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Membrane distillation of industrial cooling tower blowdown water

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ABSTRACT

The potential of membrane distillation for desalination of cooling tower blowdown water (CTBD) is investigated. Technical feasibility is tested on laboratory and pilot scale using real cooling tower blowdown water from Dow Benelux in Terneuzen (Netherlands). Two types of membranes, polytetrafluorethylene and polyethylene showed good performance regarding distillate quality and fouling behavior. Concentrating CTBD by a factor 4.5 while maintaining a flux of around 2 $l/m^{2}*h$ was possible with a water recovery of 78% available for reuse. Higher concentration factors lead to severe decrease in flux which was caused by scaling. Membrane distillation could use the thermal energy that would otherwise be discharged of in a cooling tower and function as a heat exchanger. This reduces the need for cooling capacity and could lead to a total reduction of 37% water intake for make-up water, as well as reduced energy and chemicals demands and greenhouse gas emissions.

1. Introduction

In industry it becomes more important to close water cycles. Closing water cycles and thus (internal) reuse of water relieves water stress on the environment and on other activities such as urban or agricultural water use. Industrial processes often need a considerable amount of fresh water. Among these processes, large water consumers are cooling towers (CT) using 60–70% of the total fresh water demand in industry [1]. In the cooling tower, water evaporates resulting in an increased concentration of salts and other contaminants. This leads to problems such as scaling and corrosion. Hence the concentrated cooling tower water is regularly discharged from the tower. This discharge is called cooling tower blowdown water (CTBD). Make-up water is added to the tower to compensate for the evaporated water and the CTBD. When the blowdown water can be reused, after treatment, this will save the need for about 15% of the make-up water [2]. Electrical conductivity is generally the parameter that is used to determine the rate for blowdown as salts are the main cause for problems in the tower. Treatment of blowdown water should therefore focus on the removal of salts. However, a high concentration of TOC also causes problems due to fouling. Removal of TOC is therefore also required. Several treatment options can be thought of such as desalination using reverse osmosis (RO), nanofiltration (NF) or electrodialysis (ED). A disadvantage of pressure driven membrane processes is the sensitivity of the membranes towards fouling while electrodialysis minimally removes TOC. Another option is the use of membrane distillation (MD) [3]. Although this is also a membrane process, pressure is low, temperature on the membrane is high and the hydrophobic nature of the membranes may lead to less fouling problems compared to other membrane desalination technologies [4,5]. The advantage of the combination of MD and cooling towers, is the presence of waste heat [6]. Whereas RO and ED use electricity to create a driving force, MD uses (waste) heat as driving force. Membrane distillation is a thermally driven transport of water vapor through non-wetted porous hydrophobic membranes, the driving force is the vapor pressure difference between the two sides of the membrane, which is usually caused by a temperature difference between the two sides of the membrane. Therefore the option of using membrane distillation for the treatment of cooling tower blowdown water is investigated. Desalination by membrane distillation could use the heat that would otherwise be cooled away in a cooling tower. This results in a reduction of required cooling capacity by cooling towers, thus reducing the need for more make-up water intake, costs and GHG emissions [7,8].

Cooling tower blowdown water at Dow Benelux BV in Terneuzen (NL) was used for the experimental evaluation of desalination of CTBD. The main research focuses on whether it is possible to desalinate CTBD water by membrane distillation, and what type of problems that are met. As biocides, biodispergents,

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corrosion inhibitors and antiscalants are present, it is expected that they may affect the membranes and may causes leakage or wetting of the membranes. The pores of the hydrophobic membrane may become hydrophilic because these components may enter the pores and make them hydrophilic. Furthermore the high TOC concentration may result in fouling. Both short term laboratory experiments and long term pilot scale experiments are performed to identify the general treatability and preferential set points as well as the long term behavior such as fouling impacts. As far as the authors are aware, this is the first time that CTBD from a real industrial site is used for desalination by MD on pilot scale. Experiments were executed to investigate the flux while concentrating the CTBD, to determine maximum recovery, and to test if a constant flux could be maintained over a longer period at a set concentration factor.

Potential water saving when recovering distilled water from CTBD and reusing it as make-up water will be discussed. Also the total concept to integrate membrane distillation with the cooling system of an industrial site is discussed. When this desalination is done by membrane distillation, it does not only produce desalinated water, but also uses heat. This could therefore replace part of the cooling done by the cooling towers and decrease the required capacity from the towers.

Table 1
Composition of Elsta and LHC3 cooling tower blowdown (raw water).

