43 SEQUENCING BATCH AND HYBRID ANAEROBIC REACTORS TREATMENT OF DAIRY WASTES

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INTRODUCTION

The wastewater treatment alternatives for diary wastes produced from a Turkish Milk Industry Association (SEK) plant located in Istanbul producing bottled milk, cheese, yogurt and butter were investigated. Sequencing batch and hybrid pilot reactors (SBR and HPR) were constructed and the operation of these two systems were tested using the wastewater from the SEK plant. Intermittent sequencing reactors possess operational flexibility. The number of reactors in operation can be altered depending on the daily and seasonal flow rate changes. Since aeration and sedimentation takes place in the same tank, there is no need for recycling facilities and the system is not affected by shock loads. Since the effluent is discharged intermittently, the effluent can be kept in the reactor till the effluent standards are fulfilled. Organic carbon removal, nitrification and the denitrification processes can all be achieved in a single reactor. Also during the filling and discharging, operation schemes can be changed to control the overgrowth of filamentous microorganisms.

The pilot plant sequencing batch reactor was operated for a duration of 6 months at different organic loads and operational modes. The COD of the inlet was varied between 1 000 and 4 000 mg/L. The response of the reactor to various filling times as long as 3 hours was investigated. One cycle that included the filling, aeration, mixing, settling, draining and resting operations was taken as 24 hours. The aeration time was 13 hours. For each mode of operation, SVI and the BOD removal efficiencies were measured. The SVI range was 38 to 105 mg/L and the COD removals of 91-98% were achieved. The concentration of the suspended solids in the effluent was between 30 and 110 mg/L.

The anaerobic processes are comparatively more difficult to operate and the microorganisms in anaerobic reactors are more sensitive to temperature, pH and other environmental changes. However, the anaerobic reactors have less operating costs, and the methane produced can be utilized as a valuable by-product. Following the period of start up the hybrid anaerobic reactor was operated at the loading rate varying between 1 and 8 kg COD/m^3/d. The operating parameters including suspended solids, biogas volumes and compositions were measured. COD removal efficiencies of 60% to 90% were achieved depending on the varying organic loading rates, for an operating period of four months.

PRODUCTION PROCESSES

The Turkish Milk Industry Association (SEK) is a state establishment. It has over thirty plants in different cities distributed throughout Turkey. The total capacity of all these plants is about 200,000 tons/year. In the last decade, private industry has also contributed to the production. The plant that was the subject of this investigation was SEK located in Kuleli, Istanbul. The plant's capacity is 60,000 ton/year. In the year 1989, the unprocessed milk entering the plant was 59,000 tons/year (40,000 tons of pasteurized bottled milk, 5,600 tons of yogurt, and 310 tons of butter, 28 tons of cheese).

The first step in the processes is receiving the unprocessed milk. The milk passes through quality control and centrifuged. Then it is stored after cooling to 4°C. After clarification and standardization

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Table I. Characteristics of Wastewater from the Dairy Product Industry[1]

Type of Wastewater	Unit WWater Flow Rate, m^3/t Product	BOD_5, Kg/ton Product	Suspended Solids, Kg/ton Product
Receiving station (bulk)	0.08–0.54	0.10–0.17	0.03
Fluid product	0.11-9.09	0.14-17.06	0.13-3.36
Butter	0.80-6.55	0.19-1.91	0.40
Cottage cheese	0.83-12.54	1.30-42.0	–
Natural cheese	0.20-5.85	0.30-4.04	0.10-0.27
Fluid and cottage	0.23-4.65	0.66-7.87	–
Fluid and cultured	0.46-7.95	0.35-7.84	0.20-11.6
Fluid and butter	0.75-3.34	0.33-3.26	–

the milk passes through the homogenization and deodorization and pasteurization steps. The pasteurization applied is high temperature short time (HTST) method. The pasteurized milk then is packed and stored.

The second important product is yogurt. It is produced by evaporating pasteurized milk under vacuum and by culturing.

