IJE TRANSACTIONS B: Applications Vol. 32, No. 5, (May 2019) 634-640

International Journal of Engineering

Journal Homepage: www.ije.ir

Poultry Slaughterhouse Wastewater Treatment Using Anaerobic Fluid Bed Reactor and Aerobic Mobile-Bed Biological Reactor

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P A P E R I N F O

Paper history:
Received 10 October 2018
Received in revised form 06 January 2019
Accepted 07 March 2019

Keywords:
Anaerobic Bioreactor
Biological Oxygen Demand
Chemical Oxygen Demand
Poultry Slaughterhouse
Wastewater Treatment

A B S T R A C T

This research evaluated the efficiency of combined anaerobic-aerobic processes for the treatment of slaughterhouse wastewater. The anaerobic reactor consists of a 3.95 L Plexiglas column with 60 mm diameter and 140 cm height. The cylindrical particles of polyvinyl chloride with 2 mm diameter and 1250 kg m^{-3} density packed to 60 cm of column were used as biomass saving material. The designed aerobic reactor also has a Plexiglas column with 10 cm internal diameter, 90 cm height and 60 cm useful height. Anaerobic fluid bed and aerobic mobile bed reactors were exploited for retention times of 18, 24, 32, 40 and 48 h. The efficiency of total suspended solids, biological oxygen demand and chemical oxygen demand removing were evaluated in different stages. Under the applied condition, chemical oxygen demand, biological oxygen demand and suspended solids were removed by 85.94, 92 and 66%, respectively. Maximum methane production of 3765 mL per day was obtained after 31 h at the residence time of 18 h. The anaerobic reactor plays very important role in reduction of the chemical oxygen demand, and the aerobic reactor is necessary to clear the anaerobic treated wastewater and ensure the quality of the final waste.

***doi**: 10.5829/ije.2019.32.05b.02*

1. INTRODUCTION

Slaughterhouses and meat processing industries use extensive amount of water and produce considerable wastewater with high levels of biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS) [1]. Discharge of slaughterhouse waste caused reduction of river oxygen, polluting groundwater and resulting in harmful effects of contamination [2]. Slaughterhouse wastewater is refined in anaerobic reactors due to its high oxygen demand. Anaerobic treatment methods have problems such as low sedimentation rates and require additional treatment of anaerobic waste, and usually contain ammonium ions and hydrogen sulfide. For the biological removal of nitrogen and phosphorus, an appropriate combination of anaerobic and aerobic processes is necessary [3, 4].

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Anaerobic-aerobic treatment has been attended due to its numerous advantages, such as low energy and chemical consumption, low sludge production and the less machines requirement. The use of high-speed new bioreactors leads to an increase in the organic matter removal during a shorter time period [5].

The treatment of slaughterhouse wastewater at ambient temperature resulted 96% COD removal as well as 96% and 99% reduction in total organic nitrogen and phosphorus, respectively [6].

COD removal efficiency of 91% was reported for a dilute wastewater containing of 600 mg L^{-1} initial chemical oxygen demand using a carrier anaerobic baffled reactor [7]. Debik and Coskun [8] reached to an average COD removal efficiencies more than 95% for the static granular bed reactor in two separate anaerobic processes containing granular and non-granular biomass [8]. Oxidation processes in combination to bioremediation technologies are also used as successful techniques [9]. Therefore, many processes used combined aerobic/anaerobic treatments

Please cite this article as: F. Ardestani, M. Abbasi, Poultry Slaughterhouse Wastewater Treatment Using Anaerobic Fluid Bed Reactor (AFBR) and Aerobic Mobile-Bed Biological Reactor (MBBR), International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 32, No. 5, (May 2019) 634-640

to reach higher refining yields [10]. Recently, some modern methods have been developed to remove drug residues from wastewater [11], vegetable oil wastewater refining by using submerged membrane bioreactors [12].

In this article, the efficiency of the combined aerobic-anaerobic process was investigated in the removal of chemical oxygen demand (COD), suspended solids (SS) and biological oxygen demand (BOD) from poultry slaughterhouse wastewater using anaerobic fluid bed reactor (AFBR) and aerobic mobile-bed biological reactor (MBBR).

