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# HYBRID UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR (HUASBR) TREATMENT OF DAIRY EFFLUENTS

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## ABSTRACT

This paper covers the treatability results of a laboratory-scale hybrid upflow anaerobic sludge blanket reactor (HUASBR) treating dairy effluents from a large integrated industry with a maximum production capacity of 500 tons of milk per day. The study began with the determination of effluent characteristics and pollution profile for the investigated dairy industry. As a result of observations, by-product recovery and waste reduction alternatives were investigated by in-plant control measures. Anaerobic treatability studies were conducted by a laboratory-scale hybrid upflow anaerobic reactor with an effective volume of 8 l.

The reactor was operated more that 270 days under mesophilic conditions and it was fed with the combined effluents from the investigated dairy industry. The hydraulic retention times ranged from 0.21 to 0.96 days under normal operating conditions after the start up. COD removal efficiencies of more than 87% were achieved at an organic loading rate (OLR) of 8.5 kg COD/m$^3$.d OLR was gradually increased from 2.54 to 7.1 kg COD/m$^3$.d within 15 days but the anaerobic reactor performances did not change significantly. The reactor was operated under varying feed characteristics to test the response of the system to high strength acid whey. The system can tolerate OLRs as high as 17 kg COD/m$^3$.d with an average COD removal efficiency of 75% for two weeks. Although the reactor was fed by diluted effluent with an average COD of 1070 mg/l at very high hydraulic loadings (HRT=5 hours), 75% removals of COD were achieved under these conditions.

## KEYWORDS

Anaerobic treatment, Dairy industry effluents, Dairy whey, Hybrid upflow anaerobic sludge blanket reactor, Bioenergy recovery, Waste minimization by in-plant control.

## INTRODUCTION

The Turkish Milk Industry Association (SEK) is a state establishment. SEK has over thirty plants in different cities distributed throughout Turkey. The total capacity of all these plants is about 200 000 t/y. In the last decade, private industry has also contributed to the production of the milk. The plant that is the subject of this investigation is SEK Istanbul Dairy Industry. The current capacity of the plant is 90,000 tonnes per year. The main products are bottled pasteurized milk (60,000 t/y), yogurt (5,600 t/y), butter (310 t/y) and cheese (28 t/y). The first step of the processes in the industry is receiving the unprocessed milk. The milk passes through quality control and is centrifuged. Then it is stored after cooling to 4°C. After clarification and standardization the milk passes through homogenization, deodorization and pasteurization steps. Pasteurization is by a high temperature short time method. The pasteurized milk is then packed and



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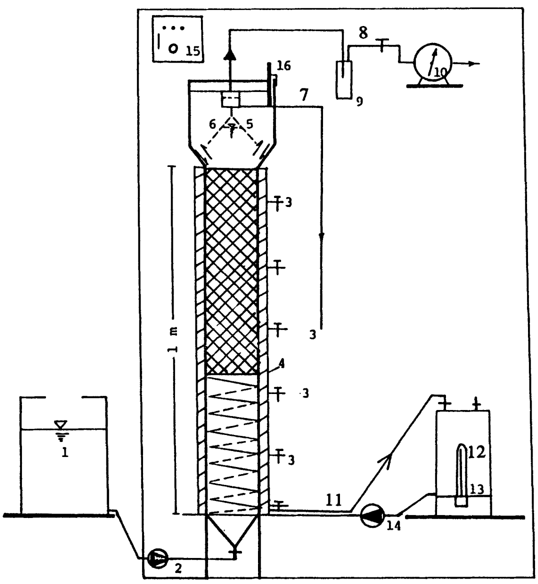
stored. The second important product is yogurt. It is produced by evaporating pasteurized milk under vacuum and by culturing.

The purpose of the study was to investigate the anaerobic treatment process as an alternative technology for dairy effluents to discharge to city sewers. The study was conducted in three stages: waste characterization, anaerobic treatability studies and wastewater treatment plant design. Experimental studies were performed at the pulp and paper research laboratory of Istanbul Technical University.

## MATERIALS AND METHODS

### The Reactor

Anaerobic treatability studies were conducted by a laboratory-scale hybrid upflow anaerobic sludge blanket reactor (HUASBR) with a useful volume of 8.1 liter. The reactor consisted of a plexiglas 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 designed as upflow anaerobic sludge blanket reactor. The treatment system 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 1.



