World Essays Journal / 10 (3): 125-137, 2022
Available online at www. worldessaysj.com
ISSN online: 2310-1377, Print: 2310-8509

Trends in Carbon Dioxide Capture/Separation Technologies: A Review

Seyed Navid Shahidinia
Science and technology university of Iran

Paper Information

Received: 4 July, 2019

Accepted: 11 August, 2019

Published: 10 September, 2020

ABSTRACT

The majority of fossil fuel power plants' carbon dioxide (CO2) emissions come from coal-fired thermal power facilities. Carbon dioxide (CO2), mercury (Hg), sulfur dioxide (SO2), and nitrogen oxides (NOx) are just some of the gases that are released into the atmosphere when coal is burned in thermal power plants. When everything else is taken into account, carbon dioxide (CO2) is by far the biggest cause of global warming. The environment's safety and security depend on the effective collection and separation of CO2. The purpose of this study is to evaluate the literature and assess the present status of various techniques and technologies used to collect and separate CO2 from flue gas produced by thermal power plants. Chemical-looping combustion, integrated gasification combined cycle, enzyme-based separation, dual-alkali absorption approach, facilitated transport membrane, hydrate-based separations, mixed matrix membrane, and calcium looping are just some of the new technologies discussed in detail in this paper.

Key words: *Carbon Dioxide, Capture, Separation*

Introduction

The escalating levels of carbon dioxide (CO2) emissions in the environment have emerged as a pressing concern in contemporary times, primarily due to their significant contribution to the phenomenon of global warming. This issue has garnered widespread attention and has become a topic of paramount importance in various academic and scientific circles. The climate of the Earth is subject to continuous variation as a result of multiple factors. These factors include changes in the Earth's orbit, fluctuations in the intensity of solar radiation emitted by the Sun, alterations in ocean currents, emissions from volcanic activity, and the accumulation of greenhouse gases (GHGs) in the atmosphere. One significant factor contributing to climate variability is the Earth's orbit. Over long periods of time, the Earth's orbit undergoes cyclical changes, known as Milankovitch cycles, which affect the amount and distribution of solar radiation received by the planet. These orbital variations can lead to shifts in global temperatures and climate patterns. Another influential factor is the Sun's intensity. The Sun is not a constant source of energy, and its output can vary over time. Fluctuations in solar radiation can impact the Earth's climate, causing periods of warming or cooling. These variations in solar activity occur on both short-term and long-term timescales. Ocean currents also play a crucial role in shaping the Earth's climate. These currents, driven by a combination of wind patterns, temperature gradients, and the rotation of the Earth, transport heat The greenhouse effect refers to the natural process by which certain atmospheric gases, such as water vapor, carbon dioxide (CO2), methane, and others, absorb and trap outgoing infrared radiation from the Earth's surface. This absorption of infrared radiation leads to a subsequent increase in the Earth's temperature [1]. The presence of an excessive amount of greenhouse gases in the Earth's atmosphere has been identified as a significant factor contributing to a range of environmental issues. These issues include the continuous rise in sea levels, the escalating frequency of ocean storms, and the occurrence of floods, among others [2]. Among the various greenhouse gases (GHGs) that contribute to the phenomenon of global warming, carbon dioxide (CO2) stands out as the primary culprit. This gas is responsible for the majority of the adverse effects associated with global warming, accounting for approximately 55% of the observed increase in global temperatures. Carbon dioxide (CO2) in isolation has been identified as the primary contributor, accounting for approximately 64% of the overall enhanced greenhouse effect [3].

Based on the projections made by the Intergovernmental Panel on Climate Change (IPCC), it is anticipated that by the year 2100, the concentration of carbon dioxide (CO2) in the Earth's atmosphere could reach a level of up to 570 parts per million by volume (ppmv). This significant increase in CO2 concentration is expected to have profound implications for the planet's climate system. It is predicted that such a rise in CO2 levels would lead to a corresponding increase in the average global temperature, with estimates suggesting a rise of approximately 1.9 degrees Celsius. Additionally, this rise in temperature is likely to contribute to a rise in sea levels, with projections indicating an average increase of 3.8 meters. These projections highlight the potential consequences of continued greenhouse gas emissions and emphasize the urgent need for effective climate change mitigation strategies.

At present, a significant proportion of the global energy demand, specifically 85%, is met through the utilization of fossil fuel thermal power plants, which primarily rely on coal, oil, and gas as their energy sources. Fossil fuel power plants are responsible for approximately 40% of total carbon dioxide (CO2) emissions, with coal-fired power plants being the primary contributor within this category [4]. The process of capturing carbon dioxide (CO2) from the flue gas emitted by power plants is a crucial component of carbon capture and storage (CCS) technology. In fact, it represents a significant portion, specifically three quarters, of the overall cost associated with implementing CCS. This cost primarily encompasses the expenses incurred in the capture phase, which involves the separation and removal of CO2 from the flue gas stream. By focusing on this critical stage, researchers and engineers aim to develop more efficient and cost-effective methods for capturing CO2, thereby advancing the feasibility and widespread adoption of CCS as a viable solution for mitigating greenhouse gas emissions. The research issue pertaining to global warming has gained significant importance in recent years due to the increasing international attention it has received [5]. This heightened focus on global warming from a global perspective has prompted researchers to delve deeper into the subject matter. In order to successfully meet the mid to long term goals of reducing CO2 emissions, it is imperative to assess the feasibility and cost-effectiveness of capturing CO2 from fossil fuel power plants and exploring various options for its subsequent sequestration. This evaluation is particularly crucial in light of the increasing global demand for energy. In the field of carbon dioxide (CO2) capture, there exists a diverse range of technologies that have been developed and implemented. These technologies encompass various methods such as absorption, adsorption, gas separation, membrane-based processes, and cryogenic separation, among others. Each of these approaches offers distinct advantages and limitations, making them suitable for different applications and operating conditions. Absorption-based technologies involve the transfer of CO2 from a gas phase to a liquid phase through the use of solvents or absorbents. This process relies on the chemical reaction between the CO2 and the absorbent, resulting in the
This paper provides a concise overview of the current and developing technologies utilized for the separation and capture of carbon dioxide (CO2) from point source emissions. The primary objective of this literature review is to furnish a comprehensive and up-to-date comprehension of the ongoing advancements in diverse capture technologies. This review aims to explore the existing technological options and shed light on the persisting challenges that hinder the further development of the main capture technologies. By examining the current state of these technologies, this review seeks to contribute to the existing body of knowledge in this field.

