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Slaughterhouse wastewater treatment using biological anaerobic and coagulation-flocculation hybrid process

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ABSTRACT

Meat processing industries consume a lot of fresh water in the slaughterhouses and livestock industries worldwide. Currently, some slaughterhouses produce large amounts of harmful wastewater, because of the slaughtering process and cleaning of equipment. In this paper, an anaerobic and coagulation-flocculation hybrid process was explored in laboratory pilot scale for removal of contaminants from a slaughterhouse effluent. The findings indicated that anaerobic treatment as the first step caused a reduction of the portion of (COD), (TSS), and turbidity. Furthermore, it was concluded that coagulation-flocculation could reduce most of the suspended and colloidal particle with an aluminum sulfate dose of 110 mg l^{-1}. (TSS), turbidity, (COD), (TDS) and (EC) have been reduced up to 71%, 41%, 76%, 49%, and 52%, respectively. Results show coagulation-flocculation can reduce most of the suspended and colloidal particles, and aluminum sulfate compare with ferric chloride and calcium oxide is a suitable coagulant for this special wastewater. On the other hand, adding coagulant generates various ions and causes an increase in TDS and EC. So, the optimal dose of aluminum sulfate was determined. Also results show that TDS and EC increased slightly after the coagulation-flocculation process compared with the anaerobic process which was due to the addition of coagulants to wastewater. Finally, the anaerobic and coagulation-flocculation hybrid process does not meet environmental standards to dispose of wastewater and requires a supplementary treatment process.

Keywords: Slaughterhouse; Wastewater treatment; Coagulation-flocculation; Anaerobic process

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1. Introduction

In many countries, meat products are one of the most valuable sources of protein and an important part of human nutrition, since the human population is growing steadily, so is the livestock slaughtered [1]. Non-automatic slaughterhouses in most small towns consume a lot of water due to the cleaning processes such as washing before and after animal slaughtering and cleaning floors and equipment [2–4]. Usually, the wastewater is discharged into the environment without any treatment or with only a simple pretreatment process. Discharging this wastewater into water bodies is one of the key environmental issues for slaughterhouses [5–7].

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Red colored wastewater of slaughterhouses contains many pollutants such as diluted blood, proteins, fats, and suspended solids [8,9]. Some studies show conventional treatment processes cannot sufficient to reduce contaminants level of slaughterhouse wastewater to meet environmental standards and combined chemical coagulation with electrocoagulation can improve Slaughterhouse wastewater as hybrid process [10]. Treated slaughterhouse wastewater quality varies depending on the kind and efficiency of the primary or secondary treatment processes [2,11]. Due to the high biodegradability of slaughterhouse wastewater, biological processes such as aerobic and anaerobic treatments are considered to be suitable for organic matter removal [12].

Anaerobic treatment offers a number of advantages, including high organic matter removal efficiency, low sludge production and generation of some valuable energy in the form of biogas [13]. There are various technologies and anaerobic processes for the treatment of strong industrial wastewater [14]. Usually, the processes such as up-flow anaerobic sludge bed, anaerobic filters, expanded granular sludge beds or internal circulation reactors are used for treating wastewater. Most of the anaerobic treatment processes can achieve high organic matter removal efficiencies, often reaching over 70%. However, effluents from these processes often contain organic matter and suspended solids that do not comply standard and need more treatment [14,15]. For instance, approved wastewater treatment standards for different metrics in seven different regions are provided in Table 1.

The anaerobic treatment of slaughterhouse wastewater is often impaired due to the accumulation of suspended solids and floating fats in the reactor which leads to a reduction in the methanogenic activity and biomass wash-out. In addition, previous research has indicated that anaerobic treatment is sensitive to high organic loading rates, and this is a serious disadvantage [13]. Although, anaerobic and aerobic biological processes are effective and economical, both of these biological processes require long hydraulic retention time and a large reactor volume. To avoid the wash-out of the sludge of reactor, they need high biomass concentration and controlling of sludge loss. Some experimental studies show that anaerobic digestion combined with another process such as dissolved air flotation can reduce more contaminants of slaughterhouse wastewater and increase the rate of the treatment process [27–29]. Furthermore, other studies have shown that physicochemical processes such as coagulation-flocculation appears to be effective in eliminating contaminants and can successfully remove the suspended solids, colloidal matter and lipids from textile wastewater by using around 25–125 mg L^{-1} of coagulant. So the investigation of coagulates effects can be started by doses of other researchers that they used [10]. Coagulation-flocculation is one of the most commonly used methods for the removal of suspended solids and colloidal particles in water and wastewater treatment processes. Coagulation can decrease or neutralize the negative charge on suspended particles or zeta potential. In flocculation, micro flocs gather together to form large flocs through physically mixing or binding action of flocculants, such as long chain polymers.

