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Boron removal from geothermal water by air gap membrane distillation

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ABSTRACT

In this study, boron removal from geothermal water with an air gap membrane distillation (AGMD) system was examined. The utilization idea of the waste heat sources in geothermal power plants for membrane distillation process is the basis of this research. During the study, six different types of commercial membranes were used and the influence of operating parameters such as feed temperature and velocity, coolant temperature and velocity and air gap distance on the permeate flux and rejection performances were investigated. First, the operating parameters were optimized and the experiments were performed with three different saline water concentrations (0.1–1.5–3% (w/v)). Then, the effect of boron concentration on permeate flux was investigated by using a synthetic geothermal water. Finally, a real geothermal water was used for the determination of AGMD system performance and min. 99.5% boron removal efficiency was achieved for all membranes. The results showed that permeate water boron concentrations were < 0.5 mg/L for all membranes which are in accordance with irrigation standards. As a result, the air gap width, feed velocity and temperature were found as dominant factors affecting the permeate flux. And also, it was observed that feed water boron concentration did not affect permeate water flux.

1. Introduction

Geothermal resources can be evaluated for several uses comprising swimming and bathing, cooling, aquacultural pond heating, heat pumps, agricultural drying, process heat for industries, greenhouse and space heating and power generation [1]. Sweden, China, Japan, USA, and Turkey have 55% of the world energy usage with the largest annual energy consumption. Because of Turkey placed in the Alpide belt, it has a high geothermal capacity which is about 31,500 MWt and nearby 77.9% of this capacity is in the Western side of Anatolia [2,3]. Due to the usage of geothermal resource increases in Turkey, management of potential environmental impacts are becoming important day by day. The most serious environmental effect of the geothermal energy is the pollution of surface and subterranean waters with toxic heavy metals because of the fractured well structure, defective re-injection operations and unrestrained discharge of waste geothermal fluids. As a result, these waters become thermally and chemically polluted [4]. The most common neutral species in the geothermal fluids are B, SiO_2, NH_3, As and noble gases. Other anions and cations are Cl^-, K^+, $SO_4^{=}$, Br^-, F^-, I^-, HCO_3^-, Na^+, Li^+, Ca^{2+}, Mn^{2+}, Cs^+, Rb, Mg^{2+} and Fe^{2+}, respectively. The most predominant salt component is sodium chloride which increases the salinity of the geothermal waters and boron has a crucial impact on vegetation, surface waters and aquatic life [1,5]. Additionally, boron has the ability to generate complexes with Cd, Ni, Pb and Cu ions which have higher toxicity than those heavy metals alone when they reach to groundwaters. Due to these reasons, removal of boron from geothermal water becomes so important and geothermal fluids should have seemed as precious resources which can be evaluated in industrial and agricultural applications along with for drinking water supplies [6,7].

Removal of boron can be provided by several technologies such as adsorption, coagulation, ion-exchange, electrocoagulation and membranes processes such as electrodialysis, Donnan dialysis, hybrid processes with reverse osmosis (RO), adsorption membrane filtration and ultrafiltration-microfiltration [6,8–12]. Besides that, membrane distillation (MD) system can be used for the geothermal water desalination.

During the recent years, there were several studies about the removal of boron from geothermal water using different technologies except for MD. Yilmaz et al. reached a 95% boron removal efficiency from geothermal water by electrocoagulation method which had a 24 mg B/L initial boron concentration [11]. Cengeloglu et al. used RO technology for the removal of boron from the geothermal water. They reported that the highest boron removal efficiency was obtained at pH 11 and the boron

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rejection was > 95% [6]. Removal of boron from geothermal water was also investigated by Kabay et al. During the studies, they used a hybrid process which included ion exchange system following by a submerged ultrafiltration module and they reached a permeate water boron concentration below 1 mg B/L [13]. Yavuz et al. examined the effect of pH on boron removal efficiency from geothermal water using with small pilot RO system. They reported that boron rejection was 94.5–95% for pH 10.5 and permeate water boron concentration was about 0.5 mg/L [14]. In the literature, there is no study specifically focused on the boron removal from geothermal water. But Sarbatly et al. and El Amali et al. were studied about the geothermal water desalination by MD [15,16]. El Amali et al. reached about 97% salt rejection value with 3–5 kg/m^2·h permeate flux while Sarbatly et al. reduced the initial TDS concentration to 102 and 119 ppm and they observed that utilization of geothermal decreased the produced water cost.

