Operation Cycle Optimization of an Aerobic Sequencing Batch Reactor for Dairy Wastewater Treatment

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Abstract: *This study was primarily focused on developing an operation cycle for aerobic sequencing batch reactor (SBR) and optimizing it when dairy wastewater is the effluent in question. Throughout the study period, wastewater collected from a yoghurt factory was adequately diluted to occupy an influent COD concentration of 2000±500mg/l (COD loading 1.80-3.00g COD/L.D) while maintaining MLVSS and pH level in the reactor at 3500±500mg/l and between 6 and 8 respectively. With the purpose of identifying performance of the SBR in treatment of dairy wastewater, the available lab scale prototype was operated with a predetermined cycle comprising of Fill (1 min), Anoxic (50 min), Aeration (10 hrs.), Settling (1 hr.), Decanting (4 min) and Idling (5 min). The results collected throughout a period of 4 weeks converged to high BOD_5, COD and NO_3-N removal rates having averages of 95.8%, 94.6% and 90.7% respectively. At the same time, potential applicability of SBR as a secondary treatment system was identified since effluent parameters of the system were well within limits imposed by Central Environmental Authority (CEA) for surface water discharges. With this knowledge in hand, the operation cycle was further analyzed to replace with an efficient cycle having a shorter duration. Thereby, primarily taking the limits imposed by CEA for surface water discharges into account, a cycle comprising of Fill (1 min), Aeration (6 hrs.), Settling (1 hr.), Decanting (4 min) and Idling (5 min) was identified as the optimum cycle.*

Keywords: *Aerobic Sequencing Batch Reactor, Dairy wastewater, Cycle optimization, Biological treatment process*

1. INTRODUCTION

Dairy wastewater is an extremely rich source of biologically degradable matter which, if discharged without proper treatment, can carry a number of harmful effects to the environment. However, unlike in many other industrial wastewaters, presence of ample amounts of biologically degradable organic matter and the absence of toxic compounds in dairy wastewater have made biological treatment methods more promising over other treatment options. On the contrary, fluctuations of the flow patterns due to batch production, presence of inhibition material and inadequacy of factory space have been identified as problems when deciding upon a suitable treatment method. Since the SBR can be developed to provide adequate treatment regardless of fluctuating flow patterns and without occupying a large space, it can beyond a doubt be justified as a suitable treatment option. Though few researches have been carried out on treatment of dairy wastewater using aerobic SBR, most of them have not focused on the development of an optimum operation cycle. At the same time, none of the researches have been carried out adhering to the local conditions. Hence, this study was conducted to further investigate on the performance of the SBR in treating yoghurt type dairy wastewater and to identify the optimum operation cycle.

2. LITERATURE REVIEW

Sequencing batch reactor (SBR) can be identified as a system based on the fill and draw mechanism. Usually, wastewater with organic effluents are filled into the reactor and allowed to react so that undesirable components in them can be brought down to an acceptable range prior to discharge.

Unlike in conventional activated sludge systems, in a SBR, operations including equalization, neutralization, biological treatment and secondary clarification are carried out in a single reactor. One operation cycle of this reactor comprises of 5 phases which are namely: fill phase, react phase, settle phase, decant phase and idle phase (Metcalf & Eddy Inc. 2003; U.S. EPA 1999).

Dairy wastewater is an extremely rich source of biodegradable organics composed mainly of milk solids that essentially consist of carbohydrates, fats and proteins. Usually dairy wastewater comprises of dilutions of whole milk and by-products (Patwardhan 2012). Furthermore, the research conducted on dairy wastewater by Janczukowicz et al (2012) has concluded that fermented dairy wastewater can even be used as an additional carbon source in phosphate removal process due to the availability of ample amount of biodegradable organics in the form of volatile fatty acids. As a result, biological treatment methods are most adequate in treating dairy effluents. The main inhibition material found in dairy wastewater is oil and fat which reduce biological activity of the treatment process due to the formation of an oil layers around microbes and at the same time lead to a drop in dissolved oxygen level (El-gawad 2014). However, Nasr et al. (2014) have identified that the system can tolerate small concentrations of oil and grease since, lower concentrations of inhibitory substances does not carry significant effects to the microbial population.