In this experimental work, the authors aimed to study the treatment capability of wastewater of a slaughterhouse using anaerobic and coagulation-flocculation treatments as a hybrid process. This slaughterhouse used for slaughtering cattle and sheep, so the wastewater has an especial characteristic and its properties are different from other wastewater on the conventional slaughterhouse.

2. Materials and methods

2.1. Materials

2.1.1. Raw wastewater

The wastewater used in this experimental work was collected from a bovine and sheep slaughterhouse, located at Quchan, Iran, and labeled as raw wastewater. The raw wastewater sample was packed in a container without any preliminary treatment and was referred for the analysis to the laboratory of water and wastewater of Islamic Azad university of Quchan for its initial characterization. The analyses for turbidity, pH, COD, TDS, EC, and TSS were performed by standard methods of the examination of water and wastewater [30–32]. The raw wastewater characteristics of slaughterhouse before and after sedimentation are shown in Table 2.

2.1.2. Anaerobic activated sludge

The anaerobic sludge for initial seeding was obtained from the outlet of a final clarifier wastewater treatment plant at Quchan. The waste anaerobic sludge of the plant contains a group of various anaerobic microorganisms with 100 mg l^{-1} of total suspended solids and 50 mg l^{-1} of volatile suspended solids. These activated microorganisms were accustomed with environmental and operational conditions.

Table 1
Comparison of standard limits for slaughterhouse wastewater discharge in different jurisdictions worldwide [16–26]

Parameter	World bank	EU	USA	Canada	Colombia	China	India	Australia	Iran
BOD (mg L^{-1})	30	25	16–26	5–30	50	20–100	30–100	5–20	50–100
COD (mg L^{-1})	125	125	n.a.	n.a.	150	100–300	250	40	100–200
TN (mg L^{-1})	10	10–15	4–8	1.25	10	15–20	10–50	10–20	10–20
TOC (mg L^{-1})	n.a.	n.a.	n.a.	n.a.	n.a.	20–60	n.a.	10	n.a.
TP (mg L^{-1})	2	1–2	n.a.	1.00	n.a.	0.1–1.0	5	2	1–2
TSS (mg L^{-1})	50	35–60	20–30	5–30	50	20–30	100	5–20	40–100
pH	6–9	n.a.	6–9	6–9	6–9	6–9	5.5–9.0	5–9	6–9
Temperature (°C change)	n.a.	n.a.	n.a.	<1°C	n.a.	n.a.	<5°C	<2°C	n.a.

Table 2
Raw wastewater properties of slaughterhouse

Wastewater characteristics	TSS (mg L^{-1})	Turbidity (NTU)	COD (mg L^{-1})	pH	TDS (mg L^{-1})	EC (μs/Cm)	T°C
Raw wastewater	666	391	5,136	7.78	17,890	33,000	18
Raw wastewater after sedimentation	666	371.5	4,750	7.51	16,805	31,000	17

2.1.3. Chemical coagulants

Calcium oxide (CAO), aluminum sulfate $(Al_2SO_4)_3.16H_2O$, ferric chloride ($FeCl_3$), and ferrous chloride ($FeCl_2$) were purchased from Merck company (a Germania chemical company) and were used as a coagulant. Chemical matters characteristics are shown in Table 3.