		Elsta		LHC3
		Average (st dev)	Number of data points	Average (st dev) 2 datapoints
EC	μS/cm	3944 (610)	11	4600 (140)
Cl^-	mg/l	549 (36)	11	487 (12)
NO_3^-	mg/l	88 (21)	8	93 (43)
HCO_3^-**	mg/l	65 (16)	8	46 (22)
SO_4^{2-}	mg/l	1109 (82)	11	1056 (68)
Na^+	mg/l	332 (41)	11	408 (8)
Ca^{2+}	mg/l	437 (45)	11	351 (14)
Mg^{2+}	mg/l	61 (7)	11	49 (0)
K^+	mg/l	81 (12)	11	59 (0)
Dissolved Fe	mg/l	< 0.2	11	< 0.2
P	mg/l	2 (3)	10	8 (0)
TOC	mg/l	53 (5)	8	
TSS	mg/l	< 15	11	
Chlorophyll A	mg/l	< 0.2	11	
pH		7.5–8	11	6.5

** This value is not very accurate as it is highly dependent of pH, and balancing with the gas composition above the liquid.

2. Material and methods

2.1. Raw water

Cooling tower blowdown water at Dow Benelux BV in Terneuzen (NL) was used for the experimental evaluation of desalination of CTBD. Two types of cooling tower waters were used: LHC3, which is cooling the exothermal processes from the Dow factories, and Elsta, which is the powerplant that provides Dow with power and steam. Currently, sand filtered surface water is used as the source for make-up water at Dow. The water is relatively high in TOC concentration [9] which is not removed during filtration and mainly consists of humic acids. Cooling tower blowdown water from the Elsta cooling tower near the Dow site in Terneuzen amounts 1*10̂6 m^3/yr. The cooling tower is operated as a natural draft counter flow CT. The make-up water for the cooling tower was supplied and monitored by Evides for 7.5 yrs (01–01–2005 to 15–06–2012) before the start of the experiments with an average conductivity was 676 μS/cm. This water is concentrated in the cooling tower by a factor 5–6.5 reaching a conductivity of 3500–4500 μS/cm. CTBD water quality from the Elsta cooling tower was analyzed for main composition (Nov 2012, Sept 2013–Jan 2014). The results are shown in Table 1. Chemicals are added to the cooling tower. These chemicals are: H_2SO_4 96% for pH-adjustment, corrosion inhibitor (Nalco, 3DT187), biodispersant (Nalsperse 7348, 4.3 mg/l), corrosion inhibitor (Nalco, 3DT199, 3.2–6.3 mg/l sodium benzotriazole), NaClO. The blowdown is currently discharged to the river directly (2 × 10 h per day).

The second type of cooling tower blowdown was called LHC3 and the composition of the blowdown is shown in Table 1. The make-up water of this tower is for at least 50% fed by the effluent from the industrial wastewater treatment plant at the Dow premises. The chemicals provided to the cooling tower are different as it is provided by a different supplier.

2.2. Laboratory experiments

Laboratory experiments were performed in a direct contact membrane distillation set-up with a membrane area of 429 cm^2. Blowdown water from two cooling towers, Elsta and LHC3, were used as raw water. A constant feed temperature and temperature difference were maintained in the set-up using an external heat exchanger. A temperature of 70 °C was maintained. Temperature difference ($T_{feed} > T_{distillate}$) was 10 °C. The circulation flow of the feed water was 3–4 l/min. Two different membranes were used: polytetrafluorethylene (PTFE) and polyethylene (PE) membranes. In all experiments no pretreatment was used. Ion concentrations in the feed and distillate were measured using ICP analysis. Electrical conductivity was measured every minute in the feed and distillate, and once in the raw water, as this was a single batch with constant quality.

2.3. Pilot experiments set-up

The pilot plant was built by Aquastill. It was built as a liquid gap MD system using external heat exchange (see Fig. 1). In liquid gap MD, water vaporizes on the hot side of the membrane, diffuses through the membrane pores and condenses on the cold side of the membrane producing a liquid gap between the membrane and the cooling plate. The temperature difference was 10 °C at a top temperature of 70 °C. A spiral wound module with membranes of 7.2 m^2 was used. The pilot experiments were all performed with the Elsta CTBD. Two runs were performed with the raw CTBD without any pretreatment or additives. Two runs were performed using a filter cartridge with an average pore size of 10 μm, as pretreatment to prevent larger particles such as sand to enter the system. The configuration was then changed to a configuration with internal heat exchange (based on the Memstill principle [10]). Two more runs were done. All experiments were performed in a feed-bleed configuration. The pressure drop at the feed side along the membrane was used as an indication for the need of cleaning. Pressure increase does not tell anything about membrane fouling, however it indicates fouling of the channels. Membrane fouling is indicated by a decrease of flux. The set-up however was not automated to measure a flux and therefore it was only possible to use pressure as an indicator for the need for cleaning. Cleaning started when the pressured had increased to 300 mbar and was done with HCl. The pH was lowered to 3 and the cleaning was stopped when the pressure had dropped to below 50 mbar.

2.4. Analysis of precipitation

Precipitation was analyzed using light microscopy and scanning