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Alternatives for Carbon Dioxide Capture

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Abstract

*Globally, the rising emissions of greenhouse gases (GHG) pose a serious problem for the environment and the general public. This rise is the result of rapidly expanding urban and industrial areas, where emissions of gases including carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NO_x) are rising. A new approach called nanotechnology is being used extensively in many different energy systems. In recent years, there has been a lot of interest in the revolutionary method of CO_2 absorption or conversion increase employing nanofluids. This review paper attempts to review for research on various CO_2 absorption methods, CO_2 Capture increase by use of nanofluids is dealt in detail in this review.*Effective *Factors in the CO_2 Absorption by Nanofluid have also been discussed.*

Key words : CO_2 capture, Nanofluids, Nanotechnology, Amines , GHG emmissions,

1.0 Introduction :

The main causes of carbon dioxide (CO2) emission are populationexpansion, economic development, an d the use of fossil fuels in industrialand domestic transportation. Global warming and climate change arec aused by the greenhouse gas effect, which is brought on by the direct release of created CO2 into the atmosphere. Since industrial processes produce CO2, a lot of researchshould be done to offer a practical a nd effective way to make them clean and avoid the environmental issues linked with them. For this purpose, many researchers have proposed several processes, including amine-based absorption (Zhou et al., 2021), membrane (Jang et al., 2022), adsorption, cryogenics and chemical looping combustion for CO2 capture. However there are many advantages and disadvantages of these various technologies. Even though their are lots of benefits of these technological approaches, their disadvantages convinced scientists to identify better ways for CO2 capture.

2.0 Methods for CO2 capture :

There are three basic types of CO2 capture: 1.pre-combustion, 2.post-combustion and 3. Oxyfuel with post-combustion. Pre-combustion processes convert fuel into a gaseous mixture of hydrogen and CO2. The hydrogen is separated and can be burnt without producing any CO2; the CO2 can then be compressed for transport and storage.Post-Combustion capture, where CO2 is separated from flue gas after fossil fuel combustion . Oxy-fuel combustion capture, where pure oxygen is fed to combustion chamber instead of air to produce a flue gas of CO2 and H2O

Among the aforementioned technologies, Post-Combustion capture is typically the one that is employed the most. Using chemical, physical, or biological methods, this capture system separates CO2 after burning **(Wang et al., 2011).** The most cutting-edge method of carbon capture at the moment is chemical absorption utilising aqueous amines. According to many researchers amines (primary, secondary, tertiary, and sterically hindered) make up the majority of the solvents utilised for chemical CO2 absorption. According to **Muchan et al. (2017),** the alkanolamines in particular exhibit excellent capacity and selectivity for CO2 absorption from various gas streams. Triethanolamine was the first amine solvent to be used commercially for gas purification (TEA). Primary amines such as monoethanolamine (MEA) and diglycolamine (DGA) were next, followed by secondary amines such as diethanolamine (DEA) and (DIPA), and tertiary amines such as methyldiethanolamine (MDEA).

2.1 Use of Ionic Liquids

The absorption of CO2 has also been done using ionic liquids (ILs). According to **Carvalho (2015)**, ILs are cation and anion salts that are liquid (at room temperature) and offer great solubility, thermal and chemical stability, and flexible structural adjustment. Due to their viscosity, ILs have a lower CO2 solubility than alkanolamines, but they also require between 25 and 50 percent less energy to regenerate **(Lian et al., 2021).**

2.2 Adsorption :

Adsorption is a possible substitute for chemical absorption techniques that is currently being considered for extensive CCS applications. According to **Varghese and Karanikolos (2020)**, the processes that produce the CO2 adsorption capability are chemisorption (chemical adsorption) and physisorption (physical adsorption). Zeolites, carbons, silica, alumina, Metal Organic Frameworks (MOFs), and Zeolite Imidazolate Frameworks (ZIFs) are the major materials that exhibit physical sorption, although surface-functionalized adsorbents exhibit chemisorption to a lesser extent. In comparison to absorption, adsorption has a lesser uptake capacity (on a volume or weight basis). Adsorption uses less energy than other processes Due to a stronger chemical interaction between the solvent and CO_2 and a greater temperature required for regeneration in the latter, the cost of regeneration is nearly 90% lower than chemical absorption by amines **(Wang 2015).**

2.3 Use of Membranes:

According to size and/or diffusion affinity, membranes are reasonably priced semipermeable sheets that can separate gases **(Lee et al., 2019)**. Polymeric, inorganic, and mixed matrix membranes, among others, are used for carbon capture (**Muthukumaraswamy Rangaraj et al., 2020,**). Other recently established methods for CO_2 capture include biological and photochemical conversion **(Yaashikaa et al., 2019),** and mineralization of waste water **(Dindi et al., 2018).** Although less developed and still being evaluated for large-scale applications, several technologies show promising future.

