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Applying the aerobic/membrane hybrid process for treatment of slaughterhouse wastewater

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ABSTRACT

Slaughterhouse wastewater is difficult to treat due to a large amount of organic matter, blood, nutrients, and suspended solids. Therefore, in this study, a combination of aerobic treatment and nanofiltration was investigated as a hybrid process to remove contaminants from bovine and sheep slaughterhouse effluent. Treatment operation in the aerobic process was performed at three levels of sludge concentration (30, 50, and 70 mg/L), four levels of aeration rate (0.3, 0.4, 0.5, and 0.6 m^3/h), and four levels of aeration time (2, 4, 6, and 8 h). The nanofiltration process was performed at three transmembrane pressure levels of 8, 12, and 16 bar and various filtration times. Findings indicated that aerobic treatment with 50 mg/L of sludge concentration, 0.5 m^3/h aeration rate, and 4 h aeration time reduced chemical oxygen demand (COD), total suspended solids (TSS), and total dissolved solids (TDS), by almost 95.4%, 15.3%, and 2.8%, respectively. The results also showed that increasing the filtration time caused the fouling phenomenon which decreased the permeate flux. Applying the filtration process led to more TDS, COD, and TSS reduction, by about 34%, 95%, and 98.8%, by this process respectively. Consequently, at the end of the hybrid process, the amounts of TDS, COD, and TSS reached 6,290, 2.73, and 1.9 mg/L, respectively. These values imply that the treated wastewater complies with environmental standards.

Keywords: Aerobic process; Membrane filtration; Slaughterhouse; Wastewater treatment

1. Introduction

Slaughterhouse wastewater has been classified as industrial waste in the agricultural and food industries [1]. Wastewaters from slaughterhouses and meat processing industries were classified by Environmental Protection Agency (EPA) as one of the most environmentally harmful wastes [1]. Non-automatic slaughterhouses consume much water due to the cleaning processes such as washing before and after animal slaughtering and cleaning floors and equipment [2–4].

The water consumption per slaughtered animal ranges from 1 to 3.8 m^3 based on the type of animal, and the processes employed in the slaughterhouse [5]. Most of this amount is discharged as wastewater, with volumes from 0.4 to 3.1 m^3 per slaughtered animal reported in the literature [5].

Effluents from the slaughterhouses of meat industries are heavily polluted and contain a high biodegradable organic material concentration. Therefore, the pollution capacity

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of these industries is high [6]. The wastewater from a cattle and sheep slaughterhouse is a mixture of the processing water from both the slaughtering and cleaning, which causes many changes in organic matter concentration. The main pollutant in slaughterhouse effluents is organic matter. The organic load contributors to these effluents are paunch, feces, fat and lard, grease, undigested food, blood, suspended material, urine, loose meat, soluble proteins, excrement, manure, grit, and colloidal particles [7,8].

Most of these industries discharge their effluents to sewer or watercourse. Untreated slaughterhouse wastewater entering into a municipal sewage treatment system may create severe problems due to its very high biological oxygen demand (BOD) and chemical oxygen demand (COD) [9].

Several studies have described the common characteristics of slaughterhouse wastewater (SWW) and reported that raw wastewater has BOD 834–16,680 mg/L, COD 1,790–27,800 mg/L), pH 6.7 to 8, and electrical conductivity (EC) = 1.99–9.14 mS [10,11]. Discrete disposal of water effluent from the slaughterhouses is a significant source of pollution. This affluent, if not disposed of properly, then causes various health and environmental issues. Singh et al. [12] suggested that there should be a controlled system of liquid waste collection in the premises of a slaughterhouse. Wastewater is sometimes discharged into the environment without any treatment or with only a simple pre-treatment [13,14]. Discharging this wastewater into water bodies is one of the critical environmental issues for slaughterhouses [13–15]. The environmental issues of slaughterhouses due to poor management and planning could badly affect the health and environment. There should be a strict policy regarding environmental management by regulatory authorities for slaughterhouses [16]. To comply with water pollution control standards and to reduce the cost of sewer surcharges, these industries have to apply an adequate treatment of their effluents. Therefore, treating slaughterhouse wastewater is very important for preventing high organic loading to municipal wastewater treatment plants. The most common methods used for treating slaughterhouse wastewaters are fine screening, sedimentation, coagulation–flocculation, trickling filter, and activated sludge processes [17–20].