2. Various options for CO2 capture

Depending on the specific configurations of plants, there are several methods that can be employed to effectively reduce CO2 emissions from thermal power plant flue gas. These methods have been extensively studied and implemented in various plant settings to mitigate the environmental impact of these emissions. By adopting these approaches, power plants can significantly contribute to the global efforts aimed at reducing greenhouse gas emissions and combating climate change.

Pre-combustion capture refers to a carbon capture and storage (CCS) technique that is employed prior to the combustion process in power plants or

Post-combustion capture refers to a carbon capture technology that is implemented after the combustion process in power plants or industrial facilities. This technology is designed

Oxyfuel combustion, also known as oxy-combustion, is a combustion process that involves the use of oxygen instead of air as the oxid

2.1. Pre-combustion carbon capture refers to a process in which carbon dioxide (CO2) is captured before it is released into

The pre-combustion process is a crucial step in the treatment of synthesis gas, also known as syngas, which is primarily composed of carbon monoxide (CO) and hydrogen. This process plays a significant role in the overall synthesis gas conversion and utilization, as it involves various techniques and technologies aimed at enhancing the quality and efficiency of the syngas for subsequent applications. By implementing pre-combustion processes, such as gasification or reforming, the syngas can be further refined and optimized to meet specific requirements and desired compositions, thus enabling its effective utilization in various industrial sectors, including power generation, The pre-combustion rate is based on the generation of syngas, the elimination of carbon dioxide (CO2), and the combustion of hydrogen (H2) [7]. This process involves the production of syngas, which is a mixture of carbon monoxide (CO) and hydrogen (H2), through a series of chemical reactions. The CO2 is then separated and removed from the syngas, leaving behind a cleaner fuel source. Finally, the hydrogen component of the syngas is combusted, releasing energy and producing water vapor as a byproduct. This pre In certain respects, the notion of capturing CO2 prior to combustion can be considered an oxymoron due to the fact that CO2 is typically not readily available for capture before the combustion process takes place. This is because CO2 is a byproduct of coal combustion rather than a natural precursor that can be easily captured beforehand. It is possible to gasify various forms of fossil fuels through processes such as partial combustion or reformation, by utilizing a sub-stoichiometric quantity of oxygen. This gasification process is typically carried out under elevated pressures, typically ranging from 30 to 70 atmospheres. The end result of this gasification is the production of a syngas, which primarily consists of carbon monoxide (CO) and hydrogen (H2). Subsequently, the process involves the introduction of steam into the syngas mixture, which is then directed through a bed that is densely packed with catalysts. Within this catalytic bed, the water gas shift reaction occurs, facilitating the conversion of carbon monoxide (CO) into carbon dioxide (CO2).

The water gas shift reaction is a chemical process in which the addition of steam and the reduction of temperature play a crucial role in promoting the conversion of carbon monoxide (CO) into carbon dioxide (CO2) and increasing the yield of hydrogen gas (H2) [8]. In the process depicted in Figure 1, a stream containing CO2 and H2 is subjected to separation, resulting in the isolation of CO2. This separated CO2 is then directed towards the compression unit. On the other hand, the remaining H2, which has been purified, is utilized as an input in a combined cycle system for the purpose of generating electricity.

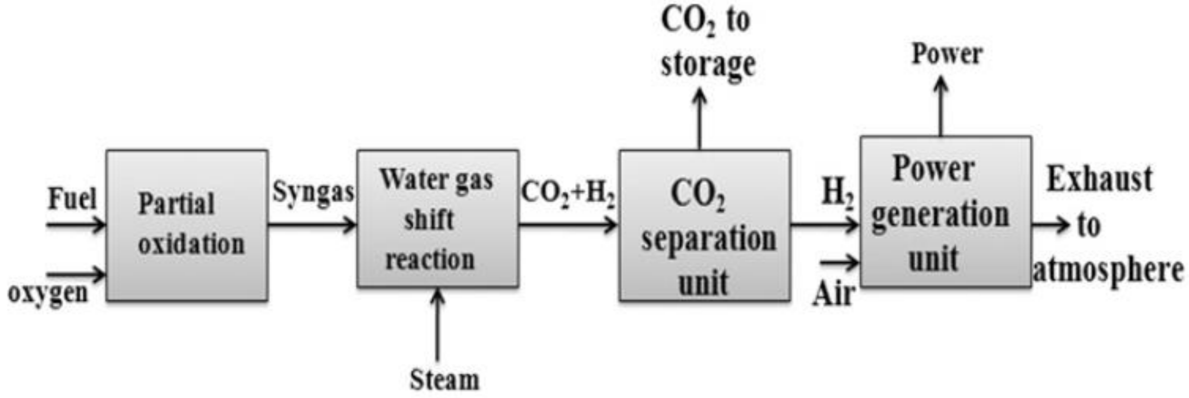

Fig. 1. Principle of pre-combustion CO2 capture [6,9,10]

Another potential avenue that is currently under development involves harnessing the power of hydrogen to fuel cells, with the ultimate goal of substantially increasing the overall efficiency of the plant. In the future, it is plausible that hydrogen gas (H2) could serve as a viable alternative for transportation fuel, as suggested by recent research [10]. This potential application of hydrogen gas as a fuel source in the transportation sector holds promise for addressing the pressing challenges associated with fossil fuel consumption and its detrimental environmental impacts. By utilizing hydrogen gas as a transportation fuel, we may be able to

In the separation process, it is common practice to employ a physical solvent, such as rectisol or selexol, due to their affordability. These solvents are readily accessible and can be obtained at a relatively low cost, making them a preferred choice for various separation applications. Carbon dioxide (CO2) exhibits solubility characteristics that are influenced by changes in pressure. Specifically, when CO2 is subjected to higher pressure, it dissolves more readily in a given solvent. Conversely, when the pressure is reduced, the dissolved CO2 is released from the solvent. This phenomenon can be observed in various natural and industrial processes, and understanding the solubility behavior of CO2 under different pressure conditions is crucial for numerous scientific and technological applications. The regeneration of the solvent does not necessitate the application of heat, thereby offering an energy-efficient process. Additionally, the release of carbon dioxide (CO2) can occur at pressures higher than atmospheric pressure, which further enhances the efficiency and effectiveness of the regeneration process. The energy requirement for the separation and compression of CO2 in pre-combustion capture is estimated to be approximately half of that needed for post-combustion capture, as indicated by previous research [8]. This discrepancy in energy demand can be attributed to the different stages and processes involved in each capture method. Pre-combustion capture involves the removal of CO2 from the fuel before it is combusted, typically through gasification or reforming processes. On the other hand, post-combustion capture involves the extraction of CO2 from the flue gas emitted after combustion. The variation in energy requirements between these two approaches underscores the importance of considering the specific capture method when evaluating the energy efficiency of carbon capture technologies. One notable advantage of this process is its utilization of physical solvents, which are readily available at a low cost and require minimal energy for regeneration [6]. This characteristic enhances the economic feasibility and energy efficiency of the process.