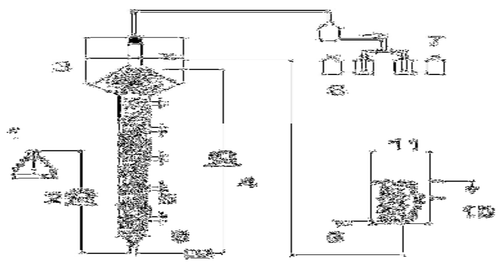

Figure 1. Experimental set up used in this study. 1) Nutrition tank, 2) Injection pump, 3) Opening part, 4) Circulating pump, 5) Sampling valve, 6) Flow meter, 7 and 8) Methane measurement vessels, 9) Aquarium pump, 10) Outlet waste, 11) Aerobic mobile bed biological reactor

2. MATERIALS AND METHODS

This research was conducted over period of 11 months on the refinement of poultry slaughterhouse wastewater, using an anaerobic bed reactor followed by a pilot scale aerobic mobile bed. At first, the reactors were fed using synthetic wastewater and then increased the organic load. After adapt the reactor with organic load similar to the poultry slaughterhouse wastewater, the reactor was finally fed with real sewage and the required data was collected.

2. 1. Materials All chemicals prepared from Merck Millipore Co. (Darmstadt, Germany) and Sigma Aldrich Co. (St. Louis, USA).

2. 2. Pilot Installation Specifications This study was conducted on a pilot scale, and the reactors were made up of transparent Plexiglas anaerobic fluid bed reactor and aerobic mobile bed biological reactor as showed in Figure 1. The anaerobic fluid bed had a height of 140 cm and an internal diameter of 6 cm. The upper part contained a 10 cm inner diameter hole acted as a solid gas separator and helped to sediment the floating beds and 20 cm free space. Measurement was conducted by using two dishes, which are connected by two tubes with the ducts, and the gas enters the container first, a part of the existing liquid in the container is transferred to the second container, which is equal to the amount of produced methane. The media used in the anaerobic fluid bed reactor was embedded in a silicone aquarium hose that was finely chopped and its outer surface was embedded to create a rugged surface to allow microorganisms to stick with it more easily. The reactor was also fitted with 5 sampling valves and fed using a peristaltic dosing pump (Longer Precision Pump Co. Ltd., Basic Series, 1-1000 rpm, 0.0002 to 380 mL min^{-1}, China). The bed was flushed by re-circulating the sewage using a bulb pump (Longer Precision Pump Co. Ltd., China). The anaerobic fluid bed reactor output was introduced into the aerated mobile bed biological reactor.

The aerobic mobile bed reactor had a total height of 90 cm, an empty space of 30 cm and internal diameter of 10 cm.

The guidance system was designed to collect and measure the volume of produced gas in anaerobic reactor. So that the outlet gas of the reactor was connected to a collecting container contained 3% sodium hydroxide [13].

2. 3. Microbial Inoculation and System Startup 1 liter of active sludge from the Fakhab wastewater treatment plant of Rasht was used with a suspended solid of 24.8 and organic suspended solid of 9.9 g L^{-1}. The first, system was fed from synthetic sewage in a closed flow for a period of one week, and then continuous flow was established. Finally, the reactor was fed with actual wastewater.

Initially, the system was launched from methanol and glucose as a substrate, so that in the first days, 75% of the total COD was related to methanol and the remaining 25% was for glucose. Subsequently, over period of time, methanol and glucose had equal COD, and then 75% of the total COD was related to glucose and the remaining 25% was for methanol. Over period of time, the actual wastewater was added with a lower percentage, and COD was increased, and the reactor was fed with real wastewater. Methanol stimulates the growth of *methanosarcina,* one of the most important bacterial species in the wastewater treatment process. Also, the concentration of ammonium chloride was increased as nutrients for nitrogen/carbon leaching during reactor boosting and new cells producing. So that in the first days 50, then 75% of the required final loading was added [14]. The feeding stages of the reactor are shown in the Table 1.

