

TREATMENT OF MILKING CENTER WASTE USING SEQUENCING BATCH REACTORS

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Received 20 August 1985, accepted 21 January 1986

Tam, P. C., K. V. Lo, and N. R. Bulley. 1986. Treatment of milking center waste using sequence batch reactors. *Can. Agric. Eng.* 28: 125-130.

Three bench-scale sequencing batch reactors were used to treat milking center wastewater at 3.7, 10.5, 21.6 and 29.8°C for a 6-mo period from January to June 1984. Over 90% of 5-day biochemical oxygen demand (BOD₅) and 70% chemical oxygen demand (COD) removals were observed even at low temperatures (10.5 and 3.7°C). Reduction in ammonia concentration was more erratic at low temperatures; however, NH₃-N reduction at 21.6 and 29.8°C was in general over 92%. Total suspended solids removal by the reactors ranged from 86 to 95%. Rapid loss of nitrate was observed in all three reactors during initial mixing of the settled sludge and supernatant at the beginning of the aeration phase.

INTRODUCTION

There are increasing problems with the handling and disposal of waste materials produced by modern dairy farms as a result of increasing livestock concentrations and increased proximity to expanding urban centers. Due to the high groundwater table in the lower Fraser Valley, British Columbia, typical methods of effluent disposal such as land application without pretreatment frequently lead to problems such as the plugging of drain tiles and the sealing of soils. An alternative treatment or pretreatment method is therefore needed to handle the milking center wastewater.

Effluents from milking parlors contain mainly milk residue and manure plus debris flushed from the parlor. The volume of cleaning water used is related to the size of the operation and the habits of the individual operators. Great fluctuations in flow and waste concentrations are normal in milking center wastes (Campbell 1982). The high oxygen demand and biodegradability of the wastewater suggest biological treatment before disposal. Many biological systems have been investigated for this purpose. In general, aerobic processes have been found more satisfactory than anaerobic processes for treating milking wastes (Lindley 1979) but any system designed to treat the waste will be required to handle large variations in flow, and concentration.

The sequencing batch reactor (SBR) is a modern version of the fill-and-draw system which originated as early as 1914 (Irvine and Busch 1979). The concept did not gain popularity in the industry because of the requirement of high manual operator attention. However, with the availability of low-cost electronic control de-

vices, interest in batch operated systems has revived (Irvine and Busch 1979; Goronszy 1979). The modern SBR systems are very dynamic and flexible in terms of operation. Semi-batch systems are also kinetically superior to the continuous-flow systems because of their kinetic resemblance to ideal plug-flow reactors. Compared with continuous flow systems, semi-batch systems can theoretically accommodate much larger fluctuation of the forcing function (Irvine and Richter 1978; Irvine et al. 1979, 1980; Goronszy 1979).

A sequencing batch reactor is deemed a suitable treatment alternative for milking center wastewater because of its periodic nature and the fact that it is not designed to operate under steady-state assumptions. Its operating characteristics are compatible with the intermittent flow pattern and fluctuating waste strength of effluent produced by milking operations.

The purpose of this research was to study the effectiveness of using a sequencing batch biological reactor for treating milking center effluent and to determine the effect of changes in operating temperature in the treatment efficiency.

MATERIALS AND METHODS

Experimental Set-up

Three 5.0-L acrylic plastic reactors 460 mm in height and 138 mm in diameter were set up in the waste-treatment laboratory. Reactor A was maintained at a constant low temperature using a continuously circulated coolant from a refrigeration unit (Julabo, Model F40). Reactor C was wrapped with a heating pad connected to a temperature-feed-back controller. A thermocouple in reactor C was connected to the controller and was set to

maintain the reactor temperature at 30±0.1°C. Reactor B was left to fluctuate with room temperature. The average temperature in the laboratory was 21.6±0.4°C, during the experimental period. A four-channel "ChronTrol" (Cole-Parmer) digital timer was used to control the operation of the reactors. A schematic of the set-up is shown in Fig. 1.

