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Application of sequencing batch biofilm reactor (SBBR) in dairy wastewater treatment

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Abstract−Application of lab-scale sequencing batch (SBR) and sequencing batch biofilm reactors (SBBR) for treatment of dairy wastewater was investigated under organic loading of 1,130-1,560 $gBOD_5/m^3 \cdot d$. The main characteristics of the dairy wastewater were: pH=4.9, chemical oxygen demand (COD)=16,264 mg/*l*; biological oxygen demand (BOD_5)=10,536 mg/*l*, PO_4-P=342 mg/*l*; total nitrogen (TN)=224 mg/*l*. SBBR was filled with the Kaldnes K1 biocarrier at 30% of the volume of empty reactor. The SBR and SBBR were operated in fixed 24 h cycles, each consisting of 30 min fill up, 22 h aeration, 1.5 h settle, 30 min decant, and idle with a hydraulic retention time (HRT) of 8 days. Operational parameters such as pH, dissolved oxygen (DO), mixed liquor suspended solid (MLSS), solids retention time (SRT) and sludge volume index (SVI) were monitored during the whole cycle. The effects of these parameters on the COD, nitrogen and phosphorus removal were discussed in this paper. As a result, adding biocarrier to the reactor had a positive effect on organic with COD removal of 63.5% for SBR and 81.8% for SBBR and nutrient removal with ammonium removal of 66.0% for SBR and 85.1% for SBBR in treatment of dairy wastewater.

Keywords: COD Removal, Dairy Wastewater, Biocarrier, Nutrient Removal, SBR, SBBR

INTRODUCTION

Dairy processing plants can be characterized by intensive water consumption and high pollution potential [1]. The amount and composition of the wastewater generated from dairy plants are closely related processed products, the production schedule, operating methods, plant design, degree of water management being applied, and subsequently the amount of water being recycled [2,3]. In general, wastes from the dairy processing industry contain high concentration of organic material as biological oxygen demand (BOD) and chemical oxygen demand (COD), suspended solids (SS), nutrients, suspended oil and/or grease, and large variations in pH [4,5]. So, treatment of dairy processing wastewater is important to prevent and minimize its effects on the environment. With environmental regulations becoming more stringent, regulatory compliance has become a matter of growing concern to dairy operators. Therefore, there is an acute need to develop effective technologies for dairy wastewater treatment. Several aerobic treatment studies on dairy effluents have been performed [6-11]. These studies show that aerobic biological systems effectively treated dairy waste.

SBR is a time-oriented process and operated over repeated cycles of five phases: fill, react, settle, decant, and idle. SBR has some advantages due to the processing characteristics such as combining the aeration reactor and with the setting tank in the same vessel, flexible operation, easy control, and different biochemical conversion reactions can be conducted by changing aeration mode simultaneously [12-14]. SBR performance can be optimized for carbon oxidation, nitrification and denitrification by controlling some process parameters such as organic loading rate, HRT, SRT, DO [7,15].

Many researchers focused on hybrid systems due to the combining of the advantages of suspended and attached growth systems. Moving bed biofilm reactors (MBBR) have been developed as one of the most attractive [16,17].

The Kaldnes MBBR is a hybrid biofilm reactor where the biomass is grown on small bio-carrier that moves freely in the reactor. The interest in this type of hybrid process is justified due to some advantages such as relatively high sludge age, no sludge recycling, and fewer bulking problems [18]. However, most MBBRs actually have very low average sludge ages. The biomass just happens to be much more active than the biomass in activated sludge systems. High loaded MBBRs for removal of organic matter typically have a biofilm retention time of only one day [19]. And also, in case of upgrading of the existing wastewater treatment plant, this process allows a continuous feed with solving head loss, clogging and backwashing problems [20].

MBBRs allow applying higher organic and hydraulics loads compared to the conventional activated sludge, in case the specific surface area (SSA) of biocarrier is sufficiently high [21]. Relatively high COD removal efficiency and low sludge production were reported at various high organic loading rates for MBBR by using the Kaldnes K1 biocarrier [20]. These process have been used in the treatment of dairy wastewater [22], chemical industry wastewater [23], municipal wastewater [24,25], textile wastewater [26,27], phenolic wastewater [28], greywater [29] and for nitrification [30,31] and denitrification [32,33].

