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Removal of chloride, sulphate, TOC and COD from aqueous solution by vacuum distillation

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ABSTRACT

In this study, treatment of strong wastewater that cannot be treated economically with conventional methods was investigated using vacuum distillation method. Low evaporation temperatures (50–60°C) and low vacuum pressures (30, 40, 60 and 70 kPa) were selected as experimental conditions. The evaporation studies were carried out at 60°C in seawater, while the salinity reduction was investigated under a vacuum of 30–70 kPa and a removal rate of up to 90% was achieved. In a study, on chemical industry wastewater, carried out at 60°C temperature and under a vacuum of 50, 60 and 70 kPa experimental conditions was achieved that COD parameter reduced from 18,800 mg/L to 500 mg/L in 180 min. Albeit COD removal was based on the experiments, parameters such as TOC, pH, sulphate and distillate amount were also resolute.

Keywords: Vacuum evaporation; Water recovery; Desalination; TOC

1. Introduction

The methods applied for water and wastewater treatment vary depending on the pollution parameters and the discharge or reuse of the treated water. The reuse of wastewaters treated with new technologies is possible, but the treatment of strong wastewaters with such technology is practically impossible [1]. The most common method for the recovery of untreatable wastewater is distillation. Distillation is a method of separating fluids with different boiling points. This process of water purification has been in use since 200 AD. The debacle associated with this traditional distillation method is the high-energy requirements, scaling and requires a large operating area for the huge amount of water. Vacuum and catalyst method has been successfully employed in food and chemical industry wastewater treatment. Vacuum distillation systems that allow water to evaporate at low temperatures were first installed in producing freshwater from seawater. In addition, it is preferred in advanced treatment systems to purify chloride at high concentrations (12–21 g/L) [2].

In previous studies, the operating conditions and efficiency of different processes such as, desalination using solar energy [3], reverse osmosis [4], membrane distillation [5], electrodialysis [6] and nanofiltration [7] have been investigated for seawater treatment. Of these, reverse osmosis systems have been widely applied in desalination plants. However, treatment and discharge of brine wastewater containing chloride at high concentrations cause environmental disadvantages [8]. In addition, application of reverse osmosis in desalination causes membrane biofouling and high amount of energy is required to run the system. Therefore, it is necessary to reevaluate how efficiently and economically the vacuum distillation systems can be expended to obtain fresh water from seawater.

In recent years, different scholars and researchers have investigated the applicability of vacuum distillation system for untreatable wastewaters by conventional methods. Researches have been carried out on the treatment of petroleum refinery wastewaters [9], coke-plant wastewa-

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ters [10], TNT red water [11], phenolic wastewater [12], paper mill wastewater [13], hexanitrobibenzil wastewater [14], and olive mill wastewater [15]. With the above processes, adequate treatment efficiencies and distillates were obtained with distillation systems in wastewater treatment.

In this study, usage of vacuum evaporation systems in environmental engineering was investigated as an alternative for treating different characteristics of wastewater. The first aim of the study was to test the performance of the system, removal of chloride and sulphate from seawater, and determine conductivity in the distillate. In addition, COD and TOC removal from the chemical industry wastewater containing heavy pollutants was examined, and pH changes were determined. Besides, the amounts of distillate collected in both studies were determined.

2. Materials and methods

2.1. Seawater and wastewater

Wastewater from seawater and chemical industry was used to test the performance of the vacuum distillation system. Seawater samples were collected from the shores of the Marmara Sea near Avcilar in Istanbul province, Turkey. Chemical industry wastewater was taken from an industry in Marmara Region, which produces organic peroxides, initiators, accelerators and paint driers. The parameters of seawater are given in Table 1, whereas wastewaters parameters in Table 2.

2.2. Experimental setup

The vacuum distillation reactor that is used for the lab-scale study has a volume of 10 liters. Rocker 811 scientific compressor was expended to provide the vacuum in the system. Experiment steps were designed as follows; filling the reactor with 3 L wastewater, then a vacuum pump was commenced after the temperature was controlled. The evaporated wastewater was condensed by glass condenser and amassed in the sample collection Erlenmeyer flask. Condensed volume, pH, COD, TOC and sulphate analyses were carried out on a sample of distillate every after 15 min. Cooling was provided by circulating the cold water through the coolant by a pump. Fig. 1 shows the vacuum distillation experimental setup.

