The Economical Benefits of using Biofilm Sequencing Batch Reactor for Dairy Wastewater Treatment

Ahmed Nazem, Walid Elbarqi and Medhat Mostafa

***Abstract*—**The dairy industry is one of the most polluting of industries, not only in terms of the volume of effluent generated, but also in terms of its characteristics as well. This study aims to investigate the economical benefits of using the biofilm sequencing batch reactor (BSBR) in comparison with the conventional treatment methods for the dairy wastewater. Two pilot plants of conventional Sequencing Batch Reactor (SBR) and BSBR systems were operated in parallel for two scenarios with two different hydraulic retention times (HRTs) of 2 and 3 days, respectively. The glucose based synthetic feed was used for both SBR and BSBR systems. The synthetic feed compositions are 7000, 120 and 60 mg/l for COD, TKN and TP, respectively. The COD and TKN removal efficiencies of the SBR system at 2 days HRT were 88.5 and 69.8% respectively. However, the COD and TKN removal efficiencies of the BSBR system at 2 days HRT were 94.8 and 73.4% respectively. It was concluded from the performance of BSBR system, the addition of suspended media of only 4% of the reactor volume reduces the reactor volume by 34% to obtain the same removal efficiencies. Also, the oxygen consumption at the aeration process for the BSBR system was less than the SBR system. Cost estimation for the hybrid system (BSBR) in comparison with SBR and Anaerobic/aerobic (An/A) treatment. Relative weight factors for all cost effective factors were considered in this study to make effective quick cost estimation for the three methods. BSBR shows capital cost reduction of 30 and 4.1% compared to SBR and An/A systems, respectively. Moreover, BSBR shows annual O & M cost reduction of 27.6 and 30.2% compared to SBR and An/A systems, respectively.

Keywords—Biofilm Sequencing Batch Reactor (BSBR); Dairy Wastewater; Cost estimation; Relative weight factors.

I. INTRODUCTION

THE dairy industry is a major enterprise in Egypt, occupying a significant place in food supply. This industry has been identified as an important contributor to the pollution of waterways especially when large industrial establishments are involved [1]. In general, wastes from the dairy processing industry contain high concentrations of organic material such as proteins, carbohydrates, and lipids, high concentrations of suspended solids, high biological demand (BOD) and chemical oxygen demand (COD), high nitrogen concentrations, high suspended oil and/or grease contents, and large variations in pH, which necessitates "specialty" treatment so as to prevent or minimize environmental problems [2].

The SBR process became more commonly applied from the mid-1980s onwards as an alternative to the more commonly encountered continuous flow systems. It is the only commonly applied activated sludge variant which is designed to operate in a cyclic or intermittent mode. Because of the latter, the operation of SBRs can be matched with the shift nature of factory operations more easily than continuous flow systems. The differences between treatment trains incorporating the continuous flow activated sludge processes and the SBR begin from the aeration vessel onwards. Typically the continuous flow activated sludge process operates with aeration vessels and secondary clarifiers. There would be sludge return from the secondary clarifier to the aeration vessel. The SBR operates without the secondary clarifier and hence would also not have the sludge return from the latter. The SBR system might be suitable to treat dairy wastewater because of its ability to reduce nitrogen compounds by nitrification and denitrification [3-6], but the SBR system still has some disadvantages such as the high excess sludge produced and the high sludge volume index [7-10]. In recent years, the combination of activated sludge and biofilm wastewater treatment processes has been increasingly used worldwide to increase the efficiencies of both organic substrate and nitrogen removals [11-14]. This technology installs either fixed or moving media for biomass natural attachment in the aeration tank of the conventional biological nutrient removal or activated sludge processes. The process primarily focuses on the improvement of nitrification process located in the temperate zone in which slow growing microorganisms could not retain in the system at low temperature. In general, the sludge retention time (SRT) as an operating parameter for the suspended wastewater treatment processes must be increased. In this study, an attached growth system was applied in the conventional SBR reactor by installing suspended plastic media in the SBR reactor to increase the system efficiency, bio-sludge quality and to reduce the excess bio-sludge. The experiments were carried out in both SBR and BSBR systems to observe the performance of the systems and the removal efficiencies and quality of the bio-sludge.

