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A comprehensive review of vacuum membrane distillation technique

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HIGHLIGHTS

- The vital role of VMD for the water shortage and energy crisis is demonstrated.
- The advantages of VMD in exploiting solar energy are reported.
- The different application areas for VMD are presented.
- The integrated processes of VMD and other technologies are introduced.
- Several classical models about heat and mass transfer in VMD process are given.

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ABSTRACT

The purpose of this review is to provide an overview of the vacuum membrane distillation (VMD) process in regard to its advantages, disadvantages and miscellaneous implementations, particularly in the solar energy field. Based on its advantages, a prominent role of VMD configuration in alleviating and tackling a sharp potable water shortage problem is presented, and multiple applications of a VMD hollow-fiber membrane module are exhibited in detail. The impact of different operating parameters on VMD output is dissected, and the diversified membrane characteristics are pointed out. Eventually, the mechanism model of the VMD heat and mass transfer is demonstrated.

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1. Introduction

Two severe problems have emerged in the 21st century: the lack of water resources; and an energy crisis [1]. The problem of a drinkable water shortage is caused by over-population, industrialization, and climate change. And it will turn into a really serious threat to humanity throughout the first half of this century. In particular, in some arid developing countries, these regions do not possess enough facilities and sufficient experience to confront and solve the problem. Thus, supplying potable water to such densely populated places is one of the biggest challenges [2,3].

Four decades ago, membrane distillation (MD) was firstly introduced by Bodell [4] as a new source of supplying clean water based on evaporation out of micro-porous hydrophobic membrane [5]. The first paper was published in 1967 by Findley [6]. However, this technique has not received enough concern until the beginning of 1980s [2,3]. Since that time, MD has started to take its position in the scientific research field [5] as a modern technology [7] for producing potable water [8] from brackish and seawater at affordable cost [9–11]. Also, it can be used as a supplement for conventional desalination processes such as multistage flash distillation (MSF) and reverse osmosis (RO) [12,13].

Membrane distillation (MD) can be defined as a process for removing water vapor from a warmed aqueous feed solution at a temperature lower than 100 °C [14,15]. It has been proposed as an alternative mode of providing potable pure water. In the MD process, the feed solution (mainly water) is not necessarily heated to boiling point. So, some renewable energy sources, such as solar energy, can be coupled with an MD module to heat the feed solution [13], so the MD process is regarded as an energy saving technology.

However, the MD technology also faces some obstacles that needed to be solved. [16]. These barriers include the following: membrane pore wetting [8]; temperature polarization phenomenon [17,18]; high resistance to water vapor flow through membrane due to the presence of trapped air in the pores [19]; and high conductive heat loss over the membrane [20,21].

2. Principle and different types of MD technique

The mechanism of membrane distillation process is illustrated in Fig. 1. In order to maintain the water vapor pressure, there are permanent differences in vapor pressure between the feed and permeate side of the membrane. There are four different modes as shown in Fig. 2: Direct Contact Membrane Distillation (DCMD) [22,23]; Air Gap Membrane Distillation (AGMD) [24,25]; Sweeping Gas Membrane Distillation (SGMD) [26,27]; and Vacuum Membrane Distillation (VMD) [28–33].

Since water vapor condensation takes place inside the membrane module, the external condenser is not necessary for AGMD and DCMD configurations compared to SGMD and VMD. All MD configurations can be applied to desalination for seawater and brackish water [8,34]. However, DCMD, AGMD and VMD are most commonly used for desalination [35,36]. The advantages and disadvantages of each type of MD are summarized in Table 1.

3. VMD technique

Vacuum membrane distillation (VMD) is believed to be attractive and cost-competitive membrane separation technology [8,34]. The vacuum pressure is applied to the permeate side of the membrane [37], as indicated in Fig. 3, and it is maintained at just less than the saturation pressure of the volatile solvent to be separated from the hot feed solution [38].

Vacuum membrane distillation is characterized by a lower operating temperature [34], lower operating hydrostatic pressure [39,40], and less demanding membrane mechanical properties, and higher salt rejection can be achieved for non-volatile solutes.

Compared with the other MD configurations, VMD permits higher partial pressure gradients, and hence higher permeate flux can be achieved [41,42]. In addition, it is better than DCMD in terms of energy consumption/permeate flow ratios, and thermal evaporation efficiency [43,44]. Besides, it overshoots reverse osmosis (RO) in reducing the

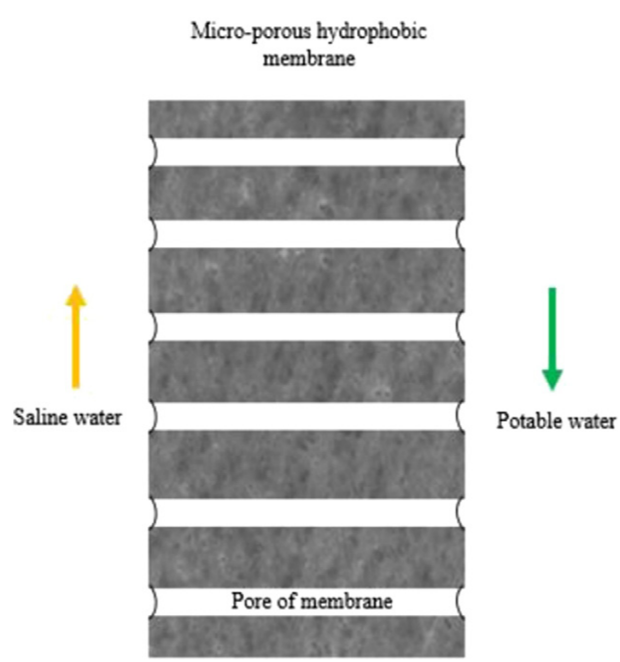

Fig. 1. Principle of membrane distillation process.