Some researchers suggested that MBBRs could be operated in a sequencing batch mode, in order to benefit from the advantages of both processes. They reported that 95% biological phosphorus and 70% nitrogen removal can be achieved in an MBBR operated as

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Table 1. Sources and chemical compositions of dairy wastewater

Sources of wastewater	Flow rate %	COD (mg/*l*)	BOD_5 (mg/*l*)	TN (mg/*l*)	PO_4-P (mg/*l*)	pH	T (°C)
Cheese production I	13.5	66739	18000	436.5	350	4.40	30.9
Cheese production II	6.25	51955	17000	352. 5	291	5.98	28.8
Yogurt production	5.25	44774	15500	320.5	298	3.82	25.8
Rinsing of milk shipping vehicles tanks	25	1248	440	19.5	23.25	7.10	25.4
Cleaning and rinsing of tanks with NaOH	25	178	-	0.19	3.71	7.41	31.4
Cleaning and rinsing of tanks with H_2SO_4	25	17	-	-	2.74	7.31	32.8

Table 2. Chemical compositions of composite dairy wastewater

Constituent	Mean±SD
pH	4.9±0.3
COD (mg/*l*)	16264±1580
BOD_5 (mg/*l*)	10536±1420
TN (mg/*l*)	224±18.9
PO_4-P (mg/*l*)	342±15.5

Table 3. Some characteristic properties for K1

Parameter	Unit	Value
Nominal diameter	mm	9.1
Nominal length (mm)	mm	7.2
SSA at 30% fill	m^2/m^3	150

Fig. 1. Kaldnes biofilm carrier.

an SBR [34].

In this paper, we have focused on organic matter, ammonium and phosphorus removal from raw dairy wastewater under high organic loads. And also, some process characteristics of SBR and SBBR were monitored such as pH and oxygen profiles, MLSS and SVI during the study period for understanding the bioconversion mechanisms.

MATERIALS AND METHODS

1. Source of Dairy Wastewater

Wastewater was collected from a dairy factory having a capacity of 50 tons milk per day in Konya, Turkey. The wastewater came from cheese and yogurt productions and rinsing and cleaning activities in the factory. After sampling, the samples were refrigerated at 4 °C to prevent biological activity and transferred into a holding tank and slowly mixed for several hours before use. Wastewater samples were collected from the dairy factory every week and composite dairy wastewater was prepared according to flow rate. The chemical properties of dairy wastewater sources and composite samples of the sources are shown in Table 1 and Table 2 respectively.

2. Operation of SBR and SBBR

Experimental studies were carried out employing a laboratory-scale SBR and SBBR with a total volume of 2 L and a working volume 1.6 L for total five weeks after that SBBR reached steady state condition for biofilm biomass content on the carriers. Oxygen was supplied by using air pump via fine-bubble diffusers. The reactors were operated at room temperature. Both processes were operated in fixed 24 h cycles, each consisting of 22 h aeration with 30 min of fill up time, 1.5 h settle, 30 min decant, and idle. During the feeding of the reactors, the system needs to be fully aerated and mixing. 0.2 L/day fresh dairy wastewater was filled into the reactor to the final volume of 1.6 L to get eight days of HRT for both reactors. Reactor was fed volumetric organic loads of 1,130-1,560 g BOD_5/m^3 and 1,850-2,780 g COD/m^3 per day. Settled sludge was withdrawn from the bottom in the same way for both reactors to adjust SRT. The SRT was calculated according to previous study [35]. SRT were 5 days and 5.7 days for SBR and SBBR, respectively.

3. Biocarriers

Kaldnes K1 biocarrier, made of polyethylene (PEHD) with a specific gravity of 0.96 g/cm^3, was developed by Kaldnes Miljøteknologi used in this study. Some characteristic properties are summarized for K1 type biocarrier shaped like small cylinders with a cross inside in Table 3.

The Kaldnes biocarrier used in this study is shown in Fig. 1. The walls inside the cylinder provided suitable and more SSA for biofilm growth. The total SSA is significantly larger than the effective SSA for these processes. The effective SSA is one of the most important parameters that determines the efficiency of SBBR. The SBBR was filled with Kaldnes K1 biocarrier to 30% of the empty volume.

