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Investigation of Aerobic - Anaerobic Integrated Bioreactor System for Treatment of Slaughterhouse Wastewater

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Abstract

A pilot-scale aerobic–anaerobic Integrated process was constructed and implemented for reduction and removal of organic carbon and nitrogen from the slaughterhouse wastewater. The advantages of this bioreactor include rapid biodegradation, low yields of sludge, and excellent process stability. When the hydraulic retention time (HRT) was shortened to 48h, the average removal efficiencies for chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD5), and total Kjeldahl nitrogen (TKN) reached 89.2%, 93%, and 39.2%, respectively. The mixed liquor suspended solids (MLSS) in the effluent amounted to only 4.1±2.5 mg/L. The spatial changes in COD measurements indicated that an oscillating change in COD between aerobic and anaerobic compartments occurred. the DO concentrations in four aerobic compartments were 2.2 ±1, 4±1.0,6.2±1.2 and 8±1 mg L−1, respectively, and in the anaerobic compartments was all nearly zero. MLSS in the compartments of bioreactor was 4.2±2, 9.9±2.5, 2.1±1.1 and 7.8±1.5, 1.6±0.8, 5±1.5, 1.2±0.9, 4.1±1.5 g L−1 along the flow direction, respectively.

Keywords: anaerobic and aerobic treatment, integrated reactor, slaughterhouse

INTRODUCTION

Slaughterhouses produce large volumes of effluents. Discharging these effluents to obtain highly concentrated water containing biodegradable organic matter has a negative impact on the environment [1]. The amount of water consumed for each slaughtered animal differs according to the animal and the specific industrial process in operation [2]. The meat industry is the largest contributor to liquid waste. In general, slaughterhouse effluent increases nitrogen, phosphorus, and solid and biochemical oxygen demand levels of the receiving water body, which consequently leads to eutrophication (Jorgenson, 1970a, b; Western Africa Department of World Bank (WAD), 1994). Slaughterhouses produce considerable quantities of animal byproducts, which are parts of the animal not intended for consumption, either because they are inappropriate for human consumption, or because they are not marketable. This type of waste normally encompasses large quantities of organic matter, mainly consisting of proteins and lipids [3] and pathogens. Disposal of such, can lead to severe environmental hazards [4, 5, 6, 7].Wastewater originating from slaughterhouses are treated in anaerobic reactors because of the high level of COD, which is used to indirectly measure the amount of organic compounds in water. Although anaerobic treatment is effectual, complete stabilization of the organic matter is not possible by the effluent produced by anaerobic process contains solubilized organic matters, which are more suited for treatment using aerobic process or anaerobic – aerobic systems which usually contains ammonium ions (NH4+), and hydrogen sulphide (HS−) [8,9]. Although anaerobic treatment is efficient, complete stabilization of the organic matter is not possible by anaerobic treatment alone, as the effluent produced by anaerobic treatment contains solubilized organic matters, which are more suited for treatment using aerobic processes or anaerobic–aerobic systems [10]. For that reason, post-treatment using aerobic treatment is necessary to meet discharge standards [11]. Furthermore, a suitable blend of anaerobic and aerobic processes is indispensable for the biological elimination of N and P nutrients [12]. Some biological configurations such as Upflow Anaerobic Sludge Blanket (UASB) [13,14], UASB–coagulation–flocculation [15], anaerobic fixed film reactor [16], anaerobic batch reactor [17], anaerobic sludge blanket (UASB) [18,19], UASB–coagulation–flocculation [20], sequencing batch aerobic reactor (SBR) [21,22], membrane bioreactor [23], anaerobic–aerobic fixed-film reactor [24], and anaerobic–anoxic sequencing batch reactor-fixed bed nitrification reactor [25] have been studied recently.

The anaerobic–aerobic integrative baffled bioreactor, a novel type of bioreactor of its kind, was designed and manufactured by our research group. According to the above-mentioned energy uncoupling theory, it is assumed that a structure formed via decoupling anabolism and catabolism of microbes may lead to a drop in biomass. Yu et al. (2006) developed a repeatedly coupling of aerobic and anaerobic process (rCAA) fixed-bed reactor based on the perspective of decoupling aerobes/anaerobes treatment [26]. The benefits of this bioreactor consist of rapid biodegradation, low yields of sludge, and excellent process stability. In the present study, a pilot-scale process was implemented to investigate the feasibility to treat the effluent generated for treating slaughterhouse wastewater. The main objective of this work was to study a sequential integrated system comprising aerobic and anaerobic parts for reducing Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Kjeldahl nitrogen (TKN) in four Hydraulic Retention Time (HRT).