2.4 Hybrid Systems :

Hybrid systems are being researched as a way to improve carbon capture efficiency overall by combining the advantages of adsorption and absorption. These systems consist of distributed and suspended solid adsorbents in liquid solvents. Due to improved heat and mass transfer and CO_2 solubility, these devices may effectively extract carbon dioxide from flue and other gas combinations while requiring less energy for sorption and regeneration. However, phase stability, material and energy costs, pumping challenges, and solvent reactivity pose challenges to the performance of hybrid systems. With regard to optimum setup and operation, the slurry hybrid system for carbon capture may ultimately be a promising In recent years, The CO_2 is captured by the hybrid systems through both adsorption and absorption processes.solution for the industrial scrubbing process.

2.5 Nanofluids for CO2 Capture :

Recently, absorption-based techniques to absorb carbon dioxide (CO_2) molecules have been used using nanofluids. The ability of nanofluids to absorb CO_2 is influenced by pressure, temperature, the kind and concentration of nanoparticles in the host liquid, and the length of gas-liquid contact. In order to maximise overall uptake and energy savings, slurry (nanofluid) systems combine the adsorption and absorption capacities of carbon dioxide **(Yu et al., 2019).**

Small amounts of nanoscale solid adsorbent are dispersed in a liquid solvent during the preparation of these hybrid systems using one- or two-step procedures . Additionally, many researchers have suggested that dispersing nanoparticles in a base fluid is a useful way to effectively capture CO_2 molecules . Methanol-based **(Kim et al., 2014; Torres Pineda et al., 2012),** monoethanolamine-based **(Jiang et al., 2014)**, methyl diethanolamine-based **(Jiang et al., 2014; Zhou et al., 2021),** and water-based **(Golkhar**

2013) processes have all been experimentally tried using nanofluids. **(Rashidi and Mamivand, 2022; Rashidi et al., 2013; Mehdipour et al., 2021)** The most commonly used nanosized additives to these base liquids are carbon nanotubes (CNT), multi-walled CNN, graphene oxide, SiO_2, TiO_2, MgO, ZnO, Al_2O_3, and carbon nanotube (CNT) **Golkhar et al., 2013; Jiang et al., 2014; Kim et al., 2014; Mehdipour et al., 2021; Torres Pineda et al., 2012; Zhou et al., 2021)**.on the CO_2 removal by nanofluids. In comparison to values seen with pure amine solvents, nanofluids have been demonstrated to improve CO_2 uptake by over 20% and the CO_2 capture rate by 2–93%. The rate of CO_2 desorption can be greatly accelerated by nanoparticles with catalytic effects on CO_2 capture by up to 4000%.

When utilising nanoparticles in the form of nanofluids in bubbling absorption systems for CO_2 capture, **Ganapathy et al.2013** discovered gas-liquid absorption augmentation that varied for each kind of nanoparticle. In a gas-liquid absorption system, the gas concentration in the liquid phase slightly rises until equilibrium is established In a study, **Fang et al. 2016** investigated the impact of nanoparticles on CO_2 absorption using a bubbling ammonia system. The effectiveness of CO_2 capture and the type of nanoparticle were shown to be related. TiO_2 > CuO > SiO_2 was the order of CO_2 capture efficiency **Sumin et al. 2013** investigated the effectiveness of CO_2 removal in a stirred reactor comprising CNT and Al_2O_3 nanoparticles. The outcomes of their research showed a significantly improved CO_2 collection.when using carbon nanotubes in the absorption solvent .

A new annular contactor (AC) that made use of a tray absorber was the subject of a study by **Pineda et al.2014** that examined the effects of adding TiO_2, SiO_2, and Al_2O_3 nanoparticles to the absorption solvent. This study indicated that adding TiO_2, SiO_2, and Al_2O_3 nanoparticles, respectively, might increase absorption rates by up to 5%, 6%, and 10% . In their studies, **Zhang et al. 2016** used a stirred reactor to study the impacts of particle size and optimal nanoparticle concentration as well as the effects of TiO_2 nanoparticle addition into propylene carbonate on the system's capture rate. **Golkhar et al.2013** removed CO_2 using a nanofluid including carbon nanotubes and silica nanoparticles in a gas-liquid hollow fibre membrane contactor. Their findings showed that CNT nanofluid has better performance in CO_2 removal with up to 40% efficiency.

Numerous studies have revealed that the performance of gas absorption can be significantly improved by adding promoters or dispersing a third phase, such as solid particles (**Sumin, L.U et al .2013)** As a result, replacing amine solvents with amine-based nanoparticle absorbents that are dispersed in the liquid phase can result in large energy savings because these absorbents don't need a lot of energy for repeated heating and cooling cycles to recover the liquid solvent **[Arshadi et al 2019]**.

