Modeling and Experimental Study of Gas-Liquid Membrane Contactor

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INTRODUCTION

The greenhouse effect keeps the earth warm by preventing all the sun's heat from escaping back out into space. Carbon dioxide is believed to contribute as a major gaseous contaminant in the atmosphere. Conventional gas processes used in capturing CO_2 from flue gas and natural gas are gas-liquid packed bed columns. These absorbers experience quite a few limitations including high energy utilization, flooding and foaming, entraining, channeling, high capital and operating costs. An alternative and promising technology is gas-liquid membrane contactor modules. Membrane contactors are devices that allow a gaseous phase and a liquid phase to come into direct contact with each other, without dispersing one phase into the other (Luis et al., 2011). Membrane contactor has the advantages of no flooding concert, large gas-liquid interfacial area, no need for phase separation, and easy scale up. In hollow fiber membrane contactor, phase separation after absorption operation is not necessary because one phase is not dispersed into other phase in the module; conversely, the drawbacks of membrane contactor are membrane fouling and membrane wetting which can also introduce another resistance to mass transfer (Luis et al., 2012). The membrane construction and performance depend upon several factors such as type of polymer, composition, temperature of quenching bath and methods of fabrication. Understanding the positive attributes in capturing CO_2 and the alternative technologies such as gas-liquid membrane contactors will contribute to the understanding of how to minimize emission of greenhouse gases into the atmosphere and hence preventing the continuous raise of earth's temperature and the consequences of melting polar ice which will raise the water level and submerged the low lying areas around the world. The present work also highlights the fabrication, characterization and testing of microporous PVDF hollow fiber membranes for use in the absorption of CO_2 from gas mixture in gas-liquid membrane contactor. Information technology is being employed through the use of the efficient COMSOL software package in the modeling and simulation of gas-liquid membrane contactor. The model was validated with the experimental data. Model predictions and experimental results were in good agreement.

BACKGROUND

Membrane gas absorption offers significant advantages compared to conventional absorption towers. Membrane contactors for gas separation have been drawing the attention of many researchers as a substitute technology (Ghasem et al., 2011; 2012; 2013). Due to the separation of the phases by a microporous membrane the contactor may be operated without limitations caused by flooding, foaming, channeling and liquid entrainment. Extremely compact hollow fiber membrane units can be made; resulting in significant savings in weight and required space. Membrane structure and performance depend upon different factors such as polymer choice, composition, temperature of coagulant and dope solution; in addition, spinning factors such as dope extrusion rate, take-up speed, bore fluid type and flow rate have to be optimized at the best conditions to manufacture the high performance membrane. Membrane pores must be small to prevent the penetration of absorbents into the pores and hence membrane wetting, on the other hand, the smaller the pore radius, the larger the liquid entry pressure (Figure 1). Completely wetted pores lead to low absorption

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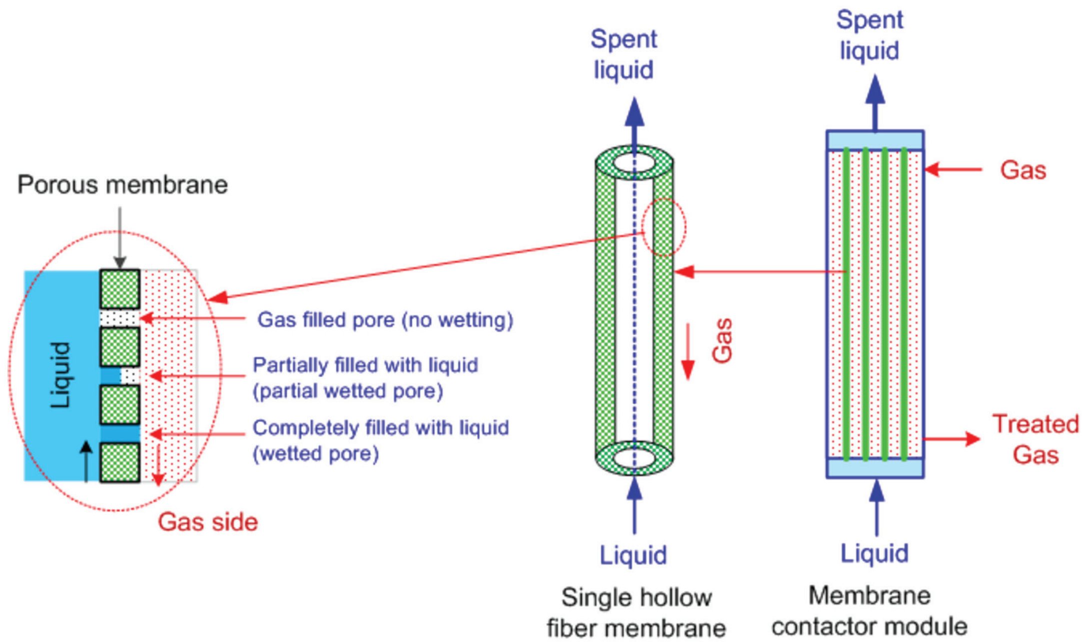
Figure 1. Hollow fiber membrane contactor for gas absorption



rate since the diffusivity of pollutant gas in the liquid phase is very much smaller than that in the gas. Membrane porosity must be large so that a large gas–liquid interface is available for gas absorption.

Microporous poly (tetrafluoroethylene) (PTFE) and poly (vinylidene fluoride) (PVDF) membranes show good gas absorption performance as well as good stability without membrane wetting. Poly (vinylidene fluoride) (PVDF) is a promising polymeric membrane material. Hydrophobic microporous membranes have been used for membrane gas absorption, mostly polyethylene (PE) and polypropylene (PP). However, microporous polyethylene and polypropylene membranes are wetted by some absorbents with low interfacial tensions, which significantly decrease the module efficiency. The key advantage of PVDF is its highly hydrophobic nature and excellent chemical resistance against corrosive chemicals. Various PVDF hollow fiber membranes were fabricated via non-solvent induced phase separation (NIPS) method and thermally induced phase separation (TIPS) method. Yeon et al (2005) carried out a sequence of tests on the absorption of CO_2 from a CO_2/N_2 mixture into aqueous amine solutions using hollow fiber membrane contactor prepared by using commercially available PVDF membranes. Xu et al. (2008) used PVDF hollow fiber membranes with an inner skinless surface prepared via the NIPS process in the removal of CO_2 from gas mixture. The experiments showed a higher CO_2 absorption rate than polyethylene membranes and attained performance levels equivalent to a PTFE membrane in the experiments of pure CO_2 absorption into water. Khaisri et al. (2009) compared the membrane resistances and absorption performances of three different commercial hydrophobic microporous membranes, including PVDF, PP and PTFE membranes, for the CO_2 absorption into aqueous MEA solutions.

There are two typical membrane preparation methods (Figure 2). Non-solvent induced phase separation (NIPS) and thermal induced phase separation (TIPS). Membranes fabricated employing NIPS method is composed of macrovoid and finger like structure, by contrast, membranes fabricated with TIPS methods are composed of a spherulites type structure.

MAIN FOCUS OF THE ARTICLE

The schematic diagram in Figure 3 shows the experimental setup used to fabricate hollow fiber membranes. Predefined amount of polymer is mixed with specific amount of solvent in the dope vessel (for example; 1000 gram of dope solutions is prepared by mixing 280 gram of PVDF polymer in 720 gram of triacetin

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