One of the primary drawbacks associated with pre-combustion carbon capture technology is the necessity of integrating a chemical plant upstream of the turbine. This requirement poses a significant challenge in terms of infrastructure and operational complexity. In complex chemical processes, it is common for additional shutdowns of the plant to occur, leading to a reduction in power output. These shutdowns are typically caused by intricate reactions and transformations taking place within the system. As a consequence, the overall efficiency of the plant is compromised, resulting in a decrease in the amount of power generated. In addition to the aforementioned drawbacks, there are several other disadvantages associated with this particular process. One such drawback pertains to the utilization of non-gaseous feed stocks, which may pose challenges in terms of their compatibility with the process requirements. Furthermore, the process necessitates the use of a cleaned gas stream, which adds an additional layer of complexity and cost to the overall operation. Additionally, the control of high NOx emissions may require the implementation of expensive scrubbing techniques, further increasing the economic burden associated with this process.

The presence of carbon dioxide (CO2) at significantly higher concentrations in syngas, which is a mixture of hydrogen and carbon monoxide produced from various feedstocks, offers a distinct advantage in terms of cost-effectiveness for pre-combustion capture compared to post-combustion capture methods. At present, the number of gasification plants that are operating at full scale is limited. Additionally, it is worth noting that the capital costs associated with these plants are higher when compared to those of pulverized coal-fired power plants [10].

2.2. Post-combustion capture refers to a carbon capture technology that is implemented after the combustion process in power plants or industrial facilities. This technology aims to capture and

Post combustion capture is a process that entails the extraction and separation of carbon dioxide (CO2) from the flue gas generated during the combustion process within a thermal power plant's combustion chamber, as depicted in Figure 2. In the current energy landscape, conventional power plants rely on the utilization of air as the primary medium for combustion processes. This combustion results in the production of a flue gas, which is typically released into the atmosphere at atmospheric pressure. It is worth noting that the flue gas emitted by these power plants generally exhibits a carbon dioxide (CO2) concentration that is below the threshold of 15%. Therefore, it can be observed that the thermodynamic driving force for the extraction of low levels of carbon dioxide (CO2) from flue gas is relatively low. This poses a significant technical obstacle in the quest to develop economically viable advanced capture processes. This assertion is supported by previous research [6]. One of the challenges associated with power-plant flue gas is the relatively low concentration of CO2 present. For instance, coal-fired power plants typically have a CO2 concentration of around 13e15%, while gas-fired power plants have a concentration of approximately 7e8% (as shown in Table 1). This low concentration necessitates the handling of a large volume of gas, leading to the requirement for larger equipment sizes and consequently higher capital costs. Based on the analysis of various separation techniques, it can be concluded that technologies relying on chemical absorption demonstrate superior adaptability in achieving effective separation. These technologies, which involve the absorption of substances into a chemical solvent, have proven to be highly efficient and reliable in the separation process. The utilization of chemical absorption-based technologies offers numerous advantages, including enhanced selectivity, improved efficiency, and greater versatility in handling a wide range of separation requirements. Consequently, it can Other technologies such as adsorption, membranes, and cryogenic processes exhibit a relatively lower suitability for post-combustion capture when compared to precombustion capture. This disparity in suitability can be attributed to a number of key factors that warrant consideration. Firstly, adsorption-based technologies, which involve the attachment of gas molecules onto a solid surface, face limitations in terms of their efficiency and capacity for capturing carbon dioxide (CO2) from flue gas streams. Similarly, membrane-based processes, which rely on selective permeation of CO2 through a membrane material, encounter challenges related to their limited separation capabilities and susceptibility to fouling. Additionally, cryogenic methods.

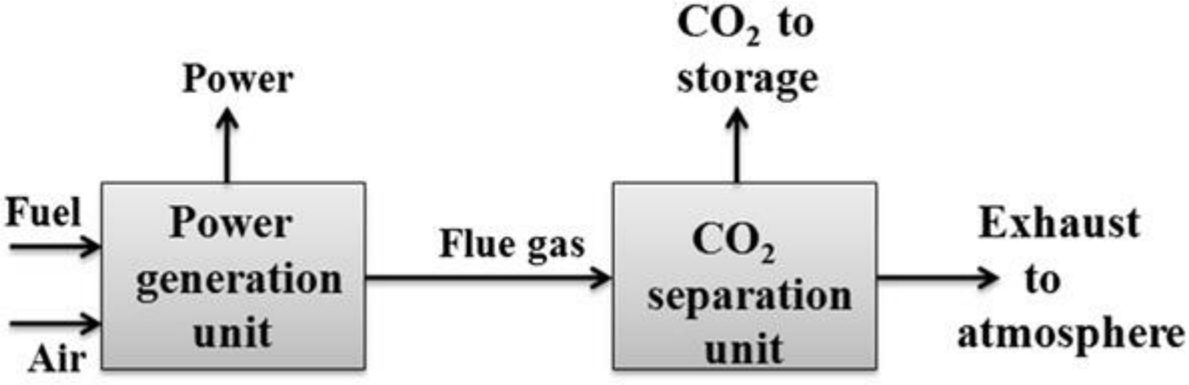

Fig. 2. Principle of post-combustion CO2 capture [6,9,10].

There is a notable disparity in the partial pressure of carbon dioxide (CO2) between post-combustion exhaust gases and syngas derived from either a gasifier or a reformer. The partial pressure of CO2 in post-combustion exhaust gases is significantly lower compared to that found in syngas.

In various industrial processes, it is not uncommon to encounter an increased concentration of particulate matter, including dusts and impurities such as sulfur oxides (SOx) and nitrogen oxides (NOx). Additionally, non-condensable gases, particularly oxygen, may also be present in larger quantities. These factors can have significant implications for the overall efficiency and environmental impact of the processes involved.

According to current research and analysis, it has been observed that post combustion capture technology exhibits a notably higher level of thermal efficiency when it comes to the conversion of fuel into electricity, as compared to the pre combustion Integrated Gasifier Combined Cycle (IGCC) approach. This finding suggests that the utilization of post combustion capture technology holds significant potential for enhancing the overall energy conversion process in power generation systems. Based on the available evidence, it is highly probable that the implementation of post-combustion capture technology in natural gas plants will result in significantly reduced total electricity costs compared to pre-combustion capture methods [4,8]. The separation of carbon dioxide (CO2) from the flue gas stream of a post-combustion system presents numerous challenges that must be overcome. These challenges arise due to various factors and complexities associated with the separation process. The elevated temperature of the flue gases presents a significant design challenge that must be addressed. Another significant challenge that arises in the context of capturing low concentrations of carbon dioxide (CO2) is the necessity of employing potent chemical solvents. These solvents, while effective in capturing CO2, present a number of drawbacks. One such drawback is the substantial energy requirement for regenerating the solvents in order to release the captured CO2. This energy-intensive process poses a significant obstacle in the overall efficiency and feasibility of CO2 capture and regeneration.