Ogbomida et al. [16] have suggested appropriate wastewater treatment procedures for a slaughterhouse to prevent the contamination of the environment, including surface and groundwater. Cost-effective implementation of technology and management approaches, such as separation by screening (solids), protein recovery (blood separation), primary settling, etc. should be carried out to reduce the period of delayed degradation [16].

The conventional activated sludge process is widely used in treating municipal and industrial wastewater. However, this technique usually suffers failure in the sedimentation and thickening due to the excess growth of filamentous bacteria in sludge suspension [21]. To overcome this drawback and improve system performance, membrane filtration technology was introduced in biological wastewater treatment [22]. Today, membrane technology is widely used in many fields such as wastewater treatment due to its low energy requirements, easy scale-up, low space need, and proper separation. Thus, its use to treat slaughterhouse wastewater seems to be appropriate [23,24].

Although different treatment technologies have been applied for treating SWW, there are insufficient studies that examine nanofiltration and combined aerobic and membrane systems for the treatment of SWW. The removal of BOD and COD was reported in some studies in the field of poultry slaughterhouse wastewater treatment in which ultrafiltration, nanofiltration, reverse osmosis, static granular bed reactor, and anaerobic membrane bioreactors (AnMBR) had been leveraged [25–30].

In our previous study [31], the treatment of slaughterhouse wastewater was evaluated by performing anaerobic and coagulation–flocculation methods as a hybrid process. The combined process means using a series of processes in which raw effluent enters the first process, then the output is used as feed for the next process, and the final output is the main product, during which the properties are measured, the effect is reported. Anaerobic treatment resulted in the reduction of the portion of COD. Coagulation–flocculation reduced most of the suspended and colloidal particles, and aluminum sulfate was a suitable coagulant for this purpose. However, adding coagulants introduced various ions, caused an increase in total dissolved solids (TDS). The anaerobic and coagulation–flocculation hybrid process did not meet the COD and total suspended solids (TSS) standards for the disposal of wastewater, and thus a supplementary treatment process is required. The approved wastewater treatment standards for different pollution indices of BOD, COD, total nitrogen (TN), total phosphorus (TP), TSS, and pH in Iran are 50–100 mg/L, 100–200 mg/L, 10–20 mg/L, 1–2 mg/L, 40–100 mg/L, and 6–9, respectively [32].Thus, the present study investigates the combined application of aerobic treatment and nanofiltration as a combined process for treating the initially treated wastewater to achieve reclamation standards.

2. Materials and methods

2.1. Materials

The wastewater used in this experimental work was collected from a bovine and sheep slaughterhouse located in Quchan, Iran, and was labeled as raw wastewater. The pollution indices values of the wastewater, which the coagulation–flocculation and anaerobic hybrid process has previously treated, are TSS = 190 mg/L, COD = 1,295 mg/L, pH = 6.8, and TDS = 9,840 mg/L [31].

The aerobic sludge for initial seeding was obtained from the final clarifier of the wastewater treatment plant of Quchan. The aerobic sludge for initial seeding was obtained from the final clarifier of the wastewater treatment plant of Quchan. The sludge contains various aerobic microorganisms with 100 mg/L of (TSS) and 50 mg/L of volatile suspended solids. These activated microorganisms were accustomed to environmental and operational conditions.

The membrane was a UTC-70UB flat-sheet membrane made by Toray Company Located in Tokyo, Japan, with an effective surface area of 98.5 cm^2 in the module. This membrane consists of three layers: (a) 0.3 μm polyamide as the dense layer, (b) 45 μm polysulfone as the support layer, and (c) 100 μm polyester as the base layer. The molecular weight cut-off of the membrane is 200 Da.

2.2. Aerobic activated sludge and membrane filtration pilot plant

The pilot plant consists of an aeration tank equipped with a mixer, an air compressor, a sedimentation tank, an intermediate tank for membrane filtration, a membrane cell, two pumps, a flow meter, a pressure gauge, and some flow regulating valves as assembled as shown in Fig. 1.