Table 1
Contents of seawater

	Conductivity µS/cm	Chloride mg/L	Sulphate mg/L
Seawater	27,780	12,134	1,110

Table 2
COD, TOC and pH parameters of chemical industry wastewater

	pH	TOC mg/L	COD mg/L
Chemistry industry	5.7	7,768	18,800

2.3. Analysis

The chloride and sulphate concentrations of aqueous solution were determined by Dionex ion chromatography ICS 1100 with Degas, Chromeleon SE. An analytical column AS9-HC (4 × 250 mm) with AG9 guard column (4 × 50 mm) and ASRS-300 (4 mm) suppressor in ion-exchange mode was used to determine water-soluble anions (Fluoride F^-, Chloride Cl^-, Nitrite NO_2^- Nitrate NO_3^-, Bromide Br^-, Phosphate PO_4^{3-} and Sulphate SO_4^{2-}). The eluent was 9 mmol Na_2CO_3 and the flow rate of the eluent was set at 1.0 mL/ min. The injection volume was 25 µL for all detection. Peak identification was confirmed based on a match of ion chromatograph retention times and standard samples. Limit of detection determined as mean, equal to 3 times the standard deviation of the field blank value corresponded to a range of 0.008–0.023 ng/L for anions. Limits of quantification were between 0.028 and 0.078 ng/L for anions. TOC was measured by SHIMADZU TOC-V CPH analyzer. Conductivity is measured by a conductivity meter.

3. Results and discussion

3.1. Seawater studies

In the initial studies, chloride and sulphate removal from seawater were explored and conductivity values were determined. Seawater studies were conducted under 30, 40, 50 and 60 kPa vacuum and at 60°C. Conductivity, chloride and sulphate parameters were determined from the samples collected from the vacuum evaporation system every after 15 min until 180 min of operation.

Beginning with the first samples, the conductivity parameter decremented rapidly and the distillate conductivity decreased by 99%. The conductivity values of the samples decreased to 173, 139, 75 and 42 µS at the vacuum values of 30, 40, 60 and 70 kPa after 90 min respectively. As the vacuum increases, the conductivity decreases further. Figs. 2 and 3 shows the conductivity and chloride concentrations variations in the process of distillation of the seawater sample. The chloride concentrations of the samples were removed considerably to 88, 66 and 36 mg/L under vacuum values of 50, 60 and 70 kPa within 180 min respectively. By changing the vacuum from 50 to 70 kPa, 99% chloride abstraction efficiency was achieved.

Similarly, the concentrations of sulphate in seawater varied between 12–28, 8–24 and 4–17 mg/L under vacuum values of 50, 60 and 70 kPa, respectively after 180 min. Fig. 4 shows the variation of sulphate concentrations during distillation. After 90 min, 98–99% removal of sulphate concentrations of distillates was achieved. About 3 L of seawater sample was expended for vacuum distillation and the variation of distillate quantities were determined. The total distillate amounts obtained at 60°C temperature after 180 min are given in Fig. 5. The distillate amounts were found to be 97 – 138 – 220 and 353 mL in 180 min for 30, 40, 60 and 70 kPa, respectively.

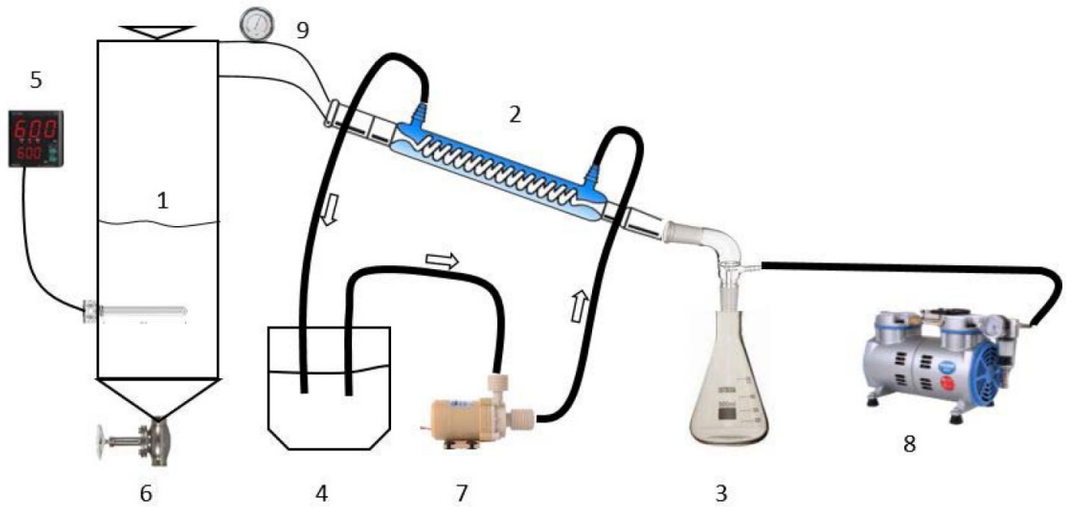

Fig. 1. Vacuum distillation experimental setup (1. Reactor, 2. Condenser, 3. Sample Unit, 4. Cooler water, 5. PID Thermometer control device, 6. Reactor bottom valve, 7. Cooler water pump, 8. Vacuum pump, 9. Manometer).

