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A feasible scheme for slaughterhouse wastewater treatment using an anaerobic digestion batch reactor followed by an aerobic treatment stage

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ABSTRACT

The sustainable management of a slaughterhouse wastewater calls for feasible treatment technologies to protect the environment and public wastewater treatment facilities. The technology of up-flow anaerobic sludge blanket provides an adequate procedural condition for the reduction of carbonaceous matter from the high organic wastewater resulted from the slaughterhouses. The scope of this research included a rapid review on current treatment technologies for the slaughterhouse wastewaters and an investigation of the treatment efficiency of an aerobic stage after a pre-anaerobic treatment in a batch system. A batch reactor system of 1 m^3 volume with a mixer was developed. The anaerobic stage of the batch reactor was initiated using 400 L of fresh slaughterhouse wastewater mixed with 40 L of primary sludge. Three samples from the anaerobic batch reactor were collected at 10 d interval and then five samples were collected from the reactor after being under aerobic condition at 4 d interval. The removal efficiency of biochemical oxygen demand, chemical oxygen demand, total Kjeldahl nitrogen and PO_4 was 25%, 62%, 42%, and 9% in 30 d, respectively. After the start of aeration system, the removal efficiency was improved up to 94%, 69%, and 93%, respectively, except for PO_4 that showed high variations within the sampling periods.

Keywords: Slaughterhouse wastewater characterization; Anaerobic–aerobic batch treatment; Industrial wastewater treatment

1. Introduction

The excessive use of cleaning water in the slaughterhouses generates a large quantity of wastewater effluent. The generated effluent contains a considerable amount of blood, fat, manure, urine, and meat tissue that causes a source of contamination. Its high content of dissolved pollutants cannot be overlooked as it is considered a source of groundwater concern. Slaughterhouse's wastewater is listed as one of the most polluted industrial wastewaters by the United States Environmental Protection Agency (US-EPA) if it is treated or managed inadequately [1]. For instance, a slaughtered cow is equivalent to the wastewater effluent generated daily from a community of 50 people [2]. Therefore, it is crucial for the proper treatment and disposal of the slaughterhouse's effluent as a public health need [3].

The high blood content of the wastewater generated from the slaughterhouses is the main polluter potential [4].

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Therefore, the adaptation of effective treatment systems became a necessity to comply with the environmental standards and legislation. The meat-processing slaughterhouse plants have the potentials to generate pollution equivalent to over 1 million population in the Netherlands [5], three million in France [6], and a 3,231 population size in Gaza [7]. The major dissolved pollutant in slaughterhouse wastewater is the blood that has a chemical oxygen demand (COD) of about 375,000 mg/L [8]. Other high concentrations of suspended solids (SS), including pieces of fat, grease, hair, feathers, flesh, manure, grit, and undigested feed are also existed in the texture of the slaughterhouse wastewater [9]. Around 50% of the pollution in slaughterhouse wastewater is resulted from the insoluble and slowly biodegradable SS, while the colloidal solids account for only 25% [10]. A wide range of parameters were used to evaluate the pollution content of the slaughterhouse wastewater such as biochemical oxygen demand (BOD), COD, total Kjeldahl nitrogen (TKN), and total suspended solids (TSS).

Research approved that the anaerobic treatment is the most effective biological treatment in treating the high-polluted slaughterhouse's wastewater, but still, it needs an aerobic post-treatment to complete the degradation of the organic matter [11]. This research study forms a priority research field due lack of feasible treatment alternatives for industrial agrifood industrial wastewater, environmental pollution to marine environment along the Mediterranean coastal zone of Gaza strip exacerbated by challenges facing governmental agencies in enforcing local by-laws for the pretreatment requirements of the industrial discharges before their disposal into municipal sewerage systems. Therefore, an overview of treatment technologies for slaughterhouse wastewater treatment were conducted and the effects of an aerobic treatment stage as a post-anaerobic digestion were assessed. The findings provide a better management for the industrial wastewater for the aim to reduce further pollution to the environment and the sewerage facilities.