The effluent was first treated through sedimentation, anaerobic treatment, and coagulation–flocculation processes. Then, it poured into the aerobic process aeration tank as feed for the present experimental study [31]. In this study, an aerobic activated sludge system was used. The effluent from the activated sludge process entered an intermediate tank for holding and subsequent use in the nanofiltration process.

3. Experimental procedure

First, experiments were performed on three levels of sludge concentration, four levels of aeration time, and a fixed aeration rate. After determining the best aeration time and sludge concentration, experiments were performed to determine the appropriate aeration rate. Then, the effluent which had been treated under the optimal sludge concentration, aeration rate, and aeration time was used as feed for the membrane process. The output of the aerobic process entered the sedimentation tank and then the intermediate tank for nanofiltration operation. The filtration process was performed for 4 h at three levels of transmembrane pressure (TMP) including 8, 12, and 16 bar, and sampling was performed every hour. After each step of the experiment, the following characteristics of treated wastewater were measured: pH (Metrohm 80027 pH meter, Switzerland), COD (Aqualytic AL800 spectrophotometer, Germany), TSS (using a conventional analytical method), and TDS (Jenway 407 conductivity meter, Germany). The analyses for pH, COD, TDS, and TSS were performed using the standard procedures of examining water and wastewater [33].

4. Results and discussion

4.1. Aerobic process

As the first step in the aerobic process, experiments were performed at a constant aeration rate for three levels of sludge concentration and four levels of aeration time. The results of this step are shown in Figs. 2 and 3. In this process, microorganisms are the leading cause of the decomposition reactions of organic matter, and the energy obtained from this metabolism is used to survive in their biological functions [13]. According to Figs. 2 and 3, the removal of the desired values of TDS, TSS, and COD was obtained at a sludge concentration of 50 mg/L and aeration time of 4 h. In the next step in the aerobic process, experiments were performed at a fixed aeration time for three levels of sludge concentration and four aeration rate levels.

As shown in Figs. 4 and 5, with the changes in aeration rate over a fixed 4 h aeration time, the values of TDS, TSS, and COD were first decreased and then did not change much as the aeration rate increased. Therefore, the optimal aeration rate of 0.5 m^3/h was selected. These results show that an adequate amount of active microorganisms and sufficient oxygen concentration in the aeration tank can quickly reduce organic matter. The results showed that the aerobic process could reduce TDS from 9,840 to 9,559 mg/L, TSS from 190 to 161 mg/L, and COD from 1,295 to 60 mg/L in wastewater; which is equivalent to a reduction of about 2.8%, 15.3%, and 95.4%, respectively.