SOURCES AND CHARACTERISTICS OF WASTEWATERS FROM THE DAIRY INDUSTRY

The sources of wastewater are listed below:

- milk spilling during receiving
- overflow from tanks
- spilling of milk and milk products during the processes
- leakage from pipes, pumps, and tanks
- washing of milk tankers
- washing of bottles and cans
- washing of processing equipments
- milk and milk products discharged during start-up and change over of units
- washing of cheese and casein and butter
- material lost through evaporators during the evaporation stage
- discharge of spoiled milk and milk products
- loss during packing operation
- discharge of cooling water

The seasonal and daily quantities of wastewater shows vast fluctuations. Daily wastewater quantities show big changes during the washing hours at the end of the shifts. The seasonal changes in the milk received to the plant directly affects the wastewater amounts and concentrations (Highest amounts occur in June and July). The amount of wastewater is dependent on the kind of process used however, it varies between 2 and 6 m^3/m^3 product.

The important wastewater parameters in the dairy wastewaters are: BOD_5, COD, SS, pH, fat and temperature. The ranges of these parameters are shown in Table II. The average results in Turkey are also given in Table II.

The effluent parameters of SEK-Kuleli plant is presented in Table III. The effluent is a mixture of all the waste discharges from the plant.

The wastewater discharged from this plant is dilute since the plant produces mostly fluid milk and the water consumption in the plant was more than usual.

SEQUENCING BATCH REACTORS

Before a treatment plant is designed, the possible ways of recovery and waste minimization must be considered. Both aerobic and anaerobic treatment methods can be applied in the treatment of dairy wastes. Screening, equalization, and if required fat removal units can be applied before the biological treatment step. Activated sludge system is the generally applied treatment method however, due to energy conservation, anaerobic reactors are being considered in the recent years. In some countries, the dairy industry consists of small plants and operating activated sludge systems in such small plants is not simple thus, sequencing batch reactors can a preferred choice.

Table II. The Ranges of the Important Pollution Parameters of the Dairy Industry[2,3]

Parameter	Unit	USA Range	USA Mean	Turkey Mean
BOD_5	mg/L	40–48,000	2,300	2,000
COD	mg/L	80–95,000	4,500	4,000
SS	mg/L	24–4,500	820	800
Total solids	mg/L	135–8,500	2,500	2,200
Nitrogen	mg/L	1–180	64	60
Fat	mg/L	35–500	209	350
P as Po_4^-	mg/L	9–210	48	–
Cl^-	mg/L	48–1,930	480	–
kg BOD_5/m^3 milk	–	0.2–7.1	5.8	–
m^3 wwater/m^3 milk	–	0.1–7.1	2.4	4
pH	–	4.4–9.4	7.2	5–10
Temperature	°C	18–55	35	30

The advantages of the sequencing batch reactors can be summarized as follows:

- Depending on the fluctuations of the influent flow rate, required number of reactors can be taken out or put into service.
- Since aeration and sedimentation take place in the same tank, there is no need for a recirculation pumping station.
- Since during the filling stage, the flow rates and concentrations are balanced, there is no need for an equalization basin.
- Since the effluent is discharged periodically, the contents of the reactor can be kept in the reactor till the requested effluent standards are met.
- Removal of organic, nitrification, and denitrification all take place in a single tank.
- During the filling and the draining phases, the operation schemes can be altered to prevent the growth of filamentous microorganisms.

The phases of sequencing batch reactors are shown in Figure 1. The schematic flow diagram of an SBR plant are given in Figure 2.[4]

EXPERIMENTAL STUDIES WITH SEQUENCING BATCH REACTORS

A plexiglass cylinder with an inner diameter of 14.5 cm and was used as a reactor. The experimental set-up is shown in Figure 3. After adaptation period, the reactor was fed with diluted fluid milk solutions. The total cycle consisting of filling, aeration, mixing, sedimentation, draining and idle phases was 24 hours. The aeration time was 13 hours. The volumetric flow rate of the feed wastewater, COD, MLSS concentration at the end of the aeration phase, SVI, COD of the liquid remaining on top of the sediment were measured.[3] The results of the experiments for different organic loadings are shown in Table IV.

The organic loadings given in Table IV are calculated using the formula:

$$L_s = \frac{(V - V_o)\, S_o}{\theta V X} \qquad (1)$$

in which L_s is the organic load in kg COD/Kg MLSS.d, V the reactor total volume in m^3, V_o is the volume of the reactor before filling in m^3, S_o is the COD concentration of the feed in g/m^3, θ is the aeration time in days, X is the mixed liquor suspended solids concentration in g/m^3.