The University of British Columbia dairy barn milking center discharge was used in this study. Two 246-L drums were situated at the outfall of the milking room floor drain to intercept the wastewater. The wastewater collected was passed through a U.S. Series No. 50 TYLER screen (0.295-mm openings) before storage at 4°C. The maximum storage time was 4 days for any batch of wastewater collected from the barn.

As a check for possible changes in waste characteristics during storage, samples of the wastewater were taken at different times during the 4-day storage periods and analyzed for BOD₅, COD₅, NH₃-N and NO₃-N.

Samples of the raw wastewater as it was being pumped into the reactors and of the effluent as it left the reactor were taken for analyses and the results used for calculating reactor treatment efficiency.

SBR Operation

A 6-h cycle was adopted (Fig. 2). Each cycle contained the following sequencing phases:

(1) *Fill (10 min)*. The timer activated a triple-headed peristaltic pump to deliver 1.5 L of wastewater from the reservoir to each of the 5-L reactors. A magnetic stirrer was activated simultaneously to mix the contents of the reservoir.

(2) *React (3.5 h)*. The timer switched off the feed pump and turned on the air pump.

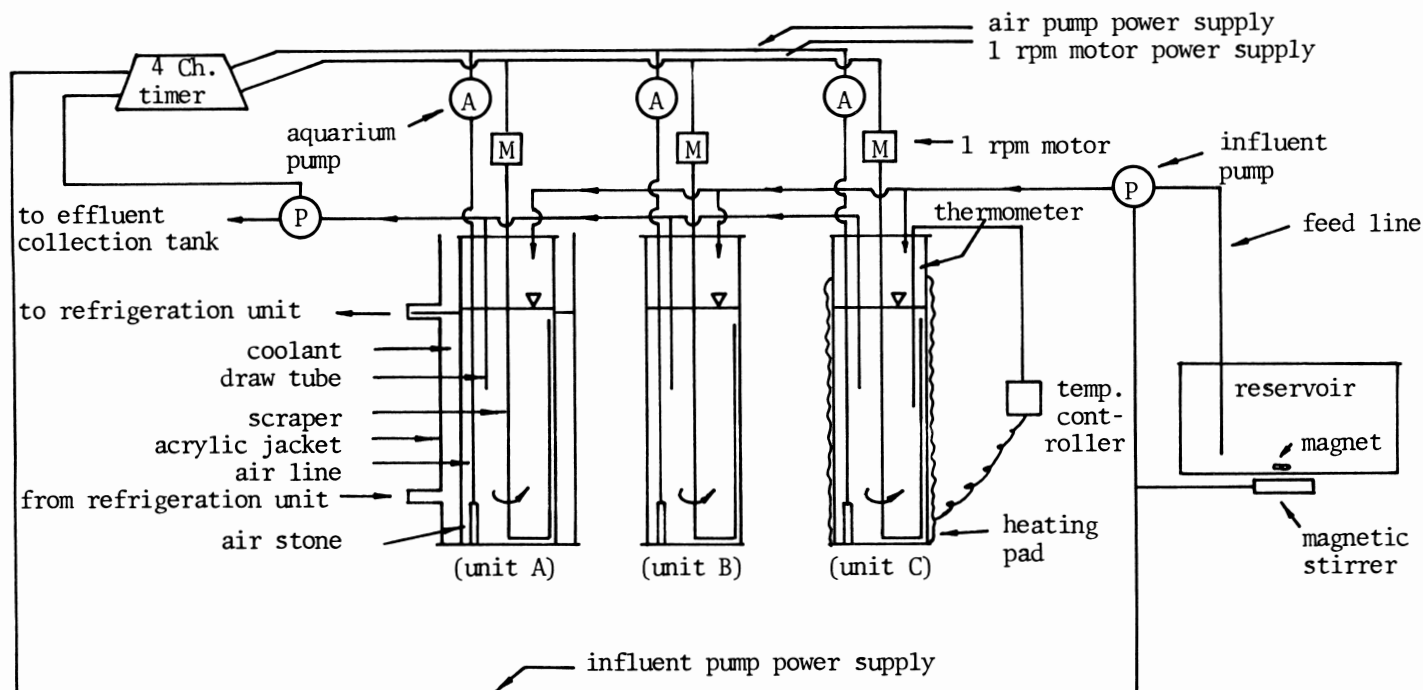


Figure 1. Schematic of experimental set up.