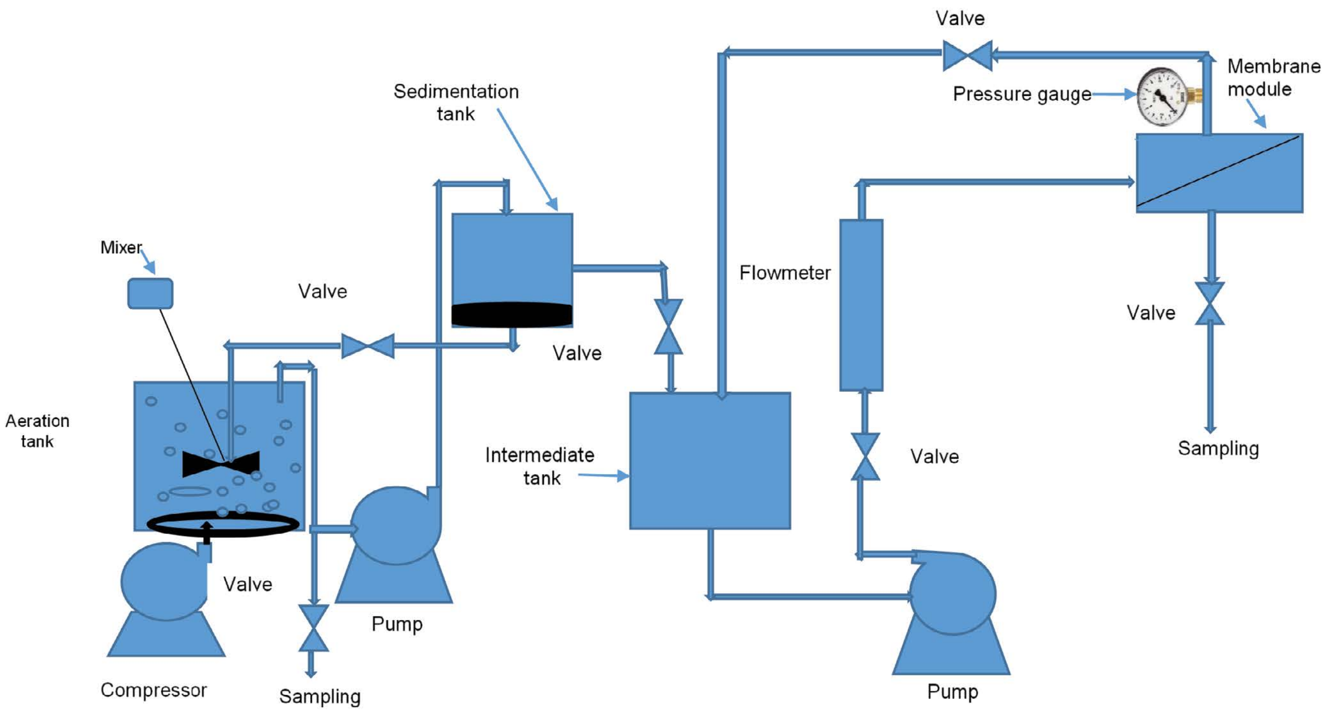

Fig. 1. Schematic diagram of the aerobic and membrane hybrid process.

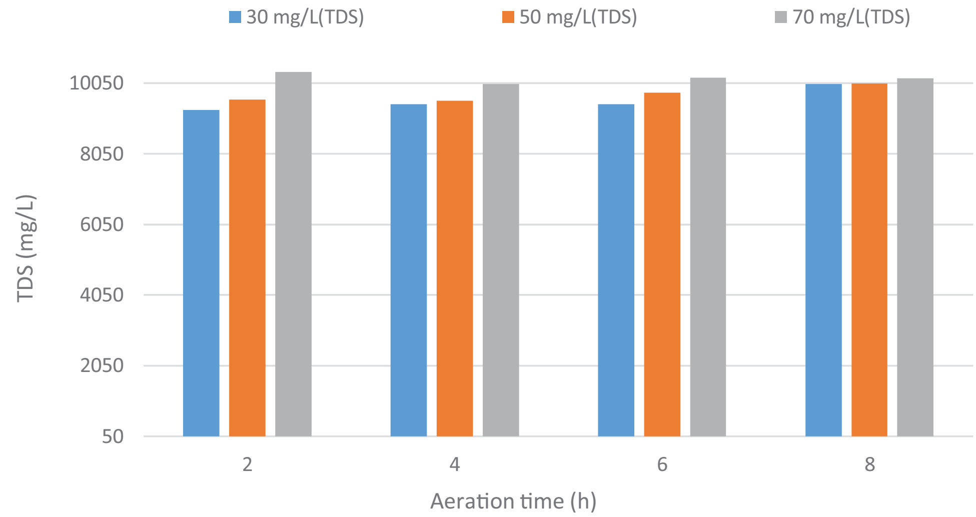

Fig. 2. TDS variations for different levels of sludge concentration and aeration time at 0.3 m^3/h aeration rate.

