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Improvement of the Membrane Distillation performance through the integration of different configurations

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ABSTRACT

In this work, the integration of two Membrane Distillation (MD) configurations was investigated as possible means to reduce the specific thermal energy consumption. Tests of Direct Contact Membrane Distillation (DCMD) and Air Gap Membrane Distillation (AGMD) were carried out on 40 cm^2 lab-scale modules equipped with a commercial flat polypropylene membrane of 0.2 μm, by sending distilled water as feed. The performance of integrated schemes with the feed exiting from the DCMD module sent as coolant stream in the AGMD module – where it is heated by the permeating vapor, before being recycled back to the DCMD unit – was analyzed. When compared to the single DCMD units, the integrated DCMD-AGMD systems led to lower specific thermal energy consumption, as well as higher Gained Output Ratio (GOR) and permeate production.

1. Introduction

In Membrane Distillation volatile species and water evaporate from an aqueous stream (feed) through microporous hydrophobic membranes and are collected, after condensation, at the permeate side. In this way, it is possible to recover purified water from a variety of polluted streams. Many are the fields where MD can find application, like the treatment of water and wastewaters, the seawater and brackish water desalination, the production of ultrapure water for semiconductor industry and, more recently, the dehydration of solid particles (El-Bourawi et al., 2006; Alkhudhiri et al., 2012; Wang and Chung, 2015; Drioli et al., 2014; Criscuoli et al., 2016). Despite the efforts made in last years for the production of membranes and modules specifically designed for MD, its implementation at industrial scale is still limited. Main critical points are the lack of long-term investigations that are essential for ensuring a good performance in time, and the high specific thermal energy consumption of the process that affects the cost. Concerning this last issue, the research in progress is addressed to the use of renewable energy, like the solar one (Wang et al., 2009; Koschikowski et al., 2009; Vega-Beltran et al., 2010; Mericq et al., 2011; Saffarini et al., 2012; Cipollina et al., 2012; Suárez et al., 2015), and to the enhancement of the internal heat recovery. Among the MD configurations, Direct Contact Membrane Distillation and Air Gap Membrane Distillation are those more investigated. In particular, DCMD is the most studied configuration at lab scale, due to its simplicity, while AGMD is the preferred configuration for the design and production of modules to be used at pilot scale, mainly because of the possibility to make the internal heat recovery inside the module-self. Specifically, in DCMD one side of the membrane is in contact with the aqueous feed (hot) to be treated while the other side is in contact with the distillate (cold). Both liquid streams cannot penetrate inside the membrane pores, thanks to the hydrophobic character of the membrane and, then, a difference of vapor pressure is established across the membrane, due to the temperature difference of the two streams. The distillation occurs by evaporation of the water/volatile species at the feed side,

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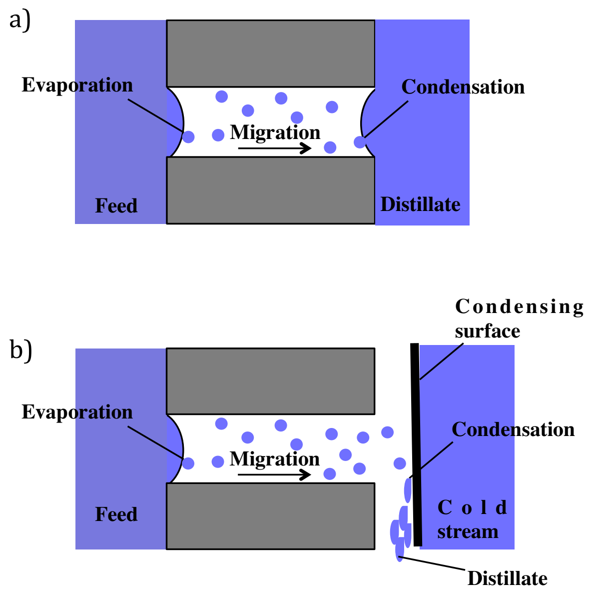

Fig. 1 – Scheme of the distillation process in DCMD (a) and AGMD (b).

the migration of water vapor/volatile molecules through the dry-pores and the condensation of the vapor/volatiles in the cold distillate (Fig. 1a). Therefore, in the membrane module the feed stream is cooled down while the distillate is heated up. In AGMD, the aqueous feed (hot) is still in contact with one membrane surface while at the other side an air gap is created between the membrane and a condensing surface. The condensing surface is in contact with a cold stream. In this configuration, the water vapor/volatile species move from the feed side through the dry-pores, the air gap and, finally, condense on the condensing surface (Fig. 1b). Inside the module, the feed stream is cooled down while the cooling stream is heated up due to vapor/volatiles condensation. In both configurations there is, then, the need to supply heat to the feed and to remove heat from the cold stream (the distillate and the cooling stream for DCMD and AGMD, respectively).

