcohol distillery (Pol and Lettinga 1986), and beet sugar (Pette et al. 1981). For example, Lettinga and Pol (1986) reported that the UASB process could reduce 84% of COD from a potato-processing effluent; this was achieved in a 6,000 m^3 reactor at 35° C with an organic loading rate of 24–45 kg COD/m^3/day and a hydraulic retention time (HRT) of 7 hr.

Accordingly, application of this technology to the treatment of brewery effluent appeared feasible. The goal of this pilot study was to develop design and operation parameters for the UASB process to remove a minimum of 90% of BOD_5.

EXPERIMENTAL

Fig. 1 illustrates the design of the 1.17 m^3 pilot UASB steel reactor. The reactor was divided into three zones: sludge bed, sludge settling, and gas. The sludge zone had a depth of 1.15 m and a volume of 0.77 m^3; whereas the respective dimensions for the settling zone were 0.5 m and 0.23 m^3, and those for the gas zone were 0.4 m and 0.17 m^3. The brewery effluent was

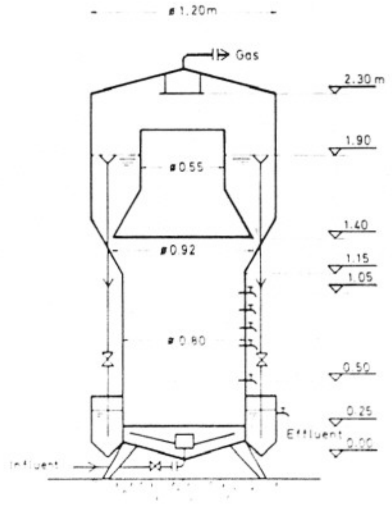

FIG. 1. UASB Reactor Design

fed through a distributor to the bottom of the reactor, flowing upward into the sludge-bed zone in which the organics were degraded into methane and carbon dioxide by the anaerobic microorganisms. The treated effluent then reached the settling zone near the top of the reactor where the sludge was settled and recycled back to the sludge zone by gravity. The supernatant was overflown and collected from six 1-in. (25-mm) tubes around the perimeter of the reactor. The product gas was collected at the top of the reactor and vented through a gas meter.

Standard methods (*Standard* 1980) were used to measure the COD, BOD_5, total suspended solids (TSS), volatile suspended solids (VSS), ammonia nitrogen, alkalinity, and fatty acids. A gas chromatograph (Shanghai analytical instrument, model 100) was used to measure the content of the product gas. Daily sample analyses included temperature, hydraulic loading, alkalinity and gas production rate, plus COD and pH of effluent before and after treatment. Analyses conducted every three days for effluent before and after treatment included BOD_5, volatile fatty acids, ammonia nitrogen, TSS, and VSS. Mixed-liquor samples were taken from five levels of the sludge bed every 10 days; TSS, VSS, and soluble COD after filtering the suspended solids (SS) of these samples were measured.

Since the effluent was acidic (pH 5.0–6.0), caustic soda was added to adjust the pH to neutral. Initial sampling showed that the brewery effluent had low levels of nitrogen and phosphorus. Thus, urea and potassium phosphate were added to provide a balanced nutrient level, keeping the BOD_5-to-N-to-P ratio at 200:5:1. The reactor temperature was kept at about 26° C throughout the five-month experimental study.