Table III. The Effluent Parameters of SEK-Kuleli Plant

Parameter	Unit	Range	Mean
BOD_5	mg/L	600–1,300	1,100
COD	mg/L	1,100–2,400	2,200
SS	mg/L	90–450	250
Nitrogen (T.Kjeld)	mg/L	67–85	76
Fat	mg/L	110–260	210
PO_4^--P	mg/L	3.5–15	12

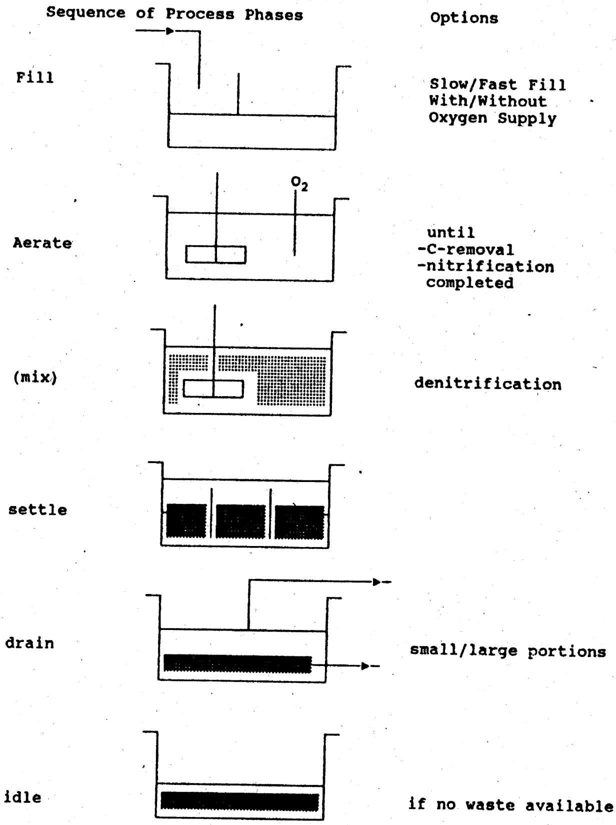


Figure 1. The phases of a sequencing batch reactor (after Wilderer, 1991).

ANAEROBIC TREATABILITY STUDIES

The Hybrid Anaerobic Reactor

Anaerobic treatability studies were conducted by a laboratory scale hybrid anaerobic reactor with a useful volume of 8.1 liter. The reactor consisted of a plexiglass column having an internal diameter of 100 mm. The total height of the reactor was 140 cm. The upper 60% of the column was filled with cylindrical plastic rings (ID = 28.5 mm, h = 28.5 mm). The specific surface area of the packing material was about 190 m^2 per m^3. The bottom 40% of the column was used as upflow anaerobic sludge blanket reactor. The HBR included a refrigerated feed tank, a feed pump, a gas liquid separator, and a gas meter. The reactor was heated by recirculating hot water through polyethylene pipes wrapped around the plexiglass column. The temperature control of the reactor was achieved by adjusting the temperature of the recirculating stream using an electrically controlled heat exchanger. The flow scheme of the reactor is shown in Figure 4.

The Feed

Skimmed milk containing 0.5% fat was used as the feed. Concentrated feed had a mean COD of 100,000 mg/L which was diluted with tap water to obtain the desired COD concentration.

Start-up of the Reactors

500 L sludge supplied from a laboratory scale upflow anaerobic sludge blanket reactor treating domestic wastewater in mesophilic conditions was used as the feed. The volatile solids (VS) content of the feed was about 20,000 mg/L. The hybrid anaerobic reactor was fed together with the dairy