4. Analytical Methods

Samples were taken from the reactors and the effluent to monitor the performance of the lab-scale SBR and SBBR. While pH and DO were measured, and recorded in every 60 minutes, soluble COD, PO_4-P, mixed-liquor suspended solids (MLSS), mixed-liquor volatile suspended solids (MLVSS), and sludge volume index (SVI) were monitored each day. Fixed biomass was obtained detaching the biomass from 10 KMT elements into certain volume of distilled water and given as milligram per liter in SBBR [18,36,37]. Samples

Table 4. Process characteristics of SBR and SBBR

Process Parameters	SBR	SBBR
Organic loading as (g $BOD_5/m^3 \cdot d$)	1139-1560	1130-1560
Organic loading as (g $COD/m^3 \cdot d$)	1850-2780	1850-2780
COD effluent (mg/*l*) as soluble	1088±414	431±194
Average COD removal (%)	63.5	81.8
Average PO_4-P effluent (mg/*l*)	41	19
Average NH_3-N effluent (mg/*l*)	12.1	5.1
Average NH_3-N removal (%)	66.0	85.1
Average NO_3-N effluent (mg/*l*)	15.1	18.2
Average PO_4-P removal (%)	88	94
Suspended biomass (TSS) (mg/*l*)	3209±961	5945±528
Attached biomass (TS) (mg/*l*)	-	792±161
Total biomass (mg/*l*)	3209±961	6738±640
Average SVI (ml/g)	113	163

were vacuumed in a membrane filter with pore size of 0.45 μm to determine soluble COD. Closed reflux titrimetric method (SM 5220 C) was used for COD analysis. DO and pH measurements were carried out by using the WTW Multi-parameter 340i. PO_4-P, NH_3-N, NO_3-N and TN were measured by DR 5000 UV-VIS spectrophotometer using Dr. Lange cuvette tests.

RESULTS AND DISCUSSION

The experiments were carried out in both SBR and SBBR with raw composite dairy wastewater containing 16,264 mg/*l* COD, 10,536 mg/*l* BOD_5, 342 mg/*l* PO_4-P, and 224 mg/*l* TN under HRT of eight days and an SRT of five days. Process characteristics of both systems in treatment of dairy wastewater are described in Table 4.

1. Dissolved Oxygen and pH Variations

pH and DO are very important parameters of all biological pro-

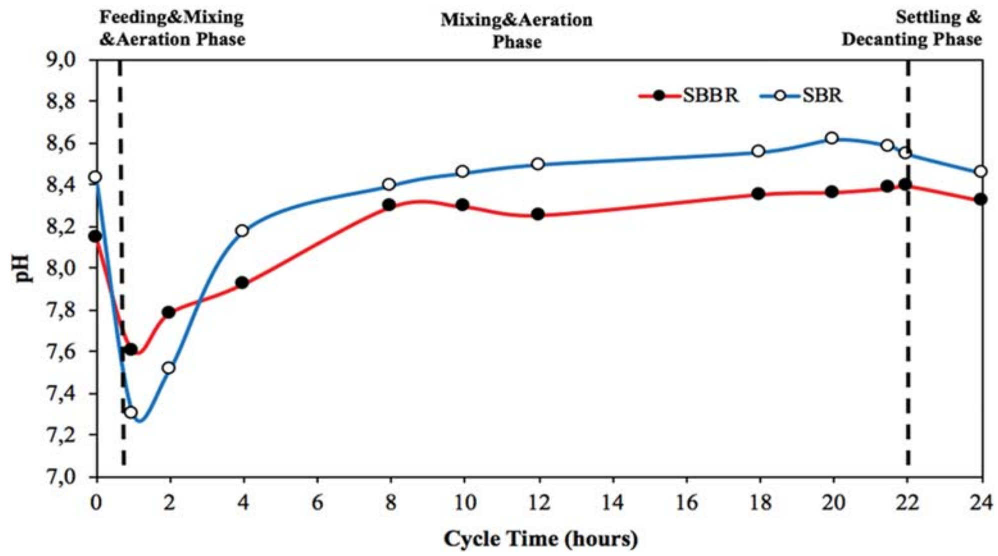

Fig. 2. Profile of pH for SBR and SBBR.

