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Performance study of milk processing effluent treatment in a sequential batch reactor (SBR)

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An investigation was done in a laboratory-scale sequencing batch reactor (SBR) for examining feasibility of treatment for combined removal of biodegradable organics (COD) and nutrients (nitrogen) from real-life dairy plant wastewater. The study was performed in a 5 L capacity model SBR with real life milk processing plant effluent containing average SCOD concentration of 1250±50 and NH_4^+-N concentration of 40±5 mg/L as N. The maximum SCOD removal and ammonia nitrogen (NH_4^+-N) was achieved 82.36 and 79.79% respectively after a total cycle period of 10 h.

Keywords: Dairy wastewater, sequential batch reactor, SCOD reduction, nitrification, denitrification, sludge volume index, mixed liquor suspended solids.

Introduction

The milk processing unit and dairy plant emanate high volume of wastewater containing formidable amount organics and nitrogenous substances (COD and N). In general, dairy industry generates about 0.2–10 L of effluent/L of processed milk[1]. All steps in dairy chain including production, processing, packaging, storage, transportation and distribution impact the environment due to release of contaminated effluent. Wastes from the dairy processing industry contain high concentrations of suspended solids, BOD, COD, high nitrogen concentrations and suspended oil, fat, grease contents, along with large variations in pH due to different cleansing strategies, which necessitates “speciality” treatment to prevent or minimize the environmental problems. A high degree of wastewater treatment would be accomplished before its discharge in water environment to maintain ecological harness.

It is well established fact that combined COD and nutrients removal for biological waste water treatment require an anaerobic/anoxic environment and subsequently to treat in an aerobic condition in a single tank to make it reasonably innocuous as an alternative tool for replacing the existing multiple units of activated sludge system that will reduce the land requirements[2]. Under such circumstances sequential batch reactor (SBR) is reported to be a space saving viable technological option. Sequential batch reactor provides aerobic as well as anoxic condition in the same tank alternatively switching to either condition[3]. Thus SBR technology is useful for COD reduction, nitrification, denitrification as well as biological phosphors removal. The different reaction cycles (aerobic-anoxic) with single tank makes the SBR extremely flexible to adapt unpredictable changes for effluent nutrient removal also the elimination of secondary clarifier makes it a low cost, space saving treatment option used in the real estates and small scale industry.

The objective of the present study was to carry out a laboratory scale SBR investigation to explore the feasibility of usefulness of SBR pertaining to treatment of real life dairy plant wastewater containing both organic and nitrogen.

Materials and methods

(A) Collection of field sample:

Real life dairy wastewater sample was collected from a local dairy processing unit located in the district South 24-

Parganas, West Bengal, India. Besides packaged milk, this dairy unit also produces curd, lassi, paneer, buttermilk and ghee. The plant produces effluent at a rate of 90–100 m^3/day on daily average basis. Effluents were collected six times in different months over the entire course of study in plastic container of 20 L capacity. The samples were brought to the Civil Engineering Department laboratory, Jadavpur University and stored in a refrigerator at 4°C. The samples were analyzed for the following parameters viz. pH, alkalinity, DO, MLSS, SCOD, NH_4^+-N, NO_3^--N as per 'Standard Methods'[4].

(B) Seed acclimatization:

A measuring cylinder of 1 L capacity was taken as an acclimatization unit. About 100 mL of non-acclimatized seed collected from nearby small scale dairy industry was mixed with 750 mL of distilled water to have a total volume of 850 mL in the cylinder. At the very initial stage dextrose (1000 mg/L) was added as organic carbon source and aeration was done continuously by means of diffused air system with the help of aquarium pumps. When initial growth was observed, the acclimatization process was carried out by using real life dairy wastewater for a period of 2 months. The growth of biomass was monitored by measuring magnitude of sludge volume index (SVI) and MLSS concentration. Seed acclimatization phase continues for two months and assumed to be complete when a steady state condition observed.