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 panel
16. Thermometer

Figure 1. Schematic of the anaerobic reactor

### The Feed

In the first part of the study (Run I), skimmed milk containing 0.5% fat was used as the feed. Skimmed milk with a mean COD of 100 000 mg/l was diluted with tap water to obtain the desired COD. Then, in the second part of the study (Run II), combined dairy effluents and dairy whey from the investigated industry were used as the feed.

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## Experimental Methods

A comprehensive monitoring program was implemented in the SEK Istanbul dairy industry. Composite samples were collected from the combined effluents and major parameters including chemical oxygen demand (COD), biological oxygen demand ($BOD_5$), suspended solids (SS), oil and grease, total kjeldahl nitrogen (TKN), $PO_4$-P, surface active agents and pH were measured. Physico-chemical analysis for effluents characterization and anaerobic treatability studies were carried out according to AWWA Standard Methods (1990).

## Experimental Design

The experimental program applied in this study is show in Table 1. HRT and OLR values were calculated by considering a reactor useful volume of 8.1 l. Major operating parameters including pH, COD, alkalinity and volatile solids concentration were analyzed according to AWWA Standard Methods (1990). Biogas flowrates were measured by a test-meter. The parameters including alkalinity, gas flow rate and temperature were measured on a daily basis but COD analysis was performed three times in a week. The VS content of the sludge was measured once in 2 or 4 weeks.

TABLE 1 Experimental Program

| Parameter | Start-up (Run I) | Normal operation (Run II) | | |
|---|---|---|---|---|
| | (0-42 d) | (43-115 d ) | (116-137d ) | (138-276 d ) |
| Feed | Skimmed milk | Skimmed milk | Combined dairy effluent | Dairy whey |
| HRT (d) | 1.40 (0.59)* | 0.96-0.35 (0.40-0.15)* | 0.21 | 1.02-0.74 |
| Average feed COD (mg/l) | 2000 | 2500 | 1020 | 6000-5960 |
| OLR, kgCOD/m$^3$.d | 1.43 (3.4)* | 2.54-7.10 (6.05-16.9)* | 5 | 5.5-17 |

* The numbers given in the brackets in Table 1 represent the corresponding values calculated by considering the volume of the empty bottom part of the hybrid reactor (3.4 l).

# RESULTS AND DISCUSSION

## Effluent Characterization

Effluent characterization includes flow rate determination and analysis of polluting parameters. The seasonal and daily flowrates of wastewater show vast fluctuations in this industry. Daily wastewater flowrates show big changes during the washing hours at the end of the shifts. The seasonal changes in the milk received to the plant directly affect the wastewater amounts and concentrations (highest amounts occur in June and July). The amount of wastewater is dependent on the type of process used, however, it varies between 2 and 6 $m^3/m^3$ product in dairy industry (Barnes *et al*, 1984). Six months average wastewater flow rate of the SEK Istanbul Factory was determined as 780 $m^3$/d considering water balance in the industry. This corresponds to a specific wastewater flowrate of 3.2 $m^3$/t milk. Polluting parameters which are based on waste characterization are given in Table 2 together with the values reported by Barnes *et al* (1984).

Table 3 summarizes major production types, wastewater flowrates and distribution of COD loads from each production process on the total organic load in the investigated industry. The values presented in Table 3 have clearly indicated that maximum share in flowrate is milk production while whey production has the

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maximum share in the COD load. Since the major pollution source is whey effluents in dairy industries, the best practical way for reducing polluting load is to prevent discharging of whey effluents into the sewer system by employing in-plant control and by product recovery measures such as membrane separation techniques. Such an application can reduce the combined COD of the effluents from the SEK Istanbul dairy industry to as low as 1700 mg/l.

TABLE 2 Wastewater Characteristics of SEK Istanbul Dairy Industry

| Production Process Pollution Parameters | Dairy Whey | Butter production Effluents | Bottle Washing | Pasteuriza-tion | Combined eff. (composite samples) | Combined eff. Aver. Barnes et al (1984) |
|---|---|---|---|---|---|---|
| COD (mg/l) | 18400-69500 | 52000 | 900 | 270 | 950-2400 | 4500 |
| $BOD_5$ (mg/l) | 83000-40000 | - | 200 | 115 | 500-1300 | 2300 |
| SS (mg/l) | 7000 | 1500 | 175 | 190 | 90-450 | 820 |
| Oil and Grease (mg/l) | 4095 | 1324 | 110 | - | 110-260 | 209 |
| TKN (mg/l) | 280-1100 | 1120 | 18 | 22 | 70-85 | 64 |
| $PO_4$-P (mg/l) | 110-135 | 1150 | 10 | 11 | 4.0-15 | 16 |
| Detergent (mg/l) | - | - | 1.2 | 2.1 | 0.9-1.1 | - |
| pH | 5-9.5 | 4.3-5.9 | 11.3 | 8.5 | 5.0-9.5 | 7.2 |