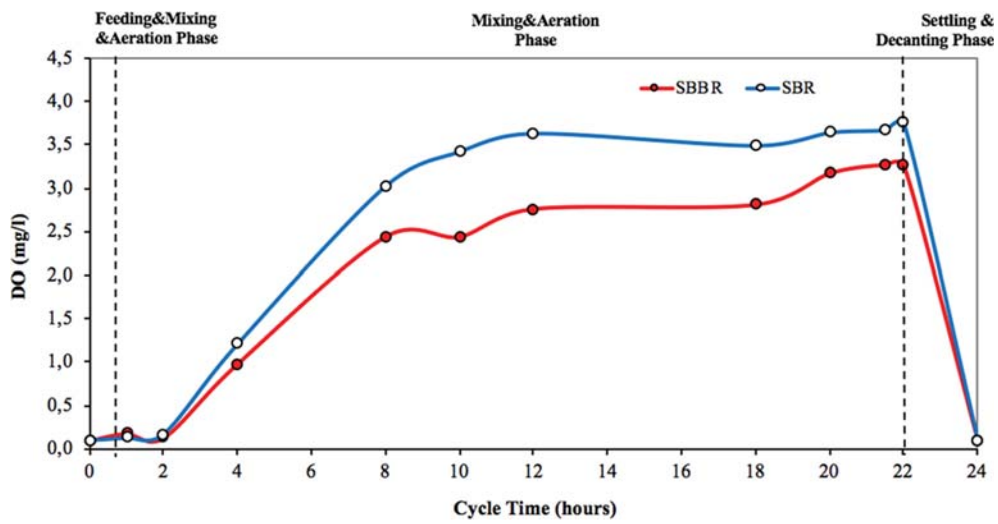

Fig. 3. Profile of oxygen for SBR and SBBR.

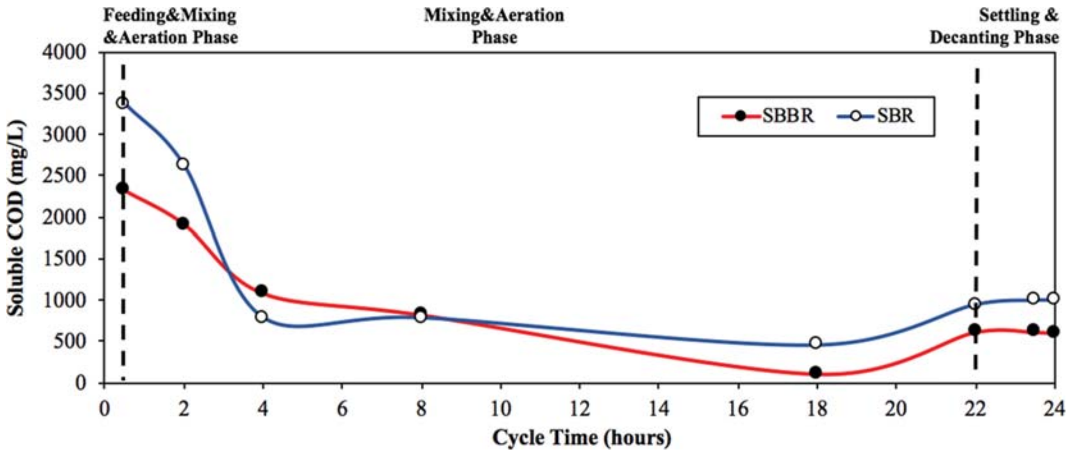

Fig. 4. COD profile in SBR and SBBR.

cess. pH and DO profiles in SBR and SBBR are seen in Fig. 2 and Fig. 3. During the feeding stage, pH was dropped from 8.43 to 7.30 due to relatively low pH of raw dairy wastewater and subsequent buildup of carbon dioxide in the reactor [38]. After this point pH started to increase to 8.54 during the aerobic phase; presumably, carbon dioxide was stripped out of the reactor by aeration [39]. Similar pathway was observed for SBBR. However, the rate of the pH changes over time in SBBR was lower than that of the SBR. Similar to our data, the same pathway of pH and DO changes was reported by researchers [40] for the treatment of dairy wastewater in SBR.

In biological processes oxygen consumption takes place within a certain pattern in accordance with biological principles, in relation to the quantity and type of oxidizing substance. Aeration for both reactors was constant with rate of 0.5 L/min up to 22 h. Amount of oxygen consumed was higher at aeration phase (up to 2 h), resulting in a drop in the DO. Because, in biological processes that operate with the fill-off principle, more oxygen is required in the initial period when the substrate concentration is high. Later on, dissolved oxygen between 2 and 8 h in SBBR and SBR sharply increased to 2.43 and 3.02, respectively. An average of 3.4 mg/L of DO in SBR from 8-22 h was reached at steady state, showing that system had enough dissolved oxygen and then started to decrease after 22 h since air pumping to the reactors was stopped for settling phase. For SBBR, dissolved oxygen for all phases was lower than that of the SBR due to bio growth on the biofilm carrier. Normally, the biofilm carriers will give increased oxygen transfer that more than compensates for the higher oxygen demand. At the same time, the biofilm thickness is an important issue due to the high thicknesses block oxygen and substrates transferred to the biofilm layers. It is controlled by aeration and mixing speed.