For acclimatization of nitrifires a separate synthetic solution prepared in a cylinder of 1 L capacity, in which NH_4Cl and $(NH_4)_2SO_4$ of a concentration of 0.10 g/L and 0.05 g/L was added as nitrogen source to stimulate the appropriate environmental conditions. Aeration was done by means of diffused air system i.e. by aquarium pumps. The value of pH was maintained in the range of 7.2–8.0 by adding required amount of sodium carbonate (Na_2CO_3). When initial growth of nitrifiers was observed, the acclimatization process was carried out using real life dairy wastewater and continued up to 2 month. The seed acclimatization phase proceeds to be over when a steady state equilibrium NH_4^+-N reduction vis-a-vis MLSS concentration was observed.

The denitrifying sludge was collected from a slaughter house wastewater treatment plant. A separate denitriftying unit was employed i.e. an aspirator bottle, kept on a magnetic stirrer, for mixing well with no supply of oxygen. The seed was acclimatized for a feed having NO_3 concentration around 40 mg/L to around 60 mg/L, by adding potassium nitrate (KNO_3) as nitrogen source. During this acclimatization process an active biomass growth was noticed. The range of pH value of this synthetically prepared wastewater was maintained as 7.0 to 7.5 by adding exact amount of acetic acid (0.01 *N*).

(C) Experimental set up and procedure:

An experimental SBR was fabricated in the laboratory of 5 L effective capacity making with 5 mm thick plexi-glass sheet. The real life effluent sample was kept in a of 25 L capacity car in higher level. The feed solution was allowed to enter into the reactor through an inlet feeding tube, with a pre-calculated rate of flow, for a pre-determined time known as fill period (0.50 h). The aeration was accomplished through supply of diffused air by means of a compressor of 0.33 kW capacity. The experimental reactor is shown in Fig. 1. A timer as a control was connected to air compressor for stopping air supply during the anoxic period. Necessary seed was done with previously acclimatized microbial culture exposed to real-life feed sample for a long time. The performance evaluation was done in (SBR) for a feed with an initial SCOD concentration around 1250±50 and NH_4^+-N 40±5 mg/L. The total reaction period was applied in three different combination such as (i) 4 h aerobic (O) + 4 h anoxic (A), (ii) 3 h aerobic (O) + 4 h anoxic (A) and (iii) 3 h aerobic (O) + 3 h anoxic (A). In addition, 0.5 h as settle and 1 h as decant period were provided as operative sequence. Each time, 50 mL of sample was withdrawn from the effluent sampling port for necessary analysis of residual COD and nitrogen concentration. Following parameters viz. pH, alkalinity, MLSS, SCOD, DO, NH_4^+-N, NO_3^--N, PO_4^{3-}-P were analyzed as per 'Standard Methods'[4].

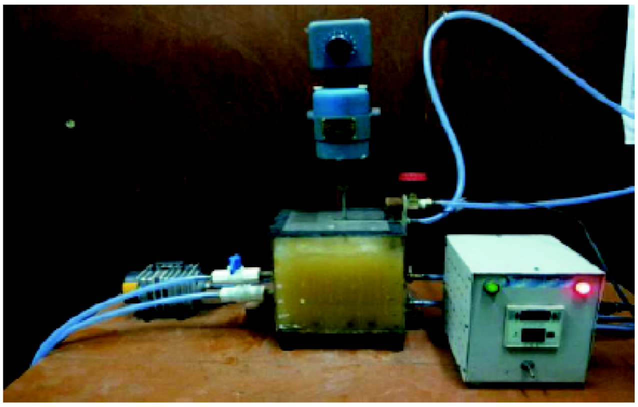

Fig. 1. Laboratory scale sequential batch reactor (SBR).