Results

The reactor was first seeded with a mixture of sludges: About half of the sludge was from an anaerobic digester of a secondary treatment plant in Shanghai, and the other half was collected from the sludge of a local pond and sieved through a fine screen. The seed sludge mixture contained 86.4 g/L of TSS and 20.7 g/L of VSS. The sludge was acclimated for one month. Suspended-solids levels steadily decreased during acclimation, as solids with poor settling characteristics were washed out. Near the end of acclimation, granular sludge was found at various levels of the sludge bed. In the first 20 days of acclimation, COD of the influent (i.e., brewery effluent) was kept at around 1,200 ppm, while the hydraulic loading was steadily increased from 1.5 m^3/day to 2.0 m^3/day. In the next 10 days, COD was then steadily increased to 2,700 ppm, while the hydraulic loading remained at 2.0 m^3/day. During this 10-day period, COD reduction consistently remained at 90% or more. Fig. 2 illustrates the hydraulic loading [Fig. 2(*a*)], COD in brewery effluent [Fig. 2(*b*)], COD loading [Fig. 2(*c*)], and degrees of COD reduction [Fig. 2(*d*)] during the acclimation period.

After one month of sludge acclimation, the system was then tested for four months. The average VSS in the sludge bed during the test period increased from 11.6 g/L to 24.5 g/L. Summary of the experimental results is shown in Table 1. The system during this period was operated on the average at a flow rate of 1.81 m^3/day (or a HRT of 13.3 hr, based on the total volume of the sludge bed and settling zones), a COD loading of 4.9 kg/m^3/day and a temperature of 26.1° C. The pH of effluent was reduced

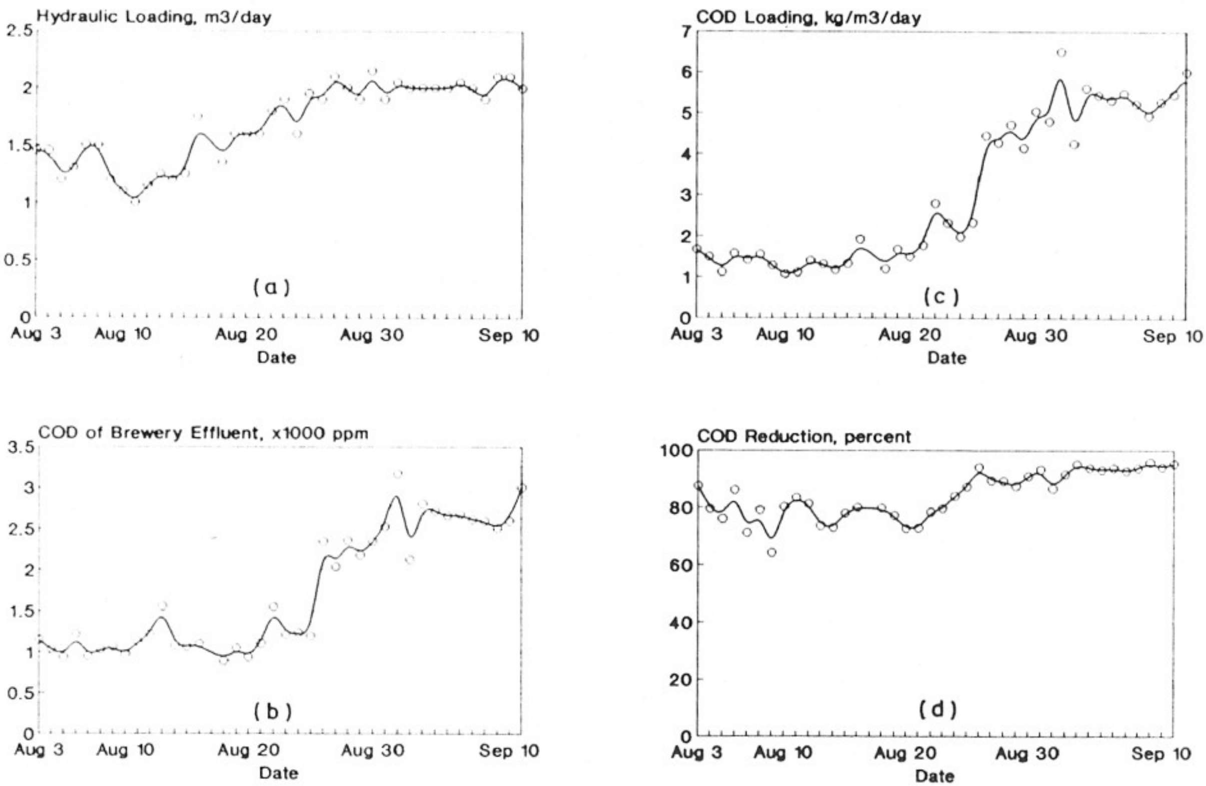

FIG. 2. Acclimation Conditions and Performance: (*a*) Hydraulic Loading; (*b*) COD of Brewery Effluent; (*c*) COD Loading; (*d*) COD Reduction

