

Reduction of CO₂ from Atmosphere Using Metal-Organic Framework (MOFs) As Adsorbents

Rakhman Sarwono

Research Centre for chemistry – National Research and Innovation Agency
KomplekPUSPIPTEK Serpong, Tangsel (15314), Indonesia

ABSTRACT

The concentration of greenhouse gases have increased continuously, especially CO₂ gas. It might cause increase the atmosphere temperature, climate change extremely. By effort of reducing CO₂ concentration to maintain the level concentration of CO₂ in atmosphere is necessary to avoid the global warming. There are many ways to reduce of CO₂ from the atmosphere namely, naturally and human efforts. Photosynthesis used CO₂ and water to make up of tissue building block of plantation. Ocean water and land are also absorbed CO₂ from atmosphere, naturally. Biochar has a high carbon content and recalcitrance can be used as soil amendment, biochar has a mean residence time in the soil on the order of hundred or thousand years. Using adsorbents to absorb CO₂ from industrial released and atmosphere are reduced the concentration of CO₂. Metal-organic framework (MOF) is best candidate to adsorb CO₂ from atmosphere.

Key words: adsorbent, CO₂, concentration, remove

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I. INTRODUCTION

Greenhouse gas such as CO₂, CO, CH₄, water and NO_x are entered to the atmosphere might cause the green house effects. Carbon dioxide concentrations are rising mostly because of the fossil fuels that people are burning for energy. Fossil fuels like coal and oil contain carbon that plants pulled out of the atmosphere through photosynthesis over many millions of years; we are returning that carbon to the atmosphere in just a few hundred. Since the middle of the 20th century, annual emissions from burning fossil fuels have increased every decade, from an average of 3 billion tons of carbon (11 billion tons of carbon dioxide) a year in the 1960s to 9.5 billion tons of carbon (35 tons of carbon dioxide) per year in the 2010s. The concentration of CO₂ in air has increased from from 270 ppm before industrial revolution to close to 405 ppm today.¹Based on analysis from NOAA's Global Monitoring Lab, global average atmospheric carbon dioxide was 414.72 parts per million (ppm) in 2021.²In May 2022 the concentration CO₂ in atmosphere is 421 ppm.³The Intergovernmental Panel on Climate Change (IPCC) has forecast an increase in global temperature 1.8 °C by 2100, largely as a result of antropogenic CO₂ emissions.⁴ About half of these CO₂ emissions are from distributed sources such as transportation and power plants.⁵

Human have led to a massive increase in CO₂ emissions as a primary greenhouse gases that are contribution to climate change. The emission of CO₂, which is thought to contribute to global warming, is a byproduct of the combustion of fossil fuels. It will increases in extreme weather and global temperatures, research is developing into CO₂ capture to help reverse climate change. CO₂ is one of the main culprit molecules of global warming because of its ability to trap energy from infrared (IR) radiation in the atmosphere. Radiation reflecting off of the earth's surface within the IR spectra is easily absorbed by CO₂, causing vibrations within the molecule and trapping the energy.⁶

Research describing a new material capable of substantially reducing carbon dioxide (CO₂) emissions at room temperature and normal atmosphere pressure. There are two main ways to stop the amount of greenhouse gases from increasing: we can stop adding them to the air, and we can increase the Earth's ability to pull them of the air. There are many terms in CO₂ concentration in atmosphere, carbon positive, negative and neutral. Carbon positive is if the amount of CO₂ emissions remove from the atmosphere is less than the amount of CO₂ emissions put into the atmosphere. Carbon negative is if the amount of CO₂ emissions remove from the atmosphere is bigger than the amount of CO₂ emissions put into the atmosphere. Carbon neutral if the amount of CO₂ emissions put into atmosphere is the same as the amount of CO₂ emissions remove from the atmosphere.⁷

Increasing CO₂ concentration into atmosphere by naturally mainly come from of breath of human life, such as animals, human being and plantation at night. Increasing CO₂ into atmosphere by human activity come from burning fuel, such as fossil fuels, coal, and biomass. Cement processing also release CO₂ gas, The

decrease of CO₂ out from atmosphere (Carbon negative) coming from the activities photosynthesis of the plantations. The decrease of CO₂ out from atmosphere by naturally coming from absorbing by ocean, lands and catching by the air at atmosphere.