Results and discussion

(A) Characterization of dairy wastewater:

The wastewater samples collected from a local dairy processing unit were characterized in the laboratory with respect to the following parameters as shown in Table 1. It is observed from the table that pH of the dairy wastewater lies between 8.18–8.32, which corroborates the range found in literature[5]. The pH values indicate the effluent is alkaline in nature when it enters to the inlet chamber to ETP due to the discharge of alkaline cleaning solutions, pH is found to be decreasing in nature after pre-treatment because of alum addition in primary sedimentation tank. Alkalinity in raw effluent was found to be within the range of 562–593 mg/L as $CaCO_3$ which is within the range of data evaluated by Danalewich *et al.*[6]. As regards to the high TDS value, the reason can be attributed for the presence of different ions which generally are major constituents of the different cleansing agents and disinfectants used during the operation and maintenance stages. As the raw effluent passes through the chemical treatment, a large portion of colloidal matter has been reduced due to the chemical coagulation and sedimentation. COD concentration of raw dairy effluent lies in the range of 1116.7 to 1361.2 mg/L[7]. COD of dairy wastewater generally remains high due to the presence of high amount of degradable organic components, about 90% of COD and BOD loadings is caused by lactose that means dairy wastewater have a high soluble COD portion, indicates high biodegradability. BOD_5 of the dairy wastewater was found to be 788.6–898.0 mg/L which is within the range, as observed by Pachpute *et al.*[8].

Table 1. Characterization of dairy wastewater (pre-treated)

Parameters	Max	Min	Mean	S.D.
SCOD	1361.2	1116.7	1240.63	100.14
pH	8.32	8.18	8.25	0.06
TSS	1850.0	1520	1680.00	134.91
TS	5380	4300	4882.50	451.84
BOD_5	898.0	788.6	828.25	48.66
Alkalinity	593	562	577.50	12.82
NH_4^+-N	58.13	41.40	49.95	7.01
NO_3^--N	23.96	19.75	21.54	1.76
DO	1.60	1.20	1.40	0.18

*All parameters except pH are expressed in mg/L.

(B) Performance evaluation of SBR:

Selection of fill period for sequential batch reactor (SBR) operation:

The feeding of substrate into the reactor over a time-period prior to the commencement of bio-chemical reaction is considered as fill period. The fill time can be operated either in aerobic or anoxic mode. However, in the present study anoxic fill in absence of air was only considered. In the present study, the influence of fill period on substrate removal was examined to identify the optimum duration of fill period in SBR operation. Such variations were adopted as 0.5 h, 0.75 h and 1 h, respectively.

In case of initial SCOD concentration of 1250±50 mg/L after 0.5 h, SCOD concentration was observed as 1245 mg/L and during 0–0.5 h period the SCOD concentration in the reactor increased steadily. At the end of aerobic react period, i.e. 4 h about 68.84% of SCOD removal was achieved for a fill period of 0.5 h. In the latter stage that is for 0.75 h fill period, 67.24% SCOD removal was observed at the end of aerobic the react period, which was comparatively lesser than the former one (Table 2). Interestingly, the SCOD removal rate was further diminished to 65.15% when the fill time was extended to 1 h (Table 2). Table 2 demonstrated that the SCOD removal efficiency after overall react period marginally affects the fill period time tough lesser fill period (0.5 h) showed maximum removal efficiency.

Table 2. Variation of SCOD removal efficiency with fill period

Fill period (h)	SCOD removal efficiency (%) At the end of aerobic react period	At the end of anoxic react period
0.5	68.84	92.85
0.75	67.24	91.03
1.0	65.15	89.40

The availability of lesser react period in the case of 0.75 and 1 h of fill period not only reduced the rate of organic carbon and ammonia oxidation but at the same time was responsible for incomplete nitrification (Table 3) in terms of nitrate formation, resulting in higher concentration of ammonia and nitrite present as residual content in finally treated effluent. Increasing fill period, in other way, resulted in reduced denitrification rate. Considering the overall performance of the reactor, from the view point of SCOD removal,

Table 3. Variation of NH_4^+-N removal efficiency with fill period

Fill period (h)	NH_4^+-N removal efficiency (%) At the end of aerobic react period	At the end of anoxic react period
0.5	91.50	94.08
0.75	81.45	85.46
1.0	72.8	81.32

ammonia oxidation and denitrification, 0.5 h of fill period was considered to be the optimum fill period for the present experimental condition.

