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## Journal of Membrane Science

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# Status and progress of membrane contactors in post-combustion carbon capture: A state-of-the-art review of new developments

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## ARTICLE INFO

## Article history:

Received 28 January 2016

Received in revised form

24 March 2016

Accepted 27 March 2016

Available online 31 March 2016

## Keywords:

Membrane contactor

Carbon capture

Gas separation

Flue gas

Post-combustion carbon capture

## ABSTRACT

Post-combustion carbon capture (PCC), which can be retrofitted to existing units in power plants worldwide, is regarded as the first technologically feasible and effective way to combat human-induced climate change. The membrane contactor is an emerging and promising membrane technology for PCC as it integrates the benefits of both liquid absorption (high selectivity) and membrane separation (modularity and compactness). This review aims to provide a state-of-the-art assessment of the research work carried out so far on membrane contactor technology in PCC. It details common aspects of membrane contactors, such as technological advantages, membrane wetting, mass transfer and module design, as well as new advances (e.g., new membranes and absorbents used in absorption processes) and novel applications (e.g., direct CO<sub>2</sub> stripping and integrated heat recovery in desorption processes). Moreover, the difference in performance between membrane absorption and conventional absorption is also compared and discussed. Lastly, we discuss the status and progress of membrane contactors in PCC and offer some recommendations for future work. This paper provides a clear overview on the recent developments of membrane contactor technology in PCC.

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**Abbreviations:** aMDEA, activated methyldiethanolamine; CA, carbonic anhydrase; CCP, CO<sub>2</sub> Capture Project; CO2CRC, Cooperative Research Center for Greenhouse Gas Technologies; DEA, diethanolamine; DEEA, 2-(diethylamino)ethanol; DMPEG, dimethyl ethers of polyethylene glycol; DOE, Department of Energy; ETIS, Energy Technology Innovation Strategy; GTI, Gas Technology Institute; ILs, ionic liquids; KPS, Kvaerner Process Systems; LEP, liquid entry pressure; MALAR, membrane assisted liquid absorbent regeneration; MAPA, 3-(methylamino)propylamine; MDEA, N-methyldiethanolamine; MEA, monoethanolamine; MEK, methyl ethyl ketone; MMMs, mixed matrix membranes; OBS, Ottestad Breathing Systems; PBTMST, poly[bis(trimethylsilyl)tricyclononene]; PCC, post-combustion carbon capture; PDMS, polydimethylsiloxane; PE, polyethylene; PEEK, polyether ether ketone; PEG, polyethylene glycol; PES, polyethersulfone; PMP, polymethylpentene; PMSQ, polymethylsilsequioxane; PP, polypropylene; PSf, polysulfone; PTFE, polytetrafluoroethylene; PTMGP, poly[1-(trimethylgermyl)-1-propyne]; PTMSP, poly(1-trimethylsilyl)-1-propyne; PVDF, polyvinylidene fluoride; SMM, surface modifying macromolecules; TFC, thin-film composite; TNO, Netherlands Organization for Applied Scientific Research; UV, ultraviolet; VOCs, volatile organic compounds

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<http://dx.doi.org/10.1016/j.memsci.2016.03.051>

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## 1. Introduction

Carbon dioxide (CO<sub>2</sub>) is the major greenhouse gas contributing to global climate change. CO<sub>2</sub> concentrations in the atmosphere have increased by more than 100 ppm since their pre-industrial levels (~280 ppm), reaching 384 ppm in 2007 [1–3]. Worldwide, fossil fuel-fired power plants are the largest point sources of CO<sub>2</sub> emissions [4]. Therefore, CO<sub>2</sub> capture from power stations is of great importance in addressing the global concern of climate change.

### 1.1. Post-combustion carbon capture

Currently, there are three widely studied technologies for carbon capture: pre-combustion capture, post-combustion capture (PCC) and oxy-fuel combustion. Of these, PCC holds the greatest promise because it can be retrofitted to existing units in power plants.

However, there are several challenges in capturing CO<sub>2</sub> from flue gas because of its special properties (Table 1). These include low flue gas pressure (~1 atm), low CO<sub>2</sub> concentration in the flue gas (typically < 16%), and small size difference among the gas molecules. All these factors reduce the effectiveness of current separation technologies and increase costs [5].

Liquid absorbent based PCC is recognized as the state-of-the-art carbon reduction technology, to a large extent due to its high CO<sub>2</sub> removal efficiency (usually > 80%) from flue gas even at low CO<sub>2</sub> concentrations [6,7]. A typical liquid absorbent based PCC system is illustrated in Fig. 1. The flue gas from the power plant undergoes pretreatment and cooling before entering the absorber. Pretreatment aims to remove undesirable particles, SO<sub>x</sub> and NO<sub>x</sub> that adversely affect CO<sub>2</sub> absorption. The flue gas temperature should be cooled to 45–50 °C to minimize evaporated solvent loss

and maximize CO<sub>2</sub> absorption [2]. The cooled flue gas is absorbed by the solvent in the absorber, forming CO<sub>2</sub> rich solvent. The scrubbed gas, along with a small amount of solvent is then water washed and vented to the atmosphere. The CO<sub>2</sub> rich solvent is preheated via a lean/rich heat exchanger by the regenerated CO<sub>2</sub> lean solvent, and then pumped to the top of the desorber. CO<sub>2</sub> is thermally released in the desorber where substantial amounts of thermal energy are supplied via the reboiler.

Currently, amine-based absorption is the leading technology for CO<sub>2</sub> capture, which occupies more than 90% of the market. In a conventional absorption plant, acid gas is brought in direct contact with lean solvent inside an absorber (usually a high column), where mass transfer takes place at the gas–liquid interface [8]. As absorption of CO<sub>2</sub> in a liquid is a process with equilibrium limitation, vapor–liquid equilibrium, operating conditions, physio-chemical properties, and reaction equilibrium and kinetics play important roles in determining the required interfacial areas, and thus the height of an equilibrium stage and the design of the

**Table 1**  
Typical properties of coal-fired flue gas after SO<sub>2</sub> scrubbing in post-combustion carbon capture (modified from [5,233]).

Flue gas	Composition or condition	Kinetic diameter (Å)
CO <sub>2</sub>	10–16 wt%	3.30
N <sub>2</sub>	70–75 wt%	3.64
H <sub>2</sub> O (vapor)	5–7 wt%	2.65
O <sub>2</sub>	3–4 wt%	3.45
CO	~20 ppm	3.75
NO <sub>x</sub>	< 400 ppm	
SO <sub>x</sub>	< 400 ppm	
Temperature	45–120 °C	
Pressure	~ 1 bar	

Note: the water vapor content is dependent upon the flue gas temperature.

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