2. Materials and methods

2.1. Experimental setup and analysis

The experimental batch cylindrical reactor is shown in Fig. 1, which consisted of 1 m^3 volume with a circular base of 1-m diameter and a height of 1.4 m. Motor with a mixing arm was fixed for aeration purposes, in addition to valves were installed for the gas release and samples collection. The reactor was filled with 400 L of fresh wastewater from Gaza central slaughterhouse, in addition to 40 L of primary sludge from a domestic wastewater treatment plant in east of Gaza to enhance the digestion process. The characteristics of the mixture are shown in Table 1. For an anaerobic digestion, the batch was completely closed, and a mild mixing was operated. Three samples at 10 d intervals were collected and were analyzed for BOD, COD, TKN, and Orthophosphate (PO_4). After 30 d of anaerobic digestion, the system was adjusted to work under aerobic conditions by opening the batch to allow the access of air at continuous mixing. Five samples were collected and analyzed at 4 d interval.

2.2. Sample analysis

Standard Methods for the examination of water and wastewater were followed to analyze the electrical conductivity (EC), hydrogen potential (pH), BOD, COD, TKN and PO_4 [12]. Auto ranging EC meter (TH-2400) was used to measure the EC value in ds/m. For the pH measurements, the field pen pH meter (HI-8424) was washed using the distilled water and dried prior to each measurement. The OxiTop test was used to measure the BOD concentration, and the dichromate reflux method (Colorimetric Method) was followed to determine the COD concentration. The TKN was analyzed following the Kjeldahl method. For the TSS test, the samples were filtered using a weighed standard glass – fiber filter and the residues were dried before recording the constant weight at 105°C following the 2540D method for the TSS measurements. We followed the sulfuric acid digestion method to measure the PO_4 concentration within the range of 2–200 mg /L.

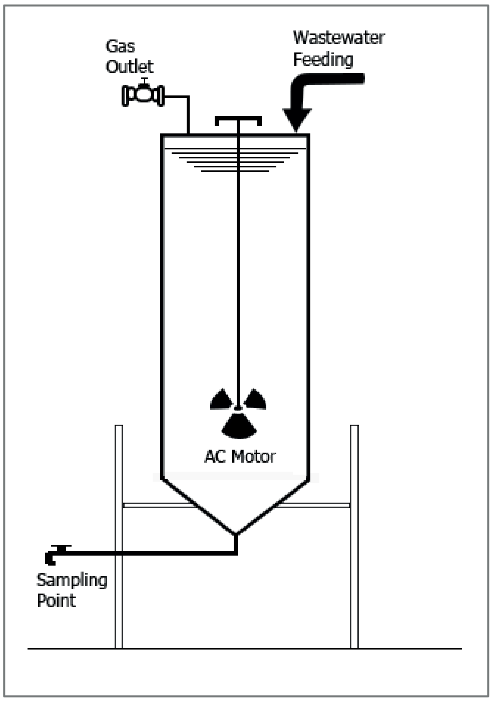

Fig. 1. Experimental batch reactor setup.

Table 1
Mixture characteristics of the experiment's slaughterhouse wastewater and sludge

Parameter	Value
EC, ds/m	3.7 ± 0.2
pH	8.1 ± 0.1
COD, mg/L	9,890 ± 155
BOD, mg/L	2,001 ± 22
TKN, mg/L	660 ± 5
PO_4, mg/L	82 ± 0.4

3. Results and discussion

3.1. An overview of the treatment schemes

The anaerobic systems showed a high efficiency of organic removal at a lower cost than the aerobic system. In addition, the anaerobic systems showed feasible production of biogas due to the arid-semi arid environmental conditions that may optimize the biochemical reaction. The feasibility of an anaerobic treatment of a slaughterhouse wastewater in up-flow anaerobic sludge blanket (UASB) reactor and in anaerobic filler (AF) was studied by [13]. Their experiment was tested at COD concentration of 8,000 mg/L and at SS range of 15% and 30%. Both reactors were operated at 37°C and the results showed a removal efficiency of COD up to 90% in case of 5 kg COD/m^3·d of organic loading rate (OLR) and 60% for an OLR of 6.5 kg COD/m^3·d. Compared with similar OLR, the AF reactor showed a lower removal efficiency and a lower percentage of methanization than the UASB. In conclusion, the study stated that the anaerobic systems are applicable to the treatment of slaughterhouse wastewaters and that the UASB reactor showed higher COD removal efficiencies than the AF reactor. Another study investigated the use of UASB for the treatment of meat processing effluent, and the outcomes showed some obstacles in the treatment process. Those obstacles occurred as a result of the accumulated floating fats that led to the reduction in the methanogenic activity and the loss of the biomass in the reactor [14].