Selection of initial MLSS concentration for SBR operation:

Initial MLSS concentration is considered to be one of the important parameters for optimization of performance of SBR for simultaneous carbon and nitrogen removal. In the present study targeted SCOD value was maintained 1250±50 mg/L, in order to simulate the condition prevailing in a primary-treated effluent of a dairy industry wastewater. The effect of initial MLSS concentration was examined for a SCOD value of 1250±50 mg/L and initial NH_4^+-N concentration of 40±5 mg/L as N. Samples were withdrawn at 1 h interval in (4+4) h aerobic and anoxic combination of total react time. Initial MLSS concentration was varied from 1350±50 to 1900±50 mg/L to evaluate the performance of SCOD and NH_4^+-N in the present SBR system. Fig. 2 shows that, the SCOD removal efficiency increases with the increase in initial MLSS concentrations, and ceases to an optimum value at an initial

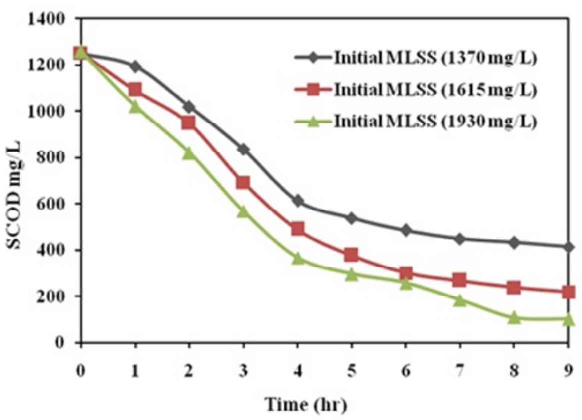

Fig. 2. SCOD profile with different MLSS concentration in SBR [SCOD = 1250±50 mg/L, NH_4^+-N = 40 mg/L as N, NO_3^- -N = 20±5 mg/L as N] cycle period (4+4) h.

MLSS concentration of 1900±50 mg/L, beyond which SCOD concentration decreases to a level that inhibits denitrification by reducing residual SCOD concentration at the start of denitrification.

Necessary reduction of ammonia nitrogen and nitrate nitrogen was achieved at afore-said MLSS concentration. The result obtained during this study were plotted graphically in Fig. 3.

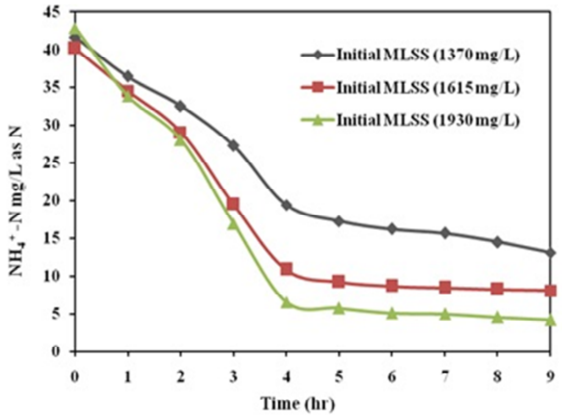

Fig. 3. Ammonia nitrogen profile with different MLSS concentration in SBR [SCOD = 1250±50 mg/L, NH_4^+-N = 40 mg/L as N, NO_3^- -N = 20±5 mg/L as N] cycle period (4+4) h.

Effect of reaction period for sequential batch reactor (SBR) operation:

The effect of react time on SCOD and NH_4^+-N removal efficiency was experimentally investigated for an initial organic substrate condition viz. SCOD of 1250±50 mg/L, for a constant initial NH_4^+-N concentration of 40±5 mg/L as N. The initial MLSS concentrations for the above conditions were maintained at the level of 1900±50 mg/L. The applied combinations of aerobic (O) and anoxic (A) react were (4+4, O/A) (3+4, O/A) and (3+3, O/A) and the data obtained in each cases are represented graphically through Fig. 4 to Fig. 9.

