Journal of Farayandno – Vol. 20 – No. 91 (2025): pp. 21-36

National Iranian Oil Refining and Ditribution Company (NIORDC)

Journal of Farayandno

Research Paper

DOI: 10.22034/farayandno.2025.2070418.2014

Laboratory Study of CO_2 Removal from Gas Mixture Using Membrane Contactor Technology

Parya Amirabedi *

Department of Chemical Engineering, Faculty of Engineering, Behbahan Khatam Alanbia University of Technology, Behbahan, Iran.

Received: 31 Aug 2025 **Accepted:** 2 Nov 2025

1. ABSTRACT

The cement industry is one of the largest sources of CO_2 emissions from human activities, accounting for about 7% of the total CO_2 emissions. Therefore, it seems necessary to use technologies that reduce CO_2 emissions in the environment. It is worth noting that membrane contactors are one of the new and effective technologies for reducing pollution from CO_2 emissions in the environment. Accordingly, in the present study, membrane contactors containing polyvinyl chloride/calcium carbonate hollow fiber membranes were fabricated to remove CO_2 from the flue gas of a reference cement plant. The average results of contact angle measurements of pure and nanocomposite membranes were 78° and 92°, respectively, indicating an increase in the hydrophobicity of the membranes due to the presence of nanoparticles. The results also showed that increasing the gas velocity had a negative effect on the absorption efficiency, but on the contrary, increasing the operating pressure and the adsorbent velocity increased the absorption efficiency. Also, analysis of the CO_2 absorption results showed that at an absorbent flow rate of 200 ml/min, the nanocomposite membrane had the highest CO_2 absorption efficiency (88%). The important issue here is the manufacture of hollow fiber membranes with low cost and high performance, which made it possible to develop membrane technology in the field of gas purification.
Keywords: CO_2, Cement Industry, Hollow Fiber Membranes, Membrane Contactors.

2. INTRODUCTION

Climate change and global warming are caused by human activities, the most important of which is the expansion of industrial activities [1]. Today, energy and climate policies have been adopted to reduce CO_2 emissions and combat climate change, with the goal of reducing them by 40% by 2030 and by 80–95% by 2050 compared to 1990 levels [2].

The International Energy Agency has stated that the cement industry is one of the largest sources of CO_2 emissions from human activities, accounting for about 7% of the total CO_2 emissions and releasing approximately 2.2 gigatonnes of CO_2 per year. About two-thirds of the CO_2 emissions in the cement industry are related to the process that results from the calcination of limestone, in which $CaCO_3$ is converted to CaO and CO_2 ($CaCO_3 \leftrightharpoons CaO+CO_2$). Meanwhile, one third of CO_2 emissions come from fuel combustion in the calciner and rotary kiln [3, 4].

Studies show that so far, processes such as the use of alternative fuels and the use of carbon capture and utilization technologies have been used to reduce CO_2 emissions in cement plants. On the other hand, it should be noted that an action such as changing the fuel of a cement plant can only reduce one third of CO_2 emissions; because, as mentioned, only one third of CO_2 emissions come from fuel combustion. In the meantime, the carbon capture and utilization process can significantly reduce both process-related and fuel-related CO_2 emissions. Thus, this method is known as the most important method that has the greatest potential to reduce CO_2 emissions in the cement industry [4].

* p.amirabedi@bkatu.ac.ir

Please Cite Thise Article Using:
Amirabedi, P., “Laboratory Study of CO_2 Removal from Gas Mixture Using Membrane Contactor Technology”, Journal of Farayandno – Vol. 20 – No. 91, pp. 21-36, In Persian, (2025).

Among the CO_2 absorption technologies, we can mention the chemical absorption process with amine [5], the calcium ring process, the oxyfuel process, the cold ammonia process and membrane processes. Among them, membrane processes are considered as one of the newest and at the same time most efficient methods of CO_2 absorption. There are various membrane processes in the field of CO_2 absorption, among which membrane contactor technology is of particular importance.
Due to the efforts to localize membrane contactor technology in Iran and considering the mass production of PVC polymer and $CaCO_3$ nanoparticles in the country, in the present study, a membrane contactor containing PVC/$CaCO_3$ membranes was investigated to remove CO_2 from the flue gas of a reference cement plant. It is worth noting that this study shows the first application of membrane contactors containing PVC/$CaCO_3$ membranes in the field of removing CO_2 from the flue gas of a reference cement plant.