2. 4. Determination of the Minimum Fluidity in Anaerobic Fluid Bed Reactor A manometer (WIKA, Germany) was used to ensure fluidity of the media in the anaerobic fluid reactor, which was recorded the pressure drop by changing the velocity of recirculation of the sewage by a circulator pump

TABLE 1. The feeding procedure of the reactor

Time (Days)	Loading (Kg COD/ m^3)	Methanol share of total COD (%)	Glucose share of total COD (%)	Slaughterhouse waste share of total COD (%)	NH_4CL (% of required final loading)
0-10	0.05-0.4	75	25	0	50
11-20	0.4-0.7	50	50	0	75
21-30	0.7-1.1	25	75	0	100
31-40	1.1-1.3	0	75	25	100
41-50	1.3-1.5	0	50	50	100
51-60	1.3-1.5	0	25	75	100

(Longer Precision Pump Co. Ltd., China). As the velocity increased, the reactor pressure drop remained almost constant. The velocity of fluid flow upwards at this point was considered as the minimum fluidity speed.

2. 5. Experiments All pilot-scale experiments were carried out continuously at 35°C. The study was carried out in two parts, the first part was fed using synthetic sewage and in the next part the reactor was fed with real wastewater with different organic loading. Each stage went on to reach the almost stable conditions. Stable conditions were considered, if the qualitative characteristics of the three consecutive samples were less than 5%. The synthetic sewage purification was carried out for 24 hours with flow rate of 195 mL min^{-1}. The reactor loading was performed by increasing the concentration of treated wastewater. So that the first loading of 0.05 g L^{-1} of COD was increased and in the final stage, reached to 1.5 g L^{-1} of COD. Then the reactor was fed into 5 different loading stages. COD in the sewage system remained constant and the change in loading was accomplished by reducing the hydraulic residence time and was considered for almost two months at any time. So that in the first stage, which lasted 48 hours, the flow rate to the reactor was 97 mL h^{-1}; in the second stage, the time was 40 hours and in the third stage, it was 32 hours and the flow rate to the reactor was 146 mL h^{-1}. In the fourth and fifth stages, the time was 24 and 18 hours and the flow rate to the reactor was 195 and 260 mL h^{-1}, respectively.

2. 6. Measurements To measure the concentration of suspended solids, first the sample was passed through the filter paper (Whatman, UK), and then dried at 105°C and weighed. COD and BOD were determined by Open Reflux and Respirometric methods, respectively [15]. Also, to measure the produced methane in anaerobic reactor, a fluid displacement method was used. In this method, a 3% sodium hydroxide solution was used to dissolve carbon dioxide but didn't affect methane.

3. RESULTS AND DISCUSSION

3. 1. The Minimum Fluidity in the Anaerobic Reactor Knowing the minimum fluidity help us to estimate the required amount of fluid for bedding. The greater distribution of particles in the reactor increases the efficiency of the system as a result of more extensive expansion of the biofilm. It can also withstand fluctuations in flow rates, COD, temperature and pH, as well as some of the operational problems, such as bed enclosures and high pressure drop in large reactors. It can have the highest efficiency in constant growth reactors because of it provides excellent conditions for mass transfer [16].

In this study, speeds of 0.1 to 0.8 m s^{-1} were used, at a speed of 0.5 m s^{-1}, the pressure drop reached 1.1kPa and remained constant at steady speeds (see Figure 2). Therefore, the speed of 0.5 m s^{-1} was obtained as the minimum fluidity rate. In this study, to ensure the fluidity of the bed during airlift condition, the accelerated velocity of 0.55 m s^{-1} was used.

3. 2. COD, BOD and TSS Removal at 48 h Hydraulic Resident Time The first step was started with 48 h hydraulic resident time (HRT) and loading of 2400 mg of COD, 1100 mg of BOD and 495 mg TSS per liter. Figures 3, 4 and 5 show COD, BOD and TSS removal efficiency at 48 h hydraulic resident time.

Figure 3 shows the initial COD of 2500 mg L^{-1}, after 9 days, the effluent of the combined reactors, reached to 600 mg L^{-1}, and the overall system efficiency in COD removal was 75%. Over time, the system reached to steady state on the 50th day with COD of 115 mg L^{-1} and the total COD removal was 95%.