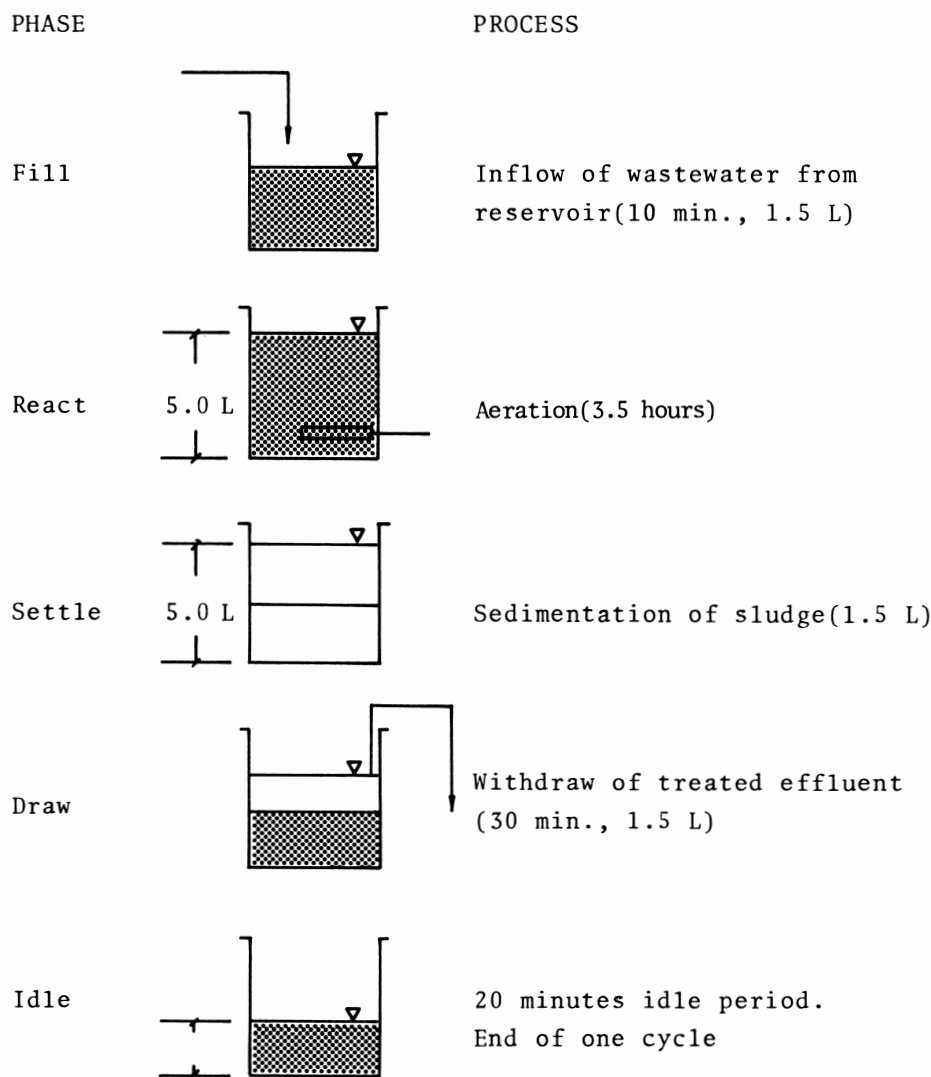


Figure 2. Schematic of the sequencing batch operation.

Completely mixed conditions were maintained during the 3.5-h aeration period. Sludge removal was achieved during the last 5 min of the aeration phase once each day by wasting the appropriate amount of mixed-liquor, i.e., wasting 1/20th of the mixed-liquor yields an average sludge age of 20 days. During the course of the experiments, sludge age was varied from 8.3 to 20 days.