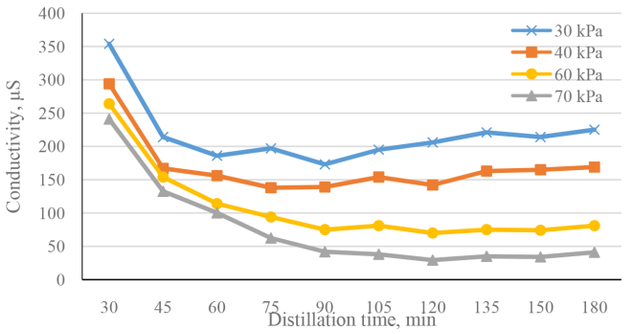

Fig. 2. Conductivity of seawater samples by vacuum evaporation (60°C).

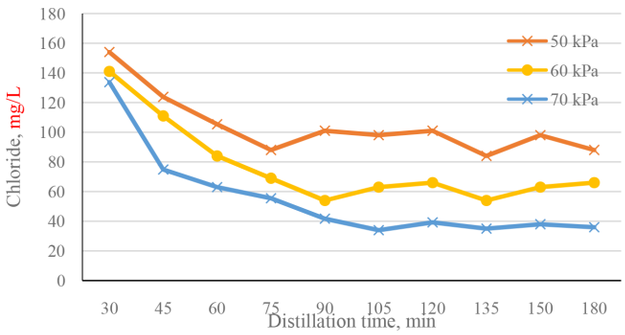

Fig. 3. Chloride concentrations of seawater sample by vacuum distillation process.

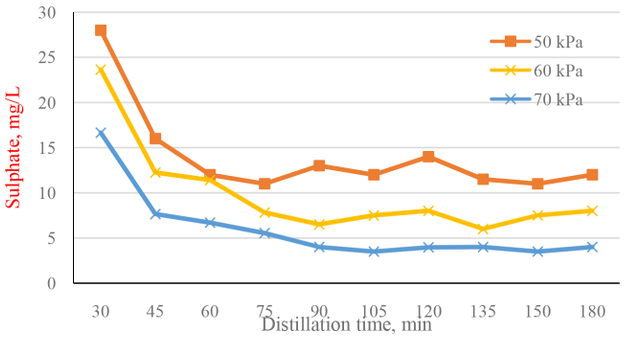

Fig. 4. Sulphate concentrations of seawater sample by vacuum distillation process (60°C).

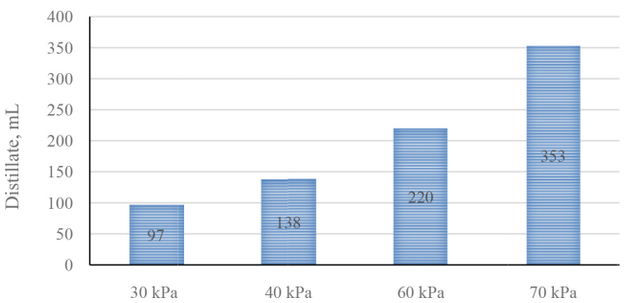

Fig. 5. Total distillate amounts of seawater sample by vacuum distillation process in 180 min (60°C).

3.2. Chemical industry wastewater studies

The pH change in the samples obtained from chemical wastewater used in further studies is given in Fig. 6. When the vacuum pressure changed, the pH values did not change significantly and were measured as 4.5–5.0. However, during vacuum pressure changes, different values were measured in the first samples, while the pH values are similar during the distillation.

Figs. 7 and 8 shows the TOC and COD values of strong wastewater distillation. When the vacuum is increased, the TOC values decreased from 540 to 388 mg/L. In the case of increased vacuum, 94–95% of removal rate was achieved within 180 min.

