Pre-combustion CO₂ capture from IGCC using membranes – An attainable region approach to the membrane system design

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Abstract

China has an ambitious CCS roadmap where capture from industry is seen as the first step. A significant share of the capture will be from the large number of coal gasification plants installed over the last decade. The gasification plants are mainly polygeneration units with production of electricity, syngas and hydrogen which can be used for different applications. The high CO₂ concentration and pressure of the syngas make pre-combustion an interesting opportunity for cost-efficient CO₂ capture [1]. Although solvent-based CO₂ capture is the most mature and demonstrated technologies for CO₂ capture, membrane processes are regarded as the most promising emerging technology with a potential to significantly reduce costs in the long run and are therefore investigated in this study [2]. A generic process flow diagram of the IGCC plant with a 2-stages membrane separation process is shown in Figure 1.

![Figure 1: Generic Process Flow Diagram of the IGCC plant with a 2-stage membrane separation process with CO₂ selective membranes for CO₂ capture.](image)

The Attainable Region Methodology [3-5] is a novel graphical design methodology developed to provide a consistent evaluation of membranes and cost-optimal multi-stage post-combustion capture processes. The methodology has been subsequently automated by implementing a numerical model for the methodology. The existing methodology cannot be directly applied to pre-combustion IGCC
processes as the syngas stream is at higher pressure and the H₂ is a valuable product that might also have specifications in addition to the CO₂ stream and any loss in H₂ is expensive. Thus the attainable region analysis and its numerical version were extended for pre-combustion CO₂ capture as a part of this work.

An illustration of the attainable region curves and visualization of the results from the numerical model for pre-combustion CO₂ capture are shown in Figure 2. The axes represent the CO₂ purity (molar fraction), with the x-axis representing the feed purity while the y-axis represents the permeate purity. The green, red and violet curves are the minimum cost curves, i.e. they represent the purity that can be attained at minimum capture cost. The blue curve represents the maximum product purity that can be obtained for a given membrane. These are calculated for a single stage membrane. The area between the curves represents the Attainable Region. The black dotted curve is an illustration of an optimized three-stage separation process. The vertical line represents the separation process while the horizontal line represents the fact that the permeate of a membrane stage is the inlet of the next separation stage.

Figure 2: Visualization of attainable region curves and an optimized 3-stage process for pre-combustion CO₂ capture from an IGCC.

Two objectives are considered in this study.

The first is to use the numerical model to identify the best membrane process for pre-combustion capture from an IGCC, considering membranes found in literature. This will include, for each membrane, the search for the process layout, design and operating conditions which minimize the electricity production cost of the IGCC plant with CO₂ capture.

This work will investigate the potential of both CO₂ selective and Hydrogen selective membranes. Indeed, while CO₂ selective membranes are particularly attractive for post-combustion capture, it is challenging to separate CO₂ selectively from mixtures with hydrogen, since the CO₂ molecule is much larger than the hydrogen molecule. In addition, alternative membrane process configurations to the conventional separation in cascade, such as separation in series, will be investigated in order to identify the full potential of both types of membrane. Finally the opportunities for dual membrane process (i.e. with both CO₂ and Hydrogen selective membranes in the process) will be discussed.
The second objective is to identify the membrane properties which are required for membrane separation processes to be cost-competitive with solvent based pre-combustion capture from an IGCC, not only considering membranes commercially available or under development. In practice, for each set of membrane properties, the numerical model will be employed to optimize the membrane capture process similarly as described above. and a cost comparison between the optimized membrane process and the reference solvent-based CO$_2$ capture process, will be conducted. As an illustration of the type of results which will be presented, previous obtained results [6] of a cost comparison between membrane- and MEA-based post-combustion CO$_2$ capture from a coal-fired power plant, are shown in Figure 3. In this representation, the membrane selectivity and permeance are used as x- and y-axes, as shown in Figure 2. The relative cost efficiency of the membrane process compared to the MEA-based process for CO$_2$ capture from the power plant flue gas is represented by differently colored areas.

Figure 3: Membrane properties required for cost-competitive membrane CO$_2$ capture from a post-combustion coal-fired power plant[6].

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References