Table 3
Characteristics of coagulants

Coagulants name	Formula	Molecular weight (g mole^{-1})
Calcium oxide	CAO	56.08
Aluminum sulfate	$(Al_2SO_4)_3.16H_2O$	666.42
Ferric chloride	$FeCl_3$	270.3
Ferrous chloride	$FeCl_2$	198.81

2.2. Experimental procedure

The wastewater after sedimentation was used for subsequent treatments. The experimental study of anaerobic biological treatment was carried out in laboratory scale using a 200-L polyethylene sealed tank batch anaerobic reactor. Table 4 shows the operation conditions and amounts of them.

Table 4
Operation conditions and amounts of them

Operation conditions	Amount
COD of wastewater	4,750 mg L^{-1}
Temperature	23°C–25°C
pH	7–8
Batch reactor volume	200 L

The coagulation-flocculation process was performed in three subsequent separate steps using a jar test apparatus to find a suitable coagulant and its optimum dose.

1. Rapid mixing: To stir coagulant at high speed of 300 rpm for 1 min.
2. Slow mixing: To form large flocs in moderate agitation speed of 50 rpm for 20 min.
3. Sedimentation: To settle out flocs in 30 min duration.

Moreover, the specifications of measuring devices are shown in Table 5.

Table 5
Specifications of measuring device

Device	Specifications
Turbidity meter	AQUALYTIC (Germany)
pH meter	Metrom 80027 (Swiss)
Spectrophotometer	AQUALYTIC AL800 (Germany)
COD vials	(Lovibond hanna 0–15,000 mg L^{-1}) 16 mm
Conductivity meter	JENWAY 407 (Germany)
Jar test	AQUALYTIC (AL50) (Germany)

3. Results and discussion

3.1. Anaerobic process

Figs. 1–5 show the variation of turbidity, suspended solids, chemical oxygen demand, dissolved solids, and pH due to the removal of soluble and tiny suspended organic matters through the anaerobic biological process. During the time, microorganisms consume and remove the organic matter and generate excess sludge [33]. In addition, some other suspended particles are removed due to excess sludge sedimentation, so as shown in Figs. 1–3, the amount of turbidity, TSS, and COD are reduced over time. Moreover, since some particles have electrically charged, the sedimentation of these particles cause the amount of TDS and EC be reduced too, as shown in Fig. 4. The equation between TDS and EC was found TDS = 0.56EC. With respect to Fig. 5, the variation of pH is around 7.5–8 which is suitable for microorganism's activities. This variation of pH is negligible during the process time.

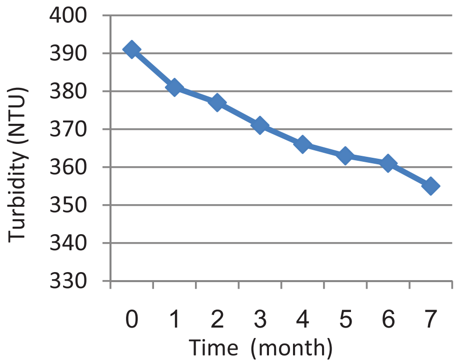

Fig. 1. Variations of turbidity in terms of retention time.

3.2. Coagulation-flocculation

Figs. 6 and 7 show the effects of various coagulants on the reduction of the turbidity and total suspended solids for different doses of coagulants such as calcium oxide, ferric chloride, ferrous chloride, and aluminum sulfate. The results show that aluminum sulfate has been better than other coagulants to separate suspend and colloidal particles. Furthermore, results show that by increasing the concentration of coagulants, the amount of suspended and colloidal particles is more decreased.

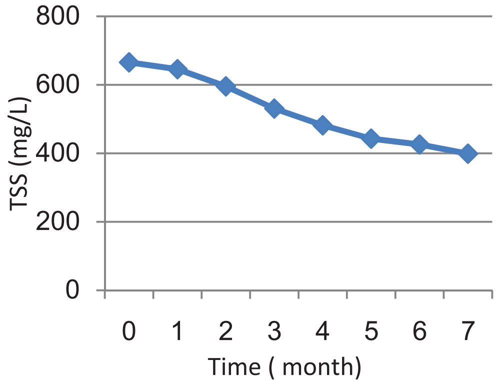

Fig. 2. Variations of TSS in terms of retention time.