The research done by Lee et al. (2007) have identified that denitrification, which is promoted during the anoxic phase, as the main mechanism of nitrogen removal in an aerobic SBR system. Meanwhile, the studies carried out by Makowska et al. 1(2013) have discovered that activated sludge flocs have irregular structures and the disperse rates relate to the accessibility of substrate and oxygen by inert layers of a floc. Considering the concentrations of different nitrogen forms inside a floc, the possibility of nitrification and denitrification processes occurring inside even during the aeration phase, has been explained. With this knowledge, the removal of anoxic phase from the SBR operation cycle was justified.

3.1. Experimental Setup

Prototype used during the experiment consisted of 3 tanks, namely: Skimming tank, Equalization tank and reactor tank. The Effluent decanted from the system was collected to another container, which was drained from time to time. The reactor used was made out of a cylindrical Perspex tank with a total capacity of 20L. Furthermore, with the purpose of supporting the settling of solids, the bottom of the reactor was modified into a conical shape by using a 2mm thick steel sheet. A stop valve was fitted at the bottom of the cone to remove excess sludge from the reactor. In addition to that, the tank was connected with an influent pipe from the top opening, an effluent motor which was submerged in the tank at level of 6.7L, a mechanical agitator powered by an electrical motor which was fixed at the top of the tank and two aquatic air pumps which were installed at bottom of the tank. A schematic diagram of the configuration is given below.

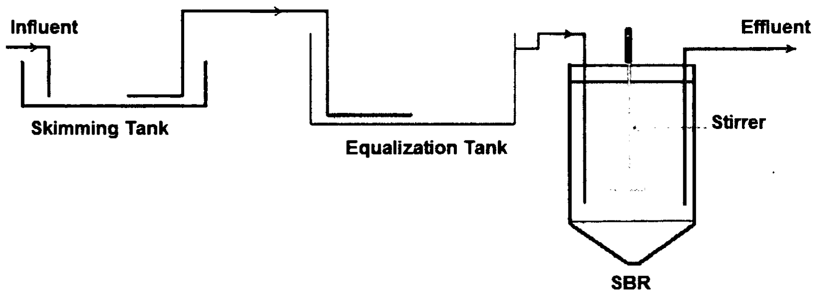

Figure 1 Schematic diagram of the reactor setup

3.2. Operational Conditions

The reactor was fed with dairy wastewater collected on a weekly basis from the university yoghurt factory and was stored under refrigeration conditions until been used. Table 1 demonstrates typical characteristic parameters of collected wastewater. Furthermore, the biomass needed for the SBR system was collected from the operating SBR unit at the temple of the tooth relic. During the study period, influent COD concentration and MLVSS in the reactor were maintained at 2000 ± 500 mg/l

(COD loading 1.80-3.00 kg COD/l.d) and 3500±500mg/l respectively. Before feeding to the reactor, the influent wastewater was sent through a skimming mechanism. Throughout the initial 4 weeks, the system was operated with a predetermined operation cycle comprising of Fill (1 min), Anoxic (50 min), Aeration (10 hrs.), Settling (1 hr.), Decanting (4 min) and Idling (5 min). The anoxic phase was arranged at the beginning of the cycle to utilize the maximum use of available organic carbon. Parameters including BOD_5, COD and NO_3-N were analysed using Winkler's method, Dichromate COD test and Nitrogen reagent powder pillows respectively, to identify potential applicability of SBR in dairy wastewater treatment. However, the ammonium concentration of the wastewater was not assessed since it was already within the CEA discharge standards. Although the research done by Lee et al. (2007) has identified that some of the nitrates in the system reduce to ammonia during the anoxic phase, it was fairly assumed that the concentration of ammonia will again decrease once the10 hours long aeration process was completed. Thus, the concentration of ammonia was considered not to increase at the end of the operation cycle. During the study period, PH level of the influent was maintained in a range of 6-8.

In second phase of the project, an optimum cycle for treatment of dairy wastewater was designed by analysing the cycle. With the purpose of determining the optimum operation cycle, a trail cycle comprising of Fill (1 min), Aeration (10 hrs.), Settling (1 hr.), Decanting (4 min) and Idling (5 min), was analysed. The samples were collected initially, after 30 minutes, after 1 hour, after 3 hours, after 6 hours and from the final effluent. To determine the most optimum cycle, BOD_5, COD and NO_3-N fluctuation of the system was analysed with time.