Another experimental study on UASB showed that the removal efficiency of COD, BOD and TSS was 85%, 95% and 80% respectively at a hydraulic retention time of 22 d [15]. A further study of an aerobic sequencing batch reactor (ASBR) containing 6,908 mg/L COD at 30°C showed a removal efficiency of COD up to 90% in 2 d retention time [16]. Different anaerobic systems were studied by [17] to investigate the efficiency of the UASB and horizontal anaerobic fixed-bed reactor (HAFBR) for the treatment of slaughterhouse wastewater effluent. The study was operated at 3.77 kg/ m^3.d OLR of COD and 0.98 d of retention time, while the conditions of HAFBR were operated at OLR of 8.46 kg/$m^{3/}$d and a hydraulic retention time average of 0.53 d. Their results showed average removal efficiencies of 31% and 23% for COD and TSS respectively in case of HAFBR, 79% and 63% for the UASB reactor. Another lab-scale study evaluated a compound slaughterhouse wastewater treatment system of sequencing batch reactor (SBR), chemical–dissolved-air flotation (DAF) system and ultraviolet (UV) disinfection [18]. Their results showed the compound's system suitability for the post-treatment of the poultry slaughterhouse anaerobic effluents, as the removal efficiencies were recorded for the high organic matter, nutrients, suspended solids, and organisms. Table 2 presents an overview of slaughterhouse wastewater characteristics and treatment schemes.

3.2. Experimental approach: anaerobic followed by aerobic digestion

The experiment was conducted in a lab scale, 400 L of slaughterhouse wastewater was mixed with 40 L of sludge from Gaza Central Wastewater Treatment Plant. The characteristics of the mixture was analyzed showing the pH of 8.1, COD, BOD, TKN and orthophosphate of 9,890; 2,001; 660 and 82 mg/L, respectively (Table 1). Slaughterhouse wastewater from a Gaza slaughterhouse is recognized with its high organic and nitrogen contents. This mainly because of the limited availability of cleaning water to be used by the operators in Gaza. Moreover, separation system is not working at the slaughter location.

For the current research, sludge retention time in 10 d interval (0, 10, 20, and 30 d) was separated to take samples over a one-month period under anaerobic conditions. The pH varied through this experimental period but finally reduced from 8.1 to 7.6 as shown in Fig. 2a. After one month of the anaerobic conditions, the reactor was exposed to open air with continuous mixing. Samples were taken in 4 d intervals for a total period of 24 d. The results of pH were raised to 9.3 at the first 8 d, then were settled at 7.6 as shown in Fig. 2b.

For the COD value under the anaerobic conditions, Fig. 3a shows that within 30 d of sludge retention time, the COD was reduced by 61% (from 9,890 to 3,800 mg/L) which is still higher than the limitations for the wastewater disposal. While the aerobic treatment showed a rapid reduction of COD to 700 mg/L as illustrated in Fig. 3b.

Meanwhile Fig. 4a illustrates the reduction in BOD value by 25% (from 2,001 to 1,500 mg/L) under anaerobic

