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Investigation on the Treatment of Slaughterhouse Wastewater in a Sequential Batch Reactor

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ABSTRACT

In the present study, the treatment of slaughterhouse wastewater was carried out in a sequential batch reactor. A lab-scale column type reactor was fabricated with Perspex material having dimensions of 10 cm diameter, 100 cm height, and an effective volume of 7 liters provided with ports at different levels. The reactor performance was evaluated in terms of COD, BOD, TSS, TKN, and phosphorus removal. The reactor was operated for 432 days; the effectiveness of the reactor is the temperature of wastewater in the reactor. The removal efficiencies of COD and BOD were84% and 80% in the reactor. The maximum TSS removal was around 87% and TKN's maximum removal efficiency was 61% in aerobic treatment. Phosphorus maximum removal efficiency was around 68%, in the meantime pH and alkalinity were also monitored, and no change in the pH was reported throughout the experiment. On the other hand, an aerobic SBR is also operated using wastewater after the DAF unit. In the same manner, the reactor was operated with initially diluted wastewater (05 times) and kept HRT 8 h. The reactor performance was studied in terms of COD, BOD, TSS, TKN, and phosphorus. The maximum removal efficiencies of COD and BOD were 80% and 81% respectively. The maximum removal efficiencies of TSS, TKN, and Phosphorus were 73%, 81%, and 69% respectively. It is concluded that the removal efficiency of COD was better in the anaerobic process as compared with the aerobic process in addition the generation of methane gas during the degradation of organic matter can be used for operating the aerobic unit by making some necessary arrangements. Besides this, it is also concluded that the removal efficiency of TKN was better in the aerobic process as compared with the anaerobic process. There was a buildup of VSS from 4500 mg.L^{-1} to 6500 mg.L^{-1} in the study.

INTRODUCTION

Water shortage and contamination of available water reserves have engrossed global attention in recent years (Khan et al. 2015). The effluent coming from various industries such as slaughterhouses, food processing industries, chemical processing plants, and paper & pulp industries remain highly contaminated. The slaughterhouse wastewater is classified under the category of agricultural and food industries as industrial wastewater. On an average 15 liters of wastewater are generated in each mechanized slaughtering, amounting to about 630 million gallons of water annually in India itself (Central Pollution Control Board, Delhi, Ministry of Environment, Forest and Climate Change, Government of India, October 2017). Studies show that effluent generated from slaughterhouses contaminates both surface and groundwater bodies because of the slaughtering process, blood, fat, urine, and undigested food are produced and added to the nearby water streams (Alam et al. 2021). Slaughterhouse industries having high suspended solids, organic matter should not be discharged on the land or in sewers directly because of their high concentration of COD, and BOD (Aziz et al. 2019, Mittal et al. 2006). Besides this, the addition of chemicals for the treatment of wastewater is not a good option because it increases the cost of the treatment, and disposal of sludge is uneconomical.

For the conventional treatment of slaughterhouse wastewater, methods based on anaerobic treatment processes are more advantageous over the other treatment system (Sindhu et al. 2012, Sunder et al. 2013) like the advanced oxidation process, electro-coagulation, and physicochemical process (Masse & Masse 2005, Del Nery et al. 2007, Khan et al. 2020). Advantages of the anaerobic process are high organic removal, less space required, less sludge generation, low energy requirement, working on high organic loading, less nutrients requirement, and methane gas production which can be used to operate the generators to be used for energy requirement in aerobic unit operations.

Few reactor configurations are used for the anaerobic treatment of industrial wastewater like upflow anaerobic sludge blanket reactor (UASB) (Rajakumar et al. 2012), completely mixed anaerobic digester, fluidized and expanded bed reactors, and anaerobic filters, anaerobic sequencing batch reactor (ASBR) (Kundu et al. 2013). Among these, the anaerobic sequencing batch reactor had gained popularity as a better biological treatment option for the treatment of industrial wastewater. SBR systems can degrade the pollutants and can withstand higher organic loading (Masse & Masse 2000, Sombatsompop et al. 2011). Overall these SBR systems have some advantages over other conventional treatment technologies such as low energy consumption, and require less space with all the operations such as Fill, React/Aeration, Settle, and Draw taking place in a single tank (Khan et al. 2019, Bustillo-Lecompte et al. 2017, Chan et al. 2009).

The objective of this study was to assess the feasibility of a lab-scale anaerobic-aerobic SBR for the treatment of slaughterhouse wastewater and a comparative analysis with aerobic SBR treatment of slaughterhouse wastewater taken after Diffused Air Flotation(DAF) unit from a running slaughterhouse effluent treatment plant.