(3) *Settle (1.5 h)*. Aeration was stopped and the sludge mass was allowed to settle. A stainless steel wire connected to a 1-rpm motor was switched on to scrape the inside circumference of the reactor. (4) *Draw (30 min)*. A triple-headed peristaltic pump was activated to transfer 1.5 L of the supernatant fluid from each of the reactors to the effluent collection tank. (5) *Idle (20 min)*. The reactors remained idle after effluent withdrawal for 20 min before the beginning of the next cycle. The contents of the reactor were not mixed or aerated during this period.

Refilling of the reservoir and emptying of the effluent collection tank were carried out manually on a daily basis. It should be noted that sludge age and food/microorganism ratio, factors of prime importance in continuous systems, have lost their significance in periodic sequencing operations (Silverstein and Schroeder 1983; Irvine et al. 1977) except for maintaining a convenient TSS level.

Sampling and Analysis

The major parameters monitored regularly and analyzed following standard

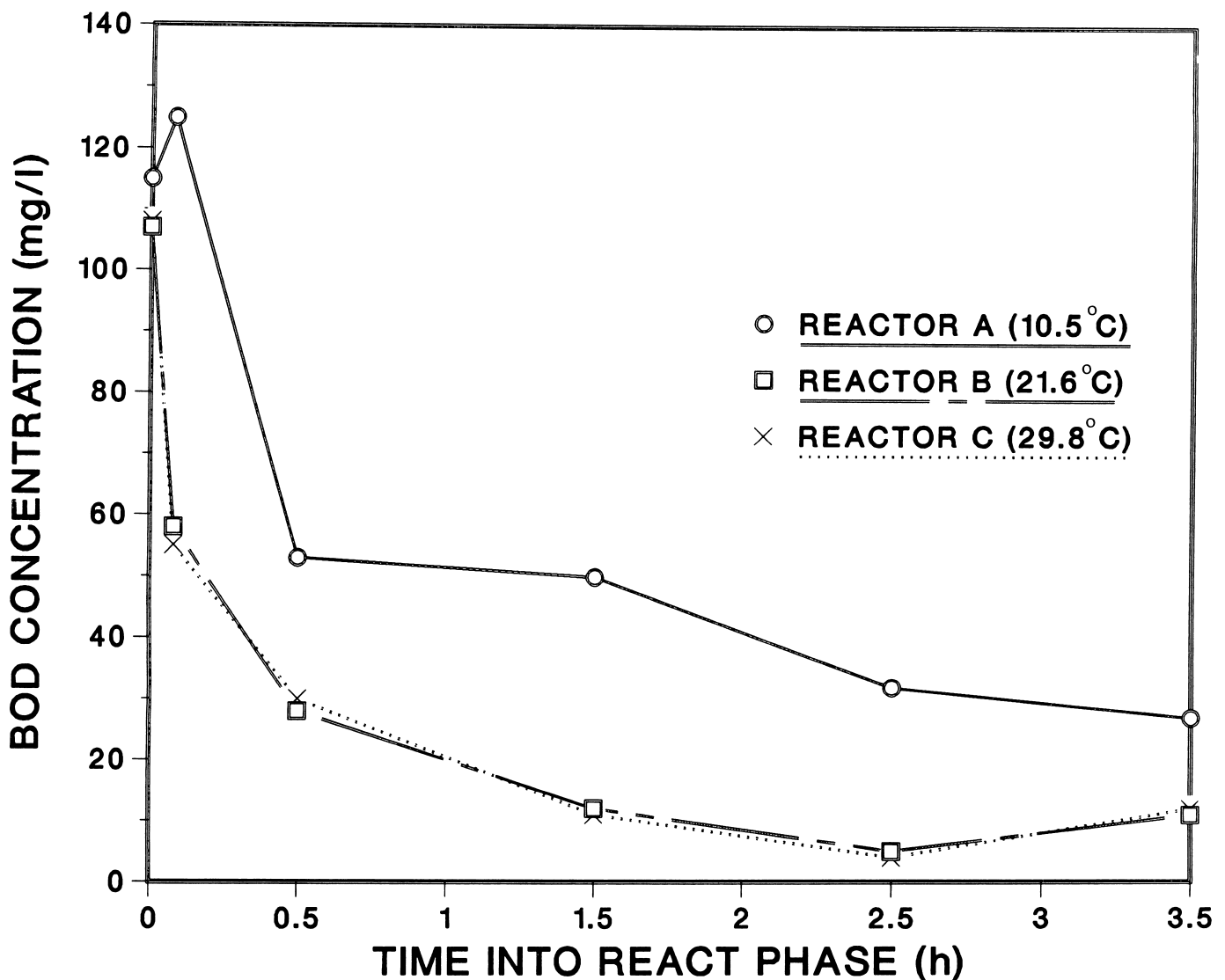


Figure 3. Track analysis of reactor supernatant soluble BOD₅ vs. aeration time.

TABLE I. INFLUENT-EFFLUENT ANALYSIS DURING EXP. 1 (TEMPERATURES OF A, B AND C WERE 10.5, 21.8 AND 29.8°C, RESPECTIVELY; FILLED VOLUME = 5 L)

Parameter	Screened raw wastewater conc. (mg/L)		Treated effluent (mg/L)			Standard deviation of effluent strength			Average % removal		
	Mean	SD	A	B	C	A	B	C	A	B	C
BOD ₅	271	89	21	11	16	6	5	8	92	95	94
COD	1330	680	268	174	186	126	103	113	80	88	87