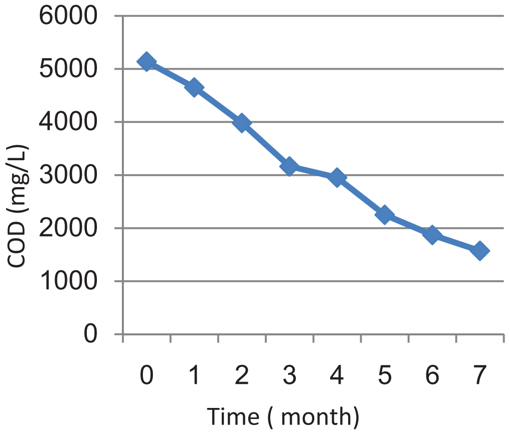

Fig. 3. Variations of COD in terms of retention time.

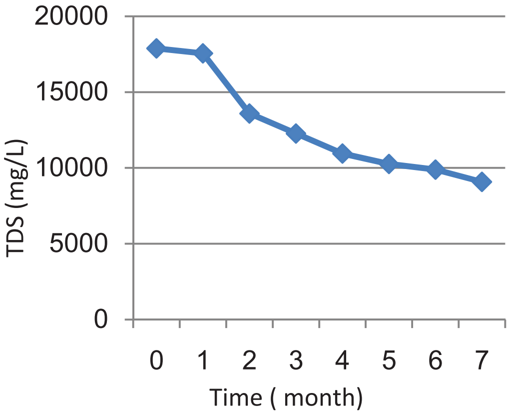

Fig. 4. Variations of TDS in terms of retention time.

The amount of reduction for COD is shown in Fig. 8. The COD reduction is due to the removal of the soluble and tiny suspended organic matters [34].

Figs. 9 show the addition of a coagulant to wastewater which results in increasing the total dissolved solids. These coagulants act as a salt and generate various ions as anion and cation in wastewater, so these ions cause an increase in TDS and EC. Moreover, calcium oxide generates more hydroxide which in turn increases pH, as shown in Fig. 10.

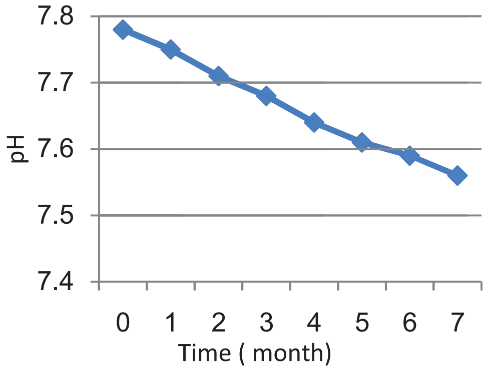

Fig. 5. Variations of pH in terms of retention time.

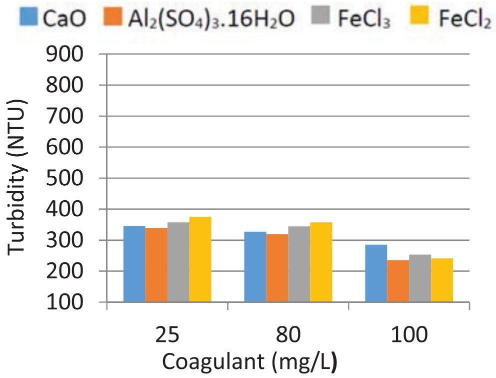

Fig. 6. Effect of various coagulants on turbidity.

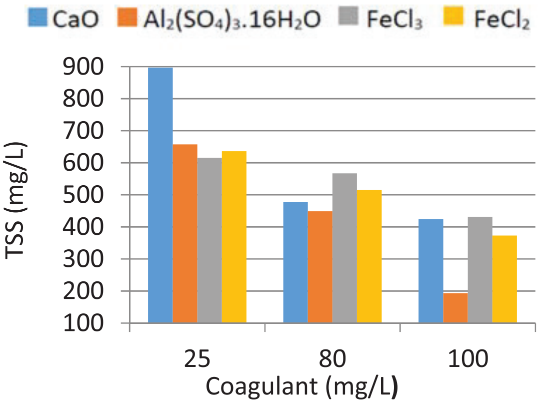

Fig. 7. Effect of various coagulants on TSS.