II. Several methods to remove of CO₂ from atmosphere

Carbon removal includes a range of approaches that remove carbon dioxide (CO₂) directly from the atmosphere. Some familiar approaches are tree planting and increasing carbon storage in soil — nature-based solutions which leverage and enhance natural carbon sinks. These are already being used around the world; however, many are ready for broader application and would benefit from public and private funding to scale up faster and improve inventory and monitoring capacity.

There are six options for removing carbon from the atmosphere:⁸

1). Forests, Photosynthesis removes carbon dioxide naturally.

The leaves of the forest trees are doing photosynthesis process. Photosynthesis is the process by which plants use sunlight, water, and carbon dioxide to create oxygen and energy in the form of sugar. Trees are especially good at storing carbon removed from the atmosphere by photosynthesis. The forest appear to be one of the more efficient forms of vegetation for converting light energy to plant material.⁹ Expanding, restoring and managing forests to encourage more carbon uptake can leverage the power of photosynthesis, converting carbon dioxide in the air into carbon stored in wood and soils. Plants photosynthesis can slowdown climate change but can't stop it.¹⁰

2). Farms Soils naturally store carbon

Agricultural soils are running a big deficit due to intensive use. Even small increases in soil carbon per acre could be impactful. Building soil carbon is good for farmers and ranchers, too, as it can increase soil health and crop yields. Integrating trees on farms can also remove carbon while providing other benefits, like shade and forage for livestock. Agriculture together with animal husbandry can be one of solutions to the problems of greenhouse gas emissions and climate change.¹¹ Farming has been shown to absorb nearly 3% of global carbon emissions;¹² some scientists estimate that with enough regenerative farming, the global carbon emissions absorbed back into the soil could be up to %15.¹³

3). Bio-energy with Carbon Capture and Storage (BECCS)

Bio-energy with Carbon Capture and Storage (BECCS) is another way to use photosynthesis to combat climate change. However, it is far more complicated than planting trees or managing soils and it doesn't always work for the climate. BECCS is the process of using biomass for energy in the industrial, power or transportation sectors. Capturing its emissions before they are released back to the atmosphere; and then storing that captured carbon either underground or in long-lived products like concrete. If BECCS causes more biomass to grow than would otherwise, or stores more carbon instead of releasing it back into the atmosphere, it can provide net carbon removal. Microalgal-based CO₂ sequestration aiming to sequester carbon back to the biosphere, ultimately reducing greenhouse effects.¹⁴

4). Direct Air Capture (DAC)

Direct air capture (DAC) is the process of chemically scrubbing carbon dioxide directly from the ambient air, and then storing it either underground or in long-lived products. This new technology is similar to the carbon capture and storage technology used to capture emissions from sources like power plants and industrial facilities. The difference is that direct air capture removes excess carbon directly from the atmosphere, instead of capturing it at the source. It is relatively straightforward to measure and account for the climate benefits of direct air capture, and its potential scale of deployment is enormous. But the technology remains costly and energy-intensive.

DAC technology can deliver large-scale negative emissions by removing carbon dioxide directly from the atmosphere; and air to fuels technology can significantly reduce the carbon footprint of transportation by creating clean synthetic fuels made from air, water and renewable power.¹⁵

5). Carbon mineralization

Carbon mineralization is the process by which carbon dioxide becomes a solid mineral, such as a carbonate. It is a chemical reaction that happens when certain rocks are exposed to carbon dioxide. The biggest advantage of carbon mineralization is that the carbon cannot escape back to the atmosphere.¹⁶

Mineralization some minerals naturally react with CO₂, turning carbon from a gas into a solid. The process is commonly referred to as carbon mineralization or enhanced weathering, and it naturally happens very slowly, over hundreds or thousands of years. Scientists are figuring out how to speed up the carbon mineralization process, especially by enhancing the exposure of these minerals to CO₂ in the air or ocean.

Technologies to capture current CO₂ emissions, reuse and store CO₂ continue to be developed. One of the common themes across these different technologies is the role of inorganic solid carbonate transformations using anthropogenic CO₂ and the development of predictive controls over these pathways. CO₂ conversion to

solid inorganic carbonates, also known as carbon mineralization, is a thermodynamically downhill route that can be adapted for integration with CO₂-emitting energy and resource generating processes.¹⁷

6). Ocean-Based Carbon Capture

Based carbon removal concepts have been proposed to leverage the ocean's capacity to store carbon and identify approaches beyond only land-based applications. However, nearly all of them are at early stages of development and need more research, and in some cases pilot testing, to understand whether they are appropriate for investment given potential ecological, social and governance impacts. Each approach aims to accelerate natural carbon cycles in the ocean.