2.3. Oxy-fuel combustion, also known as oxygen-enriched combustion, is a combustion process that involves the utilization of oxygen instead

Oxy-fuel combustion has emerged as a highly promising technological approach for the efficient capture of carbon dioxide (CO2) from fuel gas, as well as for the modification of the combustion process itself to yield flue gas with a significantly elevated concentration of CO2, thereby facilitating its subsequent separation. This technology holds great potential for addressing the pressing issue of CO2 emissions and contributing to the development of sustainable energy systems. In the aforementioned process, the combustion of fuel takes place within a designated chamber. This combustion chamber is characterized by an environment consisting predominantly of pure oxygen, with a concentration exceeding 95%. Additionally, the pure oxygen is mixed with recycled flue gas (RFG), as visually depicted in Figure 3. In the predominant iteration of this conceptual framework, the utilization of a cryogenic air separation unit is advocated for the purpose of procuring oxygen of exceptional purity.

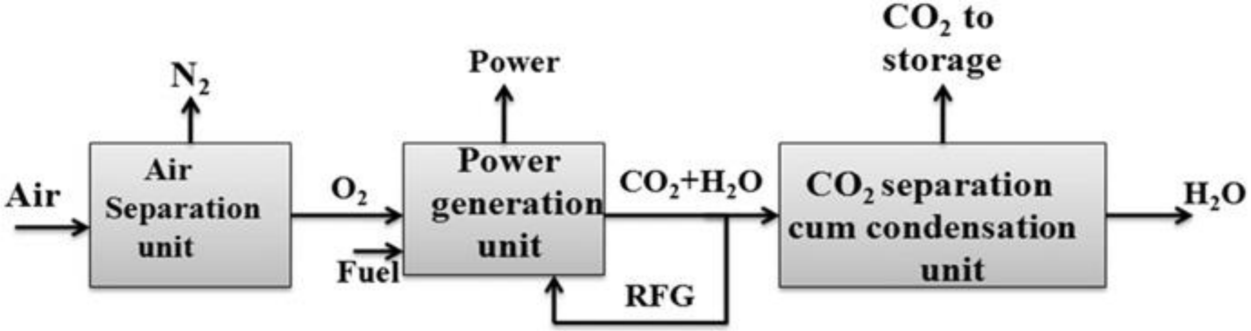

Fig. 3. Principle of oxyfuel combustion CO2 capture [6,9,10].

In order to maintain optimal combustion conditions resembling those of an air-fired configuration, it is common practice to introduce high purity oxygen into the combustion process. This oxygen is typically mixed with RFG (Recycled Flue Gas) either before combustion or directly in the boiler. By incorporating this mixture, the combustion process can be effectively controlled and regulated, ensuring efficient and effective energy generation. The necessity of addressing the issue at hand arises from the fact that the existing materials of construction are unable to withstand the elevated temperatures that are generated as a consequence of coal combustion in an environment of pure oxygen. The flue gas stream emanating from this particular system predominantly consists of carbon dioxide (CO2) and water vapor. The process of condensation readily facilitates the removal of water, thereby leaving behind the remaining carbon dioxide (CO2) for further purification. This purification step can be accomplished at a relatively low cost. The carbon dioxide (CO2) concentration in the dry flue gas exhibits a wide range of variability, typically spanning from 70% to 95%. This variation is influenced by several factors, including the type of fuel being utilized, the specific process employed, the extent of air leakage into the system, the purity of oxygen (O2) present, and the level of excess O2 maintained. These parameters collectively contribute to the observed fluctuations in CO2 content within the flue gas.

Typical CO2 compositions in process streams [1,11].

Process	CO2 Concentration (vol.%)
Power plant flue gas	14
Coal-fired boiler	14
Natural gas-fired boiler	8
Natural gas combined cycle	4
Coal-oxygen combustion	>80
Natural gas partial oxidation	40
Blast furnace gas (Before combustion)	20
Blast furnace gas (After combustion)	27
Cement kiln off-gas	14-33
Oil refineries and petrochemical plant fired heater	8

Absorption Process:

The absorption process is a common CO2 capture technique that involves the physical or chemical absorption of CO2 into a liquid solvent or absorbent material. This process is widely used in various industries and can be applied to different gas streams, including flue gases from power plants, industrial processes, and natural gas purification.

Absorption of CO2: During the absorption process, CO2 molecules come into contact with the liquid solvent or absorbent. The CO2 molecules then dissolve or react with the absorbent, leading to their separation from the gas stream.

Reaction Mechanism: In the case of chemical absorption, the reaction mechanism involves a chemical reaction between CO2 and the absorbent, resulting in the formation of a chemical compound. The chemical reaction can be reversible, allowing for the release of CO2 from the absorbent under specific conditions. Examples of chemical absorption processes include the use of solvents like aqueous amine solutions, potassium carbonate, or ammonia-based solutions.

On the other hand, physical absorption relies on the physical solubility of CO2 in the liquid solvent. In this case, there is no chemical reaction between CO2 and the absorbent. Instead, CO2 dissolves into the solvent due to its solubility characteristics. Common solvents used for physical absorption include methanol, ethanol, or other organic solvents.

Both chemical and physical absorption processes can effectively capture CO2 from gas streams, but the choice of absorption method depends on factors such as the specific application, gas composition, desired CO2 capture efficiency, and economic considerations.

It's worth noting that after the CO2 is captured through the absorption process, further steps are usually required to separate and recover the CO2 from the solvent or absorbent for storage or utilization purposes. These separation steps may include processes such as stripping, desorption, or regeneration of the absorbent.

Adsorption Process:

The adsorption process is another commonly used CO2 capture technique that involves the selective adsorption of CO2 onto a solid adsorbent material. Adsorption processes are based on the principle that different gases have varying affinities for adsorbents, allowing for the separation of CO2 from other gases in a mixture.

There are several variations of adsorption processes used for CO2 capture, including Pressure Swing Adsorption (PSA), Temperature Swing Adsorption (TSA), and Electrical Swing Adsorption (ESA).