Table 1 Characteristics of dairy wastewater

Parameter	Concentration / Value
COD	8000-14000 mg/l
pH	4-11
NO_3-N	140 mg/l
NH_4-N	17.1 mg/l
Oil and grease	91g/l
Temperature	26^{0}c

4. RESULTS AND DISCUSSION

4.1. System Performance with the Trial Cycle

A satisfactory level of BOD removal, having an average of 95.8%, was achieved throughout the study period. The results have proven that a SBR can successfully be used to remove biologically degradable matter in wastewater. Similarly, the COD removal efficiency was also at a high level having an average of 94.6%. Furthermore, the effluent BOD_5 and COD concentrations were below 30mg/l and 250mg/l respectively, which are the permissible limits identified by CEA surface discharge standards. BOD_5 and COD data collected throughout the study period are demonstrated in Figure 2.

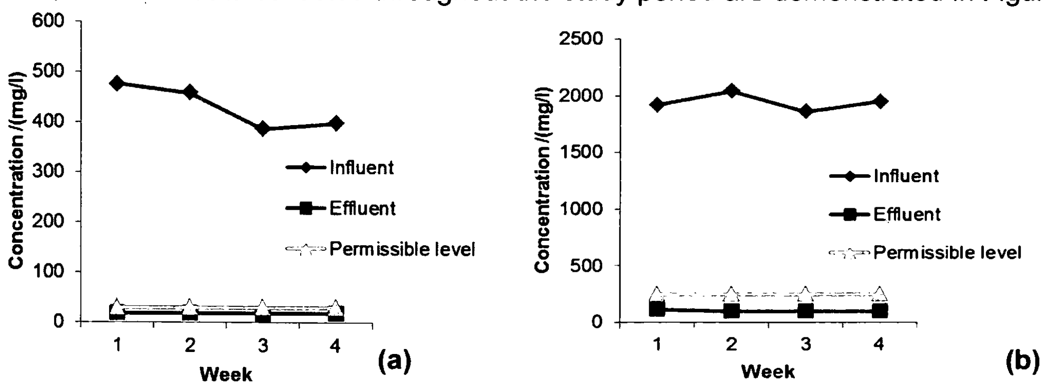

Figure 2 (a) Influent and effluent BOD_5 concentration (b) Influent and effluent COD concentration

Similarly, a satisfactory level of nitrate removal having an average over 90% was also observed throughout the study period. The effluent nitrate concentrations were well below the boundary limit identified by CEA surface water discharge standards, which is 10mg/l. Therefore, it was identified that both anoxic and aerobic phases can together be utilized effectively in Nitrate removal.

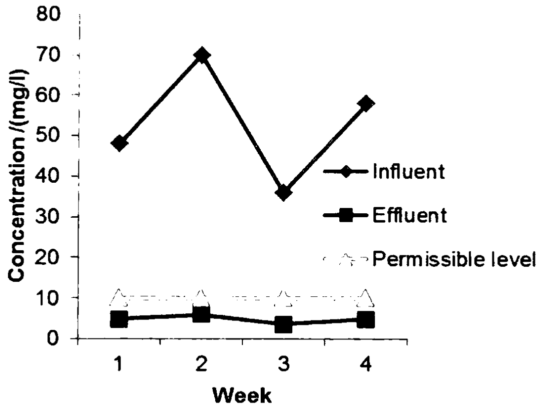

Figure 3 Influent and effluent nitrate concentration

The maximum nitrate concentration observed during the study period was only 70mg/l. Therefore, it was decided to remove the anoxic phase from the operation cycle and observe if aeration phase alone can provide the required denitrification without compromising on the efficiency.

The average influent and the effluent oil and grease concentrations were respectively 15g/l and 12g/l. This resulted in an extremely low efficiency of oil removal having efficiency as low as 22.7%. The drop in the influent oil and grease concentration, which was around 90g/l in dairy wastewater, can be explained as result of dilution. However, based on the low removal efficiencies observed via gravity removal methods, it can fairly be justified that most oil present in dairy wastewater are in the emulsified form.

4.2. Optimization of the Operation Cycle

4.2.1. Variation of the BOD_5 Concentration

In order to achieve the permissible BOD_5 effluent concentration of 30mg/l, aeration phase had to be continued for approximately 8 hours. However, the rate of removal significantly dropped after 6 hours of aeration. Through the experiments conducted, it was observed that a BOD_5 concentration slightly above the permissible level was achievable even with aeration of 6 hours. The results are graphically demonstrated in Figure 4.