They could include leveraging photosynthesis in coastal plants, seaweed or phytoplankton; adding certain minerals to increase storage of dissolved bicarbonate; or running an electric current through seawater to help extract CO. Some ocean-based carbon removal options could also provide co-benefits. For example, coastal blue carbon and seaweed cultivation could remove carbon while also supporting ecosystem restoration, and adding minerals to help the ocean store carbon could also reduce ocean acidification.

The ocean covers about 70% of the Earth's surface and already buffers a large fraction of anthropogenic CO₂ emissions. The global capacity for natural carbon sequestration is in the ocean. Natural processes on land and ocean have removed roughly 55% of emitted CO₂, but it may be possible to enhance both the uptake and longer-term sequestration potential of these processes.¹⁸ But now a growing number of researchers, companies and even national governments have begun to look at the ocean as a potential location for carbon dioxide removal. These approaches aim to leverage the ocean's natural chemical and biological processes to absorb and store more carbon from the atmosphere.¹⁹

7). Biochar

Biochar is created by the pyrolysis of biomass, and is under investigation as a method of carbon sequestration. Biochar as a pyrolyzed product of biomass, is richer in aromatic carbon (C) and poorer in oxygen which provides structural recalcitrance to it against microbial decomposition in soil. Biochar, being a stable source of C when applied to soil, remains there for longer period of time imparting long-term soil C sequestration.

Biochar is a charcoal that is used for agricultural purposes which also aids in carbon sequestration, the capture or hold of carbon. It is created using a process called pyrolysis, which is basically the act of high temperature heating biomass in an environment with low oxygen levels. What remains is a material known as char, similar to charcoal but is made through a sustainable process, thus the use of biomass. Biomass is organic matter produced by living organisms or recently living organisms, most commonly plants or plant based material. A study done by the UK Biochar Research Center has stated that, on a conservative level, biochar can store 1 gigaton of carbon per year. With greater effort in marketing and acceptance of biochar, the benefit could be the storage of 5–9 gigatons per year of carbon in biochar soils.²⁰ Multiple independent estimates show that biochar has a mean residence time in soils on the order of 1300 to 4000 years.²¹

The matter degradation is very rapid due to constantly high temperatures and moisture levels. In Australia estimates of mean residence time for naturally biochar carbon are 1300 – 2600 years.²² Biochar is stable, fixed, and recalcitrant carbon can store large amounts of greenhouse gases in the ground centuries, potentially sequester carbon in the soil for hundreds to thousands of years, like coal.²³ Carbon negative technology would lead to a net withdrawal of CO₂ from atmosphere.

Madejski²⁴ described that just four different ways to reduce CO₂ emission level:

(1) reducing the use of fossil fuel by:

- improving the efficiency of energy conversion processes.
- reducing the demand for energy
- using renewable energy sources, such as hydropower, wind, biomass, solar cell and nuclear power
- increasing the use green hydrogen energy

(2) Replace technologies using fossil fuels with a low carbon to hydrogen. (3) Capturing CO₂ from fuel combustion in power plants and other industrial processes. (4) Limiting deforestation processes and thus storing more CO₂ in biomass.

III. Direct CO₂ capture

Direct air capture (DAC) is a process of capturing carbon dioxide (CO₂) directly from the ambient air (as opposed to capturing from point sources, such as a cement factory or biomass power plant) and generating a concentrated stream of CO₂ for sequestration or utilization or production of carbon-neutral fuel and windgas. Carbon dioxide removal is achieved when ambient air makes contact with chemical media, typically an aqueous alkaline solvent,²⁵ or sorbents.²⁶ Large-scale DAC deployment may be accelerated when connected with

economical applications or policy incentives. DAC is not an alternative to traditional, point-source carbon capture and storage (CCS), but can be used to recapture some emissions from distributed sources, such as some rocket launches.²⁷ When combined with long-term storage of CO₂, DAC is known as direct air carbon capture and storage (DACCS or DACS).²⁸ DACCS can act as a carbon dioxide removal mechanism.