MD is a thermal driving filtration process in which a vapor pressure gradient occurs through a hydrophobic membrane. As a consequence, vapor molecules are transferred from high vapor pressure to the low water vapor pressure across a hydrophobic membrane. Generally, MD consists of four main configurations which are air gap (AGMD), sweeping gas (SGMD), vacuum (VMD) and direct contact membrane distillation (DCMD) [17]. In AGMD system, membrane and cold condensation surface are isolated from each other by a layer of stagnant air which reduces the heat conduction throughout the membrane [18]. Feed water has a direct contact with the surface of the hydrophobic membrane and permeate water is condensed on a condensation plate. AGMD is appropriate for all direct contact MD applications [19].

In the present work, the removal efficiency of boron from geothermal water was investigated at different operating conditions of AGMD process. The aim of this study is to treat the boron which is discharged from power generation plants using the waste heat of plant in AGMD. The waste heat of geothermal power plant was used as a driving force in MD system so the operational costs which is the most important parameter decreases. After the basic performances of membranes were determined with optimization and salt rejection experiments, the removal efficiencies of boron and flux values were investigated at the synthetic and real geothermal water. In the literature, there is no any comprehensive study for boron removal from geothermal water by membrane distillation system and this study is the first and most extensive work in this area.

2. Experimental

2.1. Equipment and material

The experimental tests were performed with the laboratory scale AGMD module, as shown in Fig. 1. The membrane cell consists of three compartments. The feed solution was passed from the bottom part of the left-side cell while the cooling water was circulated from the bottom part of the right side cell. Permeate was collected in the middle part of membrane cell which was separated from the coolant channel by 1 mm stainless steel plate. Hydrophobic flat sheet membrane, which has 44.18 cm^2 of active membrane area, was located in the middle of the feed channel and permeate collection part. The water vapor molecules diffuse throughout the membrane pores and then condensate on the stainless steel plate. Membrane module was designed to have 3 different air gap distances with 3, 7 and 11 mm. Feed water and coolant temperatures were adjusted by the heating bath (Lab Companion-CW 05G) and refrigerated circulator (Lab Companion RW 0525G). Both of them were pumped in co-current flow regime with peristaltic pumps (Masterflex L/S).

During the study, six different commercially available PP, PTFE and PVDF membranes with various pore sizes were used for the boron removal from synthetic and real geothermal water by air gap membrane

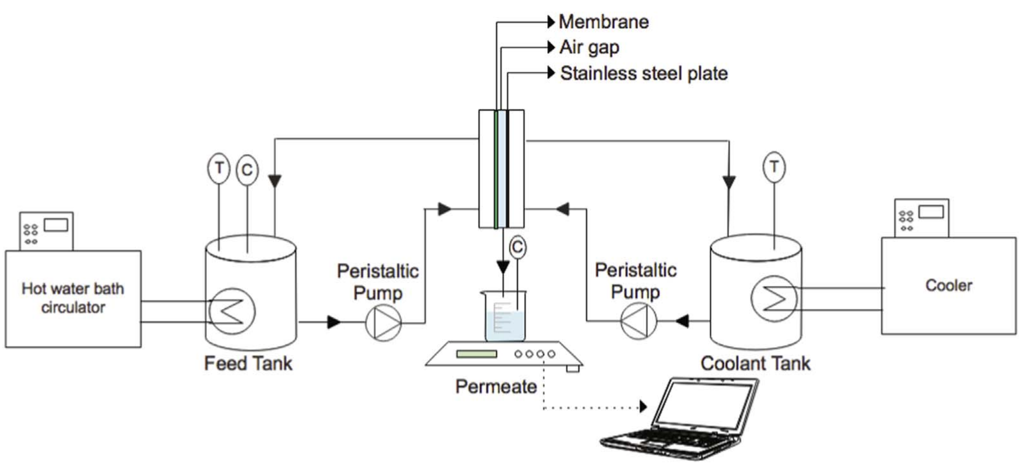

Fig. 1. Schematic diagram of laboratory scale AGMD system.

Table 1
Typical characteristics of the commercial hydrophobic membranes[a].

Membrane type	Mean pore diameter (μm)	Thickness (μm)	Air permeability[b] (psi)	Liquid entry pressure (psi)	IPA buble point (psi)
PTFE	0.22	102–152	0.2–0.4	> 14.5	> 20
PTFE	0.45	76–127	0.4–0.8	> 11	> 10
PVDF	0.22	140–250	–	–	40–60
PVDF	0.45	140–250	–	–	25–40
PP	0.20	110	–	–	15.0
PP	0.45	110	–	–	11.0

[a] The data is taken from Sterlitech company.
[b] Notes: Measured as ft^3/ft^2/min at 125 Pa.