MATERIALS AND METHODS

Slaughterhouse wastewater

The wastewater used in this work was taken from the poultry slaughterhouse of Sefidroud (Rasht - Iran).Table 1 presents the usual characteristics of poultry slaughterhouse wastewater.

Table 1. Poultry slaughterhouse wastewater composition

	Interval	*Average*
Q (m3 day-1)	***60***	-
BOD5 (mg L-1)	820-1036	900
COD (mg L-1)	2333-2941	2597
TSS (mg L-1)	877-1241	1036
TKN (mg L-1)	81.7-174	122

The bioreactor experimental setup

The experimental setup used in this study is shown in Fig. 1. It was consisted of a pilot-scale bioreactor, feed injection system, and effluent collecting system. The bioreactor had a rectangular shaped was constructed from Plexiglas sheets with dimensions of 76 × 22 × 30 cm (L × W × H) and a working volume of 40 L. It was separated into 4 aerobic and 4 anaerobic sequential compartments by vertical baffles, which formed four series of alternating aerobic and anaerobic compartments. All 8 compartments have the same volume of 4.4 L .In each aerobic compartment, a Separator was used for aeration, and the baffle was set near the outlet of each compartment to prevent sludge washout. each compartments was divided into down-flow and up-flow zones and had a 45◦guidebaffle (2 cm) at the bottom of the spacing baffle to ensure the even distribution of wastewater across the rising part. This configuration resulted in better contact and mixing of wastewater with biomass. The aeration rate in each aerobic compartment 0.06 m3h−1.

Sludge Seeding

Enrichment the starting seed biomass was activated sludge in aerobic compartments taken from Sefidrud Slaughterhouse wastewater treatment plant (Rasht, Iran) with the initial sludge concentration was 3.5 g mixed liquid suspended solids(MLSS) L−1.and anaerobic sludge was selected from sludge digesters of treatment plant. Wastewater was continuously fed to the reactors using a dosing pump. no excess sludge was discharged in the bioreactor during the whole operation period. The reactor was operated continuously HRT of 12,18,24 and 48 h for thirty two weeks at slaughterhouse plant temperature. The treatment performance was monitored by analysis of COD, BOD, TKN, DO and pH values in the effluent one or two times a week.

Bioreactor Startup and Experimental Procedure

After successful adaptation and enrichment, the process of the bioreactor was changed from batch to continuous mode by constantly feeding raw wastewater according to the factors presented in Table 1 (at HRT of 48 h).The concentrations of COD in the effluent was monitored daily. The startup phase was considered complete when the changes in removal of COD increased to over 90%. To investigate the influence of HRT on the efficiency of COD reduction, the HRT was adjusted from 12 to 48 h during 32 weeks of steady-state operation. Results showed that the removal rate of COD initially increased sharply with the increase in HRT, and then increased more steadily.

Analysis and Methods

Samples taken from the influent and effluent of the bioreactor were analyzed for COD, BOD, pH, TKN, DO, and other parameters as required at the necessary time intervals. Effluent samples were filtered through a Whatman cellulose paper filter with a pore size of 0.45 µm, and then the filtrate was analyzed. COD concentrations in the influent and effluent (filtered samples) were determined using the closed reflux method as specified in the standard method (APHA, 1998). The pH values of the influent and effluent were measured using a Jenway-3505 electrode. Hach COD Reactor with a 16-tube rack for preparing COD tubes and measuring COD. OxiTop 1S6 BOD Meters with six positions to mount BOD measurement special bottles. Perkin Elmer Spectrophotometer model Digital Lambda EZ 150 for measuring COD. Metrohm pH-meter with digital electrode for measuring PH. Sartorius Scale with 0.0001 g accuracy capable of measuring maximum weight of 160 g for weighting consuming chemical material, china crucibles and paper filters. Sigma 101 Centrifuge for separating colloidal suspended particles and conducting tests. DR4000 Hach Spectrophotometer for measuring TKN. OX196 Crison DO meter for measuring dissolved oxygen. TKN kits used for DR4000 unit.German-made Merck mercury sulfate (HgSO4) for conducting COD tests. German-made Merck silver sulfate (AgSO4) for conducting COD tests. Iranian-made sulfuric acid (H2SO4) with 95 - 98 purity for conducting COD tests, and Tekna EVO TPG solenoid dosing pump.