TABLE 3 Distribution of Wastewater Flowrates and COD Loads in SEK Istanbul Dairy Industry

| Production | COD (mg/l) | COD (mg/l) of combined eff. | | | | Share of, | |
|---|---|---|---|---|---|---|---|
| Process | (combined eff.) | With whey | | Without whey | | flowrate | COD load |
| | | min | max | min | max | (%) | (%) |
| Pasteurized milk | 950-1200 (1000) | 2300 | 6500 | 1100 | 1700 | 88 | 18 |
| Yogurt | 350-900 (600) | | | | | 4 | 0.5 |
| Butter | 20000-52000 (40000) | | | | | 1 | 8.5 |
| Whey | 18000-70000 (50000) | | | | | 7 | 73 |

## Start-up of the Anaerobic Reactor

5 l sludge supplied from a laboratory scale upflow anaerobic sludge blanket reactor treating domestic wastewater in mesophilic conditions was used as the seed. The volatile solids (VS) content of the seed was about 20,000 mg/l. The hybrid anaerobic reactor was fed together with the dairy 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. $NaHCO_3$ was added 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 a COD:N:P ratio of 500:5:1 due to N and P deficiency of the feed. This mode of operation was continued for 43 days and COD removal efficiencies of the reactor were less than 50% in this period. Starting from the 44th day the OLR was gradually increased to provide enough mixing in the anaerobic digester and the COD:N:P ratio was also increased to 250:5:1.

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An immediate response of the anaerobic digestion process to this application was a significant reduction n the effluent COD (Table 4).

## Treatability Results in the Normal Operating Period

Following the start-up anaerobic treatability studies were carried out by three types of feed: skimmed milk with an average COD of 2 500 mg/l (43-115 days), SEK Istanbul dairy industry combined effluents with an average COD of 1070 mg/l (116-137 days) and dairy whey with an average COD of 6000 (138-242 days).

TABLE 4 Operating Results From Hybrid Anaerobic Reactor Treatment of Dairy Effluents

| Time (d) | HRT (d) | Inf.COD (mg/l) | pH | Alkalin. (mg/l as $CaCO_3$) | Temp. (°C) | COD (mg/l) | Qgas (l/d) | OLR (kg COD/ $m^3$.d) | COD Removal (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1-43 | 1.40 | (2000)* | 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 |
| 116-137 | 0.21 | 1070 | 8.0 | 2500 | 35±1 | 260 | 10 | 5 | 76 |
| 138-181 | 1.02 | 2480-9400 (6000) | 7.8 | 1660 | 35±1 | 800 | 17.5 | 5.53 | 87 |
| 198-242 | 0.74 | 3840-8064 (5960) | 8.2 | 1700 | 35±1 | 770 | 27.5 | 8.5 | 87 |
| 243-276 | 0.47 | (8000) | 8.2 | 1800 | 35±1 | 2000 | - | 17 | 75 |

* Values in the brackets show averages

Table 4 summarizes the steady state operating results including hydraulic retention time (HRT), influent and effluent CODs, pH, alkalinity, temperature and volatile solids content of the reactor, biogas flowrates, organic loading rate and COD removal efficiencies.

## OLRs and COD Removal Efficiencies

HRTs ranged from 0.96 to 0.35 days at normal operating conditions after the start-up. COD removal efficiencies of more than 87% were achieved at an OLR of 7.1 kg COD/$m^3$.d in this period (Table 4). More detailed information about the treatability study results can be found in another study by Eroglu *et al* (1991). Starting from the 116th day, combined effluents with average COD of 1070 mg/l from the SEK Istanbul Dairy Industry were started to feed to the reactor. In that period (from 116th to 137th days) average COD removal was 76% at an average OLR of 5 kg COD/$m^3$.d These results have clearly indicated that anaerobic treatment is also a practical alternative for low strength dairy effluents. In the final part of the treatability studies (from 138th to 242 days) dairy whey from the SEK Istanbul Factory was used as the feed in the anaerobic reactor. OLRs were varied from 5.53 to 8.5 kg COD/$m^3$.d COD removal efficiencies were 87% at OLRs of as high as 8.5 kg COD/$m^3$.d Even under shock OLRs of 17 kg COD/$m^3$.d COD removals were in the range of 75%. Figures 2 and 3 summarize the relationships among OLR, COD removal rate($R_L$) and COD removal efficiencies, observed in this study.