From Table 4 it is observed, during (4+4, O/A) react combination, the removal of SCOD and ammonia nitrogen is 82.36% and 79.79% respectively, and it is considered as optimum. Higher initial SCOD concentration inhibits nitrification initially due to growth competition between the heterotrophs and autotrophs, so a minimum 4 h aeration phase required for nitrification viz. conversion of ammonia to nitrate, during this period maximum conversion of ammonia nitrogen to nitrate occurred, and this nitrate removed through

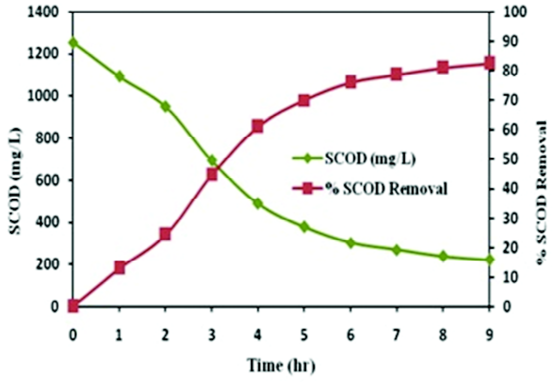

Fig. 4. Carbon oxidation profile for cycle period of (4+4) h [initial SCOD = 1250±50 mg/L and NH_4^+-N=40±5 mg/L as N, NO_3^- -N = 22±2.5 mg/L as N, initial MLSS = 1900±50 mg/L].

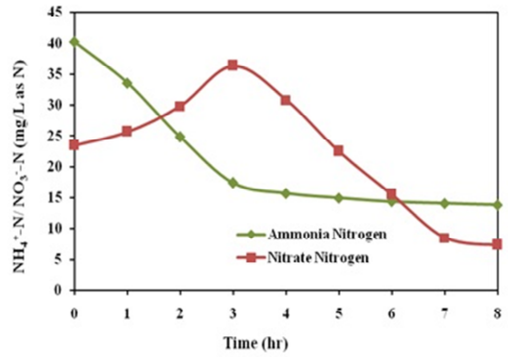

Fig. 7. NH_4^+-N and NO_3^- -N profile for cycle period of (3+4) h [initial SCOD = 1250±50 mg/L and NH_4^+-N = 40±5 mg/L as N, NO_3^- -N = 22±2.5 mg/L as N, initial MLSS = 1900±50 mg/L].

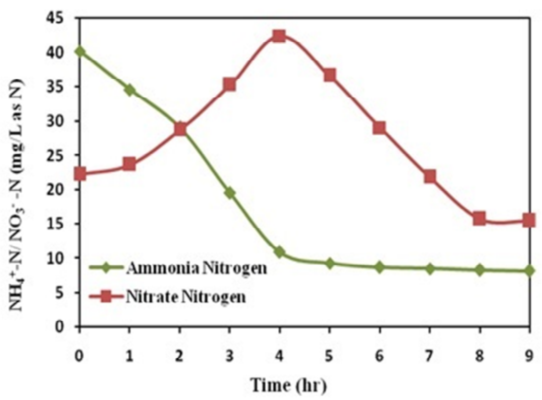

Fig. 5. NH_4^+-N and NO_3^- -N profile for cycle period of (4+4) h [initial SCOD = 1250±50 mg/L and NH_4^+-N = 40±5 mg/L as N, NO_3^- -N = 22±2.5 mg/L as N, initial MLSS = 1900±50 mg/L].

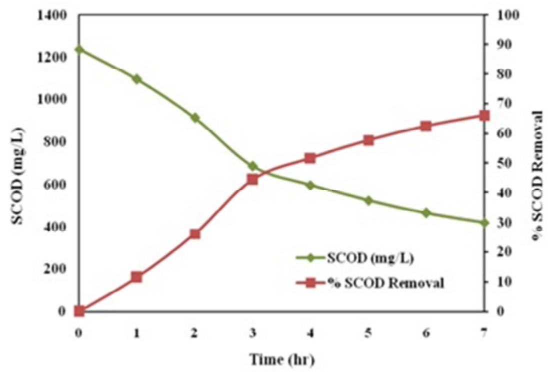

Fig. 8. Carbon oxidation profile for cycle period of (3+3) h [initial SCOD=1250±50 mg/L and NH_4^+-N = 40±5 mg/L as N, NO_3^- -N = 22±2.5 mg/L as N, initial MLSS = 1900±50 mg/L]