The results showed that at 48 h residence time, the average COD removal in the system from day 1 to day 9 was 0.19 g per day. It was 0.2 g for the 9th to 18th days and 0.28 g for days 18 to 25. Similarly, following

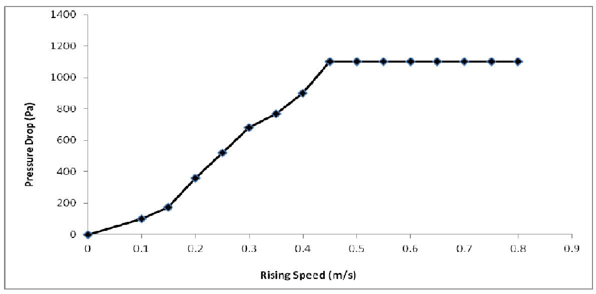

Figure 2. Pressure drop changing procedures with rising speed in anaerobic fluid bed reactor

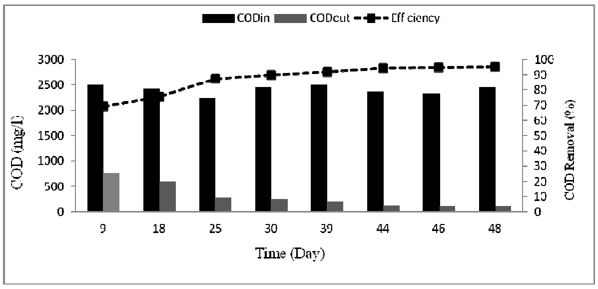

Figure 3. COD removal efficiency of the system at 48 h resident time

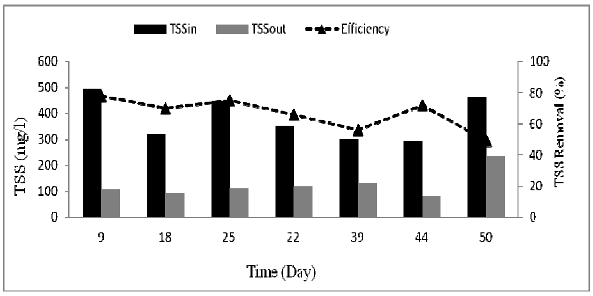

Figure 5. TSS removal efficiency of the system at 48 h resident time

the process, the average amount of COD removal per day has been increased. The average COD removal reached about 1.1 g per day in 46th to 44th day interval and finally 1.18 g per day during the 46th to 48th day period. Jafari et al. [17] reported COD removal efficiencies of 98 and 81.6% for organic loading rates of 9.4 and 24.2 g COD/l. d, and hydraulic retention times of 48 and 18 h, in average COD concentration feeding of 18.4 g L^{-1}, respectively; that is in accordance to our findings.

The average initial BOD was 1175 mg L^{-1}, at the end of the 50-day period, BOD was reduced to 40 mg L^{-1}, and the BOD removal efficiency was 97%. According to the study on aerobic-aerobic and UV/H_2O_2 systems, Cao [18] managed to remove 36.66% of total organic carbon from poultry slaughter wastewater. Del Pozo et al. [19] studied a permanent reactor for aerobic- anaerobic films for the slaughterhouse wastewater treatment plant. The best removal efficiency occurred during 48 hours, which is equivalent to 94%.

Figure 5 shows after 9 days, the average initial TSS of 495 mg L^{-1}, reduced to 106 mg L^{-1} with a maximum TSS removal efficiency of 78%. Finally at the end of the 44-day period an acceptable TSS removal efficiency of 72% has been recorded again in the designed system at 48 h resident time. Mesophilic static granular bed reactor (SGBR) involved fully anaerobic granules coupled with an ultrafiltration membrane system for poultry slaughterhouse wastewater treatment showed the COD and TSS removal of 98 and 99.8%, respectively. A combined system with higher TSS removal efficiency may required more investment and operational costs [20].

