Journal of Cleaner Production 103 (2015) 286–300

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Review

Membrane-based carbon capture from flue gas: a review

Rajab Khalilpour [a,*], Kathryn Mumford [b], Haibo Zhai [c], Ali Abbas [a], Geoff Stevens [b], Edward S. Rubin [c]

[a] Department of Chemical and Biomolecular Engineering, University of Sydney, NSW 2006, Australia
[b] Department of Chemical and Biomolecular Engineering, University of Melbourne, VIC 3010, Australia
[c] Department of Engineering and Public Policy, Carnegie Mellon University, PA 15213, USA

ARTICLE INFO

Article history:
Received 2 February 2014
Received in revised form
2 September 2014
Accepted 16 October 2014
Available online 4 November 2014

Keywords:
Post-combustion carbon capture
Flue gas
Membrane
Process systems

ABSTRACT

There has been an increasing interest in the application of membranes to flue gas separation, primarily driven by the need of carbon capture for significantly reducing greenhouse gas emissions. Historically, there has not been general consensus about the advantage of membranes against other methods such as liquid solvents for carbon capture. However, recent research indicates that advances in materials and process designs could significantly improve the separation performance of membrane capture systems, which make membrane technology competitive with other technologies for carbon capture. This paper mainly reviews membrane separation for the application to post-combustion CO_2 capture with a focus on the developments and breakthroughs in membrane material design, process engineering, and engineering economics.

1. Introduction

In the United Nation's Earth Summit held June 1992 in Brazil, a treaty known as Nations Framework Convention on Climate Change (UN-FCCC) was made in order to stabilize greenhouse gas concentrations in the atmosphere. This treaty came into force gradually as more countries signed it, which accelerated research and development on different carbon dioxide (CO_2) capture technologies. Since that time, a few technologies have been developed for post-combustion carbon capture (PCC), including liquid solvent absorption, membranes, solid-sorbent adsorption (Krishnamurthy et al., 2014), membranes (Ho et al., 2008b), and mineralization (Zevenhoven and Fagerlund, 2009).

The first commercial interest in the separation of CO_2 from flue gas was its application for enhanced oil recovery (EOR) (Herzog et al., 1997). Application of CO_2 for EOR started in the 1970s and has proved to be an effective economic approach over the years (Long et al., 2006). When the amount of CO_2 product from natural gas purification is insufficient, the CO_2 from flue gases emitted from nearby power plants can be utilized using various carbon capture technologies for the EOR application. Currently, amine-based carbon capture technologies (shown Fig. 1), such as Flour Econamine Plus, are commercially available for implementation (Aaron and Tsouris, 2005; Desideri and Paolucci, 1999; Rao and Rubin, 2002), while other technologies, including membranes, lie at different developmental stages from concept to pilot-scale testing. Solvent-based PCC, in spite of being the best available technology (BAT) for dealing with various flue gas streams given in Table 1, may not be a long-term desired technology for PCC due to its high energy penalty associated with solvent regeneration (Feron, 2009). Different from solvent technologies for post-combustion CO_2 capture, membrane technology is a physical separation process shown in Fig. 2 where gas mixtures consisting of two or more components are separated by a semipermeable barrier into a retentate stream and a permeate stream. The main advantages of membrane separation against other technologies include compactness, modularity, ease of installation by skid-mounting, ability to be applied in remote areas (such as offshore), flexibility in operation and maintenance, and, in most cases, lower capital cost as well as lower energy consumption (Seader and Henley, 2006). They also require very little chemicals compared to conventional separation processes (He and Hägg, 2012).

Aaron and Tsouris (2005) reviewed various methods for CO_2 removal from flue gas including solvent absorption, pressure- and temperature-swing adsorption using various solid sorbents, cryogenic distillation, and membranes. They concluded that the most promising method for CO_2 separation is liquid absorption using monoethanolamine (MEA); however, the development of ceramic and metallic membranes for membrane diffusion will produce membranes that are significantly more efficient at separation than

* Corresponding author.
E-mail address: rajab.khalilpour@sydney.edu.au (R. Khalilpour).

http://dx.doi.org/10.1016/j.jclepro.2014.10.050