MATERIALS AND METHODS

Two reactors were fabricated with Perspex material of similar dimensions and capacity, one anaerobic and the other aerobic as shown in Fig. 1. Considering the design and dimensions, an internal diameter of 10 cm and height of 100 cm, the working volume of the column type SBR was 7.065 L. A port at 10 cm below the top of the reactor was made for the collection of effluent, while a port at the bottom of the reactor was made for the withdrawal of excess sludge generated. Both the reactors were seeded with respective sludge. Initially, the diluted wastewater was fed to the reactor and for acclimatization of micro-organisms, the HRT of 24 h was fixed, later on changing the dilution of wastewater as well as the HRT of the reactor. The anaerobic SBR consists of an anaerobic UASB in the bottom part and a port for effluent withdrawal at 0.75 m from the bottom. The aerobic SBR had an air supply port at the bottom and an effluent withdrawal port at 0.75 m from the bottom, and an excess sludge collection port at a height of 0.2 m from the bottom was provided in both the reactors.

The anaerobic sequential batch reactor (SBR) was seeded with two L of digested slaughterhouse UASB sludge. The aerobic sludge was fed in the reactor taken from the aeration tank of an activated sludge process treatment unit. The slaughterhouse wastewater was fed to the reactors having the following characteristics as given in Table 1.

Operation Cycle

Initially, the raw wastewater was 10 times diluted in the reactor to avoid shock loading, keeping the HRT at24 h for microorganisms to acclimatize. The dilutions of the raw sample were further varied as 5 times, 4 times, and so on in the end sample without dilution, varying the HRT of the reactor gradually. The dilutions were changed accordingly on the attainment of the steady-state conditions as shown in Table 2.

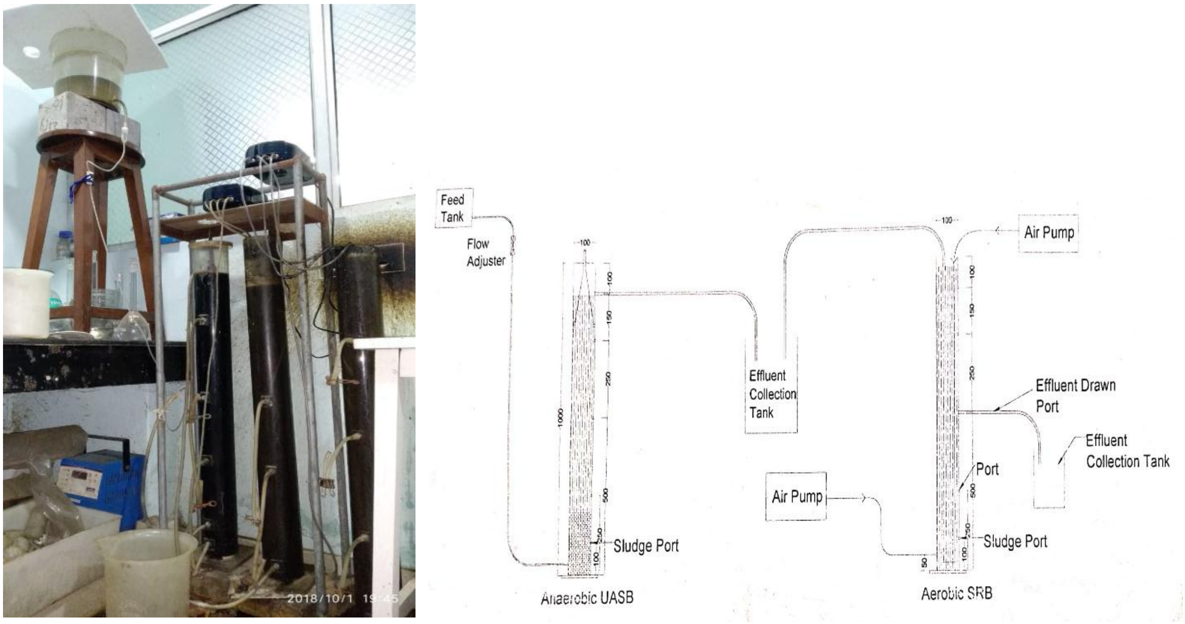

Fig. 1: Two reactors set up in parallel at lab scale and schematic diagram for the treatment of slaughterhouse wastewater.

Table 1: General characteristics of slaughterhouse wastewater.

S.No.	Wastewater Characteristics	Range
1	pH	6.8 to 8.5
2	Alkalinity (mg.L^{-1} as $CaCO_3$)	930 to 1350
3	Chemical Oxygen Demand (COD) (mg.L^{-1})	4700 to 6200
4	Biochemical Oxygen Demand (BOD) (mg.L^{-1})	2400 to 3200
5	Total Suspended Solids (TSS) (mg.L^{-1})	950 to 4200
6	Total Dissolved Solids (TDS) (mg.L^{-1})	5200 to 7200
7	Total Kjeldahl Nitrogen (TKN) (mg.L^{-1})	180 to 256
8	Phosphate (PO_4) (mg.L^{-1})	130 to 256

Aerobic SBR While Using DAF Sample

The reactor was seeded with two L of digested sludge taken from the activated sludge process unit of a running treatment plant. The slaughterhouse wastewater fed to the reactor has the following characteristics as a DAF unit as shown in Table 3.