3. 3. Methane Production in Different Hydraulic Resident Times

Figure 6 depicts methane production, after 9 days with initial COD of 2500 mg L^{-1} was 900 mL per day, at 48 h hydraulic resident time. Over period of time, the production of methane increased, and by the day 30, with initial COD of 2451 mg L^{-1}, the produced methane was 1400 mL per day. Subsequently, until 48th day, methane production slightly varied in the range of 1200 to 1400 mL per day. Subsequently, methane production was monitored at 24 h hydraulic residence time. In this process, after 5 days with input COD of 2400 mg L^{-1}, the amount of produced methane was 700 mL per day. Then gradually the methane production was reduced and then a rising trend has been recorded. The highest amount of gas produced at this stage was recorded on day 34, with an input COD of 2300 mg L^{-1} and 750 mL per day of produced methane.

By reducing the hydraulic residence time to 18 h, at the beginning of the loading, the amount of gas produced was significantly low amount due to organic load shock. On days 17 and 24, the production of methane reached from 3400 to 3700 mL per day. On 55th day, with a COD intake of 2420 mg L^{-1}, 3600 mL per day was recorded for methane production (Figure

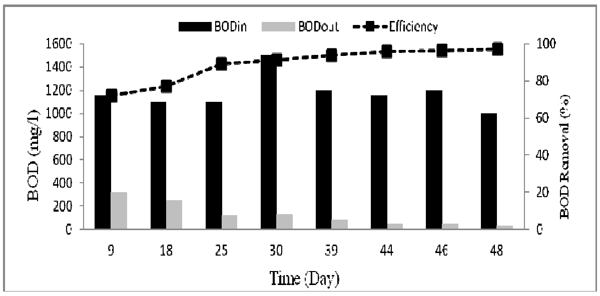

Figure 4. BOD removal efficiency of the system at 48 h resident time

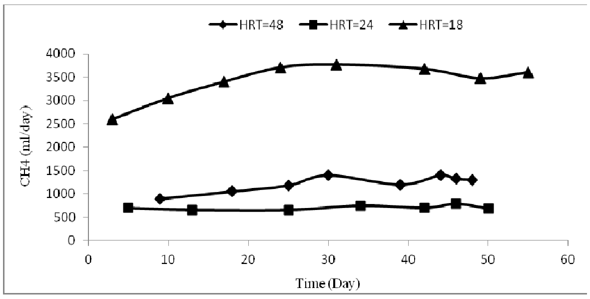

Figure 6. Methane production of the system at different hydraulic resident times (HRT) of 48, 24 and 18 h

6). As the results showed, with a reduction in hydraulic residence time from 48 to 18 h, production of methane after 30 days increased from 1400 to 3600 mL per day, and actually had a 2.5-fold increase. The results analysis showed that at hydraulic residence time of 48 h, the average methane production efficiency for each gram of removed COD per day was 3.45 liter per day.

Based on the obtained results, at 18 h residence time, the average COD removal in the system from day 1 to day 3 was 0.3 g per day. This factor was evaluated as 0.14 g for 3rd to 10th days and 0.15 g for days 10 to 17. Following the process, the average amount of COD removal per day was mentioned in the range 0f 0.17 to 0.2 g per day. The average COD removal reached about 0.2 g per day at 42th to 49th day interval and finally 0.24 g per day during the 49th to 55th day period. Then, the average methane production efficiency for each gram of removed COD per day was determined as 19.29 liters per day with a 5.6-fold increase in compare to 48 h residence time.

Figure 7 shows COD of influent, effluent and COD removal efficiency of the system at different hydraulic residence times (HRT) of 48, 40, 32, 24 and 18 h. The average COD removal efficiency was recorded respectively as 77, 86, 83, 70.85 and 49% at 48, 40, 32, 24 and 18 h hydraulic residence times (Figure 7). As the results showed, COD removal efficiency was decreased when the residence time was reduced. A process designed on 40 h residence time was defined as the optimum condition to obtain the maximum COD removal efficiency of 86%.

The BOD of influent and effluent and also BOD removal efficiency of the designed poultry slaughterhouse wastewater system at different hydraulic residence times (HRT) of 48, 40, 32, 24 and 18 h is presented in Figure 8. The average BOD removal efficiency was recorded respectively as 91.6, 87.6, 85.8, 79.65 and 63.9% for 48, 40, 32, 24 and 18 h hydraulic residence times (Figure 8). Similarly, COD removal trend, BOD removal efficiency was decreased when the residence time was reduced. The maximum BOD removal efficiency of 92% was obtained at 48 h residence time.