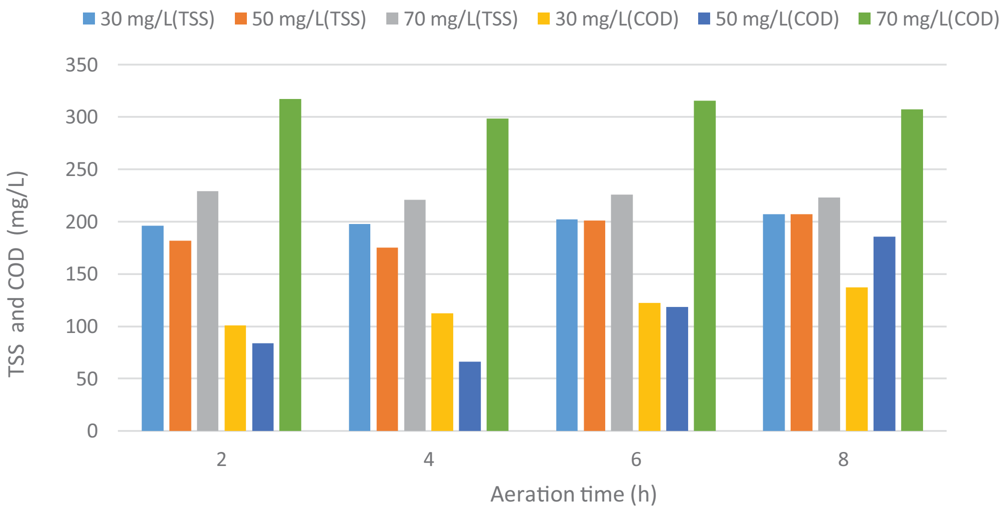

Fig. 3. TSS and COD variations for different levels of sludge concentration and aeration time at 0.3 m^3/h aeration rate.

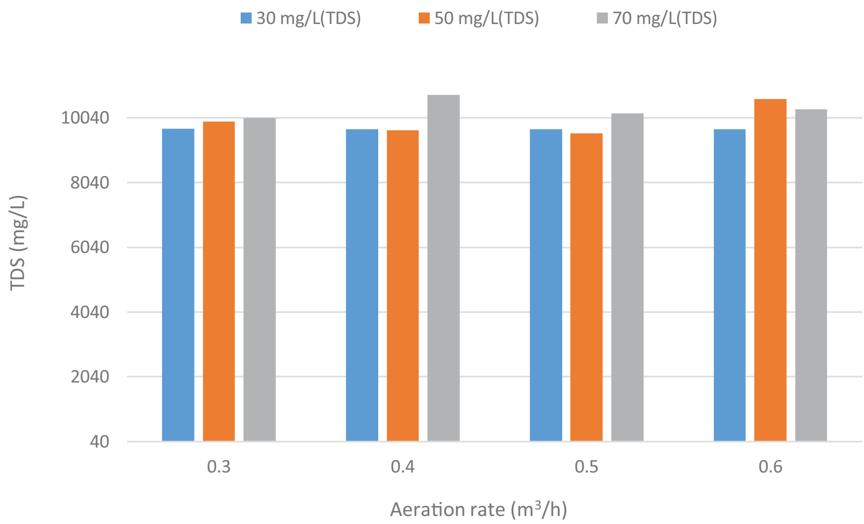

Fig. 4. TDS variations for different levels of sludge concentration and aeration rate at 4 h aeration time.

Liu et al. [4] were investigated the formation and characteristics of aerobic granular sludge for biological nutrient removal of slaughterhouse wastewater in a sequencing batch bioreactor. Their experimental results showed that the removal efficiency of COD reached 95.1%.

4.2. Membrane filtration process

Since in the previous study, the coagulation process was used, adding the coagulant increased the wastewater TDS [31]. Therefore, the use of the nanofiltration process for wastewater treatment is more logical. The results of nanofiltration experiments considering the changes in the two parameters of TMP and filtration time at three levels of TMP and the four levels of filtration time are shown in Figs. 6 and 7. With increasing TMP, the water transfer rate is higher than other wastewater components, so TDS, COD, and TSS values are reduced. However, according to Fig. 8, the flux increased due to the increased driving force of the process. Increasing the filtration time led to membrane fouling; therefore, the flux and the values of TDS, COD, and TSS of the permeate were decreased.

Applying the nanofiltration process reduced TDS, TSS, and COD to 6,290, 1.9, and 2.73 mg/L, equivalent to a reduction of about 34%, 98.8%, and 95%, respectively. These results show that the wastewater treated using the combined process complies with environmental standards for its discharge.