Al_2O_3, SiO_2, and TiO_2 nanoparticle dispersions were employed by Wang et al. in MEA base fluid for CO_2 collection operations. The greatest improvement in CO_2 absorption was shown with TiO_2 **[Wang et al 2016].** There are other reports like these in the literature. **Jiang et al.2013** conducted some studies to ascertain the impact of four SiO_2, MgO, TiO_2, and Al_2O_3 nanoparticles on the enhancement of CO_2 capture. Among the four solutions, they discovered that TiO_2-MDEA nanofluids have the best CO_2 absorption performance.

3.0 Effective Factors in the CO2 Absorption by Nanofluid

The characteristics of nanofluids have created a new area for technological development. To be used as absorbents in CO_2 absorption processes, several nanofluids have been the subject of research. In this regard, a variety of metal oxide, metallic, and nonmetallic nanoparticles, including TiO_2, MgO, SiO_2, Cu, CuO, Al_2O_3, and carbon nanotubes, have been investigated for improving CO_2 absorption **[Rahmat et al 2016]**. The key variables were chosen based on the outcomes of CO_2 absorption by nanoparticles. These include the base fluid type, flow rate, pressure, temperature, and hydrodynamics as well as the nanoparticle type, shape, size, and concentration in the base fluid, gas flow rate, CO_2 concentration in the feed stream, and gas flow rate.

3.1 Effect of Nanoparticle Concentration

The influence of temperature and ZnO and SiO_2 nanoparticle concentration in a water-based nanofluid on CO_2 absorption was studied in one experiment using an isothermal quasi-static high pressure stirred reactor. The results showed that increasing temperature marginally decreases CO_2 absorption, however adding 0.1 weight percent ZnO and SiO_2 enhances CO_2 absorption by 14% and 7%, respectively **Haghtalab, A. et al 2015. Nabipour et al. 2017** looked into the effects of adding MWCNTs to the CO_2 absorbent fluid, and the results showed that doing so increased the CO_2 equilibrium solubility by 23.2% when compared to the base fluid at a concentration of 0.02 weight percent of MWCNTs with carboxyl functional groups in the Sulfinol-M absorber.

Kim et al. 2008 tested CO_2 absorption in a bubble absorber system to assess the effectiveness of a nanofluid containing SiO_2 nanoparticles on CO_2 absorption. In comparison to pure water as its base fluid, the 0.21 weight percent nanofluid demonstrated a 24% improvement in CO_2 absorption performance . When 0.02 weight percent of Ag nanoparticles were added to the solution, the rate of CO_2 absorption rose by 55%, according to **Peng et al. Lee and Kang 2013** employed a bubble column system to study the effects of adding Al2O3 nanoparticles to a NaCl solution on the system's ability to absorb CO2 and found that as little as 0.01 vol% of Al2O3 nanoparticles can increase the CO2 solubility. All of these studies show that an absorption fluid's ability to absorb can be improved by adding tiny amounts of nanoparticles.

Recent research by **Darvanjooghi et al. [2018]** on the CO2 absorption capacity of a nanofluid containing Fe2O3 nanoparticles revealed that the maximum mean CO2 flow 105 mol/(m2.s) was attained at a Fe2O3 concentration of 1 wt.%, which declined over time.

In their investigation of the impact of Al2O3 nanoparticles on the mass transfer of a water-based nanofluid, **Periasamy Manikandan et al.** discovered the greatest CO2 absorption augmentation at 0.6 vol% Al2O3 nanoparticle concentration [95]. To test the effectiveness of a solution mixture of MEA, DEA, and diisopropanolamine in absorbing CO2 in a stirred cell, **Huang et al.** and **Park et al. [2007,2008]** added SiO2 nanoparticles to the solution. By increasing the concentration of nanoparticles, they observed a decrease in the CO2 absorption rate, which is thought to be connected to the solution's elasticity **[Komati 2008]**. These studies show that the CO2 absorption of a nanofluid is greatly improved by the addition of modest numbers of nanoparticles to the fluid.