The replacement of carbonate in cement allows for the potential absorption of carbon dioxide over concrete lifecycle. MOFs exhibit high CO₂ capacity and selectivity for CO₂,²⁹ due to their high surface functionality and porosity.³⁰

The increase of CO₂ concentration in the atmosphere and fears of resulting catastrophic global climate change have led to increased demand for CO₂ capture and storage (CCS) technologies.^{31,32} CO₂ absorption using chemical reaction is a common process in the chemical industry, along with other processes, has been applied in the treatment of industrial gas streams containing acid gases like H₂S, NO_x, and CO₂. In these gas-treating processes, aqueous amine solutions are most commonly used, especially monoethanolamine (MEA), diethanolamine (DEA).³³

IV. Solid Adsorber

CO₂ capture from various gas streams, at different concentrations, using physical adsorbents, such as activated carbon, zeolites, and metal-organic frameworks (MOFs), is attractive. Carbon dioxide is a minor component of Earth's atmosphere. On the one hand, CO₂ is regarded as the primary source of greenhouse gas due to human activities, on the other hand, it is consumed by plants photosynthesis of carbohydrates and increasingly utilized by various chemical processes for valuable products.^{34,35} The mostly anthropogenic CO₂ emissions come from the combustion of fossil fuels, which accounts for more than 80% of the total CO₂ emissions worldwide. Generally, flue gas is composed of 8–15% CO₂ and inert gases such as nitrogen, argon, and water in addition to oxygen. CO₂ capture from flue gas is the most important to prevent CO₂ emissions, and it also shows a high flexibility and does not need to change combustion cycle.

CaO is a promising material as an alternative CO₂ capture material which can be used at high temperature. It has advantages of wide availability in natural minerals, low cost and large sorption capacity, etc. However, CaO sinters to form large particles under long-term high temperature conditions, resulting in a rapid decrease of its surface area and the capacity of CO₂ capture.³⁶ CaO is considered as a good alternative material in both post-combustion capture and pre-combustion capture because of the carbonation reaction of CaO with CO₂.^{37,38} Theoretically, 1 kg CaO can absorb 785 g CO₂, producing CaCO₃ that can be decarbonated to re-form CaO and concentrated CO₂ (so-called calcium looping cycle).^{39,40} CaO is a low cost and wide available natural minerals. It has large sorption capacity and can be operated at high operating temperatures. All of these advantages makes CaO a potential promising CO₂ sorbent. However, there is a serious disadvantage for CaO. It sinters to form large particles in carbonation-calcination cycles, leading to a rapid decrease of its surface area and thus its reactivity toward CO₂.⁴¹ This characteristic is attributed to the higher carbonation and calcination temperature than the temperature of CaCO₃.⁴²

Adsorption-based processes using metal-organic frameworks (MOFs) are a promising option for carbon dioxide (CO₂) capture from flue gases. Metal-organic frameworks (MOFs) are being touted as the next generation materials for several adsorptive separation and purification processes.^{43,44} MOFs are porous crystalline materials consisting of metal centers connected by organic moieties.⁴⁵

IV. Metal-organic frameworks (MOFs)

Metal-organic frameworks (MOFs), also known as coordination polymers, are novel family of porous materials constructed by coordinate bonds between organic ligands and metal atoms or metal clusters. Owing to their ultra large surface area and porosity, high crystallinity with well-defined pore properties and easily tunable structure and chemical functionality, MOFs are attracting increasing attention in the field of CO₂ adsorption and separation over the past two decades.

Metal-organic frameworks are a new class of hybrid materials emerged in the two decades. Due to its porous structures, it is potential in the CO₂ adsorption area. Metal-organic frameworks (MOFs), also known as coordination polymers, are novel family of porous materials constructed by coordinate bonds between organic ligands and metal atoms or metal clusters. Owing to their ultra large surface area and porosity, high crystallinity with well-defined pore properties and easily tunable structure and chemical functionality, MOFs are attracting increasing attention in the field of CO₂ adsorption and separation over the past two decades.⁴⁶ Carbon capture and storage/sequestration (CCS) from point sources is one of the most promising strategies being implemented to reduce carbon emissions.

Efficient and sustainable methods for carbon dioxide (CO₂) capture are essential. Its atmospheric concentration must be reduced to meet climate change targets, and its removal from sources such as chemical feed-stocks is vital. While mature technologies involving chemical reactions that absorb CO₂ exist, they have many drawbacks. Porous materials with void spaces that are complementary in size and electrostatic potential to

CO₂ offer an alternative. In these materials, the molecular CO₂ guests are trapped by non-covalent interactions, hence they can be recycled by releasing the CO₂ with a low energy penalty.