In this regard, Jensen et al. [34] could achieve over 95% COD removal from the Australian cattle slaughterhouses wastewater using an AnMBR. Likewise, Gürel and Büyükgüngör [5] used a membrane bioreactor to remove organic substances and nutrients from slaughterhouse plant wastewater. They obtained the removal efficiencies of 97%,

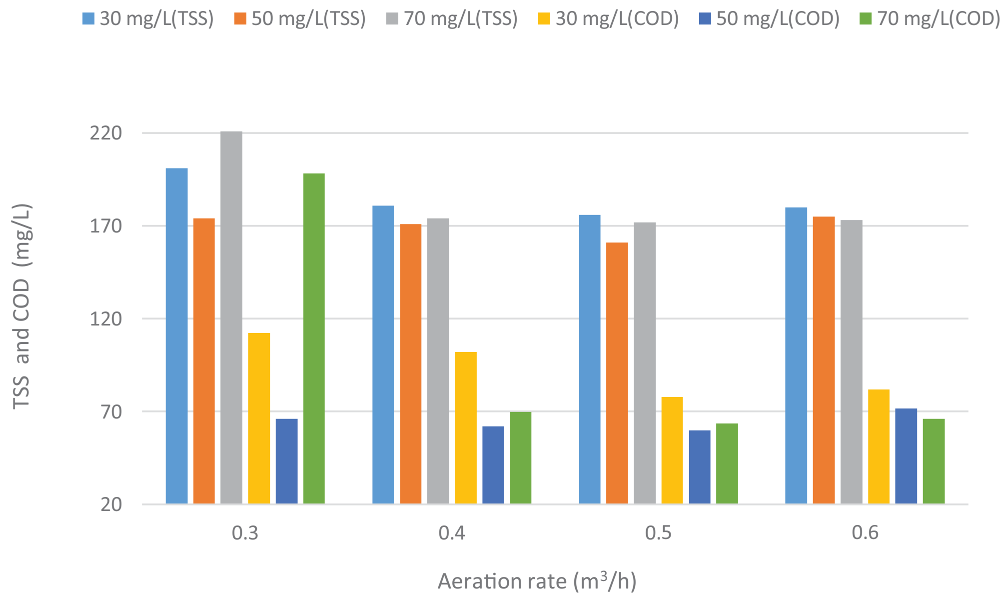

Fig. 5. TSS and COD variations for different levels of sludge concentration and aeration rate at 4 h aeration time.

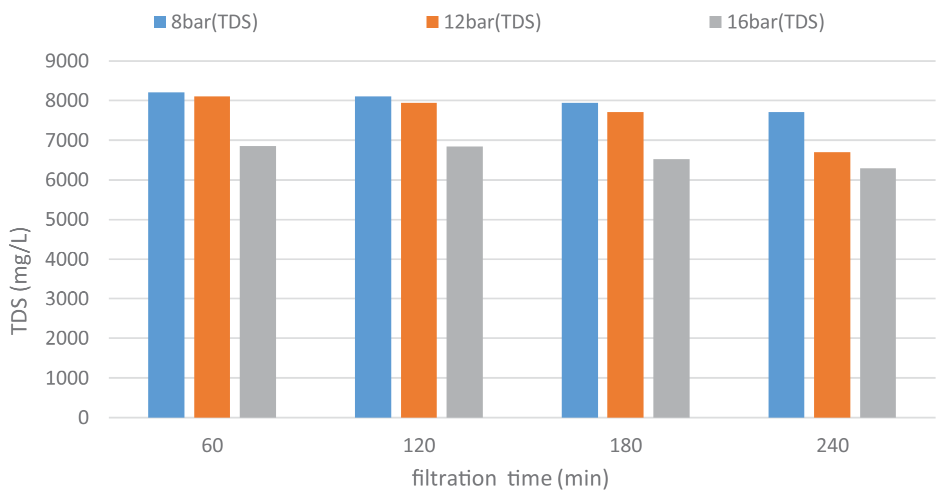

Fig. 6. TDS variations in permeate overtime at different TMPs.