## pH and Alkalinity

pH and alkalinity in the anaerobic reactor were 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 1000 mg/l as $CaCO_3$ and it generally averaged about 1500 mg/l (Fig.4). pH and alkalinity in the digester dropped below 6.5 and 1000 mg/l respectively for some times during the study due to pH control problems that originated from mechanical failures in the feed

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refrigerator and rapid increase in the OLR. Since the feed easily becomes acidic in a warm environment for several hours, the pH was precisely controlled about neutral range in the feed tank.

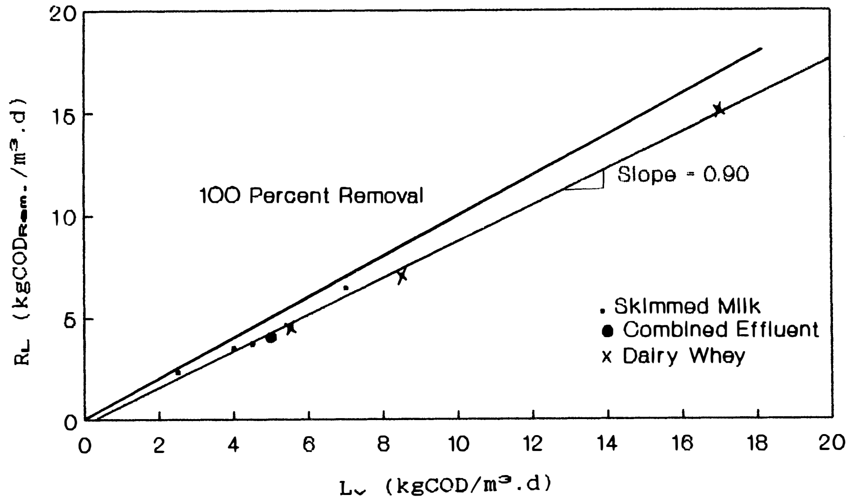


Figure 2. COD removal rate vs OLR

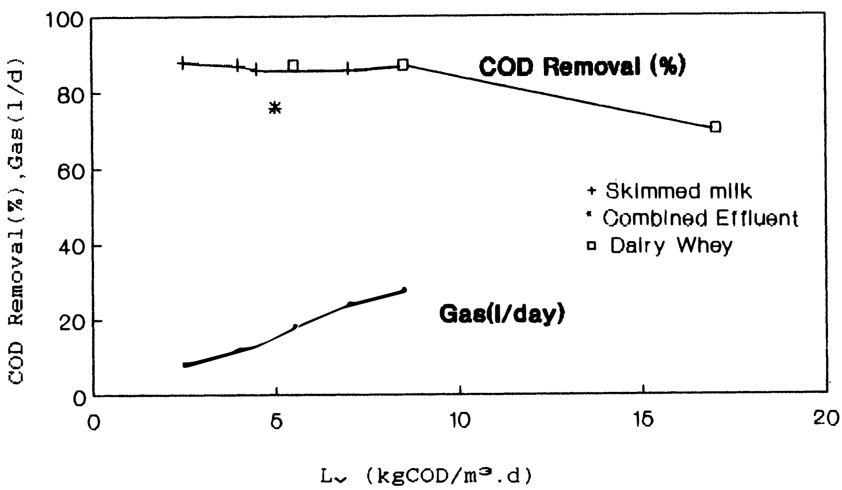


Figure 3. %COD removal and gas flowrate vs OLR

## Biogas Production and Composition

There is a very strong dependence between the OLR and the daily gas production in anaerobic treatment processes. Such a relationship can be illustrated in Figure 3 together with COD removal efficiencies for this study. From Figure 3, the observed biogas production yield was about 0.4 l per kg COD removed. $CH_4$ contents of the biogas measured by Orsat apparatus averaged about 75%. Figure 5 shows daily gas production vs time graph for this study.