Depending on the specific MD configuration, the internal heat recovery can be obtained in different ways:

- in DCMD, by coupling the membrane module to a heat exchanger where the feed and distillate streams are sent for a pre-heating and pre-cooling, respectively. The two streams are, then, heated and cooled to the desired temperatures in other heat exchangers, before being recycled back to the membrane module (see Fig. 2a);
- in AGMD, by using the feed as both cold and hot stream (Winter et al., 2011; Guillen-Burrieza et al., 2011; Jansen et al., 2013). In this case an external heat source is needed to provide the necessary difference of temperature across the membrane (see Fig. 2b).

Recently, a Vacuum Multi-Effect Membrane Distillation (VMEMD) unit has been designed, where the AGMD occurs in different stages, each one working at lower temperature and pressure than the previous one (Heinzl et al., 2012; Zhao et al., 2013; Memsys, 2016). The system is equipped with a steam raiser/heating unit and a condenser.

All mentioned internal heat recovery systems need to work at high feed temperatures (50–90 °C) in order to obtain acceptable fluxes/heat recoveries, and they cannot be efficiently used at lower feed temperatures (e.g., 40 °C). The aim of this work

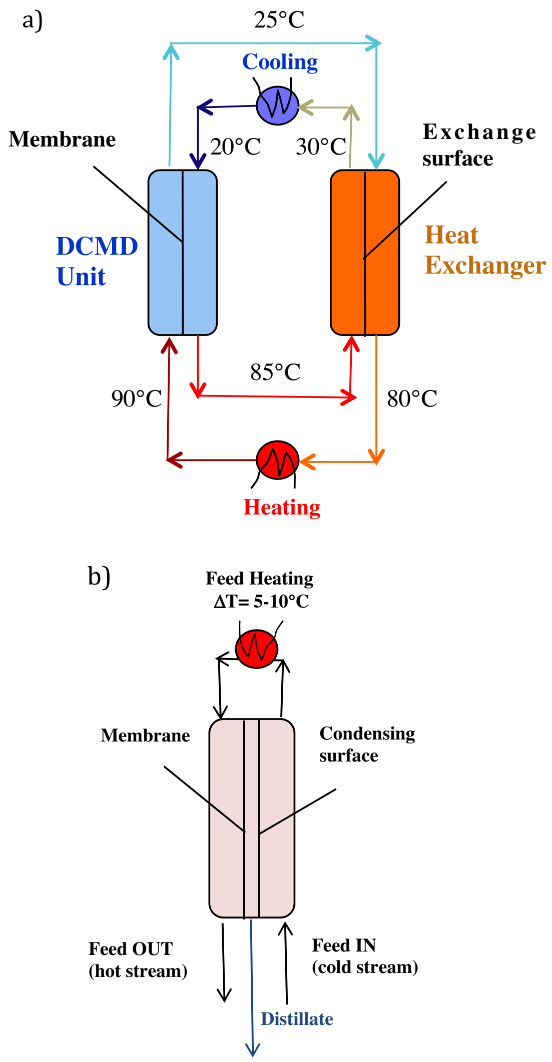

Fig. 2 – Internal heat recovery in DCMD (a) and AGMD (b).

was to evaluate the potential of the integration of DCMD and AGMD as an alternative means to reduce the specific thermal energy consumption of DCMD. The idea behind was to heat the feed stream exiting the DCMD module by using it as a coolant stream in an AGMD unit.

2. Materials and methods

2.1. Membrane and membrane modules

DCMD and AGMD modules were equipped with a 0.2 μm flat polypropylene membrane (Membrana, Germany) having a thickness of 91 μm and 70% of average porosity. In both cases the membrane area was of 40 cm^2 (4 × 10), a typical lab-module size. In the AGMD module, the condensing foil (30 μm thick) was in polypropylene and the air gap was of 3 mm.

2.2. Experimental set-up and procedure

Modules and all lines of the experimental set-up were well insulated to minimize the heat loss toward the environment. The temperatures of the involved streams were read at the module inlets and outlets by four thermocouples, whose correct functioning was previously confirmed by comparing their measures to those of a galinstan thermometer (resolution 0.1 °C). The DCMD distillate flux was calculated by