When the microorganisms were acclimating, the raw wastewater was diluted 05 times in the reactor to avoid shock loading, and the HRT was kept at 8 hours. When the microorganisms were acclimating, the dilution of the raw sample was changed 4 times, 3 times, 2 times, and without dilution, and the HRT was kept at 8 hours. When the microorganisms were acclimatizing, the dilution of the raw sample was changed 4 times, 3 times, 2 times, and without dilution, and HRT was kept as 8. The dilutions of the sample were changed when the steady-state conditions were reached as shown in Table 4.

Experimental Setup and Operational Cycle

The reactors were operated with a cycle length of 24 h initially, after steady-state conditions were reached, then the dilution of the sample and cycle length of the reactors were changed to18 h, 12 h, and 8 h. Anaerobic SBR reactor was fed continuously from the bottom and no air was supplied in the reactor. However, the aerobic SBR reactor was having

Table 2: COD values of influent feed to the anaerobic reactor.

S.No.	Dilution Factor	COD Influent in Reactor(mg.L^{-1})	Total Days
1	Ten Times	510	96 days
2	Five Times	1006	72 days
3	Four Times	1530	48 days
4	Three Times	2070	54 days
5	Two Times	3031	48 days
6	Without Dilution (Raw Wastewater)	6172	120 days

Table 3: Characteristics of slaughterhouse wastewater after the DAF unit.

S.No.	Wastewater Characteristics	Range
1	pH	7.20
2	Alkalinity (mg/l as $CaCO_3$)	1130
3	Chemical Oxygen Demand (COD) (mg.L^{-1})	4120
4	Biochemical Oxygen Demand (BOD) (mg.L^{-1})	2390
5	Total Suspended Solids (TSS) (mg.L^{-1})	2164
6	Total Dissolved Solids (TDS) (mg.L^{-1})	4200
7	Total Kjeldahl Nitrogen (TKN) (mg.L^{-1})	769
8	Phosphate (PO_4) (mg/l)	258

Table 4: COD values of Influent Feed to the Aerobic Reactor.

S.No.	Dilution Factor	COD Influent in Reactor (mg.L^{-1})	Total Days
1	Five Times	845	72 days
2	Four Times	1050	48 days
3	Three Times	1412	96 days
4	Two Times	2115	96 days
5	Without Dilution (Raw Wastewater)	4120	96 days

continuous oxygen supply to maintain the population of microorganisms, although aeration was turned off during adding of the effluent and its withdrawal.

The timing of the phase cycle for SBR was: Fill-05 min, React-23 hrs 10 min, Settle-40 min, Draw-05 min.

The analytical techniques used in this study were performed according to the method described in Standard Methods. pH, total dissolved solids, and dissolved oxygen were analyzed by using HACH HQ30d portable meter(USA) coupled with their respective probes. Analysis of alkalinity, TSS, BOD, and COD was analyzed by standard methods (APHA 2005). The analysis of Phosphate and total Kjeldahl nitrogen (TKN) was carried out by DR 5000 (HACH, USA) UV spectrophotometer.

RESULTS AND DISCUSSION

Both the reactors were operated for varying hydraulic retention times (HRT) namely 24, and 18,12, and 8 h respectively, and variable dilutions. The dilutions and HRT were changed when optimum removal was achieved in the last HRT and dilution. The maximum OLR applied was 6.172 kg COD.m^{-3}.d^{-1} for the anaerobic reactor and 1.311 kg COD.m^{-3}.d^{-1} for the aerobic SBR reactor.

The maximum removal efficiencies for the parameters COD, BOD, TSS, TKN, Phosphorus, pH, and alkalinity using anaerobic SBR treatment are tabulated as shown in Table 5.

However, the maximum removal efficiencies of COD, BOD, TSS, TKN, and Phosphorus achieved were 80%, 81%, 73%, 81%, and 69% respectively for slaughterhouse

Table 5: Maximum removal efficiencies attained in anaerobic SBR for the studied parameters.

S.No	Pollutants	Influent (mg.L^{-1})	Effluent (mg.L^{-1})	Removal Efficiency (%age)
1	pH	6.25	7.85	--
2	Alkalinity	1153	188	83%
3	COD	6250	1000	84%
4	BOD	2815	563	80%
5	TKN	1064	410	61%
6	TSS	4235	551	87%
7	Phosphorus	258	83	68%

Table 6: Maximum removal efficiencies attained in SBR for the studied parameters by aerobic SBR treatment after DAF unit.

S.No	Pollutants	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (% age)
1	pH	6.52	7.25	--
2	Alkalinity	953	160	83%
3	COD	4120	830	80%
4	BOD	2395	460	81%
5	TKN	769	204	73%
6	TSS	2164	410	81%
7	Phosphorus	258	78	69%

wastewater using aerobic SBR treatment after the DAF unit are shown below in Table 6.

The results of anaerobic-aerobic SBR using raw wastewater and employing a DAF unit were compared with Central Pollution Control Board (CPCB), INDIA effluent discharge standards as shown below in Table 7.