## Biomass Accumulation

Biomass concentration measurements were performed on samples taken from different sampling ports along the height of the reactor. The volatile solids concentration of the sludge vs height graphs for various periods of the anaerobic treatability study are shown in Figure 6. The VS concentration of the sludge in the samples

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from the first sampling port reached 33.7 g/l at the end of the 115 days study period. The food to microorganism ratio or the biological loading rate which is calculated as 0.70 kgCOD/kgVS.d for an OLR of 7.10 kg COD/m$^3$.d indicates that the biomass is very active despite the low VS concentration compared to granular sludges produced in the upflow sludge blanket reactors for various types of effluents from agro industries. (Öztürk and Demir, 1989, Ubay and Öztürk, 1990, Öztürk *et al.* 1991, Lettinga and Hulshoff, 1991). Bulking sludge caused some problems in the gas-liquid separator, especially when the OLR increased rapidly despite the plastic packing in the upper part of the reactor. This problem was expected to be eliminated when the VS content of the sludge was greater than 40 g/l according to our experiences on upflow anaerobic sludge blanket reactors.

Full Scale Treatment Plant

The results of this treatability study have been used for designing a full-scale anaerobic treatment plant for the SEK Istanbul Dairy Industry. The design flowrate and COD of the treatment plant were 1015 m$^3$ per day and 2000 mg/l respectively. The treatment plant includes the following units: Flotation Tank, Buffer Tank, Mesophilic Anaerobic Digester (UASBR), Lamella Separator, Sludge Storage Tank and Horizontal Belt Filters.

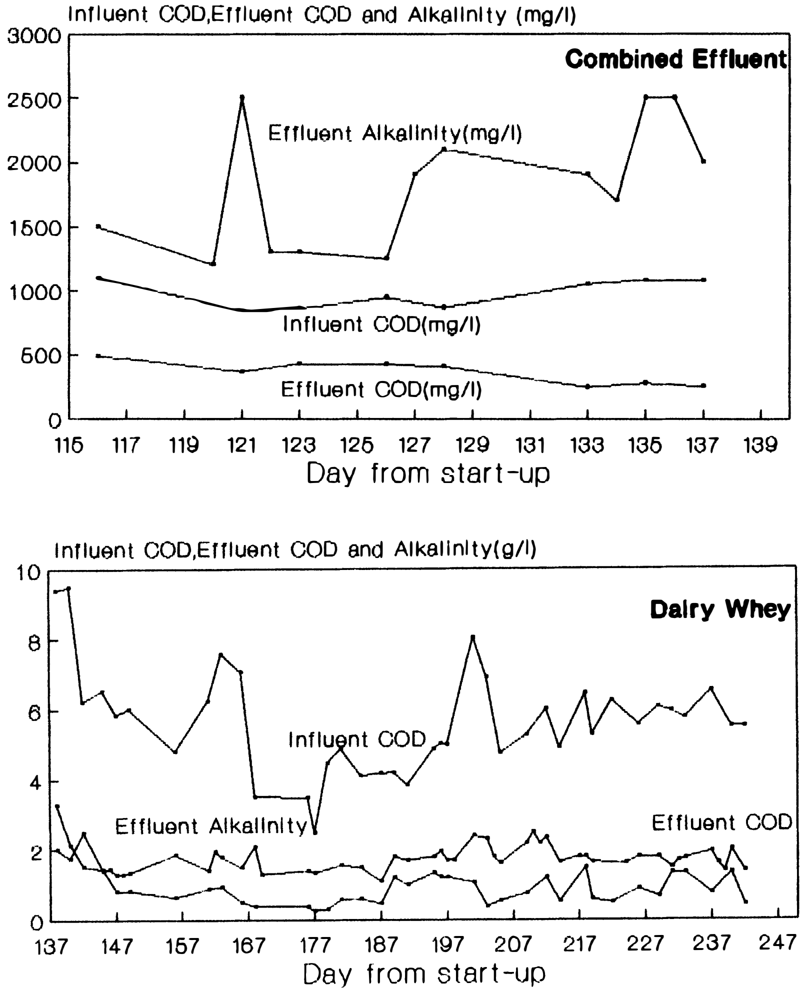


Figure 4. Influent-effluent CODs and alkalinity vs time.