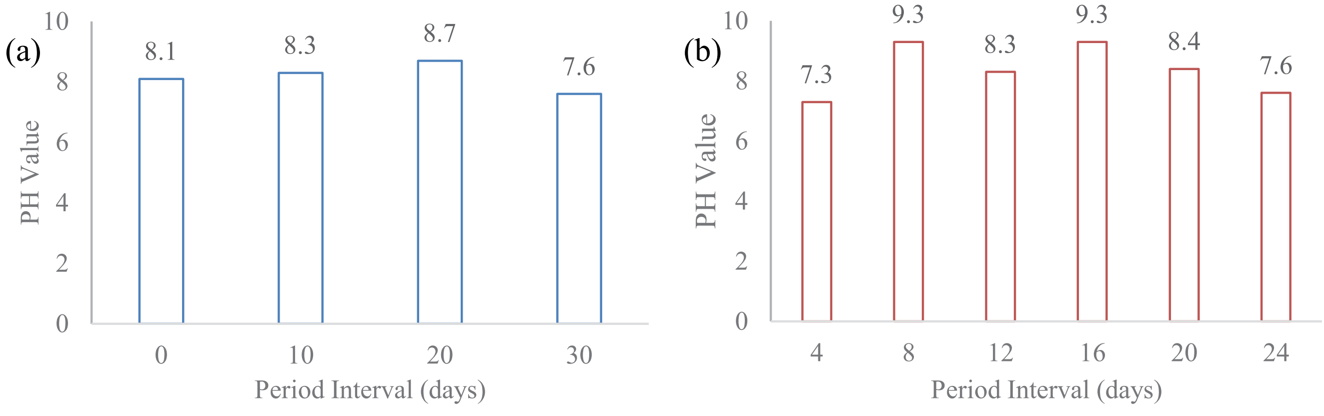

Fig. 2. Results of pH (a) anaerobic condition and (b) aerobic condition.

Table 2
An overview of slaughterhouse wastewater characteristics and treatment schemes

Slaughterhouse wastewater characteristics	Treatment schemes	Efficiency	References
A high concentration of COD reaching up to 8,000 mg/L was recorded in the content of slaughterhouse wastewater, of which 70% was proteins, and 15%–30% was SS.	The treatment set-up used an anaerobic condition for the treatment of slaughterhouse wastewaters in a UASB and AF reactors.	Operational set up of UASB ranged between of 1–6.5 kg COD/m^3·d OLR. Results had shown a removal efficiency of 90% of COD for OLR up to 5 kg COD/m^3·d and 60% for an OLR of 6.5 kg COD/m^3·d. While the AF reactor had shown lower removal efficiency of COD at the same OLR conditions than the UASB with lower percentages of methanization.	[13]
The characteristics of the slaughterhouse wastewater contained a range of 6,908 to 11,500 mg/L of COD, of which 50% was SS.	Anaerobic sequencing batch reactors was assessed.	The removal efficiency of COD went up from 90% to 96% at OLRs ranging from 2.07 to 4.93 kg/m^3·d of 2 d retention time. While the soluble COD (SCOD) was removed by 95%.	[16]
The concentration values of the slaughterhouse wastewater samples were 4,400; 3,900; and 7.5 mg/L for the COD, TSS and PO4 respectively, while pH is at 6.8.	Laboratory scale anaerobic treatment was assessed.	The operational set up of the lab-scale reactor was set at different hydraulic retention times of 5, 4, 3, 2, 1 and 0.5 d. Results showed a removal efficiency of 77%–96% for the COD, 65%–84% for the PO4 and 31%–52% for the NH_4.	[19]
Concentrations of BOD, COD were ranged from 1,300–2,300 mg/L, and 2,000–6,200 mg/L respectively. While the concentration ranges of organic and ammonia nitrogen were 50–210 mg/L and 20–30 mg/L, in turn. While total phosphate and TSS ranged from 15 to 40 mg/L and 850 to 6,300 mg/L, respectively.	Three phase separation system UASB was followed.	The range of removal efficiencies for COD, BOD and TSS were 77%–91%, 95%, and 81%–86%, respectively.	[15]
The concentration content of COD, BOD, TSS, TKN–N, for the slaughterhouse wastewater samples were 6,185; 3,000; 10,120 and 1,050 mg/L, respectively, at the pH value of 8.	A lab-scale of SBR under three different aerobic–anoxic sequences were studied for the removal of organic carbon and nitrogen from slaughterhouse wastewater. The settings of the aerobic–anoxic sequences were (4 + 4), (5 + 3), and (3 + 5) h.	Results witnessed a removal efficiency of 86%–95% of SCOD at the end of 8 h. The sequence of (4 + 4) aerobic–anoxic operating cycle showed a nitrification percentage with a range of 90.12% and 74.75% related to the initial NH_4^+–N value of 96.58 and 176.85 mg/L, respectively.	[20]
The experimental set up was controlled at an average OLR of 4.37 kg. Total chemical oxygen demand (TCOD)/m^3·d with a gradual increased up to 13.27 kg TCOD/m^3·d.	Anaerobic membrane bioreactors (AMBR) were studied for a slaughterhouse wastewater treatment.	The treatment efficiency of COD and BOD was 93.7% and 93.96%, respectively. Observations recorded less treatment efficiency of COD and BOD down to 53.6 and 73.3 respectively in case of increasing the OLR to 16.32 kg TCOD/m^3·d.	[21]
The average values of COD, BOD, TSS, oil and grease, phosphate of the slaughterhouse wastewater were 5,199; 1,680; 7,125 mg/L; 1,266 and 6.8, respectively, and pH at 6.7.	Treatment plant scale consists of screens, flow equalization tanks, skimming spades, chemical dosing systems, sedimentation tanks, carbon filter, sand filters, bag filters, and UV-light.	The treatment efficiencies were 98.7, 99.7, 100, 98.8, 100 and 100 mg/L for the BOD, COD, TSS, oil and grease, nitrate, and phosphate, respectively.	[22]