2. COD Removal

The COD removal profiles for SBR and SBBR are given in Fig 4. The highest organic matter decomposition rate occurred up to four hours. After this point, the substrate consumption rate and hence the specific growth rate decreased due to the presence of refractory organics.

The changes in the soluble COD removal efficiency in the SBR and SBBR operated for 20 days after acclimation are given in Fig. 5. The effluent soluble COD concentration was 1,088±414 and 431±194 mg/*l* in the SBR and SBBR, respectively. In other words, organic matter removal efficiency was 63.5% in the SBR and 81.8% in the SBBR as soluble COD. According to these results, the soluble COD removal efficiency of SBBR was about 18% higher than SBR under same volumetric organic loads. This phenomenon can be explained

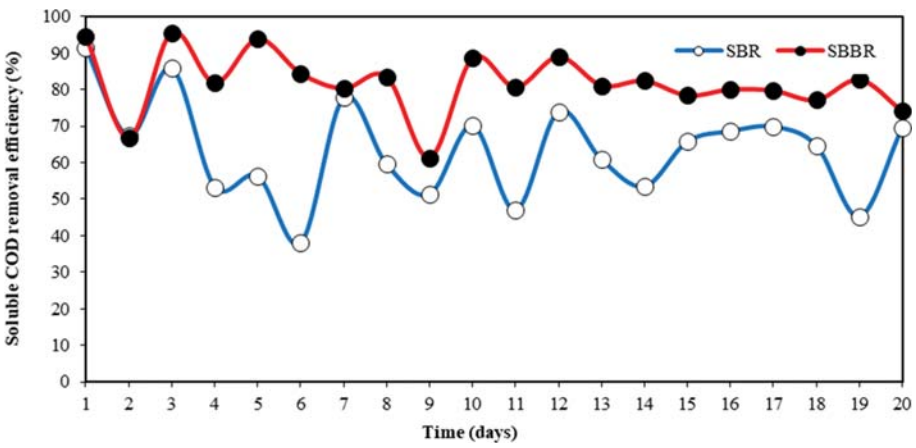

Fig. 5. Soluble COD removal efficiency in SBR and SBBR.

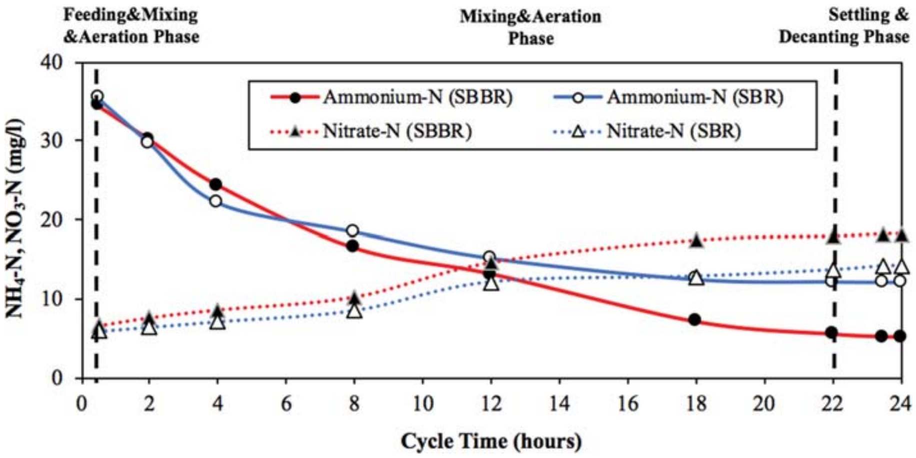

Fig. 6. Ammonium and nitrate profiles in SBR and SBBR.

by higher total biomass in the SBBR due to the increased amount of biomass (6,738±640 MLSS mg/L) based upon attached growth (792±161 MLSS mg/L) on the biofilm carrier and decreased F/M ratio. Researchers reported that similar with our findings the COD and BOD_5 removal efficiencies were about 5-7% higher in SBBR when compared to SBR in treatment of dairy wastewater [41].