1. Pressure Swing Adsorption (PSA): PSA operates by exploiting the difference in adsorption capacities of CO2 and other gases at varying pressures. The process typically involves a cyclic operation with two main steps: adsorption and desorption. In the adsorption step, a gas mixture is passed through a bed of solid adsorbent material at a relatively high pressure, allowing the adsorbent to selectively capture CO2. Subsequently, in the desorption step, the pressure is reduced, causing the adsorbent to release the captured CO2, regenerating the adsorbent for subsequent cycles.
2. Temperature Swing Adsorption (TSA): TSA utilizes the difference in adsorption capacities of CO2 and other gases at varying temperatures. In this process, the adsorbent material is exposed to a gas mixture at an elevated temperature, promoting the adsorption of CO2. Then, the temperature is reduced, causing desorption of the captured CO2 from the adsorbent. The released CO2 can be recovered for storage or utilization purposes.
3. Electrical Swing Adsorption (ESA): ESA is an innovative adsorption process that incorporates the use of an electric field to enhance the separation of CO2 from gas mixtures. The adsorbent material is modified with electrical properties, allowing for the application of an electric field during the adsorption and desorption steps. The electric field assists in the capture and release of CO2 by manipulating the charge distribution and interactions between the gas molecules and the adsorbent material.

These adsorption processes offer advantages such as high selectivity, efficient separation, and potential for regeneration and reuse of the adsorbent material. However, the choice of adsorption process depends on factors such as the specific application, gas composition, desired CO2 capture efficiency, and economic considerations.

Cryogenic Process:

The cryogenic process for CO2 capture involves the cooling of gas mixtures to very low temperatures, typically below the condensation point of CO2. By reducing the temperature, CO2 in the gas mixture can be selectively condensed and separated from other gases, facilitating its capture and removal.

In the cryogenic process, the gas mixture is subjected to a series of cooling and condensation steps. Initially, the gas mixture is compressed and purified to remove impurities and water vapor. Then, the gas is cooled using various cooling techniques, such as refrigeration cycles or cryogenic refrigerants, to lower the temperature of the gas stream. As the temperature decreases, CO2 in the mixture undergoes a phase change from gas to liquid, while other gases remain in the gaseous state. The liquid CO2 is subsequently collected and separated from the gas mixture.

Cryogenic processes offer high CO2 capture efficiencies and can be particularly effective when dealing with gas streams containing high concentrations of CO2. However, they can be energy-intensive due to the need for cooling and refrigeration equipment. The captured CO2 can be further processed for storage or utilization.

Membrane Technology:

Membrane technology for CO2 capture utilizes semi-permeable membranes that selectively allow the passage of CO2 molecules while blocking other gases present in the gas stream. The separation is based on the differences in permeability and solubility of gases in the membrane material.

In this process, the gas stream is directed through a membrane module or system containing a selective membrane. The membrane acts as a barrier, allowing the preferential permeation of CO2 molecules through its structure while hindering the passage of other gases. The separation is driven by a combination of factors, including differences in gas molecule size, solubility, and diffusion rates through the membrane material.

Membrane technology offers advantages such as simplicity, compactness, and potential for continuous operation. It can be used for various gas streams, including flue gases from power plants or industrial processes. However, the efficiency of membrane separation depends on factors such as membrane material, operating conditions, gas composition, and membrane design.

Overall, both cryogenic processes and membrane technology provide viable options for CO2 capture, each with its own set of advantages and considerations. The choice of technology depends on factors such as gas stream characteristics, desired capture efficiency, energy requirements, and economic feasibility.

Limitations and Implementation on Existing Technologies:

Limitations and Implementation of Existing CO2 Capture Technologies:

1. Energy Intensive: Many CO2 capture technologies require substantial energy inputs to operate, which can impact the overall efficiency of the process. The energy demand for processes such as absorption, adsorption, cryogenic separation, or membrane separation can increase operational costs and carbon footprint, potentially offsetting the benefits of CO2 capture.
2. High Cost: The implementation and operation of CO2 capture technologies can be expensive. The costs are attributed to factors such as equipment, materials, energy consumption, and maintenance. The high cost can pose challenges to the widespread adoption of these technologies, particularly for industries that operate on tight budgets or face economic constraints.
3. Scale and Integration: Implementing CO2 capture technologies on a large scale and integrating them into existing industrial processes can be complex. Industries often have unique operational conditions, diverse gas streams, and infrastructure limitations that may require customizations and adaptations for effective implementation. Scaling up the technologies to match the CO2 capture requirements of large industrial facilities or power plants adds further complexity.
4. Storage and Utilization: Captured CO2 needs to be stored or utilized effectively to mitigate its environmental impact. The long-term storage of CO2, commonly referred to as carbon capture and storage (CCS), requires suitable geological formations and entails monitoring and safety considerations. Alternatively, carbon capture and utilization (CCU) involves converting CO2 into valuable products or using it for enhanced oil recovery or other industrial applications. Developing efficient and economically viable storage and utilization pathways is crucial for the success of CO2 capture technologies.

Addressing these limitations and challenges is crucial for the successful implementation and widespread adoption of CO2 capture technologies. Ongoing research and development efforts are focused on improving the energy efficiency, reducing costs, optimizing integration with existing processes, and exploring innovative storage and utilization options to maximize the environmental benefits of CO2 capture. Policy support, incentives, and collaborations between governments, industries, and research institutions play vital roles in accelerating the deployment of these technologies.

Progress in CO2 Capture:
Significant progress is being made in the research and development of CO2 capture technologies, with a focus on enhancing their efficiency, cost-effectiveness, and scalability. Here are some notable advancements:

1. Novel Solvents and Absorbents: Researchers are exploring and developing new types of solvents and absorbents that exhibit improved CO2 capture performance. This includes the investigation of advanced materials, such as solid sorbents, ionic liquids, and hybrid materials, which offer higher selectivity, improved stability, and lower energy requirements compared to traditional solvents.
2. Optimization of Adsorption Processes: Efforts are underway to optimize adsorption processes, such as Pressure Swing Adsorption (PSA) and Temperature Swing Adsorption (TSA). Researchers are working on improving the selectivity, capacity, and regeneration efficiency of adsorbents to enhance their overall performance and reduce energy consumption.
3. Advanced Membrane Materials: The development of advanced membrane materials is another area of focus. Researchers are working on designing membranes with improved selectivity, permeability, and stability for efficient CO2 separation. Advances in membrane technology aim to enhance the performance and cost-effectiveness of membrane-based CO2 capture processes.
4. Direct Air Capture (DAC): DAC is an emerging approach that involves capturing CO2 directly from ambient air. Researchers are exploring various techniques and materials to efficiently capture and concentrate CO2 from the atmosphere. DAC has the potential to remove CO2 emissions directly from the air, complementing traditional capture methods and enabling carbon-negative operations.
5. Carbon Capture Utilization and Storage (CCUS): CCUS techniques encompass the utilization or safe storage of captured CO2. Efforts are being made to develop viable and economically viable pathways for utilizing captured CO2 in various applications, such as carbon-based products, chemicals, and fuels. Additionally, advancements in CO2 storage technologies and techniques aim to ensure safe and long-term storage of captured CO2 in suitable geological formations.