3. MATERIALS AND METHODS

PVC (Bulk density=530-590 (g/lit)) was purchased from Ghadir Petrochemical Company. $CaCO_3$ nanoparticles (M=100.09 g/mol, 15-40 nm) and dimethylformamide (M=73.09 g/mol, DMF) were purchased from Iranian Nanomaterials Company.

Hollow fiber membrane fabrication

To prepare the nanocomposite hollow fiber membrane, first the required amounts of PVC, DMF, and $CaCO_3$ nanoparticles were weighed. Then, a portion of the solvent (about 75%) was poured into a glass container and the required PVC was added to it. It took approximately 24 hours to obtain a clear solution. After this step, the required nanoparticles were poured into the remaining solvent and dispersed in it for one hour using ultrasound waves. Then the resulting solution was added dropwise to the previous solution. The resulting solution was left at room temperature for one hour to deaerate. Next, this solution was poured into the tank of the hollow fiber membrane manufacturing machine and about one hour was given for the deaeration process to be completed. Then the membrane manufacturing stage began and the polymer solution was discharged from the machine in the form of hollow fiber membranes.

4. RESULTS AND DISCUSSION

4.1. Membrane Structure Investigation

Figure 1 shows SEM images of the cross-section and surface of pure and nanocomposite membranes. As can be seen from the figure, all membranes have a cellular structure. Also, these images confirm the presence of nanoparticles in the internal structure and surface of nanocomposite membranes.

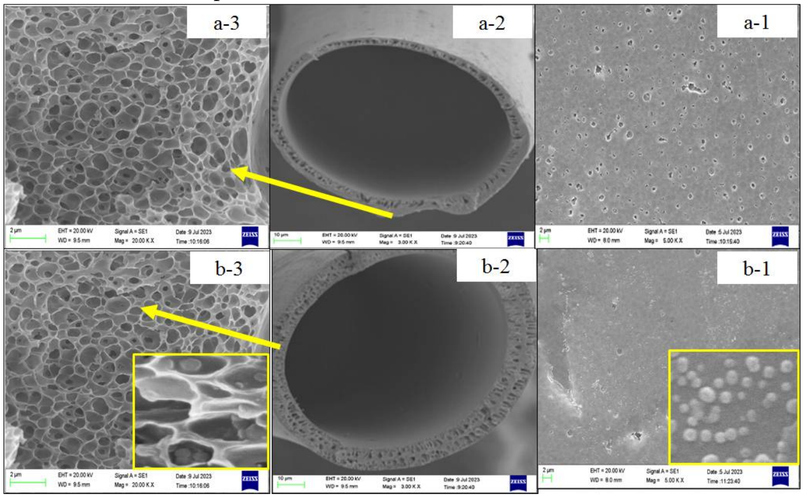

Figure 1. SEM images of (a) pure PVC membrane, (b) nanocomposite PVC membrane; (1) surface and (2, 3) cross-section of the membranes.

4.2 Contact angle and atomic force microscopy study

The average results of contact angle measurements of pure and nanocomposite membranes were 78° and 92°, respectively. One of the main reasons for the increase in the size of the contact angle of nanocomposite membranes is the increase in the surface roughness of these types of membranes due to the presence of nanoparticles. In order to investigate the effect of roughness, AFM test was used (Figure 2). By looking carefully at the figure, it can be seen that the presence of nanoparticles on the surface of nanocomposite membranes increases the roughness of the membrane surface and with increasing surface roughness, the size of the contact angle increases.

4.3 Studying the effect of gas velocity

Figure 3 shows the effect of inlet gas flow rate on CO_2 absorption efficiency and Figure 4 shows the effect of this parameter on CO_2 absorption flux. By carefully examining Figure 3, it can be seen that with increasing gas velocity, the absorption efficiency has decreased. One thing that is noteworthy is the increase in CO_2 absorption flux for increasing gas flow rate.

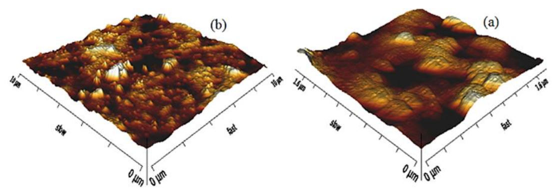

Figure 2. AFM images of (a) pure PVC membrane and (b) nanocomposite membrane.