NH ₃ -N	37.0	29.0	18.1	1.9	1.6	13.7	0.6	0.7	51	93	95
NO ₂ -NO ₃ -N	0.4	0.4	2.7	10.5	8.9	2.6	8.1	5.8	—	—	—
TSS	916	—	114	52	99	—	—	—	88	95	91

TABLE II. RESULTS FROM INFLUENT-EFFLUENT ANALYSIS DURING EXP. II (TEMPERATURES OF A, B AND C WERE 3.7, 21.8 AND 29.8°C RESPECTIVELY; FILLED VOLUME OF A AND B = 5 L; C = 4.5 L)

Parameter	Screened raw wastewater conc. (mg/L)		Treated effluent (mg/L)			Standard deviation of effluent strength			Average % removal		
	Mean	SD	A	B	C	A	B	C	A	B	C
BOD ₅	270	85	29	13	18	16	9	12	90	95	93
COD	919	141	274	155	166	69	26	61	71	83	82
NH ₃ -N	15.0	1.7	2.9	1.0	1.2	2.1	0.5	1.5	82	93	92
NO ₂ -NO ₃ -N	0.4	0.2	3.6	4.5	4.1	1.7	1.8	1.6	—	—	—
TSS	190	—	28	13	15	—	—	—	86	93	92

method (American Public Health Association 1975) included COD, BOD₅, total suspended solids (TSS), volatile suspended solids (VSS), ammonia nitrogen (NH₃-N) and nitrite-nitrate nitrogen (NO₂-NO₃-N). A Technicon Auto-Analyser II was used to measure the levels of NH₃-N and NO₂-NO₃-N (Schumann et al. 1973).

Two kinds of sampling approaches were used. Influent-effluent analysis involved sampling of the wastewater in the feed entering the reactors and the treated supernatants leaving each of the reactors. Twenty-three sets of influent-effluent data were obtained for COD, BOD₅, NH₃-N, NO₃-N throughout the 6-mo experimental period. Total suspended solids and volatile suspended solids were monitored regularly, usually one analysis every other day. Ten sets of track analysis were carried out. Track analysis involved sampling of the mixed-liquor during the