The progress in CO2 capture technologies is driven by a combination of research, industry collaboration, and government support. The goal is to accelerate the deployment of these technologies, reduce greenhouse gas emissions, and contribute to the global efforts to mitigate climate change.

Conclusion

In this discourse, a thorough examination of the present state of existing technologies for carbon dioxide (CO2) capture has been undertaken. Absorption, as a well-established technology for post combustion capture, has garnered significant attention. However, despite its maturity, certain challenges persist, including solvent losses, corrosion, and the high cost of separation. These issues have been identified as the primary obstacles impeding the widespread implementation of absorption-based post combustion capture processes. Consequently, researchers and engineers have been diligently working to address these concerns and develop innovative solutions that can enhance the efficiency and viability of this technology. By mitigating solvent losses, combating corrosion, and reducing the overall cost of separation, the potential of absorption as a sustainable and economically feasible method for post combustion capture can be fully realized. The limited selectivity and capacity of the currently available adsorbents pose significant challenges to the effectiveness of the adsorption process in large-scale industrial applications. These limitations hinder the ability of adsorbents to selectively capture and retain target molecules or contaminants, as well as their overall capacity to adsorb a substantial amount of these substances. Consequently, the efficiency and practicality of adsorption as a viable method for industrial-scale applications are compromised. The utilization of membrane processes in various industries has been recognized for its numerous advantages when compared to conventional processes. However, despite these advantages, there are still uncertainties surrounding the high capacity and stability of membrane processes. One of the key advantages of membrane processes is their ability to provide efficient separation and purification of substances. Membrane processes offer a high degree of selectivity, allowing for the separation of specific components from a mixture based on their size, charge, or other properties. This selective separation capability is particularly beneficial in industries such as water treatment, pharmaceutical The cryogenic process has successfully generated liquid carbon dioxide (CO2) without the need for any separation media. This achievement is significant as it eliminates the necessity for additional substances or materials to facilitate the separation of CO2 during the cryogenic process. By obviating the requirement for separation media, this development streamlines the cryogenic process, making it more efficient and cost-effective. The process of separation incurs a significant financial burden and necessitates stringent control measures, rendering it applicable solely to specific and exceptional situations. In the realm of technological advancements, it is widely acknowledged that each existing technology possesses its own set of advantages and limitations. However, it is the reliability, stability, and removal efficiency of these technologies that present themselves as the primary challenges to be addressed. In the realm of carbon capture and storage (CCS), there exists a pressing demand for comprehensive comprehension of the prevailing technological advancements. This imperative understanding serves as a catalyst for enhancing the overall performance of CO2 separation processes, while concurrently mitigating the associated costs and energy requirements.

References

[1] Monoj Kumar Mondal, Hemant Kumar Balsora, Prachi Varshney, Progress and trends in CO2 capture/separation technologies: A review, Energy 46 (2012).

[2] Lu JG, Cheng M, Ji Y, Hui Z. Membrane-based CO2 absorption into blended amine solutions. Journal of Fuel Chemistry and Technology 2009;37:740e6.

[3] IPCC. Policymaker's summary of the scientific assessment of climate change; report to IPCC from working group. Meteorological Office: Branknell, United Kingdom; 1990. www.ipcc.ch/activity/srccs

[4] Yang H, Xu Z, Fan M, Gupta R, Slimane RB, Bland AE, et al. Progress in carbon dioxide separation and capture: a review. Journal of Environmental Sciences 2008;20:14e27.

[5] Choi WJ, Seo JB, Jang SY, Jung JH, Oh KJ. Removal characteristics of CO2 using aqueous MEA/AMP solutions in the absorption and regeneration process. Journal of Environmental Sciences 2009;21:907e13.

[6] Figueroa JD, Fout T, Plasynski S, McIlvried H, Srivastava RD. Review e advances in CO2 capture technology e the U.S. department of energy's carbon sequestration program. International Journal of Greenhouse Gas Control 2008; 2:9e20.

[7] Steeneveldt R, Berger B, Torp TA. CO2 capture and storage closing the knowing e doing gap. Chemical Engineering Research and Design 2006;84(A9): 739e63.

[8] Gibbins J, Chalmers H. Carbon capture and storage. Energy Policy 2008;36: 4317e22.

[9] Damen K, Troost MV, Faaij A, Turkenburg W. A comparison of electricity and hydrogen production systems with CO2 capture and storage, part A: review and selection of promising conversion and capture technologies. Progress in Energy and Combustion Science 2006;32:215e46.

[10] Blomen E, Hendriksa C, Neele F. Capture technologies: improvements and promising developments. Energy Procedia 2009;1:1505e12.

[11] Car A, Stropnik C, Yave W, Peinemann KV. Pebax/polyethylene glycol blend thin film composite membranes for CO2 separation: performance with mixed gases. Separation and Purification Technology 2008;62:110e7.

[12] Rao AB, Rubin ES. A technical, economic, and environmental assessment of amine-based CO2 capture technology for power plant greenhouse gas control. Environmental Science and Technology 2002;36:4467e75.

[13] Mamun S, Dindore VY, Svendsen HF. Kinetics of the reaction of carbon dioxide with aqueous solutions of 2-((2-aminoethyl) amino) ethanol. Industrial & Engineering Chemistry Research 2007;46:385e94.

[14] Kohl AL, Riesenfeld FC. Gas purification. New York: McGraw Hill; 1960.

[15] Park SW, Lee JW, Choi BS, Lee JW. Absorption of carbon dioxide into nonaqueous solutions N-methyldiethanolamine. Korean Journal of Chemical Engineering 2006;23:806e11.

[16] Lee DH, Choi WJ, Moon SJ, Ha SH, Kim IG, Oh KJ. Characteristics of absorption and regeneration of carbon dioxide in aqueous 2-amino-2-methyl-1-propanol/ammonia solutions. Korean Journal of Chemical Engineering 2008; 25:279e84.

[17] Lasscock DA, Critchfield JE, Rochelle GT. CO2 absorption/desorption in mixtures of methyldiethanolamine with monoethanolamine or diethanolamine. Chemical Engineering Science 1991;46:2829e45.