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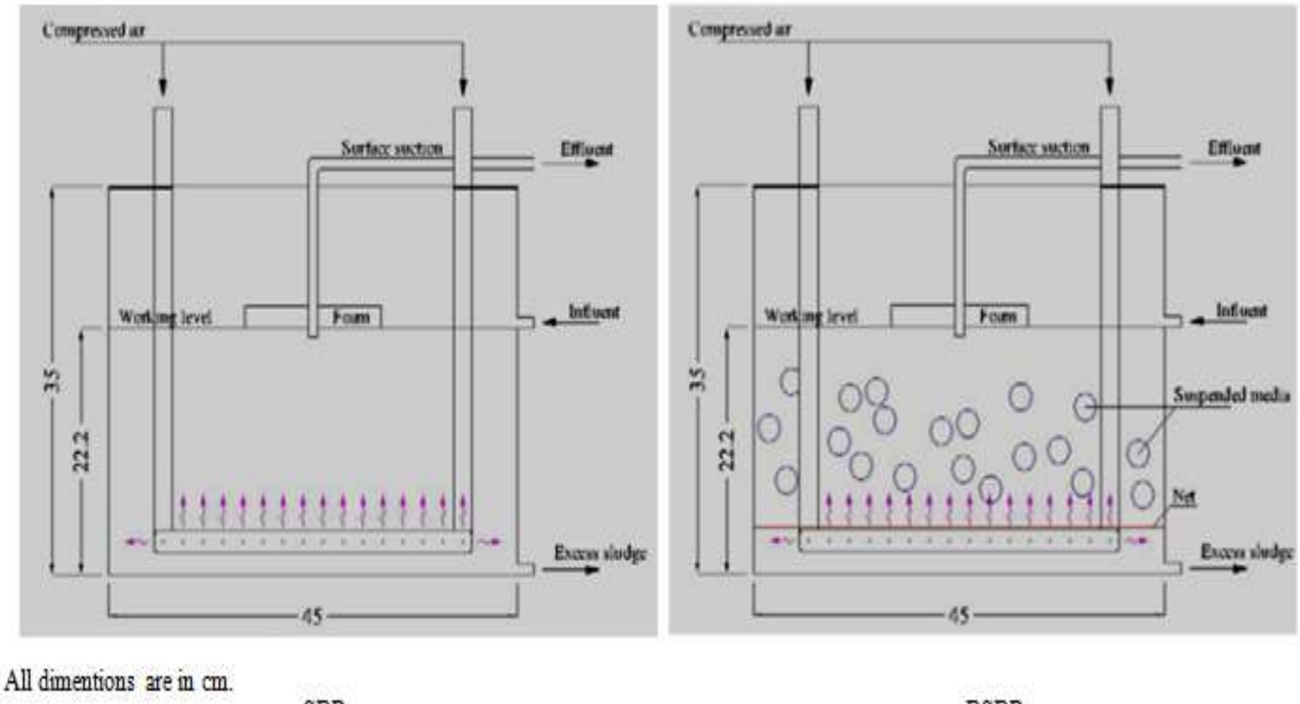

Fig. 1 The two pilot plants

II. Materials and Methods

A. Pilot plant

Two pilot plant of conventional sequencing batch reactor (SBR) and biofilm sequencing batch reactor (BSBR) systems were systems were operated in parallel, as shown in Fig. 1. Two scenarios were used with two different hydraulic retention times (HRTs) in this study. The two pilot plants were constructed in the laboratory of Sanitary Engineering Department, Faculty of Engineering, Alexandria University.

For the BSBR system, plastic media with a total surface area of 2.21 m2 (Fig. 2, Table 1) was installed on the bottom of the reactor. Both SBR and BSBR reactors were made from Plexiglas (length= width = 45 cm, max. water depth = 22.2 cm, volume of reactor = 45 liters).

TABLE I
PROPERTIES OF THE MEDIA IN THE BSBR

Properties	Value
Size of each ball	2.5 cm in diameter
Gross volume of each ball	4.6 cm^3
Net volume of each ball	2.37 cm^3
Surface area of each ball	55.206 cm^2
Surface area	1200 m^2/m^3
Weight of each ball	4.40 gm
Density of each ball	0.96 gm/cm^3
Number of balls in reactor	400 balls
Total surface area of balls	2.208 m^2
Total net volume of media in reactor	948 cm^3
Percentage of media gross volume/Reactor volume	4 %
Total weight of media in reactor	1760 gm
Cost	1480 $/$m^3$

Single ball Set of media

Fig. 2 Plastic Suspended Media

B. Wastewater characteristics

The chemical compositions of dairy industrial wastewater are depending on the type of dairy industry. According to Sirianuntapiboon et al., 2005 [16], the average concentrations of COD, TKN and TP are 7000, 120 and 60 mg/l, respectively. The synthetic sewage was prepared by diluting with tape water (1-100).