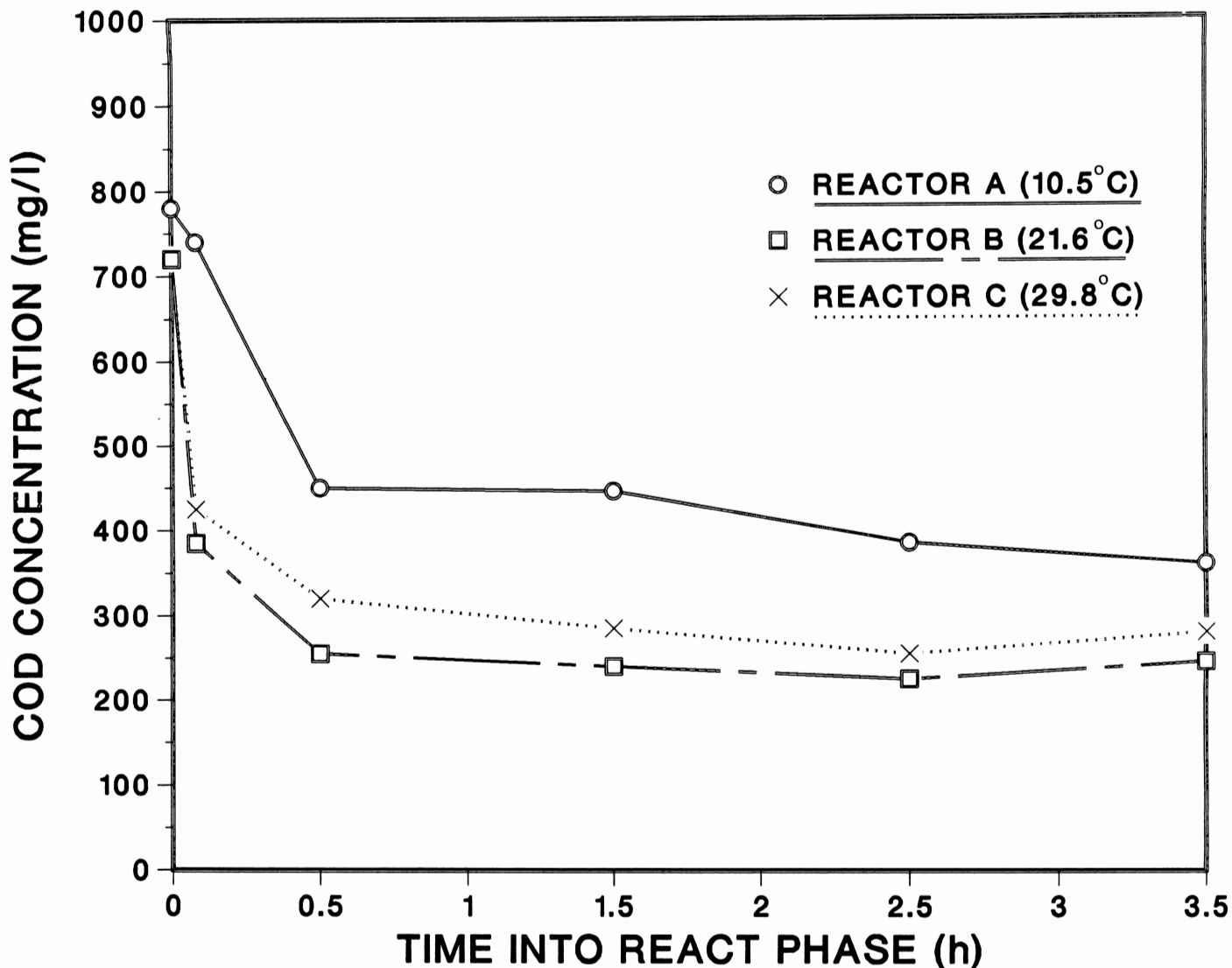


Figure 4. Track analysis of COD vs. aeration time.

REACT phase at different time intervals. The mixed-liquor samples were allowed to settle for 1.5 h before sampling the supernatant fraction for analysis. The 1.5-h settling time was added to allow settling which would normally occur in the settle phase and thus provide an estimate of the expected overall treatment efficiency.

RESULTS AND DISCUSSIONS

The experiment was divided into two phases. In exp. I, the operating temperature of reactor A was kept at 10.5°C. Filled reactor volumes were 5.0 L. In exp. II, the operating temperature of reactor A was lowered to 3.7°C. The total filled volume of reactor C was reduced to 4.5 L.

Results from influent-effluent analyses during exps. I and II are presented in Tables I and II, respectively. Typical results from track analysis of BOD₅, COD, ammonia and nitrite-nitrate during exp. I are shown in Figs. 3, 4 and 5.

