Treatment of Wastewater from a Whey Processing Plant Using Activated Sludge and Anaerobic Processes

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ABSTRACT

Wastewater from a whey processing plant was treated in two on-site pilot plants, a three-stage activated sludge plant and an anaerobic reactor, each of which had the capacity of treating 230 L/h of wastewater. The activated sludge treatment was very effective. It reduced 99% of 5-d biochemical oxygen demand of the plant wastewater (from an average of 1062 to 9 mg/L) and 91% of total Kjeldahl nitrogen (from 109 to 10 mg/L) after a total retention time of 19.8 h. The intermediate 5-d biochemical oxygen demand reductions were 86% after 3.8 h in the first stage and 97% after another 8 h in the second stage. The completely mixed anaerobic reactor reduced only 87% of 5-d biochemical oxygen demand after 2 d of retention. However, with an additional 8 h of activated sludge treatment the total 5-d biochemical oxygen demand was reduced by 99%. Both pilot plants were operated smoothly in spite of the considerable fluctuations in pollutant levels of the plant wastewater.
(**Key words**: activated sludge, anaerobic treatment, whey wastewater)

Abbreviation key: BOD_5 = 5-d biochemical oxygen demand, **COD** = chemical oxygen demand, **HRT** = hydraulic retention time, **MLVSS** = mixed liquor volatile suspended solids, **TOC** = total organic carbon, **TSS** = total suspended solids, **VSS** = volatile suspended solids.

INTRODUCTION

Whey is the liquid waste generated from the process of cheese making. It constitutes 80 to 90% of the total volume of the milk entering the process and contains more than half of the solids of the original milk, including 20% of the protein and most of the lactose (6). Because of its high levels of protein and lactose, discharging whey directly into the waterway could cause a severe pollution problem. Dairy farmers have commonly given whey to other farmers as animal feed or as fertilizer free of charge. However, the potential pollution problem still exists should other farmers decide not to haul away the whey. More recently, some dairy farmers have used sophisticated technology to process whey, producing dry protein powder and crystallized lactose. By so doing, they not only alleviate a potential pollution problem but also produce two marketable products.

This article discusses a pilot-scale study for the treatment of wastewater from processing plant that generated an average of 910 m^3 of wastewater daily. The primary aim was to develop a simple biological process to reduce the 5-d biochemical oxygen demand (BOD_5) of the wastewater from about 1000 to 250 mg/L or lower, so that the effluent could be discharged to the municipal sewage. The secondary aim was to determine the feasibility of further reducing the BOD_5 to less than 20 mg/L should that become a discharge limit in the future.

Aerobic treatment, such as activated sludge process, has been commonly used for wastewater from food industry (3, 7). However, only in recent years has anaerobic treatment emerged as a viable means for wastewaters containing high levels of organics (2); some have applied it to the treatment of dairy wastewater with certain degrees of success (4, 5, 8). In this study, both activated sludge and anaerobic processes were tested for the treatment of wastewater from the whey processing plant.

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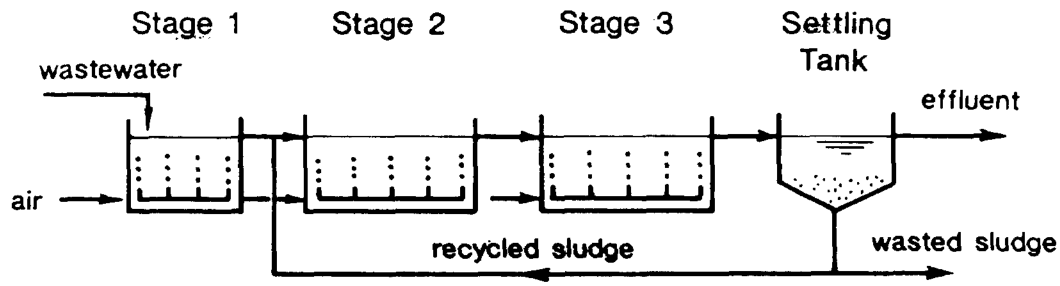

Figure 1. Three-stage activated sludge process.

MATERIALS AND METHODS

Pilot Plants

An aerobic and an anaerobic pilot plants were constructed for this study. Each pilot plant continuously treated 230 L/h of the whey processing plant wastewater that had been held in an equalization tank for 6 h to dampen any fluctuations. The 4.5-m^3 aerobic pilot plant was composed of three stages of activated sludge treatment, as shown in Figure 1. The plant wastewater was treated sequentially for 3.8 h in Stage 1 and 8.0 h each in Stages 2 and 3. Effluent from Stage 3 overflowed to a .75 m^3 circular settling tank. Part of the settled sludge was recycled to Stage 2 in order to maintain a mixed liquor volatile suspended solids (MLVSS) at 2500 mg/L level; the remaining settled sludge was discharged. Fine bubble diffusers were used for the aeration. The dissolved oxygen level in each stage was kept at about 1.5 mg/L.

