A Novel Membrane System for Carbon Capture and Conversion

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ABSTRACT.

Depending on the needs of the industry, a novel membrane system (CCC system) with hybrid matrix membranes can efficiently extract CO2 from a variety of mixed gases at a rate ranging from 90 to 99%. More significantly, the CCC system can reduce carbon emissions from numerous significant industrial emission sources, including power plants and steel mills, while also producing useful industrial chemicals from the captured CO2. Additionally, the CCC system can save energy use by over 30%, and reduce the carbon footprint.

Keywords: carbon capture; carbon conversion; hybrid matrix membranes; carbon nanotubes

1. INTRODUCTION

CO_2 is a major greenhouse gas causing global climate change. Reducing CO_2 emission can significantly reverse the negative effects of global warming, including temperature increases, extreme environmental events, and sea level rise [1]. Since carbon and fossil fuels are an essential part of the production process in steel, cement, and chemical industries, these industries are main targets to reduce the CO_2 emission. However, many existing technologies for abating the CO_2 emission have very high CAPEX and OPEX, large footprint and environmental issues. Governments and researchers worldwide work together to develop the reliable and economic ways to reduce the overall emissions from these "hard-to-abate" sectors, such as by capturing carbon emissions and converting them into products that can be used again in the production process.

The United Nations Intergovernmental Panel on Climate Change (IPCC)'s special report on global warming of 1.5 °C pointed out that CCUS (Carbon Capture, Utilization and Sequestration) technology can effectively improve global climate change. The CCUS entails capturing CO_2 from large major point sources like power generation plant or industrial facilities that use either fossil fuels or biomass as fuel. If not being used on-site, the captured CO_2 is usually compressed and converted into liquid or solid form, then transported by truck, rail, ship or pipeline to application sites, or injected into deep geological sites such as depleted oil and gas reservoirs or saline aquifers etc. The following figure illustrates the overall CCUS process.

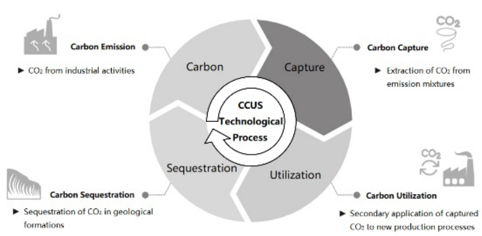

Figure. 1 CCUS process

The current industrial carbon capture technologies are chemical absorption and physical separation [2,3], these methods usually separate the CO_2 from various mixed gas, and the final product is still a gas form of CO_2 that is costly to transport to the application sites. After separation, the common practice is to compress the gas CO_2 into liquid form or solid form which involves high energy consumption and secondary environmental pollution [4,5]. After CO_2 proper conversion, the need for a well-established and extensive infrastructure for CO_2 transport, which involves pipelines, storage facilities and transportation modes, presents a considerable challenge. Furthermore, the need for extensive infrastructure for CO_2 storage presents a significant hurdle, requiring substantial investment and resources [6]. The high CAPEX & OPEX and required long-term investment pose great challenges to the commercial viability of CCUS projects. Developing a reliable and

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economical CCUS solutions for major industry, particularly in the power generation industry, present tremendous technological challenges.

2. TECHNOLOGY SOLUTION

2.1 Hybrid matrix membranes

Nowadays, membrane separation is emerging as the most promising technology because of its great energy efficiency, continuous operation, smaller footprint, and comparatively low cost. The hybrid matrix membrane combines the advantages of polymer membranes and inorganic fillers, which have good film-forming processing performance, good thermal and chemical stability, and high mechanical strength. A variety of nanomaterials have been previously used as fillers in hybrid matrix membranes, such as graphene oxide, carbon nanomaterials, zeolites, and metal oxides. As shown in the following picture.

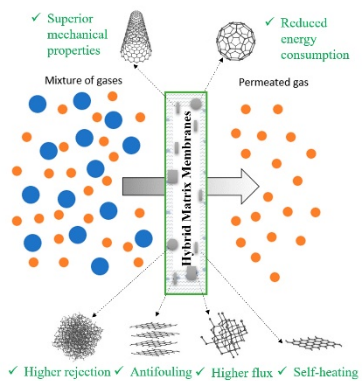

Figure. 2 Carbon nanomaterial in hybrid matrix membranes

When applied to hybrid matrix membranes for gas separation, carbon nanotubes (CNTs) provide a number of benefits. Membranes can function at high pressure without sacrificing structural integrity due to CNTs' high mechanical strength [7]. Improved permeability and selectivity in gas separation are a result of CNTs' improved gas transport characteristics [8]. CNTs have a low mass density, which helps the membranes be lightweight. CNTs' special flexibility enables them to conform to the matrix, adding to the mixed matrix membranes' overall flexibility and toughness [9]. The following picture is a scanning electron microscope image of CNTs in hybrid matrix membrane.