Irani et al. 2019 evaluated the use of a graphene-Oxide/MDEA nanofluid mixture in the gas sweetening process. Because of the higher mass transfer coefficient brought on by the hydroxyl functional groups on the graphene oxide surface, adding just 0.1 weight percent of graphene oxide to the solvent might boost its absorption capacity by 9.1%. In a different investigation, **Park et al. 2006** examined the effects of colloidal nanosilica addition to the solvent 2-amino-2-methyl-1-propanol on the effectiveness of CO2 absorption in a stirred vessel.They discovered that the absorption rate and the volumetric mass transfer coefficient in the liquid side decrease as the concentration of nanoparticles rises Because DEA is a potent chemical CO2 absorbent, **Rahmatmand et al. [2016]** have also shown that the addition of CNT nanoparticles has no discernible impact on the DEA absorption performance. However, CNTs could considerably improve the MDEA-based nanofluid's ability to absorb CO2. In general, it can be said that raising the concentration of nanoparticles in the base fluid enhances absorption capacity

3.2 Effect of Nanoparticle Size

Lot of research has also been done on effect of nanoparticle volume fraction. Al2O3, SiO2, and TiO2 nanoparticles, among many other types of nanoparticles, were used in studies of CO2 mass transfer efficiency increase by the addition of nanoparticles to aqueous solutions **[Lee 2016,Said 2016]. Nagy et al. 2007** increased mass transfer by more than 200% by mixing 10 vol% of 65 nm-sized n-hexadecane nanoparticles into a fluid. The findings show that whereas the rate of mass transfer increases slowly at greater particle concentrations (more than 6 vol%), it does so quickly at low nanoparticle concentrations Smaller Al2O3 nanoparticles were added to a NaCl solution, and Lee and Kang came to the conclusion that this increased the fluid's ability to absorb CO2 **Lee et al 2013].**

According to a review of the literature, **Kim et al 2008.** were the only research team to examine how nanoparticles affect the efficiency of mass transfer in nanofluids. They mixed water with silica nanoparticles with average particle sizes of 30, 70, and 120 nm to create a nanofluid with a concentration of 0.021 weight percent. The absorption of CO2 by a nanofluid containing 0.021 wt% nanoparticles was improved by up to 76%, with 24% of this improvement occurring in the first minute of the absorption process's eight-minute duration. The corresponding increases for nanofluids containing K2CO3 nanoparticles were 11% and 12%, respectively. Their analysis came to the conclusion that the presence of tiny bubbles in nanofluids enhanced mass transfer According to **Hwang et al.2009,** the volumetric mass transfer coefficient improves until the particle size reaches 60 nm, beyond which it has no effect on the effectiveness of nanofluid CO2 absorption **.** Increasing nanoparticle volume fraction tends to raise the enhancement factor while increasing nanoparticle size tends to lower it **[Zhang, N et al 2014].**

3.3 Effect of Temperature

Temperature is a significant factor in the enhancement of CO2 absorption by nanofluids. A new CO2 absorbent made of Al2O3 nanoparticles in a NaCl aqueous solution was developed by **Lee and Kan 2013**. In this nanofluid, they tested the solubility of CO2 at various temperatures and Al2O3 concentrations. At 30 °C, 20 °C, and 10 °C, respectively, they achieved 11%, 12.5%, and 8.7% augmentation in CO2 capture when Al2O3 nanoparticle concentration was 0.01 vol% in the solution **.**Another study by **Lee et al.2013,** conducted in a bubble reactor, showed that at 20 °C and an Al2O3 concentration of 0.01 vol%, the rate of CO2 absorption increased by 4.5%; this enhancement increased to 5.6% when Al2O3 was replaced by SiO2 nanoparticles at the same temperature. At 0.01% Al2O3 nanoparticle concentration and 10 °C, **Jung et al.2012** increased the rate of CO2 absorption by 8% in a bubble reactor. These findings suggest that higher mass transfer efficiencies were obtained at lower nanoparticle concentrations

4.0 Classification of Nanofluids Based on Base Liquid

Another difficulty is choosing the best solvent for CO2 absorption. A good solvent needs to be readily available, inexpensive, non-toxic, corrosive, and combustible with a low vapour pressure. The most popular solvents for this purpose are brine, water, ionic liquids, amines, alcohols, amines, and piperazine (PZ) **[Lin et al 2014].** The following introduces three different kinds of nanofluids: methanol, amines, and water mixes.

4.1 Amine-Based Nanofluid

Amine absorption of CO2 is seen as a chemical process in which a mass transfer between the gaseous and liquid phases takes place. For this, absorption and desorption columns are employed. The absorption capacity of the chosen amine is determined by the gas-liquid equilibrium **[Mandal, B et al 2001].** Amines absorb CO2 with quick kinetics. The amino groups in an aqueous solution enhance alkalinity while the hydroxyl functional group in the amine increases water solubility and lowers vapour pressure [108]. As a result, the most popular solvent utilised in industrial gas sweetening procedures in scrubbers is aqueous alkanolamine solutions.