The anaerobic reactor was a 11.4-m^3 vessel equipped with an agitator for complete mixing, as shown in Figure 2. The plant wastewater had a hydraulic retention time (HRT) of 48 h in the reactor. After the treatment, the effluent was settled in a settling tank; the settled sludge was then recycled to the reactor to build up the sludge level.

Both pilot plants were initially seeded with sludges obtained from a local municipal sewage treatment plant. The aerated sludge was used to seed the three activated sludge vessels, whereas sludge from an anaerobic digester was used to seed the anaerobic reactor. After seeding, both pilot plants were immediately fed with plant wastewater from the equalization

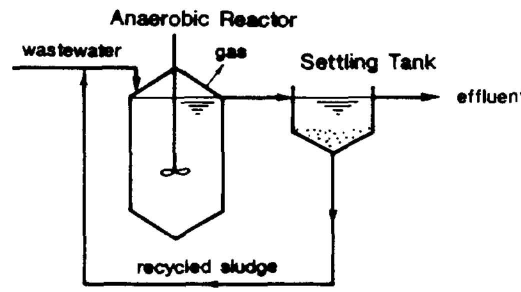

Figure 2. Anaerobic treatment.

tank at the designed rate of 230 L/h. The activated sludge was rapidly acclimated, reaching over 90% BOD_5 reduction in 1 wk. Full-scale sample collections and analyses were conducted for 12 wk, starting 2 wk after seeding. The anaerobic sludge took about 6 wk to acclimate; effluent samples were collected and analyzed for 10 wk. In the last 4 wk of the anaerobic treatment, the effluent from the reactor was diverted to the Stage 2 of the activated sludge for further aerobic treatment, as shown in Figure 3. During this period, the effluent from Stage 1 of the activated sludge process was diverted to a separate settling tank, and the operation of Stage 3 was discontinued.

Sampling and Analytical

Two months before experiments started, a program was initiated to collect daily samples of plant wastewater from the equalization tank and to analyze its characteristics while the pilot plants were being constructed. The wastewater sampling program continued until

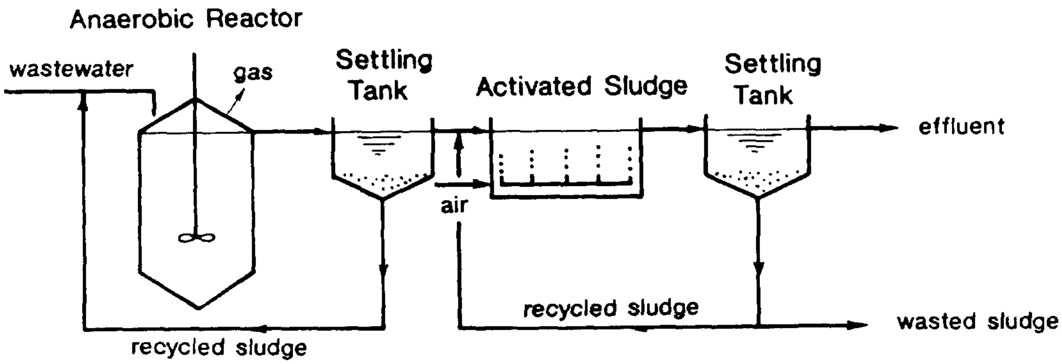

Figure 3. Anaerobic treatment followed by activated sludge.

the end of the project. During experimental stages, wastewater samples were also taken daily from various stages of treatment for analysis.

Wastewater characteristics, such as BOD_5, chemical oxygen demand (COD), total Kjeldahl N, NH_4 N, total suspended solids (TSS), and volatile suspended solids (VSS) were analyzed following the standard procedures (1), whereas the total organic carbon (TOC) was measured by a Dohrmann DC-50 TOC Analyzer.

RESULTS AND DISCUSSION

Characteristics of Wastewater

Table 1 summarizes the average characteristics of the wastewater from the whey processing plant, which had a neutral pH of 7.0, BOD_5 of about 900 mg/L and total Kjeldahl N of 109 mg/L. The BOD_5:COD ratio of .55 was comparable with the reported ratio of .52 for whey (6).