RESULTS AND DISCUSSION

Performance of the Bioreactor Reactor

This bioreactor was found to be effective for reducing COD, BOD, and removing TKN in high-strength slaughterhouse wastewater. Wastewater treatment of the single-phase anaerobic reactor indicated some shortcomings. "The multi-phase reactor anaerobic system was utilized in wastewater treatment for dealing with high concentrations of organic wastewater, acid production, and production of methane from the two reactors" [27, 28]. In

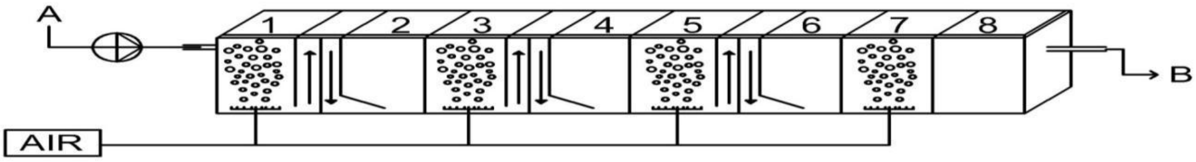

Fig. 1. The schematic diagram of the bioreactor system: sampling sites; A: inlet reservoir; 1, 3, 5, 7: aerobic compartments; 2, 4, 6, 8: anaerobic compartments; B: outlet reservoir.

this bioreactor, we have chosen four anaerobic ponds and four aerobic ponds. Based on the major constituents of slaughterhouse wastewater and various components of anaerobic biodegradation, the system was divided into a four-phase anaerobic biodegradation. According to [29], "these four ponds were designed for carbohydrates and most of the main protein was used to hydrolysis a mutual relationship between the oxygen-based protein and organic acids" [30]. The DO concentrations in four aerobic compartments were 2.2 ±1, 4±1.0, 6.2±1.2, and 8±1 mg L^{-1}, respectively, and, in the anaerobic compartments was all nearly zero according to Fig. 2. Consequently, the aerobic and anaerobic conditions were interchanged along the flow direction of the bioreactor. MLSS in the compartments of the bioreactor was 4.2±2, 9.9±2.5, 2.1±1.1 and 7.8±1.5, 1.6±0.8, 5±1.5, 1.2±0.9, 4.1±1.5 g L^{-1} along the flow direction, respectively (Fig. 3), and fluctuated much more in the first aerobic and anaerobic compartment throughout continuous operation, in which data (DO and MLSS) were similar to results of Feng et al. (2012) studied were used in the rCAA reactor [30]. And other research follows. The average Dissolved Oxygen (DO) concentration in the MBBR, anoxic zone, anaerobic zone, and aerobic zone was 3.4, 1.1, 0.5, and 6.6 mg/L on average, respectively.