BOD₅ and COD analysis

Despite the great variation in the influent strength, very high and consistent treatment efficiencies were obtained. Effluent supernatant BOD₅ removal efficiencies of over 90% were achieved by the reactors even at the low operating temperatures. Chemical oxygen demand removal was not as effective; treatment efficiency ranged from 82 to 88% at the higher temperatures and from 71% to 80% at 3.7°C.

The experimental results show that operating temperatures from 3.7 to 29.8°C do not have an effect on BOD₅ removal efficiency but reactor A was consistently less efficient at COD removal than reactors B and C. It is also interesting to note that the percentage BOD₅ removal in all three reactors was considerably higher than COD removal. The difference between BOD₅ and COD treatment efficiencies was presumably due mainly to the presence of nonbiodegradable organic substances. These substances were not

consumed by the activated sludge mass in the reactors. However, their presence in both the raw sewage and the treated effluents was detected by the COD analysis.

The track analyses, as shown in Figs. 3 and 4, traced the supernatant BOD₅ and COD in the reactors as a function of aeration time. The time-zero data points on the graph are theoretical values based on mass balance of the influent and the supernatant. It is evident that the overall BOD₅ and COD removal from the supernatant fraction (aeration followed by 1.5 h of settling) is essentially completed during the first half-hour of aeration. This is consistent with observations made by other researchers (Dennis and Irvine 1979; Hoepker and Schroeder 1979).

Ammonia and Nitrite-nitrate analysis

From Tables I and II, it is evident that ammonia removal was less efficient at low temperatures (3.7 and 10.5°C). However, there was no observable trend with decreasing temperature.