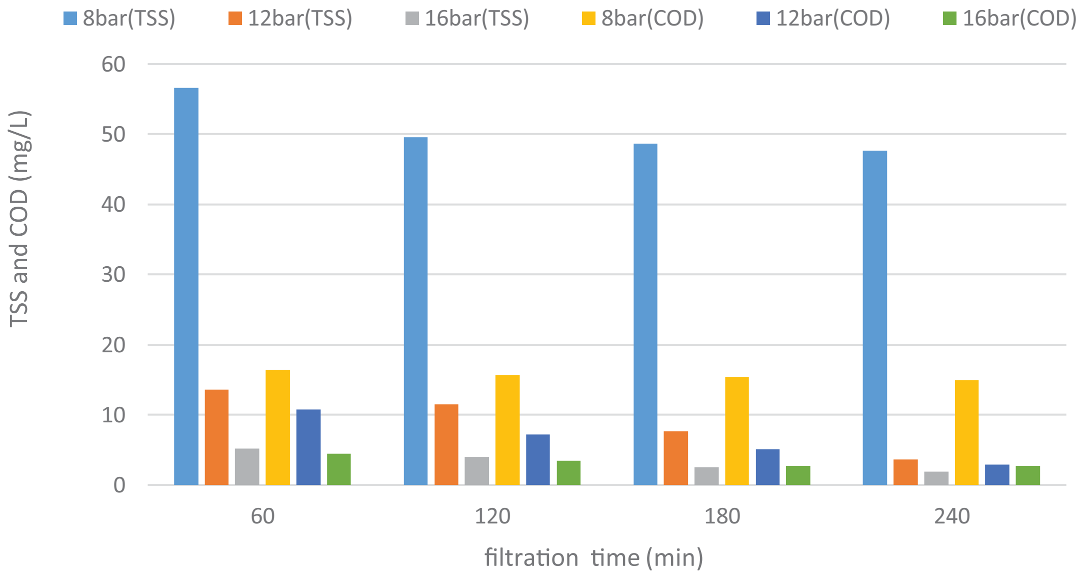

Fig. 7. TSS and COD variations in permeate overtime at different TMPs.

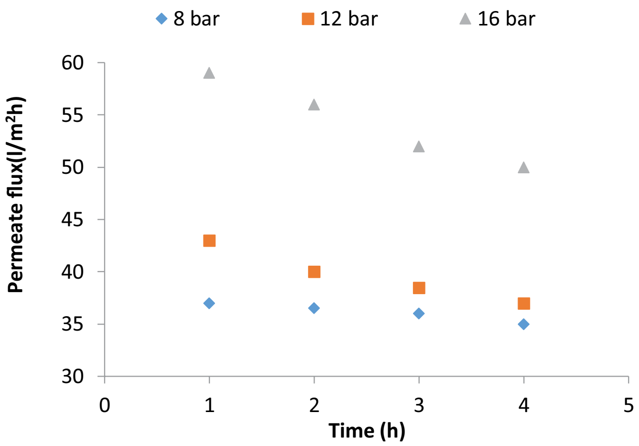

Fig. 8. Permeate flux overtime at different TMPs.

96%, 65%, and 44% for COD, total organic carbon, TP, and TN, respectively. These studies confirm that the obtained results are consistent with the literature on membrane processes in wastewater treatment.

5. Conclusion

In this study, the aerobic and nanofiltration hybrid process was explored on the pilot-scale to remove contaminants from a slaughterhouse effluent. The results showed that TDS, COD, and TSS values were reduced by almost 2.8%, 95.4%, and 15.3% at the best treatment condition using the aerobic process, respectively.

Moreover, the nanofiltration of wastewater led to the production of clear wastewater. Increasing TMP caused more water molecules to pass through the membrane than other components, so TSS and COD were reduced significantly at the end of filtration. Finally, at the best treatment condition using the hybrid process, the values of COD, TDS, and TSS were reduced by about 99.8%, 36%, and 99%, respectively. These results show that the treated wastewater complies with environmental standards.

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