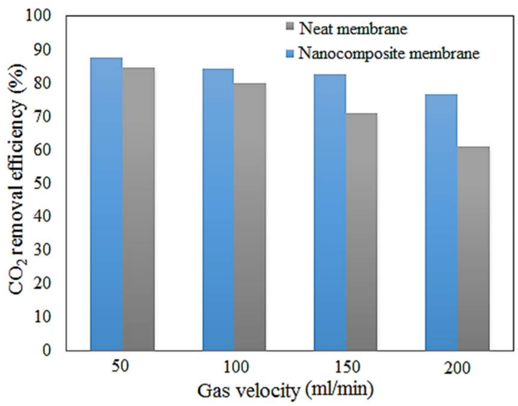

Figure 3. CO_2 absorption efficiency graph versus gas velocity (absorbent velocity = 200 ml/min and operating pressure = 1.5 bar).

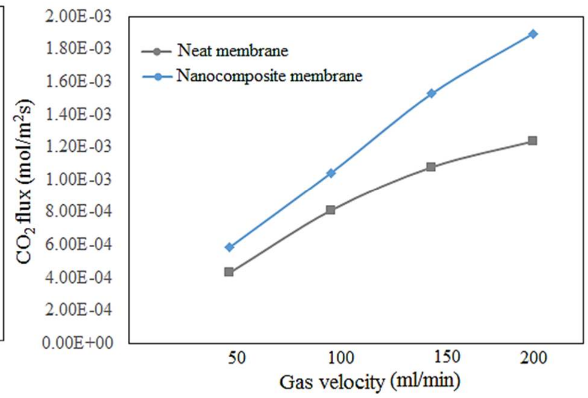

Figure 4. CO_2 absorption flux graph versus gas velocity (absorbent velocity = 200 ml/min and operating pressure = 1.5 bar).

5. CONCLUSION

In the present study, pure and nanocomposite PVC membranes containing $CaCO_3$ nanoparticles were fabricated and then tested in a membrane contactor system to absorb CO_2 from the flue gas of a reference cement plant. The results of SEM images indicated the presence of nanoparticles on the surface of the nanocomposite membranes as well as in their internal structure. These images also showed that the wide distribution of nanoparticles was a factor in increasing the surface roughness, which in turn led to an increase in the contact angle of the nanocomposite membranes compared to pure membranes. In the present study, in order to separate CO_2, a feed gas with a composition similar to the percentage composition of the flue gas of a reference cement plant was injected into the hollow fiber membranes to investigate the effect of gas velocity, adsorbent velocity, and operating pressure on the CO_2 absorption rate. The results showed that increasing the gas velocity had a negative effect on the absorption efficiency, but on the contrary, increasing the operating pressure and adsorbent velocity increased the absorption efficiency. The important issue here is the manufacture of hollow fiber membranes, at a low price and with high performance, which has enabled the development of membrane technology in the field of gas purification. Therefore, in the present work, the discussion of adjusting the price and improving the properties of membranes has a high priority and achieving it can be an effective step in the development of membrane technology in the field of flue gas purification from cement factories.

6. REFERENCES

[1] Avagyan, A.B., "Theory of bioenergy accumulation and transformation: application to evolution, energy, sustainable development, climate change, manufacturing, agriculture, military activity and pandemic challenges", Athens J Sci, 8, pp. 57-80, 2021.

[2] S.C. Galusnyak. L. Petrescu. C.-C. Cormos, "Environmental impact assessment of post-combustion CO_2 capture technologies applied to cement production plants", Journal of Environmental Management, 320, pp. 115908, 2022.

[3] S.O. Gardarsdottir. E. De Lena. M. Romano. S. Roussanaly. M. Voldsund. J.-F. Pérez-Calvo. D. Berstad. C. Fu, R. Anantharaman. D. Sutter, "Comparison of technologies for CO_2 capture from cement production—Part 2: Cost analysis", Energies, 12, pp. 542, 2019.

[4] M. Voldsund. S.O. Gardarsdottir. E. De Lena. J.-F. Pérez-Calvo. A. Jamali. D. Berstad. C. Fu, M. Romano. S. Roussanaly. R. Anantharaman, "Comparison of technologies for CO_2 capture from cement production—Part 1: Technical evaluation", Energies, 12, pp. 559, 2019.

[5] X. Liang. J. Li, "Assessing the value of retrofitting cement plants for carbon capture: A case study of a cement plant in Guangdong", China, Energy Conversion and Management, 64, pp.454-465, 2012.