Graphs were plotted (Fig. 2 to Fig. 8) to show the variation of influent and effluent Chemical Oxygen Demand, Biochemical oxygen Demand, Total Kjeldahl Nitrogen, Total Suspended Solids, and Phosphorus removal efficiencies with time. In initial the wastewater was used for feeding to the reactor was keeping 10 times diluted and HRT was 24 h. The Influent parameters concentration of the wastewater sample when dilution keeping 10 times were 510 mg.L^{-1}, 273 mg.L^{-1}, 93 mg.L^{-1}, 350 mg.L^{-1}, and 20 mg.L^{-1} respectively and the maximum removal efficiencies at this concentration were 79%, 68%, 59%, 50%, and 42% respectively at steady-state condition.

Table 7: Effluent discharge standards prescribed by the Central Pollution Control Board of India.

S.No.	Pollutants	CPCB Discharge Values (mg.L^{-1})
1	pH	6.50 to 8.50
2	COD	250
3	BOD	30
4	TKN	25
5	TSS	50
6	Phosphorus	1.0

The influent, effluent, and removal efficiency in terms of Chemical Oxygen Demand (COD) for the anaerobic-aerobic SBR with time is shown in Fig. 2 It is quite evident that, initially, when the concentration of wastewater was 10 times diluted (510 mg.L^{-1}), and keeping HRT as 24 h, the removal of COD was 78%. When the steady-state condition was attained after 16 weeks, the dilution of the sample and HRT of the sample were gradually changed, until no dilution wastewater was fed to the reactor and the HRT was 8 h, and the highest COD removal efficiency was 84 percent after 72 weeks.

In the same manner, the BOD influent was 273 mg.L^{-1} at 10 times dilutionand24 h HRT. After 16 weeks, the removal efficiency of the slaughterhouse wastewater after the anaerobic-aerobic process was 77%. Once the steady-state condition was reached, we gradually changed the dilution and HRT of the sample to 5 times and HRT to 18 h. After 28 weeks, the removal was 78% as shown in Fig. 3. Finally, after 72 weeks of feeding wastewater to the reactor without dilution and holding the HRT at 8 h, the maximum removal efficiency was obtained at 80%.

The influent and effluent Total Suspended Solids (TSS) concentration and removal efficiency for treated wastewater are shown in Fig. 4 In which the initial concentration of TSS was (350 mg.L^{-1}) at 10 times dilution and the HRT

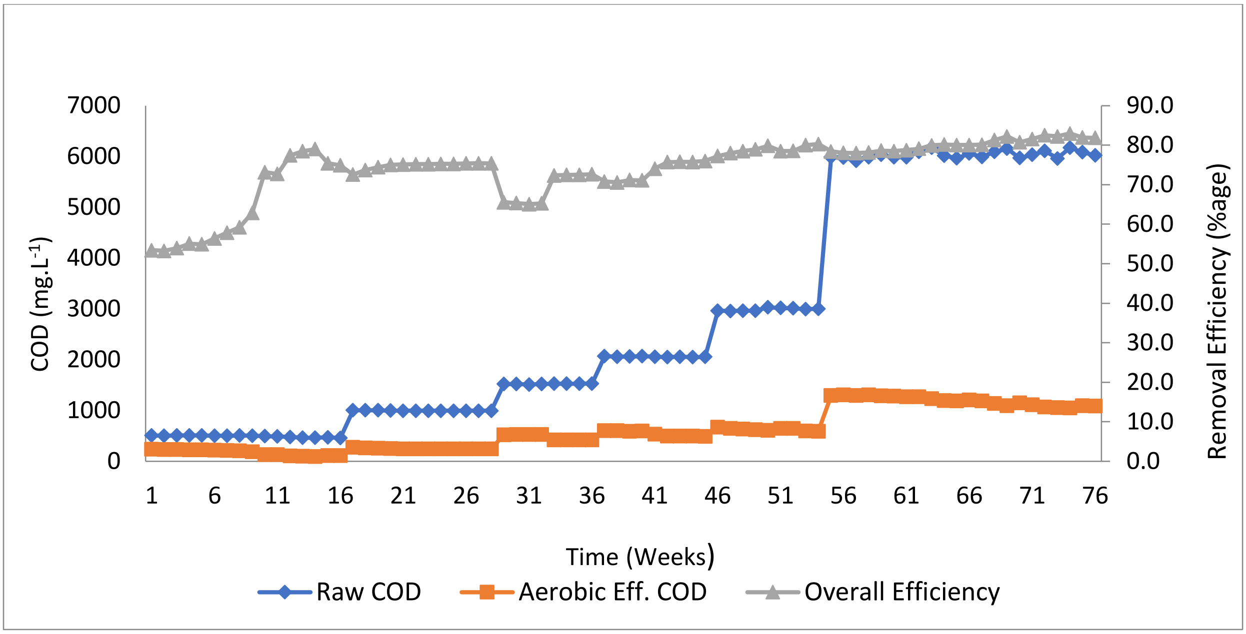

Fig. 2: Influent, effluent, and removal efficiency of COD with time.