TABLE 1. Average Process Conditions and Average Characteristics of Brewery Effluent and Treated Effluent during Four-Month Test Period

Condition/characteristics (1)	Process condition (2)	Brewery effluent (3)	Treated effluent (4)	Degree of reduction (%) (5)
Temperature (°C)	26.1	—	—	—
Alkalinity (ppm)	664	—	—	—
Flow rate (m^3/day)	1.81	—	—	—
HRT (hr)	13.3	—	—	—
COD load (kg/m^3/day)	4.9	—	—	—
pH	—	7.3[a]	6.4	—
COD (ppm)	—	2,692	295	89
BOD_5 (ppm)	—	1,407	122	92
TSS (ppm)	—	778	201	74
VSS (ppm)	—	694	162	77
VFA (ppm)	—	98	70	—
VSS/TSS (%)	—	88	81	—

[a]After pH adjustment by caustic soda.

from 7.3 to a constant 6.4 after treatment; the slight acidity in the treated effluent was due to the residual volatile fatty acids (VFA) that were not degraded by the methane formers. The brewery effluent had an average COD of 2,692 ppm, BOD_5 of 1,407 ppm, and TSS of 778 ppm. After the treatment, they were reduced to 295 ppm, 122 ppm, and 201 ppm, respectively, corresponding to reductions of 89% COD, 92% BOD_5, and 74% TSS.

Although the reductions of COD and BOD_5 were satisfactory, the TSS level in the treated effluent remained high. This was probably due to the inadequate size of the settling area in the settling zone. A number of treated effluent samples were filtered and measured for soluble COD. Comparison of COD data between filtered and unfiltered samples showed that the SS, on the average, accounted for 75% of the COD in the treated effluent. Thus, a more effective separation of SS should further lower the COD from 295 ppm to 75 ppm (i.e., 97% total reduction). This appeared to be in good agreement with the VFA data in treated effluent. Since the theoretical COD equivalent of acetic acid is 1.07 kg-COD/kg, 70 ppm of VFA (as acetic acid) in the treated effluent also corresponds to 75 ppm of soluble COD. Results also showed that the COD equivalent of VSS was 1.36 kg-COD/kg, which was comparable to the estimated 1.2 kg COD for each kilogram of biomass (Mosey 1981).

Granular sludge with the size of 1.2–2.0 mm was found at all levels of the reactor during the test period. The average VSS steadily increased from 11.6 g/L after acclimation to 24.5 g/L by the end of the four-month operation. The VSS/TSS ratio was increased from 0.24 to 0.40 in the first two months, and gradually leveled off at 0.43, which was still low compared to 0.90 (Pol et al. 1983). The lower VSS/TSS ratio was probably due to the poor quality of the seed sludge. On the other hand, the VSS/TSS ratio in the treated effluent was 0.81, which was higher than that in the sludge bed. This showed that the VSS had a higher tendency to be washed out. Mixed-liquor samples were taken at five levels of the sludge bed for four