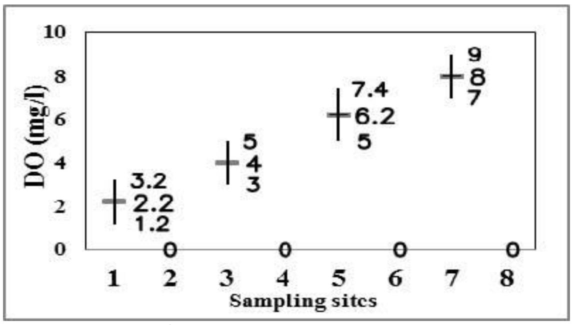

Fig. 2. Changing of dissolved oxygen in per compartments

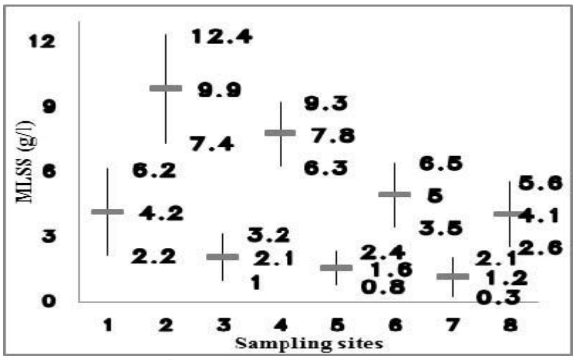

Fig. 3. Changing of MLSS in per compartments

Inflow and Effluent COD Concentrations and Removal Rate of COD

The COD concentrations in the inflow and effluent are presented in Fig. 4. It was observed that the COD of the effluents extended from 160.2 to 1427.3 mg/L, and that these values were relatively stable even with significant fluctuations of COD of the inflow (from 1614 to 2026 mg/L). For the meantime, more than 90.0% of effluent COD values were found to be below 200 mg/L. The variation in the removal rate of COD plotted against time is shown in Fig. 4. The results indicate that COD observed a 50–94% reduction. The effluent COD values clearly remained relatively stable and the maximum removal rate of COD reached 94% during a period of 32 weeks of steady-state operation. less than 200 mg/L, and the maximum removal efficiency of COD was more than 90% through a 48 h HRT.

The Effect of HRT on COD and COD Reduction Efficiency

Hydraulic Retention Time (HRT) is an important factor for any bioreactor used for treating wastewater. Fig. 4 shows the effect of HRT on COD and reduction percentage of COD. To examine the impact of HRT on the efficiency of COD reduction, the HRT was varied from 12 to 48 h after 32 weeks of operation. Results showed that the removal rate of COD initially increased sharply with the increase in HRT, and then increased more steadily. By increasing the HRT from gradually reduced from 2941 to 160 mg/L, and the total removal rate of COD increased from 60 to 94%.12 to 48 h, the COD of the effluent The COD concentration of effluent was Diez et al. were used to integrated anaerobic–aerobic fixed-film reactor for slaughterhouse wastewater treatment. The best removal efficiency Occurred in HRT=48h, which is equivalent to 94%. These results are similar to our results [24]. Similar results are as follows: in (HRT from 2.6 days to 1.6 days), the removal efficiency for COD fluctuated from 55% to 92% (average, 77%); at an HRT of 1.3 days and with internal recycling, the removal efficiency for COD remained at 72–95% from day 68 today 83 (average, 86%) [31].

Spatial Changes in COD Concentration along the Flow Direction

The spatial changes in COD concentrations specified that an oscillating change in COD had occurred between aerobic and anaerobic compartments (Fig. 5), which was comparable to results of the study carried out by Xin-Hui Xing where microporous spherical carriers were used in the bioreactor [32]. The COD was slightly higher than that in the influent in the first anaerobic compartment, and it then decreased sharply in the second aerobic compartment. The

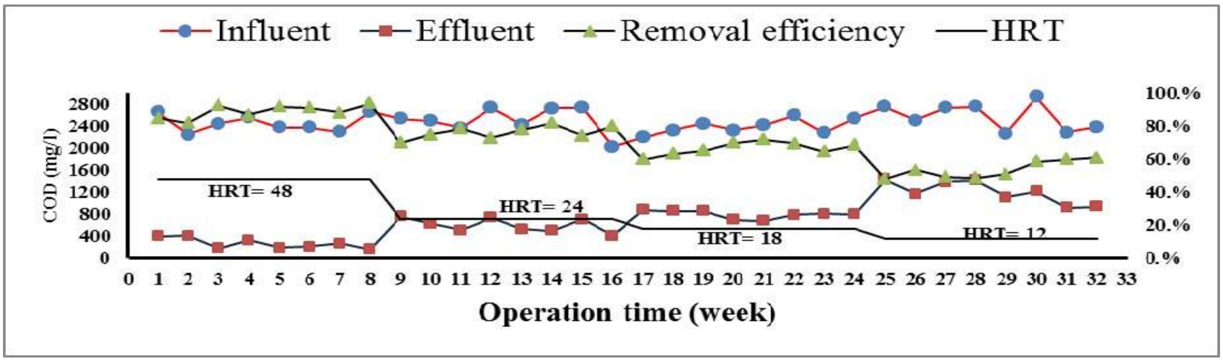

Fig.4. Relationship between COD and time. Inflow and effluent COD versus time and the removal rate of COD versus time. The relationship between COD with HRT