V. Synthesis of Metal-Organic Framework

Porous materials of MOFs are constructed from organic metal clusters and organic linkers, offering near unlimited tenability with respect to component diversity and structural hierarchies.⁴⁷ MOFs are porous crystalline materials of one, two, three dimensional networks constructed from metal ions/clusters and multi-dentate organic linkers via coordination bonding, which are emerging as an important group of materials for energy storage, CO₂ adsorption, and catalysis.⁴⁸

Adsorbents must be designed with consideration of many parameters including CO₂ affinity, kinetics, energetics, stability, capture mechanism, in addition to cost. MOFs porous materials with hierarchical structures, and highlights the vital roles of compositions, morphology, and the hierarchically porous structure in applications, including delivery and catalysis.⁴⁹ Here, we perform a systematic catalysis regarding the key technical parameters that are required for the best CO₂ capture performance using physical adsorbents. The main contribution of micropores, especially ultra-micropores, to CO₂ adsorption has been widely recognized. Many studies evidenced that the CO₂ capacity at 1 atm was related to the pores smaller than 0.8 nm in diameter, and pore sizes of less than 0.5 nm were effective for removal of CO₂ at low partial pressure.⁵⁰

As a new class in the family of microporous materials, metal-organic frameworks (MOFs) were considered as a versatile nanoporous materials with flexible structures.⁵¹ These materials became an excellent candidate for various application including hydrogen and other gases storage, gas purification, catalyst and drug delivery as it has the ability to store the guest molecules inside porous structure.^{52,53} The metal organic skeleton is a novel porous compound formed by a multi-dentate organic ligand containing nitrogen, oxygen or the like and a metal ion bonded by a coordination bond. Compared with traditional silica-alumina molecular sieves, MOFs have high porosity and specific surface area, adjustable pore size and structure, and unique coordination structure. They have good properties in gas storage, separation, catalysis, biochemistry and pharmaceuticals. Application prospects.^{54,55}

After more than two decades of research and development, great advances have been made in the synthesis of MOFs. New synthesis methods such as the electrochemical, microwave-assisted, mechano-chemical synthesis, microfluidic synthesis method, have all been reported.⁴⁸ The development timeline for the most common synthesis approaches of MOFs was summarized.⁵⁶

Metal-organic frameworks (MOFs) are a class of porous crystalline materials constructed of metal centers with organic linkers, creating one-, two-, or three-dimensional well-organized frameworks with very high surface areas. Porous materials are a class of solid compounds with an ordered and/or disordered pore structure, high pore volume, and large surface area. Porous materials have shown great application values in some traditional industries, such as the oil and gas processing, industrial catalysis, adsorption/separation, and fine chemical industries.⁵⁷ MOFs synthesis methods are conventional solvothermal/hydrothermal, microwave-assisted, sonochemical, electrochemical, mechanochemical, ionothermal, dry-gel conversion, and microfluidic synthesis.⁴⁸

Solvothermal/Hydrothermal synthesis. Metal-organic frameworks (MOFs)^{58,59} are a literal and figurative extension of coordination chemistry.⁶⁰ These crystalline materials employ organic substituents (ligands) to link multiple metal centers together. By adjusting the length of the organic ligand, the size of the formed cavity or pore can be controlled. Not only can the pore size be controlled with chemical synthesis, but the shape of the pore can also be specifically designed by employing organic ligands with different functionalities or different metal centers. Metals have preferred coordination geometries (octahedral, tetrahedral, square planar, etc.); therefore, they are direct the assembly of the framework.

Metal-organic frameworks (MOFs) are porous crystalline materials consisting of metal centers or clusters with organic linkages where carboxylic acids containing N are usually used by frameworks with zinc, copper, chromium, aluminum, zirconium, and other elements.⁴⁸ Due to its large surface area, high pore volumes uniformly sized pores, flexible structure, and adjustable pore size, MOFs have widely used in CO₂ adsorption,⁶¹ separation process,^{62,63} storage processes,⁶⁴ catalysis and others.⁶⁵

Hydrothermal conditions have been widely used to access many classes of materials including the synthesis of metal-organic frameworks (MOFs),⁶⁶ covalent organic frameworks (COFs),⁶⁷ extended metal oxides,⁶⁸ and polyoxometalates (POMs).⁶⁹ Also, to help speed up the discovery and optimization of new materials, high-throughput hydrothermal methods which allow the systematic investigation of the parameters have been developed.^{70,71} The conditions of chemical reaction, the synthesis temperature has little effect on the morphology, but the effect on the size is significant under low temperature conditions. Additives have an important influence on the morphology and size of MIL-121.⁷²