The findings demonstrated that the suitable dose of coagulants were around 100 mg L^{-1}. In order to find the effect of other concentrations for aluminum sulfate as almost the best coagulant a many four coagulants, more examination has been carried out for concentrations of 90 and 110, 120, 150, and 200 mg L^{-1}. The results are shown in Figs. 11–16, As these figures show, increasing the coagulant concentration results in a reduction of pollution indices such as TSS, turbidity, and COD and increase of the TDS and EC [35]. It was also concluded that the trend of pollution indices for the

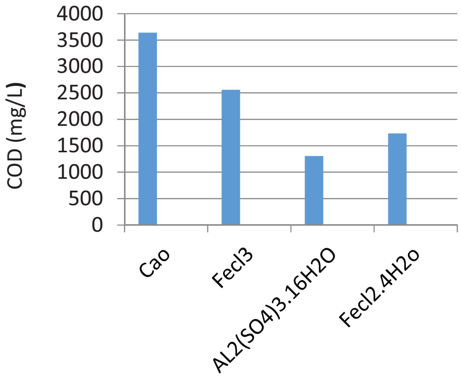

Fig. 8. Effect of various coagulants on COD.

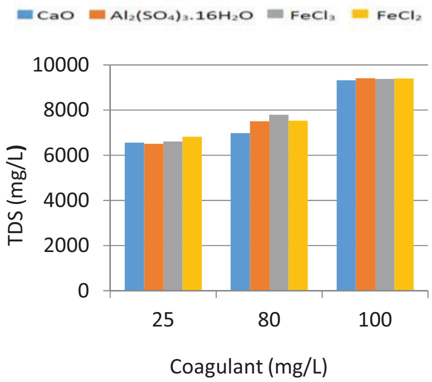

Fig. 9. Effect of various coagulants on TDS.

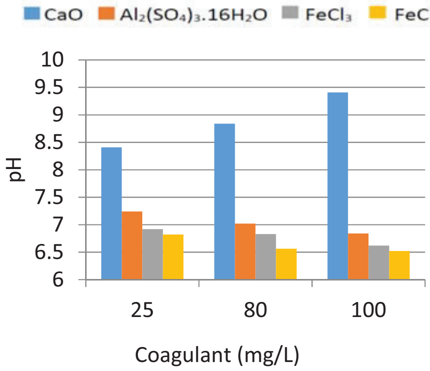

Fig. 10. Effect of various coagulants on pH.

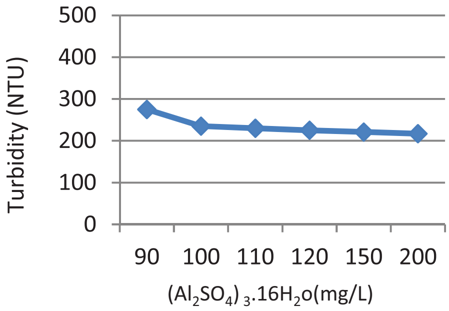

Fig. 11. Effect of concentrations of aluminum sulfate on turbidity.

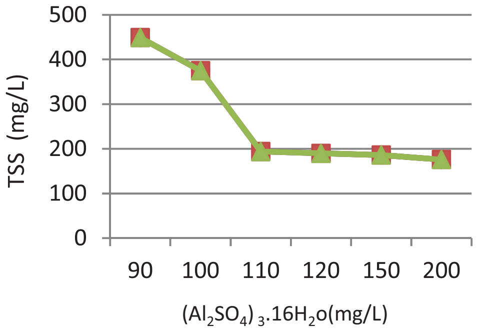

Fig. 12. Effect of concentrations of aluminum sulfate on TSS.

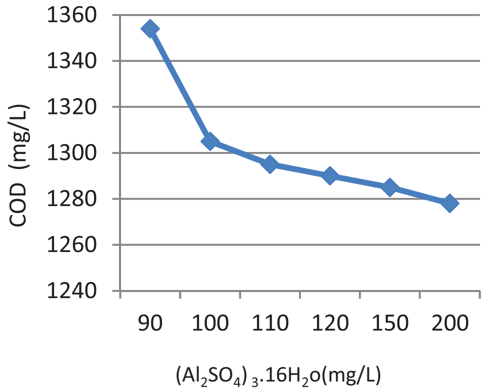

Fig. 13. Effect of concentrations of aluminum sulfate on COD.