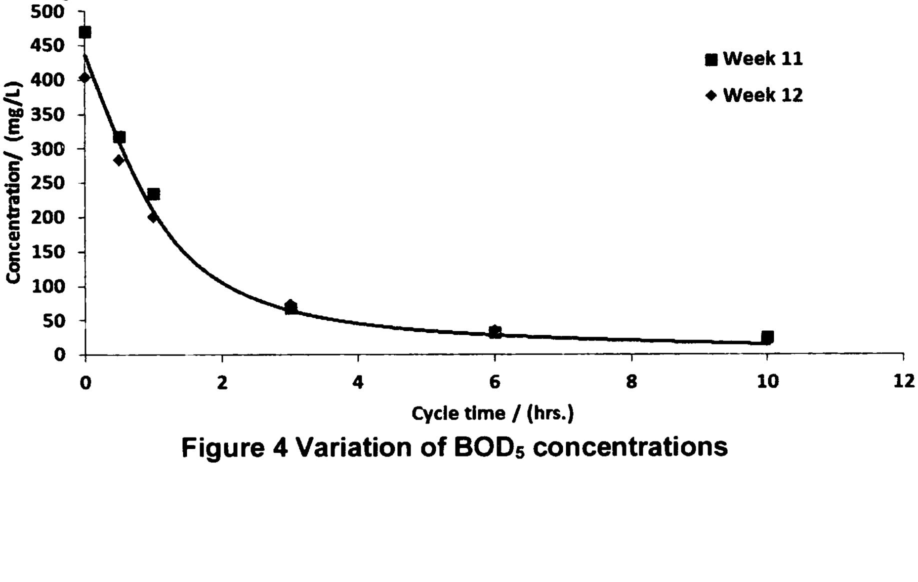

Figure 4 Variation of BOD_5 concentrations

Since the drop-in concentration reduces significantly after 6 hours of aeration, it would be extremely viable to consider that as the duration of aeration in terms of BOD_5 removal. Furthermore, this can save both money spent on aeration and at the same time increase the number of cycles carried out per day. During the initial 1.5 hours of aeration, a significant drop in the BOD_5 concentration was observed. This could partly be due to the denitrification process occurring inside floc since, organic carbon acts as oxidising agent in the reduction of nitrite to nitrogen. Furthermore, the exponential drop in BOD_5 readings depict the necessity of arranging anoxic phase at the beginning of the operation cycle, in case it is required. However, with the addition of an external carbon source, anoxic phase will become applicable even at a later stage.

4.2.2. Variation of the COD Concentration

Permissible COD concentration limit imposed by the Central Environmental Agency, which is 250mg/l, was met approximately with 5 hours of aeration, which amounted to nearly 87% removal in terms of COD. The results collected are demonstrated graphically in figure 5.

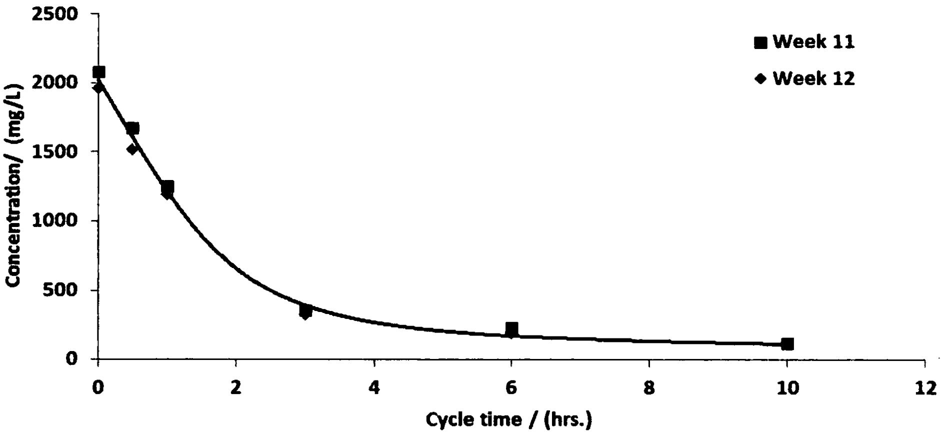

Figure 5 Variation of COD concentrations

The above figure represents a drastic drop in the COD concentration during the initial 1.5 hours of aeration. The demand for organic matter during the denitrification process may have contributed to this behaviour of the curve. However, additional aeration of 5 hours after reaching the limiting value caused insignificant effect to the removal efficiency.