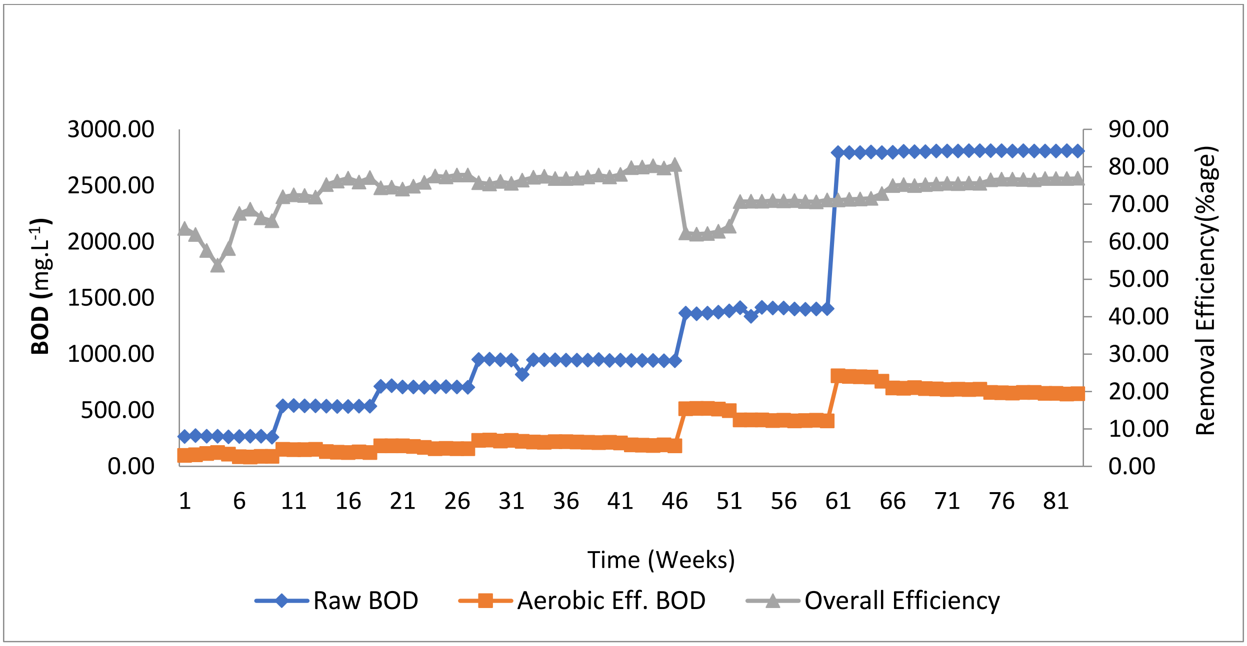

Fig. 3: Influent, effluent, and removal efficiency of BOD with time.