C. Operation

The operation program of both SBR and BSBR systems consisted of five steps: fill (2 hrs), react (aeration)(19 hrs), settle (2), draw and idle (1). The acclimatized bio-sludge was inoculated in each reactor of both the SBR and SBBR systems, and synthetic samples were added (final volume of 45 l) within 2 h (fill step). The two scenarios for SBR and BSBR were operated each for 40 days.

D. Chemical analysis

The Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), Suspended Solids (SS) Total Kjeldahl Nitrogen (TKN), and pH of influent and effluent, Mixed-Liquor Suspended Solids (MLSS), excess sludge, and Sludge Volume Index (SVI) were determined by using standard methods for the examination of water and wastewater [15]. Solid Retention Time (SRT) and sludge age was determined by measuring the average residence time of the suspended microorganisms (suspended bio-sludge) in the system. The F/M was presented as a ratio of COD loading and the total bio-sludge of the system.

E. Cost analysis

Cost analysis was performed to conduct a comparison between three methods of dairy wastewater treatment, which are SBR, BSBR and Anaerobic/aerobic systems. This cost analysis was performed using relative weight factors for each effective component of the three systems. Table 2 shows all of the considerable cost categories, elements and dependent items.

III. Results And Discussion

A. Performance results

Summary of the results for the steady state operation for SBR and BSBR pilot plants in the two scenarios is shown in Table 2. For all scenarios, the COD % and TKN% removal for the BSBR pilot plant was higher than the SBR pilot plant. However, the effluent SS and excess sludge for the BSBR was smaller than that for SBR system. Also, the residual DO forBR was less than that for BSBR system, which mean of more oxygen consumption.

TABLE II
Summary Of The Results For Sbr And Bsbr Pilot Plants In The Two Scenarios.

HRT (d)	2		3	
Reactor	SBR	BSBR	SBR	BSBR
Organic loading ($gCOD/m^3d$)	3500		2333	
Hydraulic loading (m^3/m^3d)	0.50		0.33	
SRT (d)	15		15	
COD removal %	88.52±0.22	94.8±0.20	95.34±0.10	98.9±0.05
TKN removal %	69.75±0.46	73.4±0.60	71.69±0.59	78±0.50
Effluent S.S (mg/l)	554±10	209±6	322±9	49±9
Residual DO (mg/l)	0.79±0.21	1.40±0.33	1.26±0.08	5.10±0.32
Excess sludge (g/d/L)	0.81±0.02	0.63±0.04	0.53±0.03	0.43±0.05

B. Cost analysis results

<u>Analysis considerations</u>

All analysis and assumptions for the three systems were performed according to the following considerations:

1. All percentages or relative weight factors were considered according to the lab-results, simple calculations, field considerations and references.
2. The cost effect for both volume and area are equal.
3. All necessary chemical additions for pH adjustment or nutrients supplementation are out of consideration.
4. The bio-gas end products for the anaerobic/aerobic treatment system were considered to be not used for heat or any commercial purposes. Performance of the Anaerobic/Aerobic method is an average of different systems subjected to the same organic load rate [13].
5. The required COD and TKN removal efficiencies to be achieved are ranged between 94-95.5% and 71.5-73.5%, respectively.
6. The relative weight factors or percentages for the items related to volume/area were determined according to the required HRT.
7. The total cost of treatment systems is classified into two categories, Capital Cost (90%) and annual Operation and Maintenance cost (10%)[17].
8. The percentages of each volume/area and media in the capital cost were used according to the following equation [17]:

$$CC = 72\,Q + 368043$$ where:

CC: capital cost, dollars; Q: average design flow, m3/d which is calculated according to HRT of 6 hrs. Construction costs include costs of basins, air supply equipment and piping, and blower systems.

By assuming the flow rate of 200 m3/d and HRT of 2 days, the following results are produced:

CC = 72 (200) (48/6) + 368043 = 483243 dollars; Media cost = 0.04 (200) (2) (1480 $/m^3 media) = 23680 dollars; It means that volume/area has 95.3% of the total capital cost if media (4% of the working volume) is used in the process.

9. The items which are related to basins or equalization tanks consist of the reactor body and all necessary pumps, valves and inlet or outlet pipes.

10. The cost element which is related to electrical power is classified into three main items; Heat, aeration and pumps. Weights' percentages for each item were considered according to the following:

According to Metcalf & eddy (2003)[4], comparison of energy balance for aerobic and anaerobic processes for the treatment of a wastewater with the following characteristics: wastewater flow rate = 100 m^3/d; wastewater strength = 10 kg/m^3; and temperature = 20^{o}C was performed. The results show that:

a. The aeration process consumes 1.9 x 106 KJ/d (52.3% of the total required energy).

b. Increasing the wastewater temperature to 30^{o}C consumes 2.1 x 106 KJ/d (47.3% of the total required energy).