(Continued)

Table 2

Slaughterhouse wastewater characteristics	Treatment schemes	Efficiency	References
The value range of COD, BOD, and SS were 4,700–5,900 mg/L, 1,500–2,300 mg/L, and 4,000–8,000 mg/L, respectively.	Moving bed sequencing batch reactor was studied for a piggery wastewater treatment.	At higher OLR up to 1.18–2.36 kg COD/m^3·d, the removal efficiency of COD and BOD was also higher reaching to 80% and 90%, respectively and the TKN removal efficiency was 86%–93%.	[23]
Samples used a raw wastewater with COD and BOD ranges of 5,817 ± 473 and 2,543 ± 362 mg/L.	Chemical coagulation and electrocoagulation techniques were assessed.	The removal efficiency of COD and BOD were up to 99% in case of adding 100 mg/L PACl and voltage of 40 V.	[24]
The range values of the slaughterhouse wastewater of COD, soluble COD, BOD, SS, alkalinity (as $CaCO_3$), VFA (as acetate) were 3,000–4,800 mg/L, 1,030–3,000 mg/L, 750–1,890 mg/L, SS 300–950 mg/L, 600–1,340 mg/L, and 250–540 mg/L respectively at pH ranges of 7–7.6.	Hybrid up-flow anaerobic sludge blanket (HUASB) reactor was studied for the treatment of a poultry slaughterhouse wastewater.	The setup of HUSB reactor operated at 19 kg COD/m^3·d OLR. The removal efficiencies of TCOD and SCOD were 70%–86% and 80%–92%, respectively. The range values of biogas were in between 1.1 and 5.2 m^3/m^3/d with a maximum methane content of 72%.	[25]
The range values of COD, BOD and SS were 22,000–27,500 mg/L, 10,800–14,600 mg/L, and 1,280–1,500 mg/L, respectively.	Anaerobic hybrid reactor was operated with a lightweight floating media.	Results had shown a reduction percentage of 86%–93.58% and 88.9%–95.71%, for the COD and BOD respectively.	[26]
Two reactors of HAFBR and UASB were operated. The operation conditions of UASB were settled at 3.77 kg/m^3·d OLR of COD and 0.98 d of retention time, while the conditions of HAFBR were operated at OLR of 8.46 kg/m^3·d and hydraulic retention time average of 0.53 d. The pH was managed at 6.8 over the time of 150 d.	HAFBR followed by an UASB reactor was assessed for the slaughterhouse wastewater treatment.	The removal efficiencies of COD and TSS were 31% and 23% for the HAFBR, while the values were 79% and 63% for the UASB reactor.	[17]
The characteristics of the slaughterhouse wastewater were 5,817 ± 473 mg/L for the COD, 2,543 ± 362 mg/L for BOD and 3,247 ± 845 mg/L for TSS. The pH and conductivity values were 7.31 ± 0.12 and 9,140 ± 1,512 µs/cm, respectively measured for 48 samples.	A 30 L UASB reactor used for the treatment of actual slaughterhouse wastewater at a hydraulic retention time of 1.24 d and at temperatures in the range of 35°C ± 0.5°C for 320 d.	The highest removal efficiency of COD was about 94.6%, while the lowest rate was at about 40.5%. The pH value was variated in between 6.68 and 8.03.	[27]
The COD, BOD, TSS, total nitrogen (TN) parameters of the slaughterhouse wastewater were 5,000; 3,000; 3,000 and 450 mg/L, respectively and pH value at 6.5.	The study investigated the treatment efficiency of a combined system that consists of ABR-AS-UV/H_2O_2. A 36-L ABR was established with five chambers of equal volumes and individual biogas collection, a 12.65-L aerobic activated sludge (AS) reactor with a constant dissolved oxygen concentration of 2 mg/L by controlling the air flow, and a 1.35-L UV-C photoreactor with recycle, output power of 6 W, and uniform light distribution.	The results had shown a maximum removal efficiency reached up to 99% for COD, BOD, Total organic carbon, TSS, TN, and total phosphorus (TP) by the study combined system operated in continuous mode.	[28]