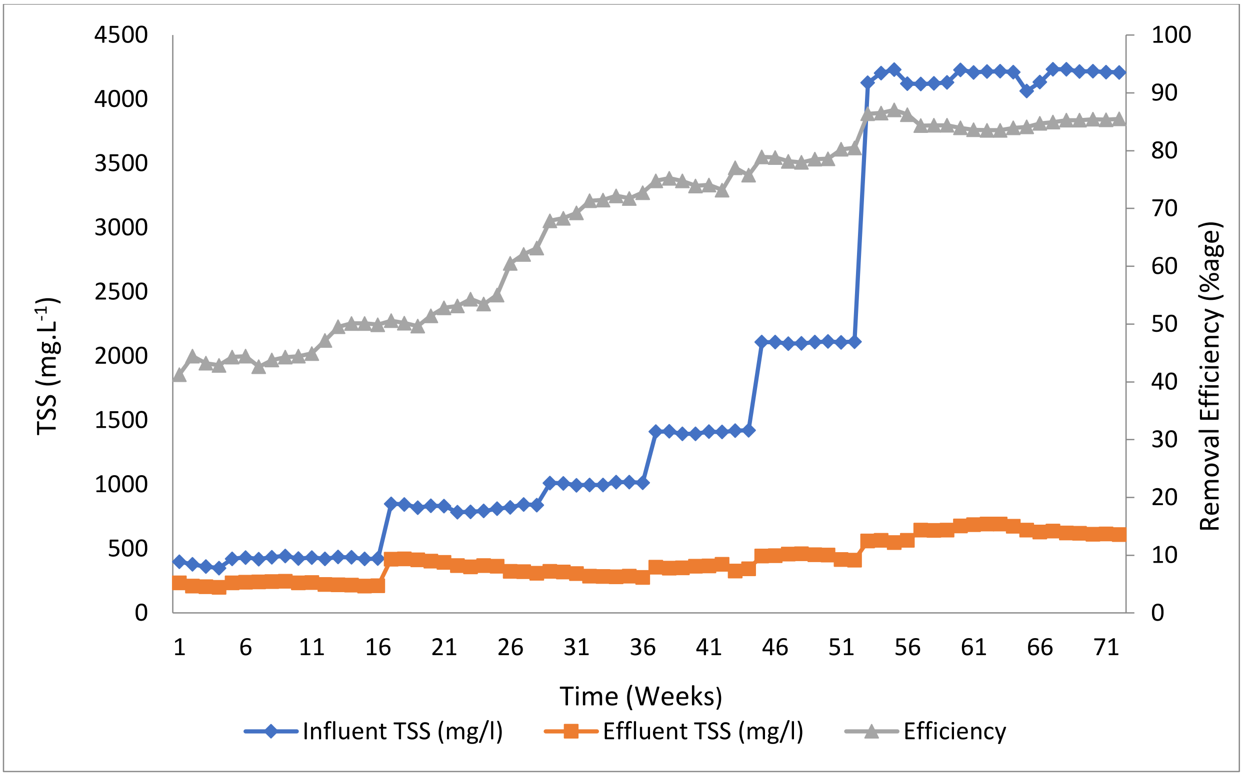

Fig. 4: Influent, effluent, and removal efficiency of TSS with time.

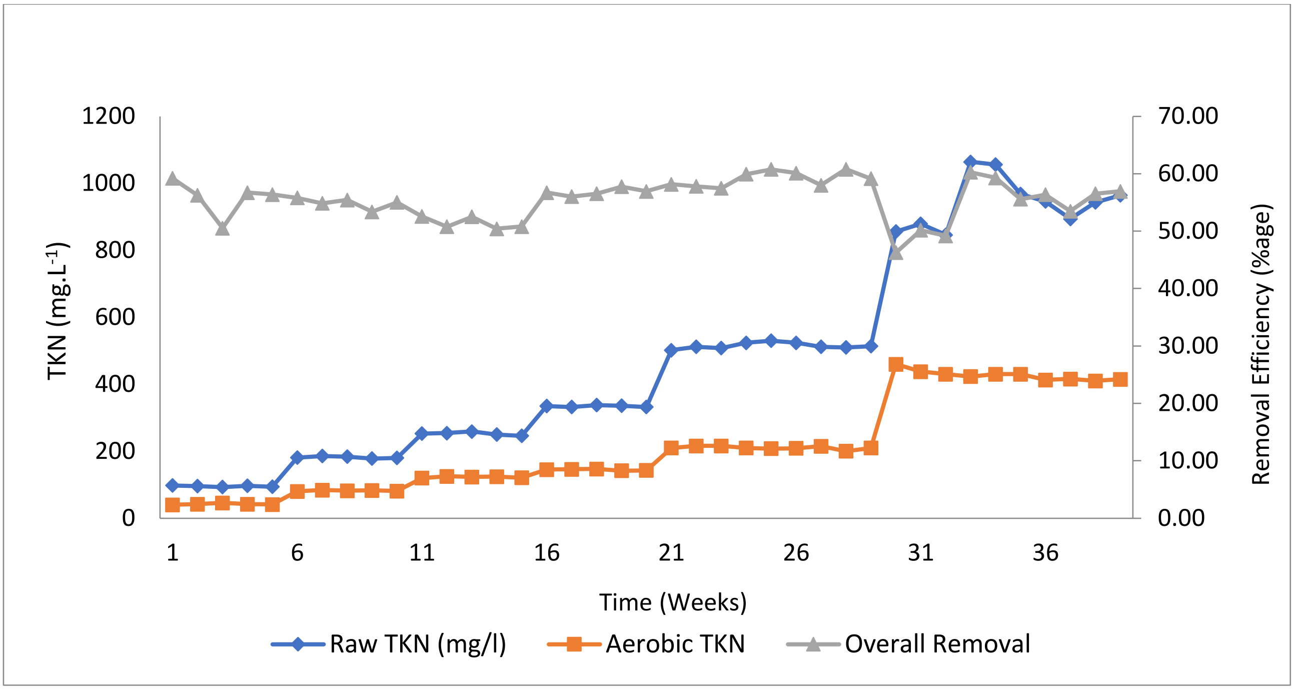

Fig. 5: Influent, effluent, and removal efficiency of TKN with time.

was 24 h. After 16 weeks, the removal efficiency of anaerobic-aerobic SBR was achieved at 50%, and the dilution of the sample and HRT of the rector were gradually changed, with a dilution of the sample 5 times, 4 times, 3 times, 2 times, and without dilution being used, and the HRT being reduced to 18 hours, 12 h, and 8 h for the system. The removal efficiencies of the system for TSS was 63% after 28 weeks, at a dilution of 5 times. The concentration of the sample was (850 mg.L^{-1}). In the end, the maximum removal efficiency of the TSS was 87% when the concentration without dilution of sample was (4235 mg.L^{-1}) at HRT of 8 h after 72 weeks of reactor run.

The influent Total Kjeldahl Nitrogen (TKN) was (93 mg.L^{-1}) at dilution 10 times. The removal efficiency was 50% when the steady-state condition was reached. The dilution of the sample was gradually changed to 5 times, 4 times, 3 times, and 2 times, and the sample was used without dilution. In the end, the maximum removal efficiency of the TKN in the anaerobic-aerobic SBR system was 61%, keeping the HRT of the system was 8 h as shown in Fig. 5. The removal efficiency of TKN in the anaerobic SBR system was reported less as compared with the aerobic system. The removal efficiency of TKN did not increase throughout the process, and was in the range of 50% to 61% in the anaerobic-aerobic SBR system, as indicated in the graph.