4.2.3. Variation of the Nitrate Concentration

The limiting nitrate concentration of 10mg/l was achieved within the initial two hours of aeration. From there onwards, the additional aeration did not pose much influence on the nitrate removal. The results collected are demonstrated graphically in figure 6.

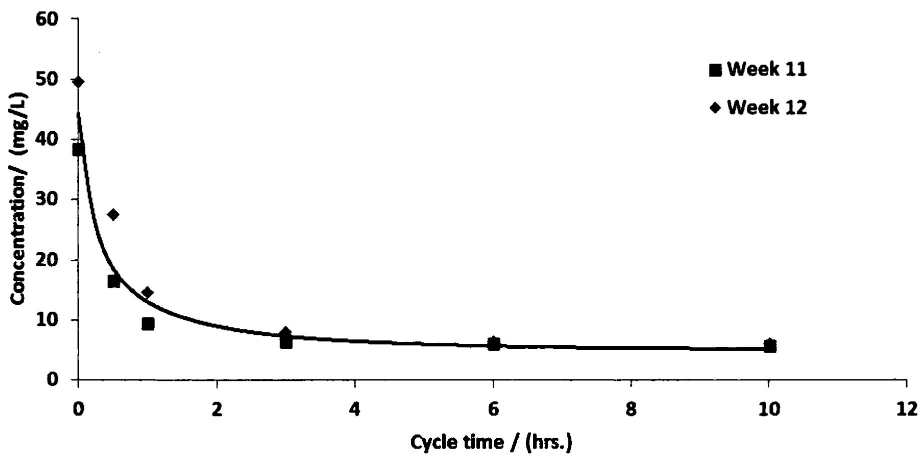

Figure 6 Variation of COD concentrations

The above figure further justifies denitrification process occurring within the floc. Accordingly, 79% nitrate removal was achieved within 2 hours of aeration. Ultimately, the nitrate removal reached 87% with 10 hours of aeration, which was only 3.3% lower compared with the 90.8% nitrate removal achieved by the predetermined cycle with both an anoxic phase and 10 hours of aeration. This fact can be used to emphasize the insignificance of the anoxic phase when the nitrate concentration is low. Furthermore, the significant drop in the nitrate concentration observed in the initial 1.5 hours can be used to justify the similar drop in BOD_5 and COD concentrations.

4.2.4. Optimum cycle

According to the above data, in terms of BOD_5, COD and nitrate removals, 6 hours of aeration appeared necessary in order to provide the adequate treatment economically. Accordingly, the optimum cycle can be identified as in the following table. Considering Figures 4, 5 and 6, it can be identified that BOD_5, COD and nitrate removals of 92%, 89% and 85% respectively can be achieved through the optimized operation cycle.

Table 2 Optimum operation cycle

Phase	Duration/(min)
Fill	1
Aeration	360
Settling	60
Decant	4
Idle	5
Total cycle time	430

5. CONCLUSION

The research was conducted to identify the performance of aerobic sequencing batch reactor when treating dairy wastewater and to optimize the operation. The results demonstrated a potential applicability of the system as a secondary treatment system. The initial COD concentrations of the yoghurt dairy wastewater ranged between 800-14000mg/l. However, the system was fed with a concentration ranging between 1500-2500mg/l (COD loading 1.80-3.00), which means the wastewater had to be diluted to that range in order to feed the SBR. In practical applications, a biological treatment system and an oil removal mechanics can be installed prior to the SBR to serve this purpose. However, the oil removal mechanism must carry the ability to remove oil in emulsified form, since gravity methods performed unsatisfactorily. The study reflected that, after treatment with the SBR, wastewater can be directly discharged into open water bodies of the island since all the discharge regulations were met.

Furthermore, additional aeration produced insignificant effect, despite the additional time and the cost of aeration. Due to the exponential drop observed each parameter, it might perhaps be viable to go for a separate system once this point is reached. Considering the capital and operational costs involved, it would be much advisable to follow the above procedure when determining the cycle. In addition, when designing an operation cycle for an aerobic SBR treating dairy wastewater, the behaviour of BOD_5 and COD must be analysed carefully since, they act as the bottlenecks.

The anoxic phase of the SBR cycle was identified unnecessary at small concentrations of nitrate, since the inter floc denitrification can sufficiently reduce the effluent concentration.

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