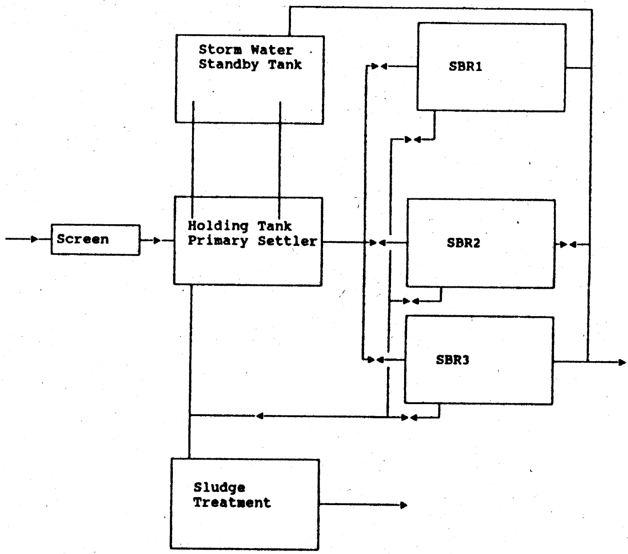


Figure 2. Flow diagram of a SBR plant (after Wilderer, 1991).

effluent with an average COD of 2,500 mg/L at a flowrate of 5.8 L/d. The corresponding organic loading rate (OLR) was 1.43 kg COD/m^3/d during the start-up period. pH was maintained in the range of 7.0–7.8 and the average temperature was kept at 35 ± 1. Na HCO_3 was added directly to maintain the required alkalinity level when it was necessary. Urea (NH_4OH) and phosphoric acid (H_3PO_4) were supplemented into the feed to provide COD:N:P ratio as 500:5:1 due to N and P deficiency of the feed. This mode of operation was continued for 42 days and COD removal efficiencies of the reactor were less than 50% in this period. Starting from the 43rd day the OLR was gradually

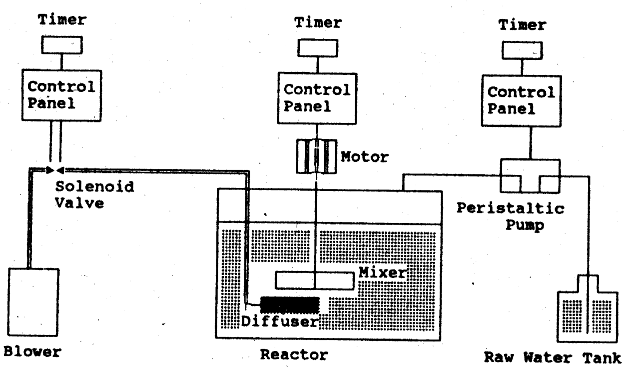
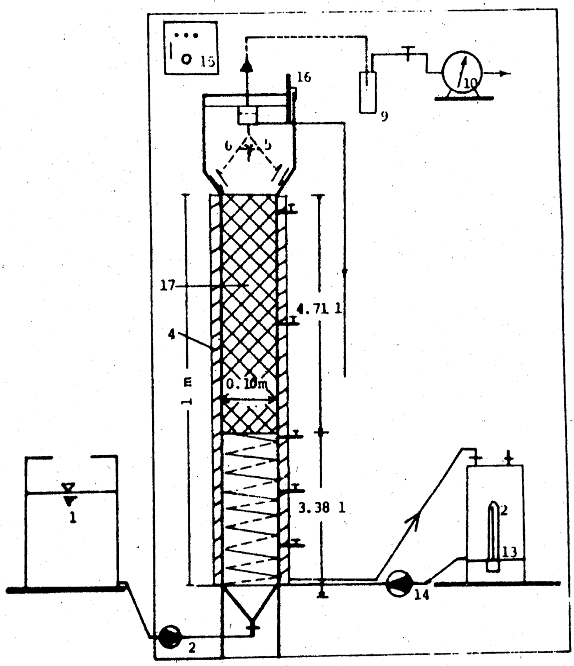


Figure 3. Experimental set-up used in the SBR experiments.

Table IV. Sequencing Batch Reactor Experiment Results

Number of Samples	COD Inlet g/m^3	COD Outlet[a] g/m^3	MLSS g/m^3	Organic Load kg/kg.d	Effici. %	SVI mL/g
38	2,300 ± 635	130 ±73	5,050 ±1,000	0.64 ±0.16	95 ±3	47 ±7

[a] Soluble COD.