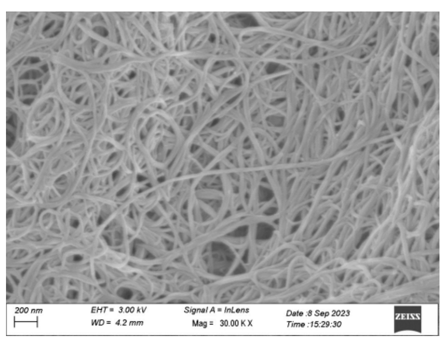

Figure. 3 SEM image of CNTs

2.2 CCC system

A good membrane is a start point for Carbon separation, an efficient system is a critical to capture and convert the CO_2 (gas) into valuable industrial products. Recently we patented a novel membrane system named as CCC (Carbon Capture and Conversion) system. Combining chemical solution absorption with nanocomposite membrane separation to achieve energy-efficient and energy-saving CO_2 capture and conversion. In CCC system, once CO_2 is captured and concentrated, it can be converted into different chemical compounds depending on industries and environments. For CO_2 conversion into chemicals, materials, or fuels, this can be achieved in an advanced membrane reactor system. The following figure illustrates CCC process in the patented novel membrane system.

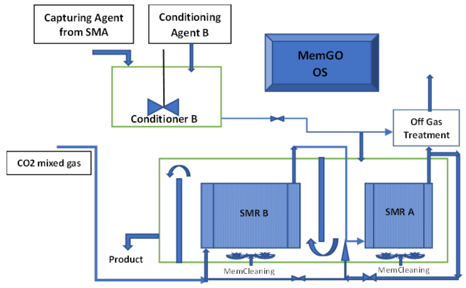

Figure. 4 CCC system process

In this CCC system, surface-functionalized hybrid nanofibrous materials and CO_2-selective hybrid membranes are developed with a unique structure of heterogeneous asymmetric multilayers. The newly invented rSWCNT nano-reactive particles are combined with enhanced novel polymers to form innovative hybrid matrix membranes with superior selectivity and higher CO_2 permeability while maintaining the mechanical stability of cPVDF/cPES nanofibrous membranes, which have the potential for large-scale industrialization. As show in the following picture. The CCC system utilizes a newly invented SMA unit to efficiently generate CO_2 capture agents with a 28% improvement in energy efficiency. The unique CCC system of this project is composed of a special membrane reactor system and an intelligent OS system. The CCC system has a separation efficiency of over 99% and a carbon (CO_2) capture and conversion rate of over 99%. Compared with traditional CCS/CCUS systems, the overall energy efficiency has improved by 78%. The CCC system with modular engineering design can be reliably extended to various industrial applications and can be optimized remotely (globally) by experts.

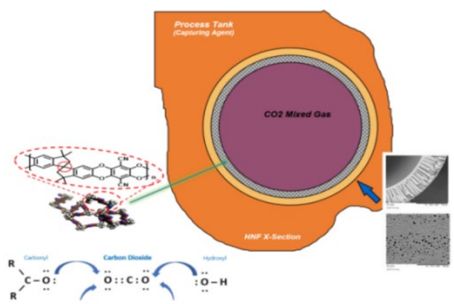

Figure. 5 Mechanism of the membrane system capturing CO_2

The CCC system presents economic benefits as the captured CO_2 is utilized as a feedstock for various industrial processes, providing a revenue stream and making the technology economically attractive comparing to many traditional CCUS. The CCC system directly utilizes captured CO_2, often in processes such as manufacturing or fuel synthesis, providing a more immediate and direct benefit compared to storage-oriented approaches. Moreover, the CCC system can reduce the reliance on extensive carbon sequestration infrastructure, addressing challenges associated with large-scale facilities required in the traditional CCS/CCUS. The CCC system contributes to the concept of a circular economy by converting waste CO_2 into valuable products, promoting sustainability and resource efficiency.

3. SUMMARY

In summary, a new membrane system (CCC system) can effectively capture the CO_2 from various mixed gas with the capturing rate varied from 90-99% depending on industrial requirements. More importantly, the CCC system not only can improve capture efficiency but also provide profitable technological solution for minimizing carbon emission from many major industrial emission sources such as power plants, steel industries etc. and converting the captured CO_2 into valuable industrial chemicals such as $NaHCO_3$. Furthermore, the CCC system can reduce the energy by more than 30% and ultimately lower the carbon footprint.

Through this research, we can expect to see ever more selective and efficient processes evolving as a result of this effort, and consequently, carbon dioxide can be anticipated to figure more and more as a valuable feedstock for the production of commodity chemicals.

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