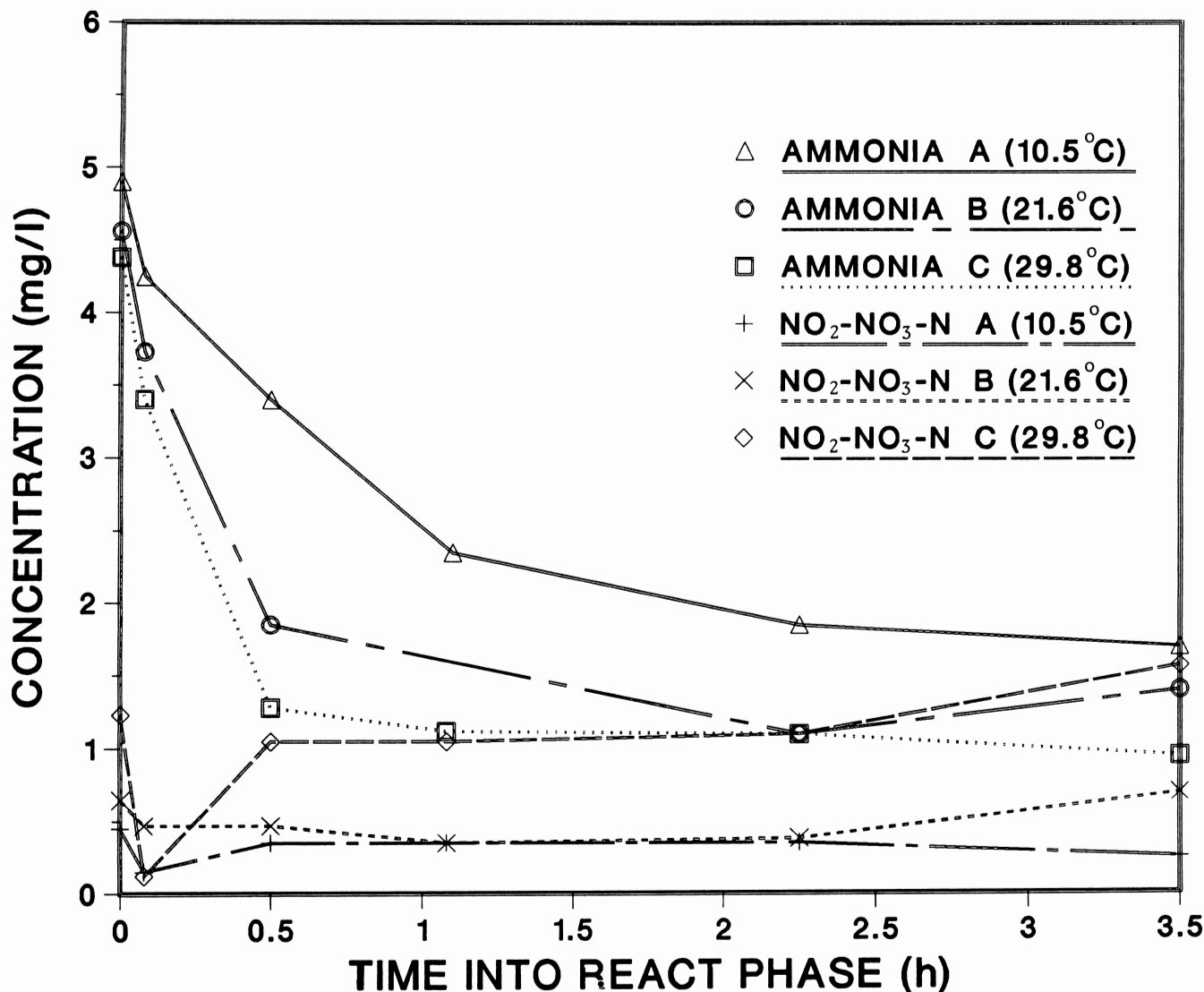


Figure 5. Track analysis of ammonia and nitrite-nitrate vs. aeration time.

It appears that at the higher temperatures (21.8 and 29.8°C) the system is able to reduce ammonia levels ranging from 15 to 37 ppm to final concentrations of less than 2 ppm. At the lower temperatures no pattern relating NH_3 and NO_3 concentration emerged and the effluent supernatant contained 43% (3.7°C) and 56% (10.5°C) of the influent ammonia as $\text{NH}_3\text{-N}$ and $\text{NO}_2\text{-NO}_3\text{-N}$.

Figure 5 shows a typical track analysis of supernatant ammonia and nitrite-nitrate nitrogen during aeration. Ammonia dropped sharply at the beginning of the react phase. After approximately 0.5 h to 1 h of aeration, ammonia removal proceeded at a much slower rate. Nitrate concentrations also dropped rapidly in all three reactors immediately after mixing began. Even though the dissolved oxygen levels never fell below 0.7 mg/L there was an apparent rapid denitrification process taking place when the settled sludge was remixed with the fresh waste. It appears that during sedimentation, the

sludge mass turned locally anaerobic and that denitrifying enzymes were produced and accumulated at this stage. Aeration mixed this accumulated enzyme with the supernatant nitrite-nitrate resulting in denitrification. The subsequent aerobic environment in the reactors prevented further denitrifying action; $\text{NO}_2\text{-NO}_3\text{-N}$, therefore, increased with the oxidation of ammonia nitrogen. Separate experiments were carried out to investigate this denitrifying process. It was found that the introduction of new feed was essential for this denitrification to occur to any significant extent. Further investigations into the effects of feed concentration, length of settling time and sludge age on the disappearance of nitrate will be necessary to gain additional understanding of this process.

CONCLUSIONS

The results of this study indicate that a sequencing batch biological reactor can be an efficient and reliable treatment method

for the wastewater from modern dairy milking centers. Over 90% BOD_5 and 70% COD removal was achieved even at low temperatures (10.5 and 3.7°C). At 21.6 and 29.8°C the reduction in ammonia concentration was over 92%, although the reduction in $\text{NH}_3\text{-N}$ was more erratic at low temperatures. Total suspended solids removal by the SBR reactors ranged from 86 to 95%. It was found that rapid denitrification would take place during the beginning of aeration; an anoxic stir period was not required. However, introduction of substrate was essential for this denitrification to occur to any significant extent.

ACKNOWLEDGMENTS

We acknowledge the financial support provided by the British Columbia Ministry of Agriculture and Foods.

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