[18] Versteeg GF, Kuipers JAM, van Beckum FPH, van Swaaij WPM. Mass transfer with complex reversible chemical reactions—II. parallel reversible chemical reactions. Chemical Engineering Science 1990;45:183e97.

[19] Freeman SA, Dugas R, Wagener DV, Nguyen T, Rochelle GT. Carbon dioxide capture with concentrated, aqueous piperazine. Energy Procedia 2009;1: 1489e96.

[20] McCann N, Maeder M, Attalla M. Simulation of enthalpy and capacity of CO2 absorption by aqueous amine systems. Industrial & Engineering Chemistry Research 2008;47:2002e9.

[21] Versteeg GF, van Dijck LAJ, van Swaaij WPM. On the kinetics between CO2 and alkanolamines both in aqueous and nonaqueous solutions, an overview. Chemical Engineering Communications 1996;144:113e58.

[22] Bishnoi S, Rochelle GT. Absorption of carbon dioxide into aqueous piperazine: reaction kinetics, solubility and mass transfer. Chemical Engineering Science

2000;55:5531e43.
[23] Blauwhoff PMM, Versteeg GF, van Swaaij WPMA. Study on the reaction between CO2 and alkanolamines in aqueous solutions. Chemical Engineering Science 1983;38:1411e29.
[24] Alvarez-Fuster C, Midoux N, Laurent A, Charpentier JC. Chemical kinetics of the reaction of carbon dioxide with amines in pseudo m-nth order conditions in aqueous and organic solutions. Chemical Engineering Science 1980;35: 1717e23.
[25] Laddha SS, Danckwerts PV. Reaction of CO2 with ethanolamine: kinetics from gas-absorption. Chemical Engineering Science 1981;36:479e82.
[26] Sada E, Kumazawa H, Han ZQ, Matsuyama H. Chemical kinetics of the reaction of carbon dioxide I with ethanolamines in nonaqueous solvents. AIChE Journal 1985;31:1297e303.
[27] Sada E, Kumazawa H, Osawa Y, Matsuura M, Han ZQ. Reaction kinetics of carbon dioxide with amines in non-aqueous solvents. Chemical Engineering Journal 1986;33:87e95.
[28] Versteeg GF, Oyevaar MH. The reaction between CO2 and diethanolamine at 298 K. Chemical Engineering Science 1989;44:1264e8.
[29] Caplow M. Kinetics of carbamate formation and breakdown. Journal of American Chemical Society 1968;90:6795e803.
[30] Danckwerts PV. The reaction of CO2 with ethanolamines. Chemical Engineering Science 1979;34:443e6.
[31] Crooks JE, Donnellan JP. Kinetics and mechanism of the reaction between carbon dioxide and amines in aqueous solution. Journal of the Chemical Society Perkin Transactions 1989;2:331e3.
[32] da Silva EF, Svendsen HF, Initio AB. Study of the reaction of carbamate formation from CO2 and alkanolamines. Industrial & Engineering Chemistry Research 2004;43:3413e8.
[33] IPCC. IPCC special report on carbon dioxide capture and storage. Cambridge University Press: Cambridge, United Kingdom and New York; 2005. www. cambridge.org
[34] Mandal BP, Biswas AK, Bandyopadhyay SS. Absorption of carbon dioxide into aqueous blends of 2- amino-2-methyl-1-propanol and diethanolamine. Chemical Engineering Science 2003;58:4137e44.
[35] Yamasaki A. An overview of CO2 mitigation options for global warming e emphasizing CO2 sequestration options. Journal of Chemical Engineering of Japan 2003;36:361e75.
[36] Kundu M, Bandyopadhyay SS. Solubility of CO2 in (water þ diethanolamine þ N methyldiethanolamine). Fluid Phase Equilibria 2006;248:158e67.
[37] Bello A, Idem RO. Comprehensive study of the kinetics of the oxidative degradation of CO2 loaded and concentrated aqueous monoethanolamine (MEA) with and without sodium metavanadate during CO2 absorption from flue gases. Industrial & Engineering Chemistry Research 2006;45: 2569e79.
[38] Resnik KP, Yeh JZ, Pennline HW. Aqua ammonia process for simultaneous removal of CO2, SO2 and NOx. International Journal of Environmental Technology and Management 2004;41:89e104.
[39] Yeh JK, Resnik KP, Rygle K, Pennline HW. Semi-batch absorption and regeneration studies for CO2 capture by aqueous ammonia. Fuel Processing Technology 2005;86:1533e46.
[40] Feng B, Du M, Dennis TJ, Anthony K, Perumal MJ. Reduction of energy requirement of CO2 desorption by adding acid into CO2-loaded solvent. Energy and Fuels 2010;24:213e9.
[41] Lepaumier H, Martin S, Picq D, Delfort B, Carrette PL. New amines for CO2 capture III, effect of alkyl chain length between amine functions on polyamines degradation. Industrial & Engineering Chemistry Research 2010;49: 4553e60.
[42] Mondal MK. Solubility of carbon dioxide in an aqueous blend of diethanolamine and piperazine. Journal of Chemical & Engineering Data 2009;54:

2381e5.
[43] Quadrelli R, Peterson S. The energy climate challenge: recent trends in CO2 emission from fuel combustion. Energy Policy 2007;35:5938e52.
[44] Sakwattanapong R, Aroonwilas A, Veawab A. Reaction rate of CO2 in aqueous MEA-AMP solution: experiment and modeling. Energy Procedia 2009;1: 217e24.
[45] Dey A, Aroonwilas A. CO2 absorption into MEA-AMP blend: mass transfer and absorber height index. Energy Procedia 2009;1:211e5.
[46] Mandal BP, Guha M, Biswas AK, Bandyopadhyay SS. Removal of carbon dioxide by absorption in mixed amines: modelling of absorption in aqueous MDEA/MEA and AMP/MEA solutions. Chemical Engineering Science 2001;56: 6217e24.
[47] Pipitone G, Bolland O. Power generation with CO2 capture: technology for CO2 purification. International Journal of Greenhouse Gas Control 2009;3: 528e34.
[48] Appl M, Wagner U, Henrici HJ, Kuessner K, Volkamer F, Ernst-Neust N. Removal of CO2 and/or H2S and/or CO2 from gases containing these constituents. US Patent 4336233;
[49] Xu GW, Zhang CF, Qin AJ, Gao WH, Liu HB. Gas-liquid equilibrium in CO2-MDEA-H2O system and the effect of piperazine on It. Industrial & Engineering Chemistry Research 1998;37:1473e7.
[50] Bishnoi S, Rochelle GT. Thermodynamics of piperazine/methyldiethanolamine/water/carbon dioxide. Industrial & Engineering Chemistry Research 2002;41:604e12.
[51] AxeL M, Xiaoshan S. Research and development issues in CO2 capture. Energy Conversion and Management 1997;38:37e42.
[52] Abass A, Olajire A. CO2 capture and separation technologies for end-of-pipe applications e a review. Energy 2010;35:2610e28.
[53] Riemer P. Green gas mitigation technologies, an overview of the CO2 capture, storage and future activities of the IEA greenhouse gas R & D programme. Energy Conversion and Management 1996;37:665e70.
[54] Wong S, Bioletti R. Carbon dioxide separation technologies. In: Carbon and energy management. Edmonton: Canada: Alberta Research Council; 2002.
[55] Gupta M, Coyle I, Thambimuthu K. Strawman document for CO2 capture and storage technology roadmap. Canada: Canmet Energy Technology Centre, Natural Resources; 2003.
[56] Tuiniera MJ, Annalanda MS, Kramerb GS, Kuipers JAM. Cryogenic CO2 capture using dynamically operated packed beds. Chemical Engineering Science 2010; 65:114e9.
[57] Mckee B. Solution for 21stcentury, zero emissions technologies for fossil fuels. Technology status report. IEA Working Party on Fossil Fuels; 2002. p. 1e47. http://www.iea.org
[58] Brunetti A, Scura F, Barbieri G, Drioli E. Membrane technologies for CO2 separation. Journal of Membrane Science 2010;359:115e25.
[59] Thiruvenkatachari R, Su S, An H, Yu XX. Post combustion CO2 capture by carbon fibre monolithic adsorbents. Progress in Energy and Combustion Science 2009;35:438e55.
[60] Burdyny T, Struchtrup H. Hybrid membrane/cryogenic separation of oxygen from air for use in the oxy-fuel process. Energy 2010;35:1884e97.
[61] Evan J, Granite T, O'Brien T. Review of novel methods for carbon dioxide separation from flue and fuel gases. Fuel Processing Technology 2005;86:1423e34.
[62] Hossain MM, Lasa HI. Chemical-looping combustion (CLC) for inherent CO2 separations-a review. Chemical Engineering Science 2008;63:4433e45.
[63] Abu-Khader MM. Recent progress in CO2 capture/sequestration: a review. Energy Sources 2005;28(14):1261e79.
[64] Christou C, Hadjipaschalis I, Poullikkas A. Assessment of integrated gasification combined cycle technology competitiveness. Renewable & Sustainable

Energy Reviews 2008;12:2459e71.

[65] Huang HP, Shi Y, Li W, Chang SG. Dual alkali approaches for the capture and separation of CO2. Energy and Fuels 2001;15(2):263e8.

[66] Dilmore R, Griffith C, Liu Z, Soong Y, Hedges SW, Koepsel R, et al. Carbonic anhydrase-facilitated CO2 absorption with polyacrylamide buffering bead capture. International Journal of Greenhouse Gas Control 2009;3:401e10.

[67] Hagg MB, Kim TJ, Li B. Membrane for separating CO2 and process for the production thereof. WO Patent 2005,089,907; 2005.

[68] Li S, Fan S, Wang J, Lang X, Wang Y. Clathrate hydrate capture of CO2 from simulated flue gas with cyclopentane/water emulsion. Chinese Journal of Chemical Engineering 2010;18(2):202e6.

[69] Kang SP, Lee H, Lee CS, Sung WM. Hydrate phase equilibria of the guest mixtures containing CO2, N2 and tetrahydrofuran. Fluid Phase Equilibria 2001; 185(1e2):101e9.

[70] Linga P, Kumar R, Englezos P. The clathrate hydrate process for post and precombustion capture of carbon dioxide. Journal of Hazardous Materials 2007;3: 325e9.

[71] Tantekin-Ersolmaz SB, Atalay-Oral C, Tatlier M, Erdem-Senatalar A, Schoemanb B, Sterte J. Effect of zeolite particle size on the performance of polymer-zeolite mixed matrix membranes. Journal of Membrane Science 2000;175:285e8.

[72] Kusakabe K, Ichiki K, Hayashi J, Maeda H, Morooka S. Preparation and characterization of silica-polyimide composite membranes coated on porous tubes for CO2 separation. Journal of Membrane Science 1996;115:65e75.

[73] Apichatachutapan W, Moore RB, Mauritz KA. Asymmetric nafion/(zirconium oxide) hybrid membranes via in situ sol-gel chemistry. Journal of Applied Polymer Science 1996;62:417e26.

[74] Anson M, Marchese J, Garis E, Ochoa N, Pagliero C. ABS copolymer-activated carbon mixed matrix membranes for CO2/CH4 separation. Journal of Membrane Science 2004;243:19e28.

[75] Zimmerman C, Singh A, Koros WJ. Tailoring mixed matrix composite membranes for gas separations. Journal of Membrane Science 1997;137: 145e54.

[76] Mahajan R, Koros WJ. Factors controlling successful formation of mixed matrix gas separation materials. Industrial & Engineering Chemistry Research 2000;39:2692e6.

[77] Blamey J, Anthony EJ, Wang J, Fennell PS. The calcium looping cycle for largescale CO2 capture. Progress in Energy and Combustion Science 2010;36: 260e79.

[78] Abanades JC, Alonso M, Rodriguez N. Experimental validation of in situ CO2 capture with CaO during the low temperature combustion of biomass in a fluidized bed reactor. International Journal of Greenhouse Gas Control 2011; 5:512e20.

[79] Anthony EJ. Solid looping cycles: a new technology for coal conversion. Industrial & Engineering Chemistry Research 2008;47:1747e54.

[80] Harrison DP. Sorption-enhanced hydrogen production: a review. Industrial & Engineering Chemistry Research 2008;47:6486e501.

[81] Zhang J, Webley PA, Xiao P. Effect of process parameters on power requirements of vacuum swing adsorption technology for CO2 capture from flue gas. Energy Conversion and Management 2008;49:346e56.

[82] Favre E. Carbon dioxide recovery from post-combustion processes: can gas permeation membranes compete with absorption. Journal of Membrane Science 2007;294:50e9.

[83] Aboudheir A, Tontiwachwuthikul P, Chakma A, Idem R. Kinetics of the reactive absorption of carbon dioxide in high CO2-loaded, concentrated aqueous monoethanolamine solutions. Chemical Engineering Science 2003;58:5195e210.

[84] Lund H, Mathiesen BV. The role of carbon capture and storage in a future sustainable energy system. Energy 2012;44:469e76.
[85] MacDowell N, Florin N, Buchard A, Hallett J, Galindo A, Jackson G, et al. An overview of CO2 capture technologies. Energy and Environmental Science 2010;3:1645e69.