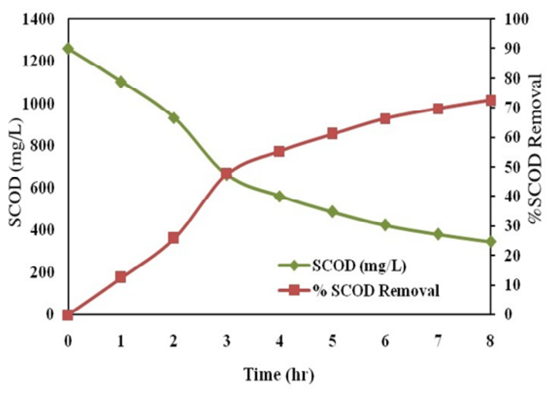

Fig. 6. Carbon oxidation profile for cycle period of (3+4) h [initial SCOD = 1250±50 mg/L and NH_4^+-N = 40±5 mg/L as N, NO_3^- -N = 22±2.5 mg/L as N, initial MLSS = 1900±50 mg/L].

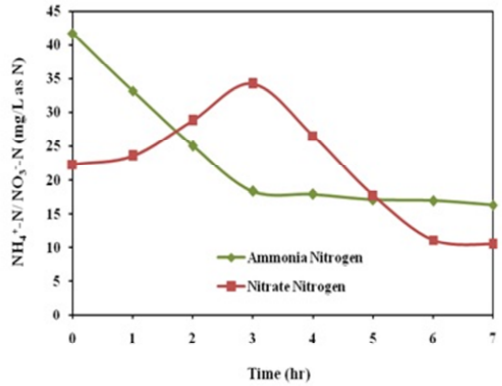

Fig. 9. NH_4^+-N and NO_3^- -N profile for cycle period of (3+3) h [initial SCOD=1250±50 mg/L and NH_4^+-N = 40±5 mg/L as N, NO_3^- -N = 22±2.5 mg/L as N, initial MLSS = 1900±50 mg/L].

Table 4. % Reduction of SCOD, NH_4^+-N and NO_3^--N at various react period

React Period	% SCOD Reduction	% NH_4^+-N Reduction	% NO_3^--N Reduction
(4+4) O/A	82.36	79.79	63.50
(3+4) O/A	72.61	65.60	79.95
(3+3) O/A	66.10	60.84	69.44

denitrification during anoxic phase, so further 4 h required for achieving denitrification.

Conclusion

Both COD and NH_4^+-N present in milk processing wastewater was successfully treated under aerobic condition followed by anoxic phase in sequential manner in SBR. The experimental results show that removal efficiency in SBR depends on duration of operative cycle period.

References

1. M. Vourch, B. Balannec, B. Chaufer and G. Dorange, *Desalination*, 2008, **219**, 190.
2. Metcalf and Eddy Inc., "Wastewater Engineering Treatment Disposal and Reuse", 4th ed., McGraw-Hill Publisher, 2002.
3. A. H. Mahvi, *Iran Journal of Health Science and Engineering*, 2008, **5**, 79.
4. APHA, Standards for examination of water and wastewater, 21st Edition, American Public Health Association, Washington DC, USA, 2005.
5. U. B. Deshannavar, R. K. Basavaraj and N. M. Naik, *Journal of Chemical and Pharmaceutical Research*, 2012, **4**, 2895.
6. J. R. Danalewich, T. G. Papagiannis, R. L. Belyea, M. E. Tumbleson and L. Raskin, *Water Research*,1998, **32**, 3555.
7. H. Chaiudhari, Dipali and R. M. Dhoble, *Current World Environment*, 2010, **5**, 373.
8. A. A. Pachpute, S. B. Kankal and M. V. Jadhav, *International Journal of Scientific Engineering and Research*, 2014, **2**, 38.