P ollutant levels in the wastewater fluctuated considerably. The standard deviations in the whey plant wastewater were over 30% of the averages for TOC, COD, and BOD_5, and 70% or more for total Kjeldahl N, NH_4 N, TSS, and VSS. The high degrees of fluctuation in the pollutant levels have been reported as a common phenomenon in dairy effluent (6). However, ratios of some measurements, such as BOD_5:COD, BOD_5:TOC, COD:TOC, NH_4 N:total Kjeldahl N, and VSS:TSS, also shown in Table 1, deviated much lesser from the averages. This seems to indicate that, although the pollutant levels in wastewater fluctuated, the constituents and the nature of the pollutants were rather consistent.

Three Stage Activated Sludge Treatment

Table 2 summarizes the average characteristics of the influent and effluent samples at various stages of treatment. Stage 1, which had an average temperature of 24°C, HRT of 3.8 h, and MLVSS level of 699 mg/L, reduced 86% of BOD_5. However, Stages 2 and 3 both had about 21°C of temperature, 8 h of HRT and

TABLE 1. Characteristics of wastewater from whey processing plant.

Characteristics[1]	Average	SD
Temperature, °C	25.5	2.5
pH	7.0	2.0
BOD_5, mg/L	896	310
COD, mg/L	1624	556
TOC, mg/L	546	167
TKN, mg/L	109	80
NH_4 N, mg/L	8.5	6.3
TSS, mg/L	261	180
VSS, mg/L	188	149
BOD_5:COD	.55	.09
BOD_5:TOC	1.69	.20
COD:TOC	3.02	.02
NH_4 N:TKN	.084	.047
VSS:TSS	.72	.16

[1]BOD = 5-d Biochemical oxygen demand, COD = chemical oxygen demand, TOC = total organic carbon, TKN = total Kjeldahl nitrogen, TSS = total suspended solids, and VSS = volatile suspended solids.

TABLE 2. Summary of three-stage activated sludge treatment.

Characteristics[1]	Stage 1	Stage 2	Stage 3	Overall
Temperature, °C	24.1	20.9	20.6	. . .
TOC_{inf}, mg/L	630	299	69	. . .
TOC_{eff}, mg/L	269	81	43	. . .
BOD_{5inf}, mg/L	1062	165	25	. . .
BOD_{5eff}, mg/L	149	29	9	. . .
TKN_{inf}, mg/L	109	. . .	. . .	. . .
TKN_{eff}, mg/L	. . .	. . .	10	. . .
NH_4 N_{inf}, mg/L	8.5	. . .	. . .	. . .
NH_4 N_{eff}, mg/L	. . .	. . .	.7	. . .
MLVSS, mg/L	699	2566	2423	. . .
Volume, m^3	.87	1.82	1.82	4.51
HRT, h	3.8	8.0	8.0	19.8
BOD_5 Loading rate, g/m^3 per d	6707	493	75	. . .
TOC Reduction, %	57	68	34	93
BOD_5 Reduction, %	86	79	62	99
TKN Reduction, %	. . .	. . .	. . .	91
NH_4 N Reduction, %	. . .	. . .	. . .	92

[1]TOC = Total organic carbon, inf = influent, eff = effluent, BOD_5 = 5-d biochemical oxygen demand, TKN = total Kjeldahl nitrogen, MLVSS = mixed liquor volatile suspended solids, and HRT = hydraulic retention time.

2500 mg/L of MLVSS by recycling settled sludge, respectively, reduced 79 and 62% BOD_5 of their influents overflowed from the proceeding stages. The respective TOC reductions were 57, 68, and 34% for Stages 1, 2, and 3. The overall reductions for the three-stage treatment were 99% for BOD_5, 93% for TOC, and 91% for TKN.

Table 2 also shows that, after 3.8 h of treatment in Stage 1, the wastewater BOD_5 was reduced from 1062 to 149 mg/L, which was sufficient to meet the primary target of 250 mg/L or less. Stage 2 further reduced BOD_5 to 29 mg/L, corresponding to an overall reduction of 97%; the additional Stage 3 further lowered BOD_5 to 9 mg/L, which met the secondary target of 20 mg/L or less.

Stage 1 was operated as a completely mixed activated sludge reactor without sludge recycle. At an average BOD_5 loading of 6707 g/m^3 per d, Stage 1 was operated at a very high ratio of food to microorganisms, which normally could have resulted in sludge bulking at the downstream settler. However, because effluent from Stage 1 was under extended aeration in Stages 2 and 3, there was no bulking at the final settler throughout this study. On the average, for each gram of BOD_5 removed in Stage 1, .77 g of sludge was produced.

The TOC:BOD_5 ratios steadily increased from .59 of the plant wastewater to 1.81 after Stage 1, to 2.76 after Stage 2, and to 4.78 after Stage 3. This clearly indicated that, as the treatment progressed, the remaining organics became less and less biodegradable, as would be expected. The TOC:BOD_5 ratio was rather consistent for each stage; standard deviations were about 15% of the averages.