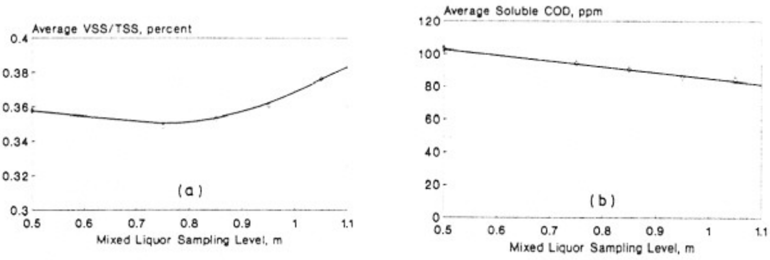

FIG. 3. Mixed Liquor Characteristics in Sludge Bed: (*a*) Average VSS/TSS; (*b*) Soluble COD

months. Results also showed that the average VSS/TSS ratio increased with height, as shown in Fig. 3(*a*).

Fig. 3(*b*) shows that the average soluble COD decreased very slightly with height, from 103 ppm at 0.5 m down to 74 ppm at 1.05 m, compared to the brewery effluent's average COD of 2,692 ppm as it entered the reactor through the distributor at 0.25 m. It thus appeared that the liquid phase in the sludge bed was close to complete mix. Furthermore, from a material balance, it was estimated that the process generated 0.054 kg VSS for each kg of COD removed, which was higher than the reported 0.020–0.025 kg VSS (de Zeeuw and Lettinga 1981).

The process consistently generated 0.45 m^3 of gas for each kilogram of COD removed, which was comparable to those reported in literature, such as 0.25–0.40 m^3 (Pol and Lettinga 1986), 0.27–0.46 m^3 (Pette et al. 1981), and 0.53 m^3 (Riera et al. 1985). The product gas was composed of 70% methane, 25% carbon dioxide, and 5% nitrogen, also comparable to the reported 75% methane (Vieira and Souza 1986) and 58% methane (Riera et al. 1985).

Initial sampling showed that the brewery effluent was low in nitrogen and phosphorus. As a result, urea and potassium phosphate were added to maintain a BOD-to-N-to-P ratio of 200:5:1. After two months of testing, the average ammonia nitrogen in the treated effluent was quite high (67.2 ppm), indicating an overdose of urea. Further analyses of brewery effluent showed that it actually contained an average of 28 ppm ammonia nitrogen, which meant that the nitrogen level could be adequate for the healthy growth of anaerobic microorganisms even without urea addition. As a result, the addition of urea and potassium phosphate was discontinued in the last 30 days of operation. It appeared to have little effect on the process, as the degrees of COD and BOD_5 reduction remain unchanged.

In general, the pilot plant was operated satisfactorily with very consistent performance, as reflected by the effluent pH, COD, BOD_5, and the gas production rate. The brewery was pleased with the 92% reduction of BOD_5. The brewery decided to proceed with the design and construction of a full-scale treatment plant, based on parameters developed in this study. It was recognized that this pilot study was not conducted under optimal conditions. It seemed like the plant under pressure, however, could optimize the operating parameters in the future full-scale operation. One likely improvement would be raising the reactor temperature from 26° C to 37° C, which could likely increase the sludge activity by 60% (Lettinga and Pol 1986; Lettinga and Vinken 1981). Other improvements may include using higher-quality seed sludge, increasing COD loading, and increasing the sludge settling area.

Conclusion

This five-month pilot study has demonstrated that the brewery effluent with high organic loadings could be effectively treated by the UASB process. At pH 7.3 and 26.1° C, the process on average removed 89% of COD and 92% of BOD_5, with an HRT of 13.3 hr and a loading rate of 4.9 kg COD/m^3/day. The SS in treated effluent could account for about 75% of COD. A more effective separation of SS could further lower the final COD. The gas production rate was 0.45 m^3/kg COD with a methane content of 70%. The sludge was granular, 1.0–1.2 mm in size, and had an average density of 50 kg/m^3 in the sludge-bed zone. The sludge yield was 0.054 kg VSS/kg COD removed. Overall, this process operated satisfactorily and smoothly, as reflected by the constant effluent pH and gas production rate, as well as the consistently high degrees of reduction of COD and BOD_5.

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