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Properties and performances of polymer composite membranes correlated with monomer and polydopamine for flue gas dehydration by water vapor permeation

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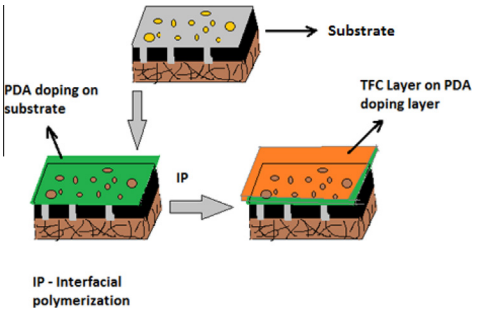
HIGHLIGHTS

- Water vapor was separated by thin-film-composite membrane for flue gas dehydration.
- Membranes were characterized for the presence of thin film and coating layer.
- Effects of polydopamine coating time and monomer concentration were investigated.
- Conditions for preparation of membranes were optimized by their performances.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, PES-based thin film composite (TFC) membranes were prepared by polydopamine (PDA) coating time and different monomer concentrations (i.e. m-phenylenediamine (MPD) and trimesoyl chloride (TMC) concentration). To investigate the influence of coating time by hydrophilic PDA material and monomer concentration, TFC membranes were classified into three different cases and tested under the same operating conditions. Various TFC membranes were characterized by using FE-SEM, ATR-FTIR, AFM and water contact angle to verify the modification on the surfaces. As a result, it is discovered that this membrane modification mainly improves the hydrophilicity on surface and the thickness of selective layer. Water vapor permeance and water vapor/N_2 selectivity obtained here showed a close correlation to coating time and each monomer concentration. TFC membranes fabricated by interfacial polymerization (IP) show the better performances than other techniques for gas separation. Conditions for interfacial polymerization process to be efficiently utilized in permeation of water vapor were optimized to achieve the higher permeance and selectivity.

1. Introduction

Membrane technology has been widely applied in the field of separation process for several years. Polymeric membranes are efficiently used for gas separation apart from microfiltration, dialysis, pervaporation etc., as well as nowadays polymer materials are mostly used as commercial membranes in various applications. Water vapor separation also utilizes a polymeric membrane for applications, including dehydration of natural gas, drying of compressed air, flue gas dehydration, dehydration of organic compounds and steam recovery [1–5].

For flue gas dehydration, removal of water vapor is essential. Presence of water vapor in flue gas may incur the corrosiveness

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of a stack due to the condensation [1,6]. Recovered water from flue gas is also contaminated with the aggressive minor components, such as SO_2 (50–100 vppm) and HCl/HF (1–7 vppm), just before the condensation system equipped in a coal-heated power plant [1,3]. For recovery of water vapor, there are some conventional technologies such as condensation system and absorbents [7,8] For one of the adsorbents, molecular sieve (e.g. synthesized zeolite) shows the large amount of adsorbed water under the low water activity. The zeolites are not only good materials to increase the flux, but also useful in microsystems for chemical synthesis and fuel cell application [9–11]. On the other side, absorbents consume a vast amount of additional energy for their reuse. For the regeneration, a high temperature around 160–200 °C is required [5]. Due to these disadvantages above, water vapor permeation by membrane technology is employed for dehydration of flue gas. If the water vapor is recovered with high quality through polymeric membrane which has the high vapor selectivity, the permeants can be recycled and reused for water supply into steam cycle process [12]. In particular, the energy-efficient membrane technology does not require the additional energy for phase change generally involved in the other conventional dehydration system [13].

In a field of water treatment, polymer-based TFC membranes have been investigated for several years with the extent of similar applications such as reverse osmosis, desalination, etc. [14,15]. Interfacial polymerization (IP) shapes uniform and rigid micropores in the highly thin cross-linked layer. Cross-linked polyamide (PA), a sort of the several classes of polymers synthesized by IP, is the most popular form of commercially available reverse osmosis (RO) membranes [16,17]. A thin selective layer with uniformly packed structure on substrate may serve as a good candidate of high selectivity for gas separation membrane, and has solvent and chemical resistance [18]. Based on the accumulated researches in the bio-inspired material and the potentials for water vapor permeation, the novel membrane combined with interfacial polymerization should be developed to separate the water vapor and improves its performance for gas separation application [19,20].