3. Ammonium Removal

Consistent trends were observed for ammonium removal and nitrate formation in both SBR and SBBR processes as seen in Fig. 6. However, more nitrate formation was observed in SBBR, which was a result of attached growth on biofilm carriers as addition to suspended growth. This is supported by previous studies [42-44]. Oxygen is used by heterotrophic bacteria due to the high organic content at the beginning of the cycle; thus, nitrification process should not start [45,46]. Autotroph bacteria became predominant, oxygen was utilized to oxide ammonia to nitrite. These autotrophs are in the reactor all the time, but there is not enough oxygen at the beginning of the cycle to penetrate the activated sludge flocs and nitrify. There was a competition to use oxygen between the ammonia oxidizers and nitrite oxidizers and then nitrification was triggered after eight hours due to the decrease in C/N ratio [47]. The increase in specific growth rates of autotroph bacteria results in nitrate formation. The effluent NH_4-N concentration decreased down to 5.12 and 12.05 for SBBR and SBR, respectively. Besides, the effluent NO_3^--N concentration increased up to 14.1 mg/L for SBR and 18.2 mg/L for SBBR. In this study, for both processes, the conversion of ammonium was terminated by nitrate oxidation because no anoxic/anaerobic zone was formed.

4. Phosphorus Removal

Phosphorus removal biologically requires altering of anaerobic and aerobic conditions [34,48]. It can be achieved simultaneously in a biofilm process under aerobic conditions and then removal of excess biomass [49]. The biofilm thickness and density which significantly affect the oxygen penetration in biofilms and the deeper layers in the biofilm are anoxic [50].

As shown in Fig. 7, during the first four hours the phosphorus released in both reactors relatively low oxygen due to high organic load and after first four hours phosphorus concentration was decreased during mixing and aeration phase by increasing dissolved oxygen. Biological removal of phosphorus depends on the quantity of excess biomass withdrawn from the reactor and on the phosphorus content in the biomass. Phosphorus removal efficiency was 88% in the SBR and 94% in the SBBR. As a result, biofilm growth on the carrier had a significant influence on the phosphorous re-

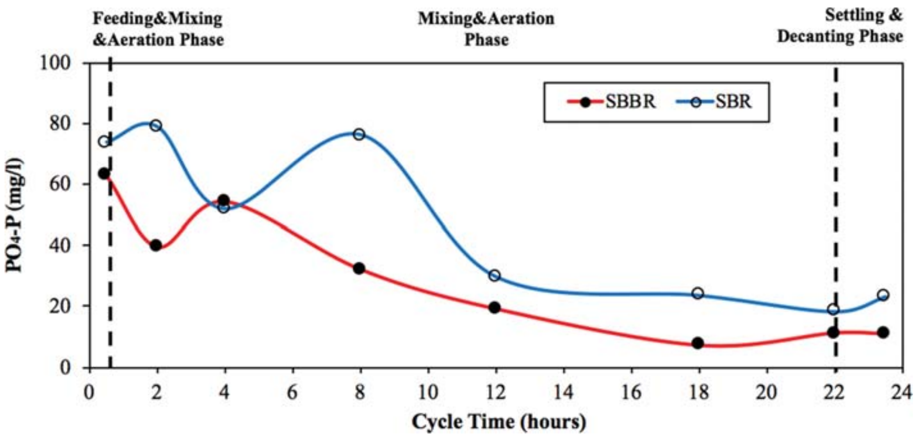

Fig. 7. Phosphate profiles in SBR and SBBR.

moval. In the SBBR, biological phosphorus removal was higher than SBR due to the occurrence of the mechanism of phosphate release and uptake throughout the biofilm thickness.

CONCLUSION

The applicability of SBR and SBBR filled with Kaldnes K1 plastic media to the treatment of dairy wastewater was evaluated in a lab-scale plant. SBBR displayed superior performance in terms of removal COD, ammonium and phosphorus efficiencies when compared to SBR; and also, the effluent quality of SBBR was more stable than SBR at the during same operating conditions. It can be concluded that the conventional activated sludge process such as SBR can be upgraded to handle high organic loads by adding packed media to the reactor. Higher COD, ammonium and phosphorus removal efficiency at SBBR can be explained by higher total biomass, attached growth on carrier in addition to suspended growth and anaerobic, anoxic and aerobic bacteria growth in the same time at SBBR.

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