Figure 9 presents influent and effluent TSS as well as TSS removal efficiency of the combined bioreactors system at different hydraulic residence times (HRT) of 48, 40, 32, 24 and 18 h. The average amount of TSS removal efficiency was obtained respectively as 66.5, 50, 48.6, 50.8 and 45% at 48, 40, 32, 24 and 18 h hydraulic residence times (Figure 9). Similarly, COD and BOD removal trend, TSS removal efficiency was decreased when the residence time was reduced. The maximum TSS removal efficiency of 66% was obtained at 48 h residence time.

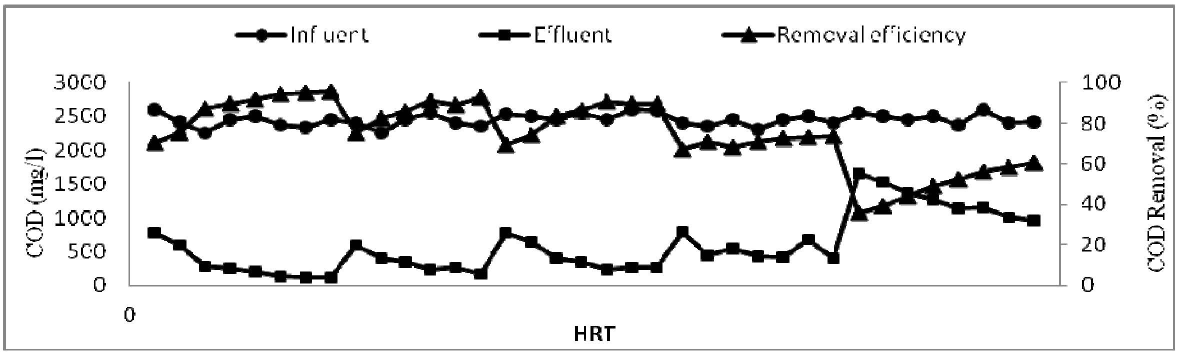

Figure 7. COD removal efficiency of the system at different hydraulic resident times (HRT) of 48, 40, 32, 24 and 18 h, respectively

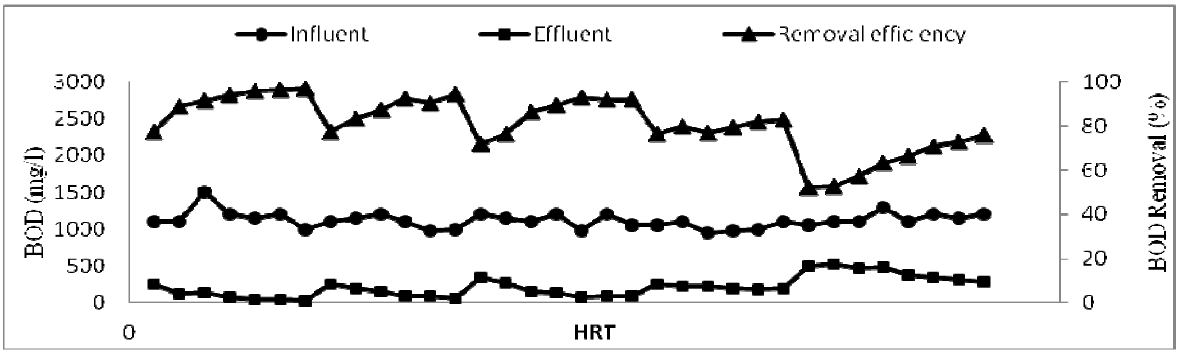

Figure 8. BOD removal efficiency of the system at different hydraulic resident times (HRT) of 48, 40, 32, 24 and 18 h, respectively