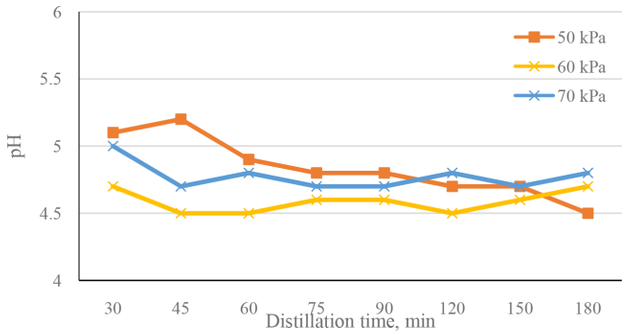

Fig. 6. pH values of chemical industry wastewater by vacuum distillation process (60°C).

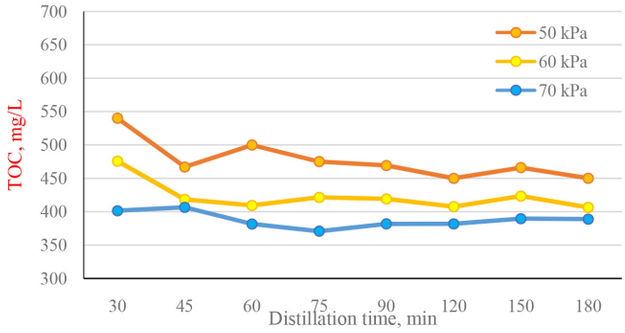

Fig. 7. TOC values of chemical industry wastewater by vacuum distillation process.

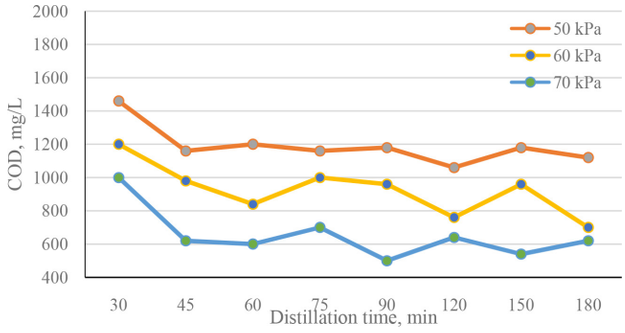

Fig. 8. COD values of chemical industry wastewater by vacuum distillation process.

In the same study, the COD values of the samples were found to decrement from 1,460 to 500 mg/L. Abstraction efficiencies of COD values were determined as 94, 96 and 97% at 50, 60 and 70 kPa vacuum values, respectively.

Three litres of wastewater were utilized for vacuum distillation of chemical industry wastewater and the change of distillate quantities was resolute. The total distillate amounts obtained after 180 min are given in Fig. 9. Distillate quantities for the 180 min distillation time were determined as 739, 770 and 868 mL for 50, 60 and 70 kPa, respectively.

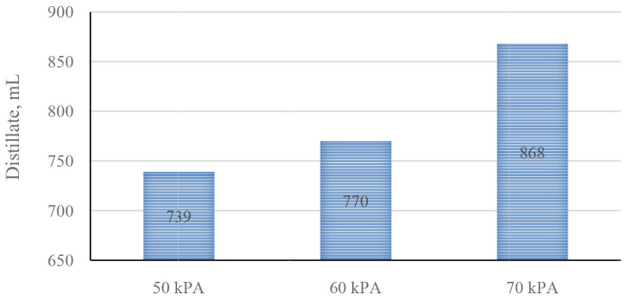

Fig. 9. The total distillate amounts of chemical industry wastewater by vacuum distillation process (60°C).

3.3. Economical evaluation of vacuum evaporation system

The hazardous waste disposal business in Turkey is carried out with a licensed disposal company as well as all over the world. The cost is approximately $1650/tonne excluding concrete storage, intermediate storage, equipment and other expenses. The volume reduction for hazardous waste targeted by the vacuum distillation method was calculated as 29% in 180 min under 60°C temperature and vacuum of 70 kPa. The electricity cost of the laboratory scale device was calculated as $ 172/tonne in 180 min.

4. Conclusions

In the lab-scale vacuum distillation system, chloride and sulphate from seawater and TOC and COD removal from chemical industry wastewater were examined and the following evaluations are made:

- The total volume of recycled water per hour by vacuum distillation ranges from 3.5 to 12.5%.
- The vacuum distillation system is highly effective for abstraction of impurities that are impossible under conventional treatment processes.
- High concentration of chloride has a higher removal rate than sulphate in the seawater.
- The pH of the distillate does not change with the vacuum pressure but it depends on the low boiling point components in the wastewater.

The vacuum distillation system is highly effective in the treatment of wastewater with high content of TOC and COD parameters.

Recycling of water and wastewater can be achieved by vacuum distillation in a short time and economically without the membrane or reverse osmose processes and chemicals.

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