The classification of amines into three groups—primary amines like MEA, secondary amines like DEA, and tertiary amines like MDEA—is typically based on how many hydrogen atoms of an ammonia molecule are substituted with other functional groups **[Hafizi et al 2020].** Secondary amines react quickly with acidic gases like CO2 and have a higher rate of regeneration energy consumption than tertiary amines. The primary amine of MEA, which is highly reactive and practical from an economic standpoint, is the amine solvent utilised in large plants the most frequently. However, this solvent is aggressive and needs a lot of energy to regenerate. When nanoferrofluids were utilised as the enhancing agent, **Komati et al 2008.** were able to increase the rate of absorption of CO2 capture by amine solutions. They claimed that adding 0.39 vol% of nanoparticles to the base fluid increases its absorption capacity by 92.8% compared to the base fluid.The CO2 absorption has been investigated using three base liquids (water, amine, and methanol). Water has captured more interest among researchers as a base liquid than the two other base liquids due to availability and being cheaper.

5.0 Future Perspective of nanofluids for CO2 Capture :

Currently, hybrid systems can take the place of conventional procedures because of their effectiveness for CO2 absorption. On the other hand, hybrid systems, due to their novelty, need additional research to comprehend the impact of parameters, the performance of nanomaterials, and analysis of the process to attain an ideal rate of absorption. Blockage, phase stability, a lack of data on solvent qualities, pump power, the expense of solid materials, an increase in heat and energy transfer, and the imposition of additional investment expenditures are a few of the difficulties associated with adopting hybrid systems.In this regard, in addition to accelerating mass transfer and enhancing gas-phase absorption by solid particles, two energy and economic difficulties in these systems can be managed by appropriately choosing nanoparticles and base liquid. In general, by analysing the interaction between mechanisms and carrying out thorough research on the role of nanofluids in CO2 absorption, a hopeful viewpoint might be anticipated in the future and at large sizes. Future research will focus further on CO_2 removal and absorption processes employing nanoparticles and other techniques.

Conclusion

In this study, we have investigated various methods for CO_2 absorbtion, application of hybrid systems,and their wide application in CO_2 absorption. Accordingly, we can conclude that such technology provides one of the effective solutions for CO_2 absorption. In this review study main focus is given on use of nanofluid & its application for the CO_2 absorption, From this review we can conclude that CO_2 absorption using nanofluids depends on several factors, i.e., particle size, nanoparticle type, temperature, and base liquid. The CO_2 absorption in the nanofluid depends on the different surfaces of the nanoparticles; as a nanoparticle has a larger surface, it is dispersed better in the base liquid, increasing the absorption level. There are different nanoparticles with particular applications and properties, but among them, making use of the metal oxide nanoparticles, e.g., Fe_3O_4, ZnO, Al_2O_3, TiO_2, CuO etc., have captured significant interest in industrial applications due to being cheaper. In general, according to the research conducted in the realm of mass transfer and CO_2 absorption so far, we can conclude that using nanofluids is an effective method for increasing the CO_2 absorption in terms of the base liquid that can decrease the energy consumption and equipment costs.With consideration of setup and operation circumstances, hybrid systems are an alluring under-investigation technique that could replace conventional processes. They still require further research to improve their performance and comprehend key factors because they are not yet fully developed.

References

Jeong, Y.; Kim, S.; Lee, M.; Hong, S.; Jang, M.-G.; Choi, N.; Hwang, K.S.; Baik, H.; Kim, J.-K.; Yip, A.C.K.; et al. A hybrid zeolite membrane-based breakthrough for simultaneous CO_2 capture and CH_4 upgrading from biogas. ACS Appl. Mater. Interfaces 2022, 14, 2893–2907.

J. Jiang et al.Chemical Absorption Kinetics in MEA Solution with Nano-particles,Energy Procedia Volume 37, 2013, Pages 518-524

Zhang, S.; Shen, Y.; Wang, L.; Chen, J.; Lu, Y. Phase change solvents for post-combustion CO_2 capture: Principle, advances, and challenges. Appl. Energy 2019, 239, 876–897.

Yu, W.; Wang, T.; Park, A.-H.A.; Fang, M. Review of liquid nano-absorbents for enhanced CO_2 capture. Nanoscale 2019, 11, 17137–17156.

Mehdipour, M.; Keshavarz, P.; Rahimpour, M.R. Rotating liquid sheet contactor: A new gas-liquid contactor system in CO2 absorption by nanofluids. Chem. Eng. Process. Process Intensif. 2021, 165, 108447.

Golkhar, A.; Keshavarz, P.; Mowla, D. Investigation of CO2 removal by silica and CNT nanofluids in microporous hollow fiber membrane contactors. J. Membr. Sci. 2013,

Sumin, L.U.; Min, X.; Yan, S.U.N.; Xiangjun, D. Experimental and theoretical studies of CO2 absorption enhancement by nano-Al2O3 and carbon nanotube particles. Chin. J. Chem. Eng. 2013, 21, 983–990.