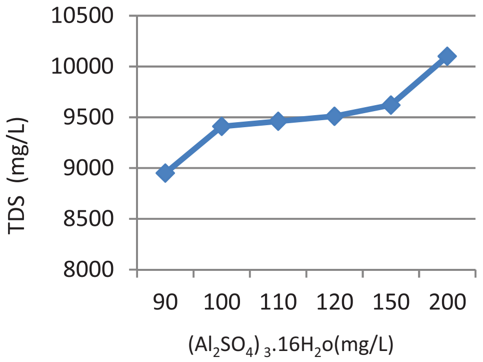

Fig. 14. Effect of concentrations of aluminum sulfate on TDS.

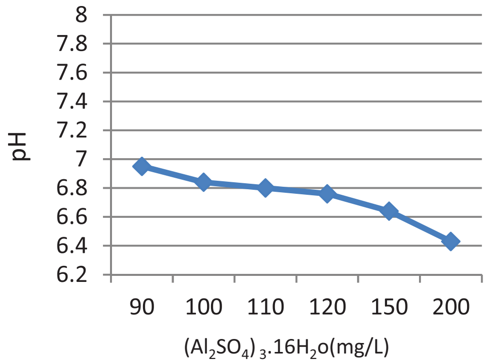

Fig. 15. Effect of concentrations of aluminum sulfate on pH.

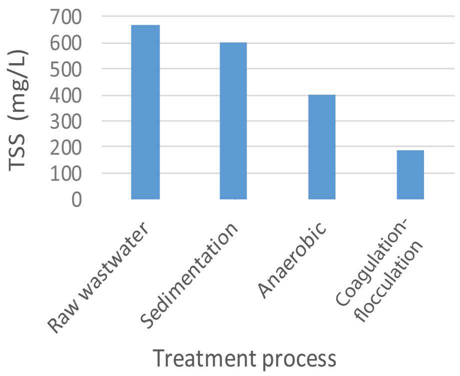

Fig. 16. TSS amount before and after treatment.

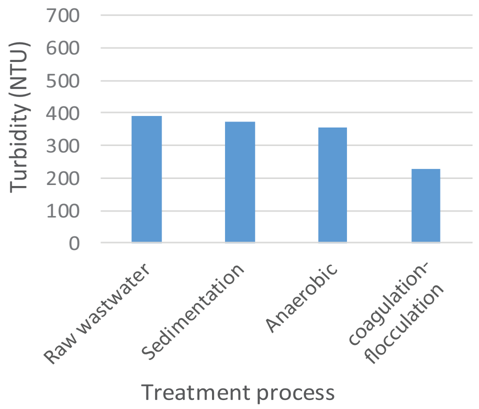

Fig. 17. Turbidity amount before and after treatment.

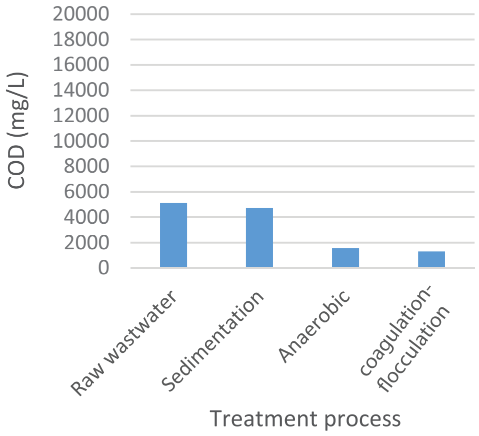

Fig. 18. COD amount before and after treatment.

concentrations more than 110 mg L^{-1} is slowly, therefore, with respect to consume coagulants; 110 mg L^{-1} can be selected as the optimal concentration.