The phosphorus present in the sample was due to the breakdown of the proteins, initially, the concentration was (20 mg.L^{-1}) at 10 times dilution, keeping HRT at 24 h. The removal efficiency of the phosphorus was only 38%, and the removal of phosphorus from the wastewater is very less. As the steady-state condition was reached, we gradually changed the HRT and dilution of the wastewater to 5 times, 4 times, 3 times, 2 times, without dilution, and HRT decreased to 18 h, 12 h, and 8 h. The maximum removal efficiency of phosphorus was 68% in the anaerobic-aerobic treatment system of SBR after 72 weeks, the removal efficiency and the influent and effluent phosphorus variation with time as shown in Fig. 6.

In an anaerobic-aerobic system the influent, pH was more or less unchanged throughout the experiment but at some points when the dilution of the sample changed then little bit changes were reported in the pH concentration, otherwise the pH remained unchanged as shown in Fig. 7. But the pH concentration of the treated effluent increased from 6.25 to 7.75.

Initially, the alkalinity of the wastewater was (1156 mg.L^{-1}) without dilution sample, and effluent alkalinity was obtained after treatment (188 mg.L^{-1}) the maximum removal of alkalinity is reported as 83% from the anaerobic-aerobic treatment system at HRT 8 h of the reactor the graph as shown in Fig. 8

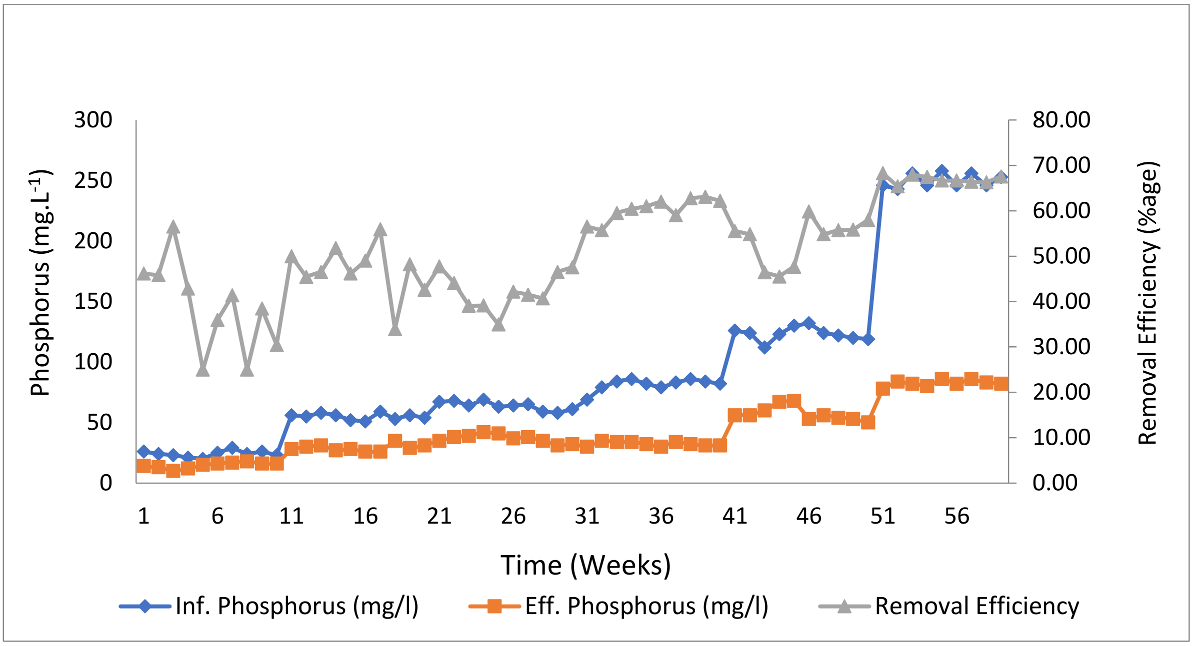

Fig. 6: Influent, effluent, and removal efficiency of phosphorus with time.