PES (polyethersulfone), which is widely used, was selected as support layer in this study [21]. Modification on PES substrate by PDA was conducted to improve the hydrophilicity. As an adhesive polymer inspired by mussels, PDA can be strongly attached onto virtually all types of inorganic and organic surfaces, and it maintains the stability of coating area even on the wet surfaces [22]. PDA-coated layer can be prepared by oxidant-induced polymerization, which is material-independent and multifunctional for surface modification [23]. Even though the work on PDA material is quite explored and TFC membrane has been studied for a while, its application generally shows a limit to the osmosis process for desalination or the pervaporation of organic solution [24–27]. Effect of PDA coating time and formation of PA on the permeation of water vapor was investigated. With the optimized coating time of PDA, it is concluded that the effect of monomer concentration ratios (MPD/TMC) also determines the thickness of selective layer and influences the membrane performance. Results obtained in this study may provide significant insight into the vapor separation and membrane design conditions.

2. Materials and methods

2.1. Membrane preparation

2.1.1. Materials

Polyethersulfone (PES, Ultrason® E6020P, BASF, Germany) and N,N-dimethylformamide (DMF, 99%) as a solvent were used to prepare the support layer. Dopamine, *m*-phenylenediamine (MPD) and trimesoyl chloride (TMC) were purchased from Sigma–Aldrich for modification such as hydrophilic coating and IP process. N-hexane (99.9%, Fisher Scientific, NJ) was purchased and used as a solvent for TMC. Deionized water (DI) from a Milli-Q ultrapure water purification system (Millipore) was used for vaporized feed gas. Pure nitrogen was used for dilution and carrier gas. All chemical reagents used for this study were used as received.

2.1.2. Preparation of polyethersulfone (PES) support membranes

The microporous PES membrane was prepared by phase inversion technique similar method as discussed elsewhere [28,29]. Polyethersulfone polymer (15 wt.%) was dissolved in

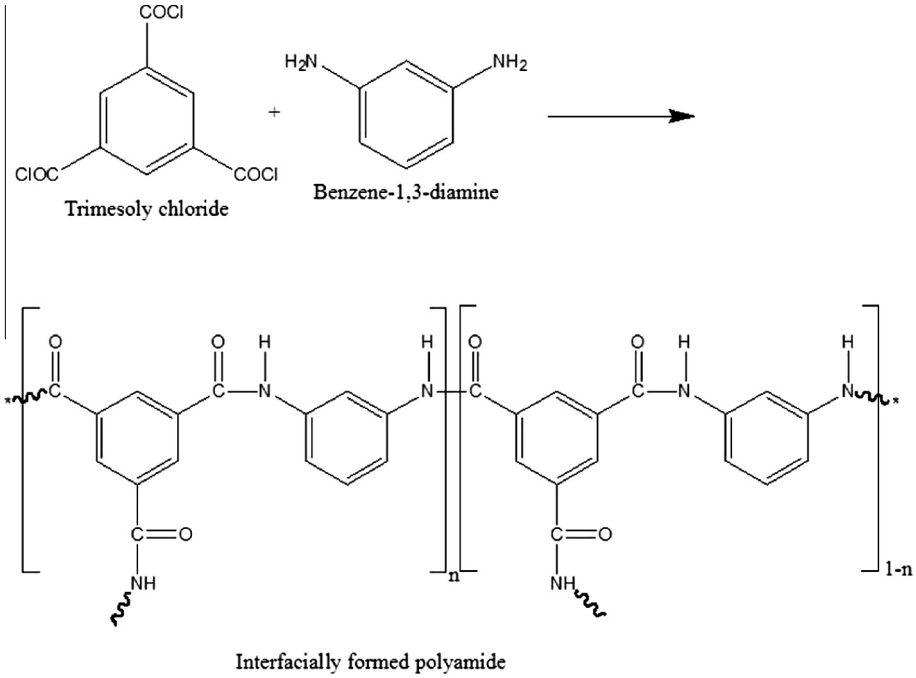

Fig. 1. The chemical reaction of interfacial polymerization by MPD and TMC and the cross-linked polyamide structure.