Figs. 16–20 show the results of wastewater analysis before and after treatment. As shown in Fig. 16–19, at the final stage, pollution indices such as TSS, turbidity, COD, and TDS were reduced up to 71%, 41%, 75%, 49%, and 53% respectively. The results show achieving more efficiency of contaminant removal needs more different treatment process such aerobic and membrane filtration can be followed each other as hybrid process. On the other hand, the results show that TDS and EC values increased slightly after the coagulation-flocculation process compared with the anaerobic process, and this is due to the addition of a coagulant to the wastewater. Fig. 20

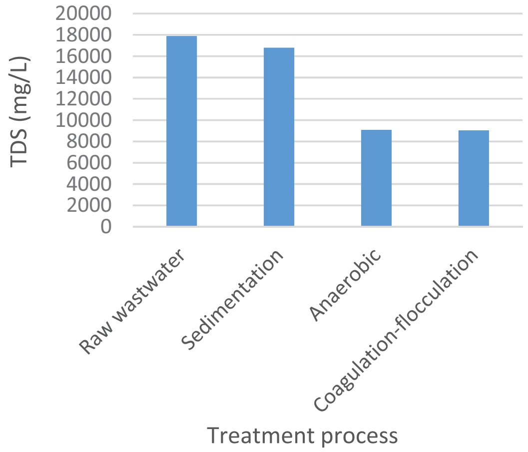

Fig. 19. TDS amount before and after treatment.

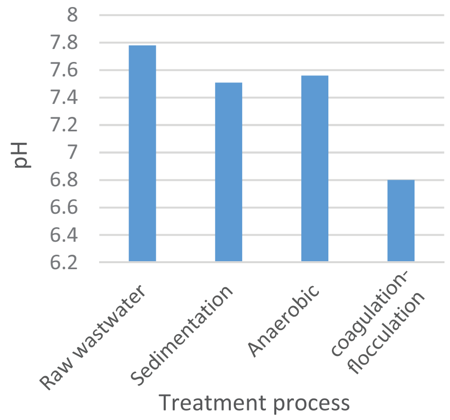

Fig. 20. pH amount before and after treatment.

Table 6
Final results of optimum properties of slaughterhouse

Wastewater characteristics	TSS (mg L^{-1})	Turbidity (NTU)	COD (mg L^{-1})	pH	TDS (mg L^{-1})
Raw wastewater	666	391	5,136	7.78	17,890
Sedimentation	600	371.5	4,750	7.51	16,805
Anaerobic	399	355	1,570	7.56	9,080
Coagulation-flocculation	190	230	1,295	6.8	9,040

shows that the variation of pH for processes before coagulation-flocculation is negligible the sensible reduction of pH after coagulation-flocculation is due to the addition of aluminum sulfate and formation of sulfuric acid in the wastewater.

4. Conclusion

In this experimental study, Slaughterhouse wastewater treatment was evaluated by performing anaerobic and coagulation-flocculation as a hybrid process. The final results of optimum condition for each steps of wastewater treatment are shown in Table 6.

Based on the results of this work, it can be concluded:

- Sedimentation as a simple pretreatment process can reduce a portion of contaminants and it is economic and suitable for small cities where there is enough land for construction.
- Anaerobic treatment results in the reduction of the portion of COD.
- Coagulation-flocculation can reduce most of the suspended and colloidal particles and aluminum sulfate is a suitable coagulant for this purpose. On the other hand, adding coagulant generates various ions and causes an increase in TDS and EC. So, the optimal dose of aluminum sulfate was determined.
- Anaerobic and coagulation-flocculation hybrid process does not meet the COD and TSS standards to dispose of the wastewater and thus a supplementary treatment process is required. Therefore, we are going to perform aerobic treatment and membrane filtration processes to achieve reclamation standards at the next step for this treated wastewater.
- With respect to coagulants consumption, the findings demonstrated that the suitable dose of aluminum sulfate was around 100 mg L^{-1}.

Acknowledgment

The authors would like to thank Quchan Islamic Azad University Water and Wastewater Laboratory and Quchan slaughterhouse for helping and cooperating with this research project.

Symbols

TSS	–	Total suspended solids
COD	–	Chemical oxygen demand
TDS	–	Total dissolved solids
EC	–	Electrical conductivity

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