1. Feed tank
2. Feed pump
3. Sampling ports
4. Heat isolation
5. Gas collector
6. Effluent weir
7. Effluent line
8. Gas pipes
9. Gas-liquid seperator
10. Wet Test Meter
11. Hot water recirculation line
12. Heat exchanger
13. Temperature controlled heater
14. Hot water recirculation pump
15. Control pannel
16. Thermometer
17. Plastic packing

Figure 4. The flow scheme of the pilot plant.

increased to provide enough mixing in the anaerobic digester and COD:N:P ratio was also increased to 250:5:1 which is optimum for anaerobic digestion.

Experimental Design

The experimental procedure used in this study is shown in Table V.

HRT and OLR values were calculated by considering a reactor useful volume of 8.1 L. The numbers given in the brackets in the table represents the corresponding values calculated by considering the volume of the empty bottom part of the hybrid reactor (3.4 L). Major operating parameters including pH, COD, alkalinity and volatile solids concentration were analyzed according to standard methods (AWWA, APHA and WPCF, 1990). Biogas flowrates were measured by a wet test-meter. The parameters including alkalinity, gas flow rate and temperature were measured on a daily basis but COD analysis were performed three times in a week. The VS content of the sludge was measured once in 2 to 4 weeks.

Table V. Experimental Procedure

Parameter	Start-Up (0–42 Days)	Normal Operation (43–115 Days)
HRT, (days)	1.40 (0.59)	0.96–0.35 (0.40–0.15)
Average feed COD (mg/L)	2,000	2,500
OLR kg $COD/m^3/d$	1.43 (3.4)	2.54–7.10 (6.05–16.9)

RESULTS OF THE ANAEROBIC TREATABILITY STUDIES

COD Removal

Anaerobic treatability studies on synthetic dairy effluents characterizing dairy industries producing pasteurized milk have been carried out 115 days including the start-up. Table VI summarizes the steady state operating results including hydraulic retention time (HRT), influent and effluent COD's, pH, alkalinity, temperature and volatile solids content of the reactor, biogas flowrates, organic loading rates, and COD removal efficiencies.

The low COD values encountered during the start-up were attributed to the nutrient deficiency of the feed and starting from the 50^{th} day, nutrient supplement was increased 100% to provide COD:N:P ratio as 250:5:1. An immediate response of the anaerobic digestion process to this application was a significant reduction in the effluent COD. Figure 5 shows the variation of the influent and effluent COD's and alkalinity in the reactor during the anaerobic treatability studies. The hydraulic retention times ranged from 0.96 to 0.35 days at normal operating conditions after the start-up. COD removal efficiency of more than 87% was achieved at an OLR of 7.10 kg $COD/m^3/d$ for the total volume basis. OLR was gradually increased from 2.54 to 7.10 kg $COD/m^3/d$ within 15 days but the anaerobic reactor performances were quite stable despite this rapid increase in OLRs (Figure 6). About 87% of the daily organic loading can be effectively removed by the hybrid anaerobic reactor at OLRs as high as 7.1 kg $COD/m^3/d$ or more. Starting from the 66^{th} day, DOSFOLAT (a complex tetrahydropholic acid) was used at a concentration of 0.5 mg/L in the feed to activate biosynthesis and to improve sludge characteristics. This application resulted in a very stable reactor performance, increased biomass production and biogas production in the system. The VS concentration at a location 13 cm from the bottom of the reactor was about 23.6 g/L before DOSFOLAT application but it was gradually increased to 33.7 g/L in an application period of 50 days. Sludge bulking was also taken under control depending on the improvements of the sludge characteristics.

pH and Alkalinity

pH and alkalinity in the anaerobic reactor was continuously monitored. pH of the feed was maintained around 6–7 by adding NaOH solution. The alkalinity adjustments were made using $NaHCO_3$ and/or NaOH solutions. The alkalinity in the reactor was maintained above 100 mg/L as $CaCO_3$ and it generally averaged about 1,500 mg/L (Figure 5). pH and alkalinity in the digester dropped below 6.5 and 1000 mg/L, respectively, for three times during the study due to pH control problems that originated from mechanical failures in the feed refrigerator and rapid increase in the OLR. Since the feed easily becomes acidic in a warm environment for several hours, the pH should be precisely controlled about neutral range prior to the mesophilic anaerobic digester.