Jiang, J.; Zhao, B.; Zhuo, Y.; Wang, S. Experimental study of CO2 absorption in aqueous MEA and MDEA solutions enhanced by nanoparticles. Int. J. Greenh. Gas Control 2014, 29, 135–141.

Rashidi, H.; Mamivand, S. Experimental and numerical mass transfer study of carbon dioxide absorption using Al2O3/water nanofluid in wetted wall column. Energy 2022, 238, 121670.

Ganapathy, H.; Shooshtari, A.; Dessiatoun, S.; Alshehhi, M.; Ohadi, M.M. Experimental investigation of enhanced absorption of carbon dioxide in diethanolamine in a microreactor. In International Conference on Nanochannels, Microchannels, and Minichannels; American Society of Mechanical Engineers: New York, NY, USA, 2013.

Fang, L.; Liu, H.; Zhu, Y.; Zhang, H.; Cao, T. Influence of nanoparticles on bubble absorption of gaseous CO2 in ammonia water. Chem. Eng. China 2016, 5, 6.

Pineda, I.T.; Choi, C.K.; Kang, Y.T. CO2 gas absorption by CH3OH based nanofluids in an annular contactor at low rotational speeds. Int. J. Greenh. Gas Control 2014, 23, 105–112.

Haghtalab, A.; Mohammadi, M.; Fakhroueian, Z. Absorption and solubility measurement of CO2 in water-based ZnO and SiO2 nanofluids. In Fluid Phase Equilibria; Elsevier: Amsterdam, The Netherlands, 2015; Volume 392, pp. 33–42.

Nabipour, M.; Keshavarz, P.; Raeissi, S. Experimental investigation on CO2 absorption in sulfinol-M based Fe3O4 and MWCNT nanofluids. Int. J. Refrig. 2017, 73, 1–10.

Kim, W.-G.; Kang, H.U.; Jung, K.-M.; Kim, S.H. Synthesis of silica nanofluid and application to CO2 absorption. Sep. Sci. Technol. 2008, 43, 3036–3055.

Pang, C.; Wu, W.; Sheng, W.; Zhang, H.; Kang, Y.T. Mass transfer enhancement by binary nanofluids (NH3/H2O+ Ag na-noparticles) for bubble absorption process. Int. J. Refrig. 2012, 35, 2240–2247.

Lee, J.W.; Kang, Y.T. CO2 absorption enhancement by Al2O3 nanoparticles in NaCl aqueous solution. Energy 2013, 53, 206–211.

Komati, S.; Suresh, A.K. CO2 absorption into amine solutions: A novel strategy for intensification based on the addition of ferrofluids. J. Chem. Technol. Biotechnol. 2008, 83, 1094–1100. [Google Scholar] [CrossRef]

Lee, J.W.; Pineda, I.T.; Lee, J.H.; Kang, Y.T. Combined CO_2 absorption/regeneration performance enhancement by using nanoabsorbents. Appl. Energy 2016, 178, 164–176

Pineda, I.T.; Lee, J.W.; Jung, I.; Kang, Y.T. CO_2 absorption enhancement by methanol-based Al_2O_3 and SiO_2 nanofluids in a tray column absorber. Int. J. Refrig. 2012, 35, 1402–1409.

Zhang, N.; Zhang, X.; Pan, Z.; Zhang, Z. A brief review of enhanced CO_2 absorption by nanoparticles. Int. J. Energy Clean Environ. 2018, 19, 3–4.
Rahmatmand, B.; Keshavarz, P.; Ayatollahi, S. Study of absorption enhancement of CO_2 by Si, O2, Al_2O_3, CNT, and Fe_3O_4 nanoparticles in water and amine solutions. J. Chem. Eng. Data 2016, 61, 1378–1387.

Ganapathy, H.; Shooshtari, A.; Dessiatoun, S.; Alshehhi, M.; Ohadi, M.M. Experimental investigation of enhanced absorption of carbon dioxide in diethanolamine in a microreactor. In International Conference on Nanochannels, Microchannels, and Minichannels; American Society of Mechanical Engineers: New York, NY, USA, 2013.

Fang, L.; Liu, H.; Zhu, Y.; Zhang, H.; Cao, T. Influence of nanoparticles on bubble absorption of gaseous CO_2 in ammonia water. Chem. Eng. China 2016, 5, 6.

Pineda, I.T.; Choi, C.K.; Kang, Y.T. CO_2 gas absorption by CH_3OH based nanofluids in an annular contactor at low rotational speeds. Int. J. Greenh. Gas Control 2014, 23, 105–112.

Haghtalab, A.; Mohammadi, M.; Fakhroueian, Z. Absorption and solubility measurement of CO_2 in water-based ZnO and SiO_2 nanofluids. In Fluid Phase Equilibria; Elsevier: Amsterdam, The Netherlands, 2015; Volume 392, pp. 33–42.