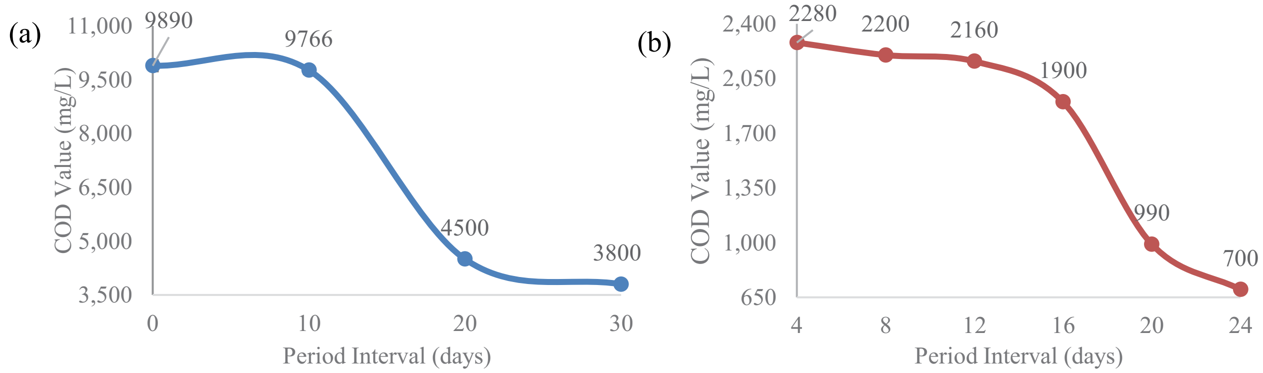

Fig. 3. Results of COD (mg/L) at different sludge retention time (a) anaerobic condition and (b) aerobic condition.

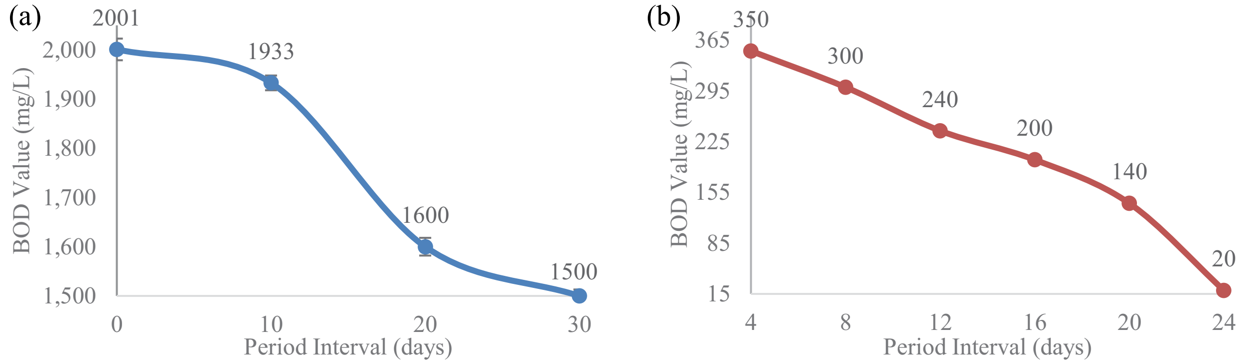

Fig. 4. Results of BOD (mg/L) at different sludge retention time (a) anaerobic condition and (b) aerobic condition.