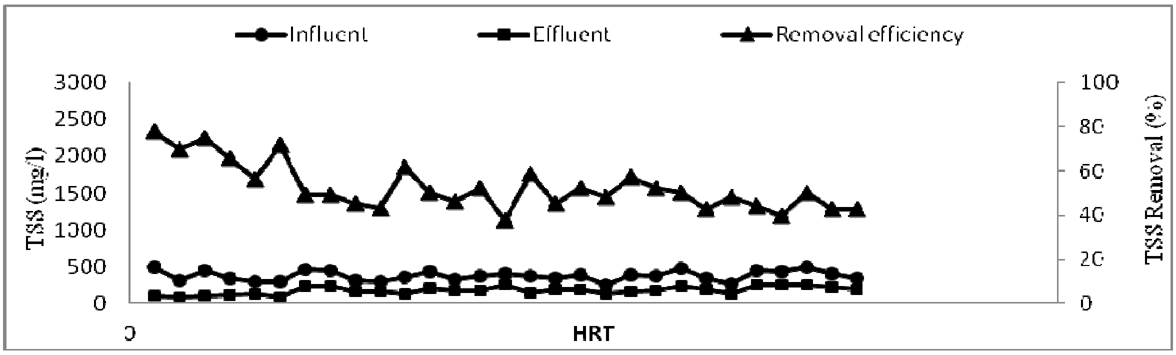

Figure 9. TSS removal efficiency of the system at different hydraulic resident times (HRT) of 48, 40, 32, 24 and 18 h, respectively

4. CONCLUSION

Anaerobic treatment of high organic content wastewaters has the advantages of significant degradation efficiency with low levels of nutrients and usually produces less sludge. This process also produces biogas as a valuable byproduct. The efficiency of the combined aerobic and anaerobic bioreactors for poultry slaughterhouse wastewater treatment was investigated in this work. The efficiency of COD, BOD and TSS removing under anaerobic- aerobic condition were evaluated at different stages. The designed system had an acceptable ability to reduce the organic load of poultry slaughterhouse wastewater. A good methane production capacity was recorded for the applied system. The anaerobic bioreactor had a key role in COD removal while the aerobic section of the setup, clears the anaerobic section effluent and ensure the quality of the final wastewater.

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PAPER INFO

Paper history:
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Wastewater Treatment

چکیده

این تحقیق به منظور تعیین کارایی ترکیب فرآیندهای بی‌هوازی- هوازی برای تصفیه فاضلاب کشتارگاه انجام شد. راکتور بی‌هوازی از یک ستون پلکسی گلاس ۳/۹۵ لیتری با قطر ٦۰ میلی‌متر و ارتفاع ۱٤۰ سانتی‌متر تشکیل شده است. ذرات استوانه‌ای شکل از جنس پی‌وی‌سی با قطر ۲ میلی‌لیتر با دانسیته ۱۲۵۰ کیلوگرم بر متر مکعب معادل ٦۰ سانتی‌متر از ارتفاع ستون به عنوان نگهدارنده بیومس استفاده شد. راکتور هوازی دارای یک ستون پلکسی گلاس با قطر داخلی ۱۰ سانتی‌متر و ارتفاع ۹۰ سانتی‌متر با ٦۰ سانتی‌متر ارتفاع مفید بود. راکتورهای بستر سیال بی‌هوازی و بستر متحرک هوازی تحت پنج زمان ماند هیدرولیکی به ترتیب ۱۸، ٢٤، ۳۲، ٤۰ و ٤۸ ساعت بهره‌برداری شد و راندمان حذف مواد جامد معلق، اکسیژن خواهی بیولوژیکی و اکسیژن‌خواهی شیمیایی در مراحل مختلف مورد ارزیابی قرار گرفت. تحت شرایط به کار گرفته شده، کاهش اکسیژن‌خواهی شیمیایی، اکسیژن‌خواهی بیولوژیکی و مواد جامد معلق به ترتیب برابر ۸۵/۹٤٪، ۹۲٪ و ٦٦٪ بود. بیشترین میزان تولید متان معادل با ۳۷٦٥ میلی‌لیتر در روز پس از ۳۱ ساعت با زمان اقامت ۱۸ ساعت به دست آمد. راکتور بی‌هوازی نقش بسیار مهمی در کاهش اکسیژن‌خواهی شیمیایی بازی می‌کند و راکتور هوازی برای زلال‌سازی فاضلاب تصفیه شده بی‌هوازی و اطمینان از بهبود کیفیت پساب نهایی مورد نیاز می‌باشد.

doi: *10.5829/ije.2019.32.05b.02*