Nabipour, M.; Keshavarz, P.; Raeissi, S. Experimental investigation on CO_2 absorption in sulfinol-M based Fe_3O_4 and MWCNT nanofluids. Int. J. Refrig. 2017, 73, 1–10.

Kim, W.-G.; Kang, H.U.; Jung, K.-M.; Kim, S.H. Synthesis of silica nanofluid and application to CO_2 absorption. Sep. Sci. Technol. 2008, 43, 3036–3055.

Lee, J.W.; Kang, Y.T. CO_2 absorption enhancement by Al_2O_3 nanoparticles in NaCl aqueous solution. Energy 2013, 53, 206–211.

Darvanjooghi, M.H.K.; Esfahany, M.N.; Esmaeili-Faraj, S.H. Investigation of the effects of nanoparticle size on CO_2 absorption by silica-water nanofluid. Sep. Purif. Technol. 2018, 195, 208–215.
Manikandan, S.P.; Akila, S.; Deepapriya, N. Mass transfer performance of Al_2O_3 nanofluids for CO_2 absorption in a wetted wall column. Int. Res. J. Eng. Technol. 2019, 6, 1329–1331.

Hwang, B.-J.; Park, S.-W.; Park, D.-W.; Oh, K.-J.; Kim, S.-S. Absorption of carbon dioxide into aqueous colloidal silica solution with different sizes of silica particles containing monoethanolamine. Korean J. Chem. Eng. 2009, 26, 775–782.

Golkhar, A.; Keshavarz, P.; Mowla, D. Investigation of CO_2 removal by silica and CNT nanofluids in microporous hollow fiber membrane contactors. J. Membr. Sci. 2013, 433, 17–24.

Sumin, L.U.; Min, X.; Yan, S.U.N.; Xiangjun, D. Experimental and theoretical studies of CO2 absorption enhancement by nano-Al2O3 and carbon nanotube particles. Chin. J. Chem. Eng. 2013, 21, 983–990.

Rahmatmand, B.; Keshavarz, P.; Ayatollahi, S. Study of absorption enhancement of CO2 by Si, O2, Al2O3, CNT, and Fe3O4 nanoparticles in water and amine solutions. J. Chem. Eng. Data 2016, 61, 1378–1387.

Zhang, Y.; Zhao, B.; Jiang, J.; Zhuo, Y.; Wang, S. The use of TiO2 nanoparticles to enhance CO2 absorption. Int. J. Greenh. Gas Control 2016, 50, 49–56.

Manikandan, S.P.; Akila, S.; Deepapriya, N. Mass transfer performance of Al2O3 nanofluids for CO2 absorption in a wetted wall column. Int. Res. J. Eng. Technol. 2019, 6, 1329–1331.

Park, S.-W.; Choi, B.-S.; Kim, S.-S.; Lee, J.-W. Chemical absorption of carbon dioxide into aqueous colloidal silica solution containing monoethanolamine. J. Ind. Eng. Chem. 2007, 13, 133–142.

Park, S.-W.; Choi, B.-S.; Kim, S.-S.; Lee, B.-D.; Lee, J.-W. Absorption of carbon dioxide into aqueous colloidal silica solution with diisopropanolamine. J. Ind. Eng. Chem. 2008, 14, 166–174.

Komati, S.; Suresh, A.K. CO2 absorption into amine solutions: A novel strategy for intensification based on the addition of ferrofluids. J. Chem. Technol. Biotechnol. 2008, 83, 1094–1100.

Lee, J.W.; Pineda, I.T.; Lee, J.H.; Kang, Y.T. Combined CO2 absorption/regeneration performance enhancement by using nanoabsorbents. Appl. Energy 2016, 178, 164–176.

101. Said, S.; Govindaraj, V.; Herri, J.-M.; Ouabbas, Y.; Khodja, M.; Belloum, M.; Sangwai, J.; Nagarajan, R. A study on the influence of nanofluids on gas hydrate formation kinetics and their potential: Application to the CO2 capture process. J. Nat. Gas Sci. Eng. 2016, 32, 95–108.
Nagy, E.; Feczkó, T.; Koroknai, B. Enhancement of oxygen mass transfer rate in the presence of nanosized particles. Chem. Eng. Sci. 2007, 62, 7391–7398.

Jung, J.-Y.; Lee, J.W.; Kang, Y.T. CO2 absorption characteristics of nanoparticle suspensions in methanol. J. Mech. Sci. Technol. 2012, 26, 2285–2290.

Lin, P.-H.; Wong, D.S.H. Carbon dioxide capture and regeneration with amine/alcohol/water blends. Int. J. Greenh. Gas Control 2014, 26, 69–75.