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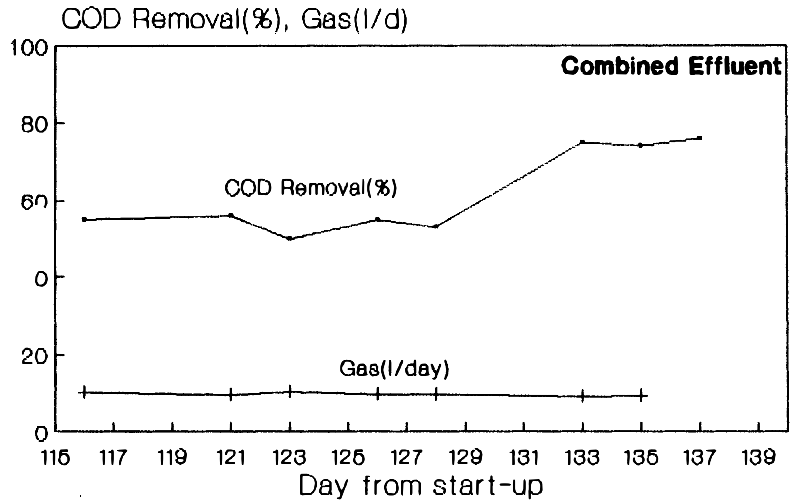


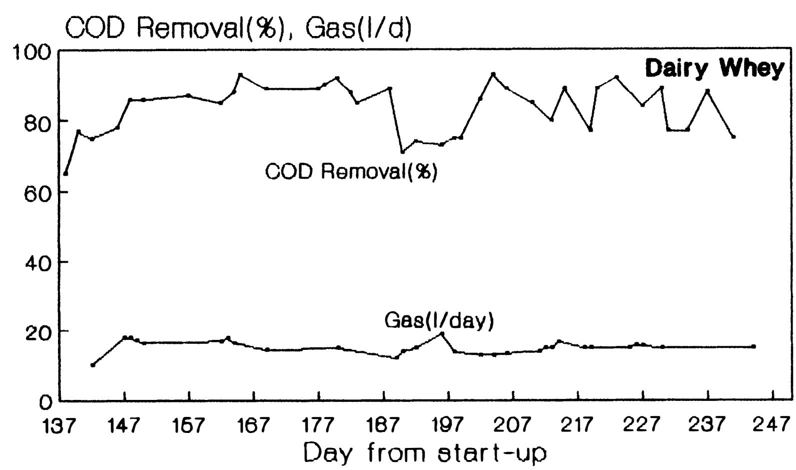


**Figure 5.** %COD removal and gas flowrate vs time.

## CONCLUSIONS

The results of this study demonstrate that the hybrid anaerobic treatment of dairy effluent is highly effective for COD removal and bioenergy recovery. Such a system can be successfully used as a pretreatment step before discharging industrial effluents into the municipal sewer system. A COD removal efficiency of about 87% can be achieved by a hybrid anaerobic reactor treating dairy whey at an OLR of 10 kg COD/m$^3$.d or more, for a HRT of 18 hours. Scum and bulking sludge cause problems at high OLRs. An external sludge separator, such as a lamella separator, can be used for recycling biomass from the anaerobic digester.

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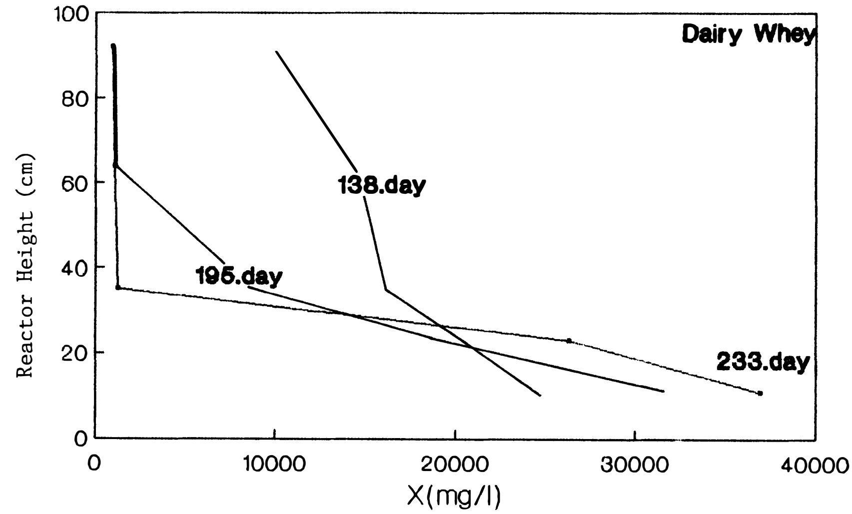


Figure 6. Variation of biomass concentrations along the height of the reactor

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