For the required energy of pumps using the same flow rate and hydrostatic head of 8m, calculations showed that:

c. Energy = Kw x time; Kw = ((1x1.157x8) / (75x0.8x0.9)) x 0.7457 = 0.1278 Kw; Energy (KJ/d) = 0.1278 x 24 x 60 x 60 = 11044 KJ/d (0.4% of the total required energy).

11. The evaluation Dependency for the different dependent items are as follow:

- Basins – Equalization tank: The Required HRT and/or number of basins
- Aeration: The Required air quantity and/or aeration period
- Pumps: The required capacity
- Heat: The required temperature and the required heating period.
- Excess sludge: The required SRT and MLSS concentration.

12. The relative weight factors for the item, which is related to Excess sludge were determined according to both MLSS concentrations and the required SRT for each treatment system.

TABLE III
THE COST ANALYSIS COMPONENTS AND CONSIDERATIONS

<table>
<tr><th colspan="2">Cost Categories</th><th colspan="2">Elements/Category</th><th>Dependent items/Element</th></tr>
<tr><td colspan="2" rowspan="2">Capital Cost
(CC)</td><td colspan="2">Volume/Area</td><td>Basins - Equalization tanks</td></tr>
<tr><td colspan="2">Media</td><td>Media usage</td></tr>
<tr><td colspan="2" rowspan="3">Operation and Maintenance
(O & M)</td><td colspan="2">Electrical power</td><td>Pumps - Aeration - Heat</td></tr>
<tr><td colspan="2">Sludge</td><td>Excess sludge</td></tr>
<tr><td colspan="2">Maintenance</td><td>Basins - Aeration</td></tr>
<tr><td rowspan="3">Input</td><td>% for each cost category and element according to its cost.</td><td rowspan="3">Output</td><td colspan="2" rowspan="2">Relative weight factor for each item with respect of all previous cost distribution.</td></tr>
<tr><td>% for each item according to its cost.</td></tr>
<tr><td>Relative weight factor for each item according to its dependence.</td><td colspan="2">Accumulated relative weight factors for CC and annual O & M for the three systems.</td></tr>
</table>

Table IV shows the capital cost reductions and the annual operation and maintenance cost reductions, which are calculated according to the BSBR resulted factors.

TABLE IV
COST ANALYSIS RESULTS ACCORDING TO DEPENDENT RELATIVE WEIGHT FACTORS

Treatment method						SBR		BSBR		Anaerobic /Aerobic	
Cost		Cost element	%	Dependent item	%	Item weight factor	value	Item weight factor	value	Item weight factor	value
Capital cost	90%	Volume/Area	95.4	Basins	87	3	2.2409	2	1.4940	2	1.4940
				Equalization tanks	13	1	0.1116	1	0.1116	2	0.2232
		Media	4.6	Media	100	0	0.0000	1	0.0414	0	0.0000
Annual O & M	10%	Electrical power	85	Pumps	0.4	1	0.0003	1	0.0003	2	0.0007
				Aeration	47.3	1	0.0402	0.7	0.0281	0.15	0.0060
				Heat	52.3	0.05	0.0022	0.05	0.0022	1	0.0445
		Sludge	10	Excess sludge	100	1	0.0100	0.7	0.0070	0.43	0.0043
		Maintenance	5	Basins	40	1	0.0020	1	0.0020	2	0.0040
				Aeration system	60	1	0.0030	0.7	0.0021	0.15	0.0005
Total capital cost factor						2.353		1.647		1.717	
CC Reduction % for BSBR							30.0%		4.1%		
Total annual O & M cost factor						0.058		0.042		0.060	
Annual O&M Reduction % for BSBR							27.6%		30.2%		

IV. CONCLUSIONS

- Based on the observations and the results obtained from this study, the following points could be concluded:
- Biofilm Sequencing Batch Reactor (BSBR) had a higher COD and TKN removal efficiencies and lower excess sludge compared with Sequencing Batch Reactor (SBR).
- Adding plastic suspended media of just 4% of the working reactor volume saved about 34% of reactors' volume to reach the same efficiencies.
- The oxygen consumption at the aeration process for the BSBR system was less than the SBR system, which makes it economic to use tapered aeration system.
- Cost analysis was performed between SBR, BSBR and Anaerobic/Aerobic treatment systems. BSBR shows capital cost reduction of 30 and 4.1% compared to SBR and An/A systems, respectively. Moreover, BSBR shows annual O & M cost reduction of 27.6 and 30.2% compared to SBR and An/A systems, respectively.

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