Mazari, S.A.; Ghalib, L.; Sattar, A.; Bozdar, M.M.; Qayoom, A.; Ahmed, I.; Muhammad, A.; Abro, R.; Abdulkareem, A.; Nizamuddin, S.; et al. Review of modelling and simulation strategies for evaluating corrosive behavior of aqueous amine systems for CO2 capture. Int. J. Greenh. Gas Control 2020, 96, 103010.

Hafizi, A.; Mokari, M.; Khalifeh, R.; Farsi, M.; Rahimpour, M. Improving the CO2 solubility in aqueous mixture of MDEA and different polyamine promoters: The effects of primary and secondary functional groups. J. Mol. Liq. 2020, 297, 111803.

Mandal, B.; Guha, M.; Biswas, A.; Bandyopadhyay, S. Removal of carbon dioxide by absorption in mixed amines: Modelling of absorption in aqueous MDEA/MEA and AMP/MEA solutions. Chem. Eng. Sci. 2001, 56, 6217–6224.

Arshadi, M.; Taghvaei, H.; Abdolmaleki, M.; Lee, M.; Eskandarloo, H.; Abbaspourrad, A. Carbon dioxide absorption in water/nanofluid by a symmetric amine-based nanodendritic adsorbent. Appl. Energy 2019, 242, 1562–1572.

Wang, T.; Yu, W.; Liu, F.; Fang, M.; Farooq, M.; Luo, Z. Enhanced CO2 absorption and desorption by monoethanolamine (MEA)-based nanoparticle suspensions. Ind. Eng. Chem. Res. 2016, 55, 7830–7838.

Irani, V.; Maleki, A.; Tavasoli, A. CO2 absorption enhancement in graphene-oxide/MDEA nanofluid. J. Environ. Chem. Eng. 2019, 7, 102782.

Park, S.-W.; Choi, B.-S.; Lee, J.-W. Effect of elasticity of aqueous colloidal silica solution on chemical absorption of carbon dioxide with 2-amino-2-methyl-1-propanol. Korea Aust. Rheol. J. 2006, 18, 133–141.

Nematollahi, M.H et al Green solvents for CO2 captureCurrent Opinion in Green and Sustainable Chemistry Volume 18, August 2019, Pages 25-30

Lian.S.et alRecent advances in ionic liquids-based hybrid processes for CO2 capture and utilization Journal of Environmental SciencesVolume 99, January 2021, Pages 281-295

Varghese A.M. et al CO2 capture adsorbents functionalized by amine – bearing polymers: A reviewInternational Journal of Greenhouse Gas Control Volume 96, May 2020, 103005

Wang M et al Process intensification for post-combustion CO2 capture with chemical absorption: A critical review Applied Energy Volume 158, 15 November 2015, Pages 275-291

Pailin Muchan, Chintana Saiwan Teeradet Supap a, Raphael Idem a Selection of components for formulation of amine blends for post combustion CO2 capture based on the side chain structure of primary, secondary and tertiary amines Chemical Engineering ScienceVolume 170, 12 October 2017, Pages 542-560

Xiaowei Zhou et al A Novel Dual-Stage Phase Separation Process for CO2 Absorption into a Biphasic Solvent with Low Energy Penalt, Environ. Sci. Technol. 2021, 55, 22, 15313–15322September 13, 2021

Mun-Gi Jang a, Seokwon Yun b, Jin-Kuk Kim a Process design and economic analysis of membrane-integrated absorption processes for CO2 capture Journal of Cleaner Production Volume 368, 25 September 2022, 133180

Y Zhao, Y Zhang, Y Cui, Y Duan, Y Huang, G Wei… Pinch combined with exergy analysis for heat exchange network and techno-economic evaluation of coal chemical looping combustion power plant with CO2 capture- Energy, 2022

Vengatesan Muthukumaraswamy Rangaraj1, Mohammad A. Wahab2,3, K. Suresh Kumar Reddy1,Metal Organic Framework — Based Mixed Matrix Membranes for Carbon Dioxide Separation: Recent Advances and Future DirectionsFront. Chem., 03 July 2020 Sec. Chemical and Process Engineering
Volume 8 - 2020 | https://doi.org/10.3389/fchem.2020.00534

P.R. Yaashikaa a, P. Senthil Kumar a b, Sunita J. Varjani c, A. Saravanan ,A review on photochemical, biochemical and electrochemical transformation of CO_2 into value-added products Journal of CO_2 Utilization,Volume 33, October 2019, Pages 131-147

Abdallah Dindi, Dang Viet Quang, Inas AlNashef, Mohammad R.M. Abu-Zahra ,A process for combined CO_2 utilization and treatment of desalination reject brine, Desalination,Volume 442, 15 September 2018, Pages 62-74