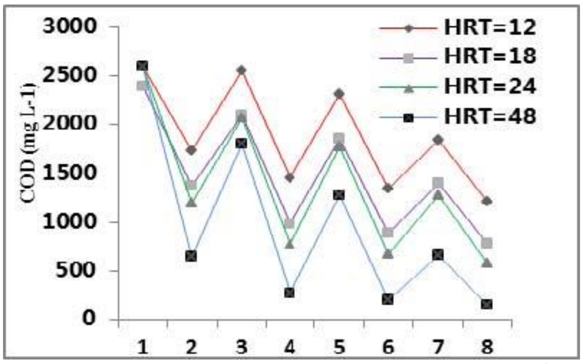

Fig. 5. Spatial changes in COD concentration along the flow direction in the bioreactor

COD value initially increased and then decreased in the subsequent anaerobic and aerobic compartments. In the meantime, a steady decrease in the maximum value for the COD in the supernatant was perceived along the flow direction in both the aerobic and anaerobic sections. The possible two reasons for this are "1) when the residual sludge flows from an aerobic region into the subsequent anaerobic compartment, digestion of the uptake sludge releases COD and phosphorus into the liquid phase, and 2) excess phosphorus release might also occur when aerobic sludge flows into the anaerobic environment" [33]. In the meantime, the reverse process would occur and new biomass would be generate in the following aerobic compartment. Fluctuations in COD showed that recurrent changes between soluble organic carbon and biomass through cryptic growth occurred due to irregular aerobic and anaerobic conditions along the flow direction [34]. And reason other research refers to increase in COD in the anoxic zone may have been caused by the lysis and degradation of the obligate aerobes under a low concentration of DO environment; the lysis and degradation of the organisms can induce there lease of a large amount of organics. The COD concentrations in the anaerobic and aerobic zones decreased again. The probable cause of the decrease in COD was the demand for organic carbon for the growth and metabolism of the heterotrophic bacteria in these zones [31].

BOD Removal

Fig. 6. portrays the BOD removal by the bioreactor process operated at different HRTs. The BOD concentrations in influent alternated from 719 mg/L to 1320 mg/L (average, 980 mg/L). Regardless of influent concentration or HRT the BOD concentration in effluent remained at 27.4–273.5 mg/L (average, 120.8 mg/L) as the operation progressed. At the beginning of the operation (HRT from 48 h), the removal efficiency for BOD fluctuate from 90% to 96.2% (average, 93%); at an HRT of 24 h, the removal efficiency for BOD remain at 84–93.2% from day 56 to 112 day (average, 89.45%). Removal efficiency for HRT 18 and 12 hours were 82 and 66.4, respectively. There was a lot of fluctuation in raw sewage, maximum value of the fluctuation occurred at the HRT 48 hours. However, with an average removal efficiency of 93%, is only slightly higher than the permissible discharge standards of Iran (50 mg/L).

Nitrogen Removal

Kumar et al. (2006) reported that combined anaerobic/aerobic digestion could remove up to 90% of the ammonia nitrogen by nitrification/denitrification. Kumar et al. (2006) operated laboratory digesters in the same manner as this study with sludge fed to the digestion units once per day [35]. They showed that denitrification took place over several hours instantly after feeding anaerobically digested sludge into the aerobic digester. The dissolved oxygen increased and nitrification occurred following exhaustion of the readily degradable organic material. The TKN levels in the influent ranged from 78.8 mg/L to 174 mg/L (average, 117.3 mg/L).

The TKN concentration in the effluent fluctuated from 26.6 mg/L to 141 mg/L (average, 72.8 mg/L) during the HRT period of 48–12 hours. The removal efficiency for TKN fluctuated from 15% to 70% (average, 39.2%). TKN can be removed mainly through biological nitrification–denitrification process and biomass assimilation. In addition, Diez et al. achieved a 70% performance in the removal of TKN in best conditions [24]. effluent to less than 160 mg/L and increased the maximum removal rate COD to 94%.The TKN concentration of the effluent was maintained at 39.2 mg/L. The sludge was solubilized upon flowing from an aerobic compartment into the next anaerobic compartment. The digested sludge solution was then metabolized and treatment of slaughterhouse wastewaters.