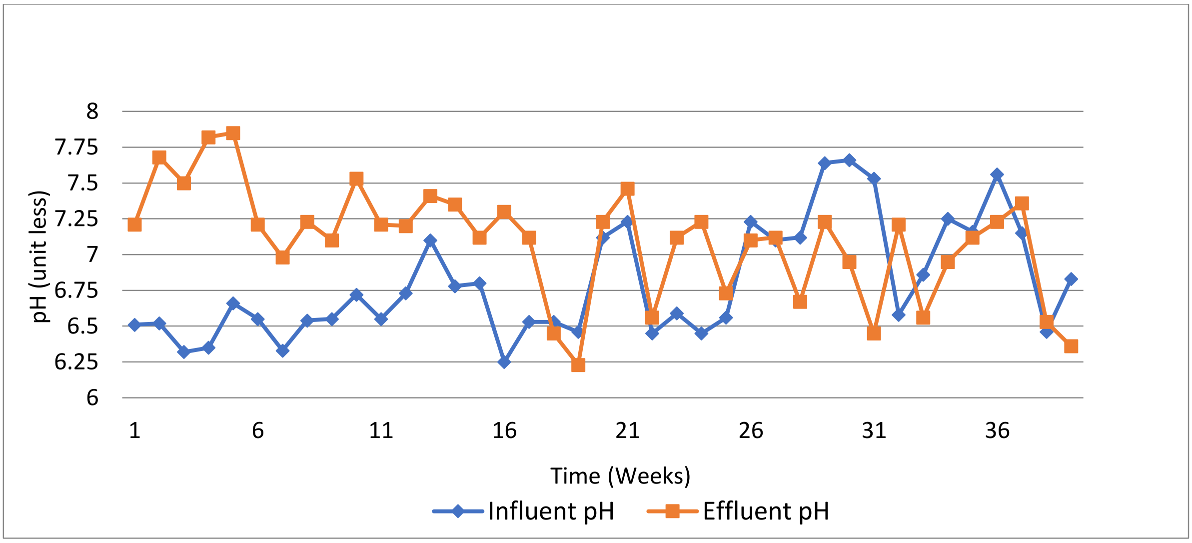

Fig. 7: Influent, effluent pH with time.

CONCLUSION

This study used anaerobic and aerobic sequencing batch SBR reactors for slaughterhouse wastewater treatment, which proved to be easy to operate, less energy-consuming, requiring less space, and extremely efficient when compared to other conventional processes. In terms of addressing high organic loading and obtaining high removal efficiencies under steady-state conditions, an anaerobic-aerobic SBR system was found to be a better solution for the treatment of slaughterhouse effluent. The maximum removal rates attained for Chemical oxygen demand, Biological oxygen demand, Total suspended solids, Total Kjeldahl nitrogen, and Phosphorus were 84%, 80%, 87%, 61%, and 68% respectively. It may also be concluded that the removal efficiency of COD/BOD in an anaerobic SBR system is better as compared with an aerobic SBR system using wastewater after the DAF unit. However, removal of TKN and Phosphorus from the waste-

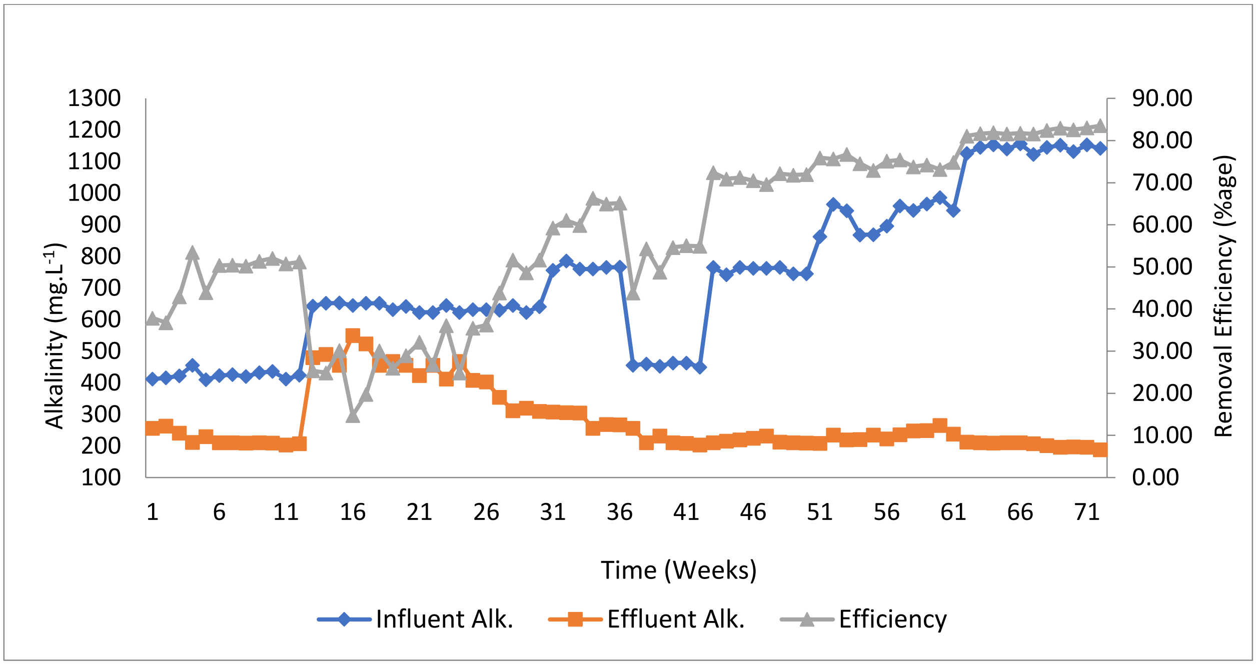

Fig. 8: Influent, effluent and removal efficiency of alkalinity with time.

water is better in aerobic SBR as compared with anaerobic SBR.

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