Biogas Production and Composition

Because the COD removal rate (R_L) in the hybrid anaerobic reactor increased with an increase in the OLR (Figure 6), a similar relationship may be observed between the daily gas production and the COD loading as illustrated in Figure 7. The observed biogas production yields were about 0.40 L per kg COD removed. CH_4 contents of the gas were measured by Orsat apparatus and the average CH_4 value measured was 75%. This represents about 86% energy recovery value from the dairy effluent.

Table VI. Operating Results from Hybrid Anaerobic Treatment of Dairy Effluents

Time (d)	HRT (d)	Inf.COD (mg/L)	pH	Alkalin mg/L as CaCO3	Temp. (°C)	COD mg/L	Qgas (L/d)	OLR (kgCOD/ m^3.d)	COD Rem. Eff. E(%)
1–43	1.40	(2000)[a]	7–7.8	1200	35 + 1	1100		1.43	45.0
44–88	0.96	1200–3080 (2440)	7.5	2000	35 + 1	255	7.3	2.54	89.5
89–93	0.54	2210–2265 (2240)	8.0	1700	35 + 1	230	11.10	3.91	89.0
94–102	0.50	2200–2785 (2320)	7.95	2000	35 + 1	263	12.20	4.36	88.6
103–115	0.35	2200–2800 (2565)	7.50	2000	35 + 1	330	23.40	7.10	87.0

[a]Values in the bracket show averages

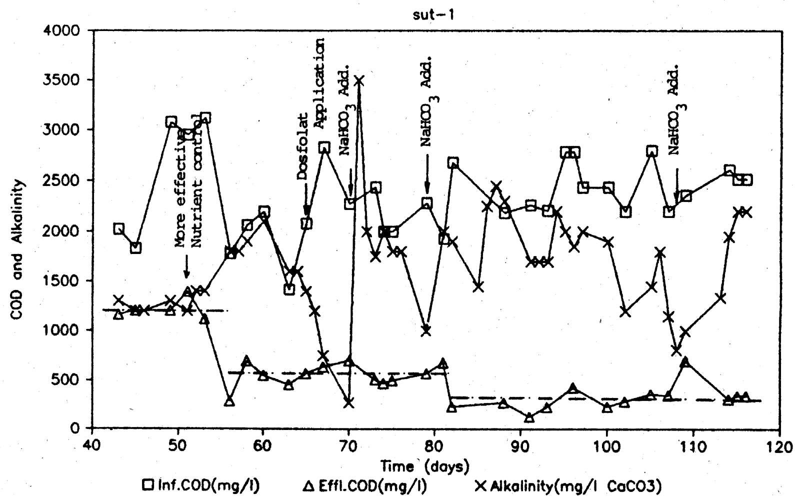


Figure 5. COD and alkalinity vs time.

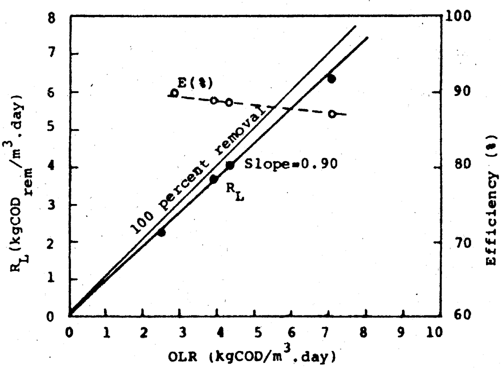


Figure 6. COD removal and efficiency vs OLR.

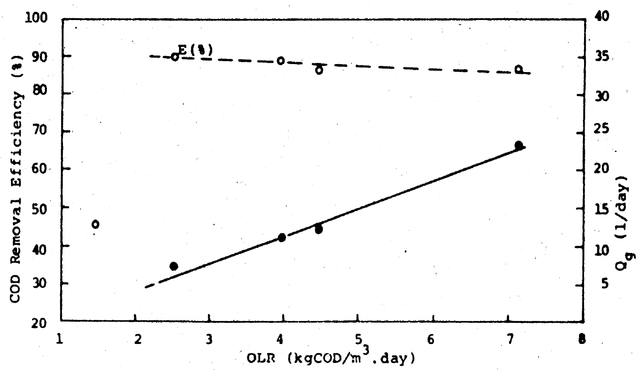


Figure 7. COD removal efficiency and gas flowrate vs OLRs.