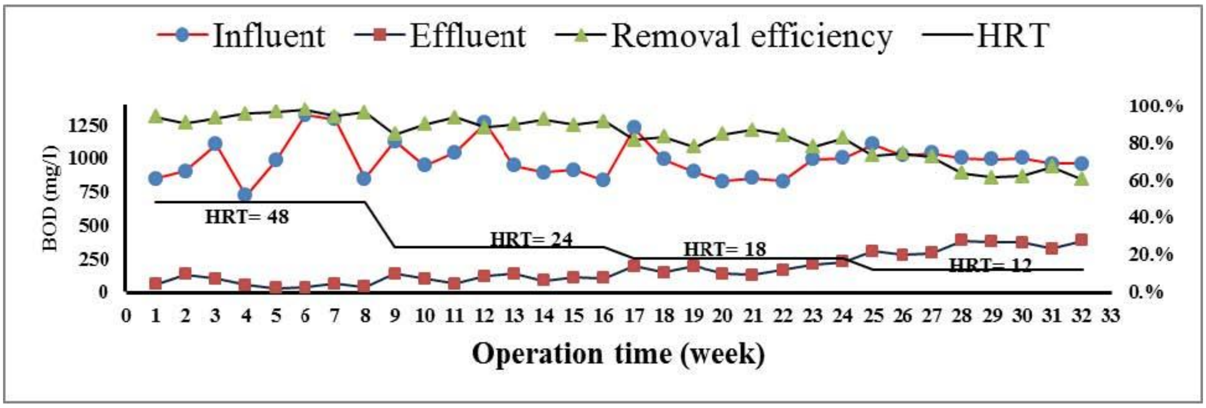

Fig.6. Relationship between BOD and time. Inflow and effluent BOD versus time and the removal rate of BOD versus time. The relationship between BOD with HRT

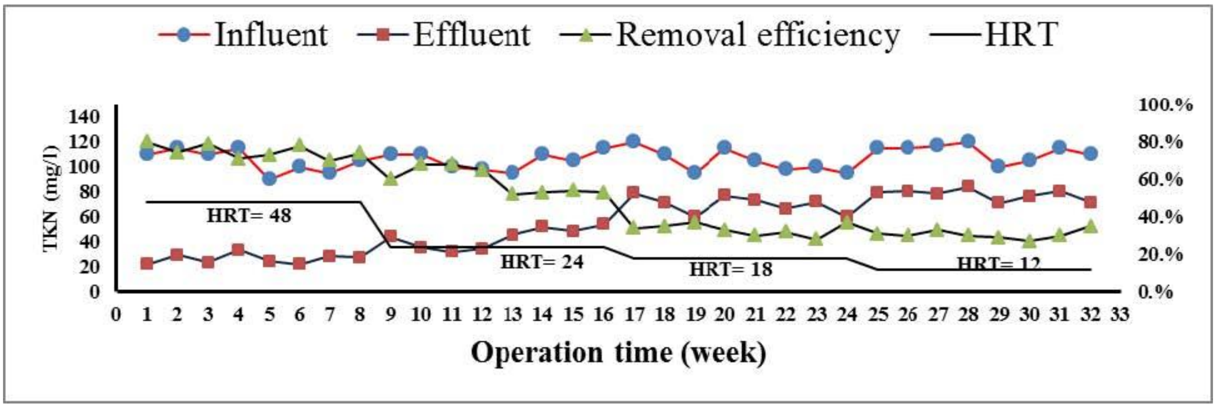

Fig. 7. Relationship between TKN and time. Inflow and effluent TKN versus time and the removal rate of TKN versus time. The relationship between TKN with HRT

CONCLUSION

Industrial wastewaters generally contain high organic content and cannot be treated similar to domestic wastewaters. In this sense, integrated anaerobic and aerobic treatment processes are more promising solutions. A new type of aerobic–anaerobic reactor configuration, the aerobic–anaerobic integrative baffled bioreactor was proposed for the The treatment of slaughterhouse wastewater using the aerobic–anaerobic integrative baffled bioreactor, with a dissolved oxygen in four aerobic compartments were 2.2 ±1, 4±1.0, 6.2±1.2, and 8±1 mg L−1, respectively, and in the anaerobic compartments was all nearly zero. reduced the COD concentration of the new cells through cryptic growth in the next aerobic compartment.

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