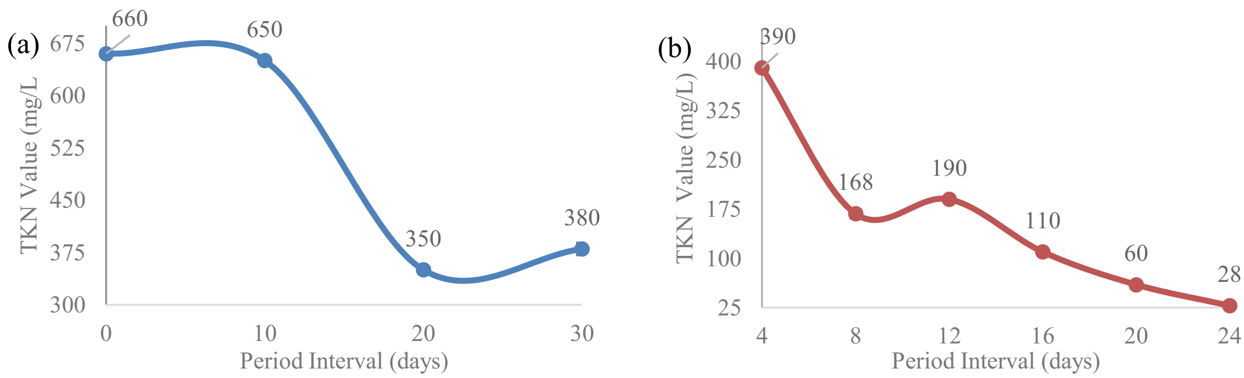

Fig. 5. Results of TKN (mg/L) at different sludge retention time (a) anaerobic condition and (b) aerobic condition.

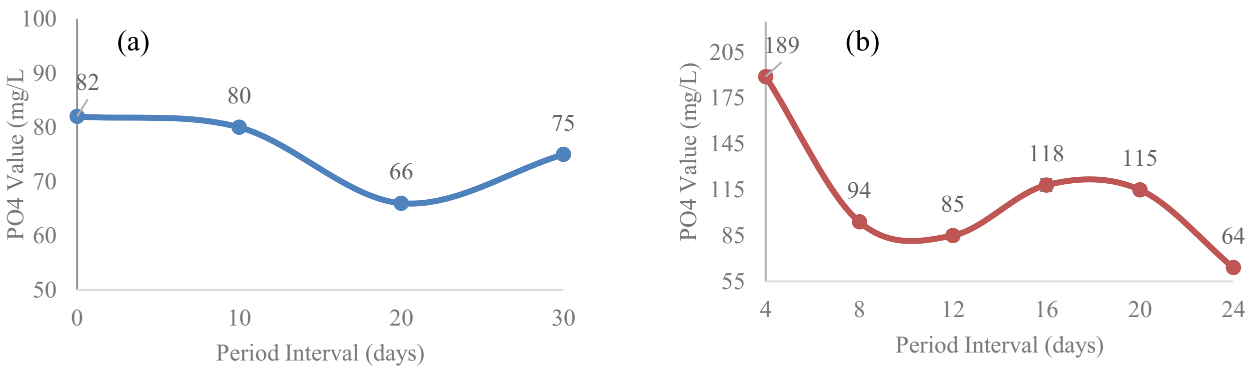

Fig. 6. Results of PO_4 (mg/L) at different sludge retention time (a) anaerobic condition and (b) aerobic condition.

conditions. This value was sharply dropped to 20 mg/L as shown in Fig. 4b.

Figs. 5 and 6 show the experiment's results of TKN and PO_4. The anaerobic processing shows that TKN reduced from 660 to 380 mg/L, while insignificant reduction in PO_4 occurred after 30 d due to the variation in PO_4 at different sludge retention times. The increase in PO_4 between the end of the anaerobic digestion and the onset of aerobic digestion might be explained by the hydrolysis of the organic P through an enhanced bio-P process, where P is released under anaerobic conditions. A noticeable drop in PO_4 shows that after 20 d of sludge retention time (66 mg/L), the PO_4 value was raised up to 75 mg/L. While the outcomes resulted from the aerobic conditions showed a rapid drop of TKN and PO_4 to 28 and 64 mg/L, respectively.

4. Conclusion

An overview of treatment schemes showed that the anaerobic treatment of slaughterhouse wastewaters shown the most common treatment systems ranked as UASB. The study results underlined that the anaerobic conditions of the slaughterhouse wastewater treatment were considerably efficient in decreasing the contents of COD, BOD, and TKN up to 62%, 25% and 44%, respectively. The study also revealed that a substantial improvement occurred in the removal of BOD, TKN and PO_4 when the batch system was operated in a post-aerobic treatment stage. Removal efficiency of more than 94% of BOD, 93% of TKN and 66% of PO_4 was achievable under the aerobic conditions.

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