Biodegradation of lactose would reduce the organic levels in the wastewater but would not affect the nitrogen levels. Results of this study

TABLE 3. Summary of anaerobic treatment.

Characteristics[1]	A[2]	B[2]
TOC_{inf}, mg/L	794	710
TOC_{eff}, mg/L	393	59
BOD_{5inf}, mg/L	1196	1334
BOD_{5eff}, mg/L	141	12.4
Temperature		
Anaerobic, °C	26	21
Activated sludge, °C	. . .	21
HRT		
Anaerobic, h	48	48
Activated sludge, h	. . .	8
TOC Reduction, %	46	85
BOD_5 Reduction, %	89	99

[1]TOC = Total organic carbon, inf = influent, eff = effluent, BOD_5 = 5-d biochemical oxygen demand, and HRT = hydraulic retention time.

[2]A = 48 h of anaerobic treatment alone; B = 48 h of anaerobic treatment followed by 8 h of activated sludge.

showed that the total Kjeldahl N:TOC ratio increased only slightly, from .20 in wastewater to .23 in the final effluent. This seems to indicate that the pollutants in wastewater were composed primarily of proteins and, to a much lesser degree, lactose.

Anaerobic Treatment

The anaerobic treatment was conducted at an average temperature of 26°C. In the first 6 wk of anaerobic treatment, the TOC and BOD_5 reductions after 48 h of retention time were 46 and 89%, respectively. The average BOD_5 was reduced from 1196 to 141 mg/L, which met the primary target of 250 mg/L or less. For comparison, Landine et al. (5) recently reported that the BOD_5 in a dairy effluent was reduced by 94% by anaerobic treatment at 30 to 32°C and an HRT of 6 d, from 1970 to 111 mg/L. Hickey and Owens (4), however, reported an 80% reduction on COD of dilute whey at 35°C in an anaerobic fluidized bed reactor.

In order to meet the secondary target, the effluent from the anaerobic reactor was further treated by the activated sludge with 8 h of HRT in the last 4 wk of experiment. Results showed that the BOD_5 in the final effluent was further lowered to 12 mg/L, which was below the 20 mg/L target. The overall reductions were 85% for TOC and 99% for BOD_5. Results of both anaerobic treatments are summarized in Table 3.

CONCLUSION

This study has demonstrated that wastewater from whey processing plant could be effectively treated either aerobically or anaerobically. The BOD_5 of wastewater was reduced from about 1000 to below 150 mg/L by 3.8 h of activated sludge treatment or by 48 h of anaerobic treatment. To lower the BOD_5 to the 20 mg/L, further treatments were required. Two additional stages of activated sludge treatment reduced BOD_5 in the initial activated sludge effluent to 9 mg/L; one additional activated sludge treatment reduced the BOD_5 of the anaerobic effluent to 12 mg/L. Although the pollutant levels in the wastewater fluctuated considerably, depending on measurement, both pilot plants were operated smoothly. No noticeable operation problem was observed.

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REFERENCES

1 American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1985. Standard methods for the examination of water and wastewater. 16th ed. Am. Publ. Health Assoc., Washington, DC.

2 Fang, H.H.P. 1989. Anaerobic treatment of agricultural and industrial wastewater. Hong Kong Eng. 17(2):9.

3 Gilde, L. C., and O. M. Aly. 1976. Water pollution control in the food industry. Page 5.1 *in* Industrial wastewater management handbook. H. S. Azad, ed. McGraw-Hill, New York, NY.

4 Hickey, R. F., and R. W. Owens. 1981. Methane generation from high strength industrial waste with the anaerobic biological fluidized bed. Biotechnol. Bioeng. Symp. 11:399.

5 Landine, R. C. 1988. Anaerobic treatment of dairy wastewater. Page 701 *in* Proc. 42nd Industrial Waste Conference, Purdue Univ., West Lafayette, IN. Lewis Publ., Chelsea, MI.

6 Marshall, K. R., and W. J. Harper. 1984. The treatment of wastes from the dairy industry. Page 296 *in* Survey in industrial wastewater treatment. Part 1. D. Barnes, C. F. Forster, and S. E. Hrudey, ed. Pitman, Marshfield, MA.

7 Metcalf and Eddy. 1979. Wastewater engineering: treatment, disposal, reuse, 2nd ed. McGraw-Hill, New York, NY.

8 Sobkowicz, A. M. 1987. Celrobic anaerobic treatment of dairy processing wastewater. Page 458 *in* Proc. 41st Ind. Waste Conf., Purdue Univ., West Lafayette, IN. Lewis Publ., Chelsea, MI.