Microwave-Assisted synthesis. Microwave synthesis techniques have been widely applied for rapid synthesis of nano-porous materials under hydrothermal conditions.⁷³ Fast crystallinity, narrow particle size distribution and facile morphology control.^{74,75} The microwave synthesis of MOF-199 was compared with the conventional hydrothermal synthesis. MOF-199 obtained a much shorter time with improved yield and textural properties under the microwave irradiation.⁷⁶

Sonochemical Synthesis. Sonochemical methods via homogeneous nucleation can also achieve a reduction in crystallization time and significantly smaller particles size than those by the conventional solvothermal synthesis.⁷⁷

Electrochemical Synthesis. The electrochemical synthesis of MOFs uses metal ions continuously applied supplied through anodic dissolution as a metal source instead of metal salts, which react with the dissolved linker molecules and a conducting salt in the reaction medium. The metal deposition on the cathode is avoided by employing protic solvent, the process is generated H₂.⁷⁸

Efficiently capturing carbon dioxide from diverse sources and under different conditions of temperature, pressure and composition is vital in mitigating the impact of continuously increasing CO₂ level into the atmosphere. Adsorption presents particular prominence mainly due to low energy consumption, cyclability, fast kinetics, versatility of potential adsorbent materials, range of operating conditions, and the fact that it is environmentally- friendly.⁷⁹

VI. Controlled MOF's properties and its application to adsorb CO₂

MOFs properties that appropriate to absorb of CO₂ gas from ambient atmosphere should be led to the absorption capacity, selectivity and cyclability.⁸⁰ Porous materials of MOFs are constructed from inorganic metal clusters and organic linkers, offering near unlimited turn-ability with respect to component diversity and structural hierarchy.⁴⁹ Recently, MOF nanoparticles have drawn great interest as promising candidates for novel catalysts and biomedicines, as their nanoscale sizes allow for a high ratio-exposed active sites and rapid diffusion.⁸¹ Dimension control can be divided into three groups, namely 1D, 2D and 3D. Through adjusting reaction conditions resulted of MOFs as nanocubes, nanorods, nanowires, and nanoplates. Control of MOF morphology involved choosing preferred growth orientations to create various geometries.⁴⁹ The morphology of the crystals was dictated by competition between growth in the <100> and <111> directions.

MOFs are a material with high porosity, large surface area, adjustable micro-pore size, and easy functional structure and unique coordination structure.⁸² MOFs based on coordination bonds, are usually less stable than covalent bond based materials. The stability of MOFs plays a vital role in real world applications.⁸³ The MOFs characteristics make a promising candidates for a myriad of applications including gas/liquid separation, gas storage, catalysis, sensors, medicine and electronics.⁸⁴ MOFs nanoparticles as their nanoscale sizes allow for high ratio of exposed active sites and rapid diffusion.⁸¹ MOF nanoparticles can also serve as basic building blocks for assembly of superstructures with complicated morphologies, which require nanoparticles with high uniformity and turn-able. It is common to obtain a mixture of particles with various morphologies and a high dispersity, making it difficult to control the properties of the material on a bulk scale.

MOF nanoparticles with controllable morphologies. The growth of MOF crystals is an enthalpy driven assembly, whose anisotropic nature allows for controllable growth of specific crystal faces, resulting in the dimension control of MOF crystals. Based on the morphology of MOF crystal obtained, dimension control can be divided into three groups, namely 1D, 2D and 3D. Through reaction conditions, can be fabricated of nanocubes, nanorods, nanowires, and nanoplates of MOF.⁴⁹ The success in synthesizing MOF particles with well-defined sizes and geometries allows for the construction of more complicated structures.

Therefore, effective capture techniques are needed to reduce the concentration of CO₂. In this regard, metal organic frameworks (MOFs) have been known as the promising materials for CO₂ adsorption. Hence, study on the impact of the adsorption conditions along with the MOFs structural properties on their ability in the CO₂ adsorption will open new doors for their further application in CO₂ separation technologies.⁸⁵

MOFs only 100 of about 20,000 MOFs synthesis, have the feature of flexible behaviour. Recently MOF discovered an Indium-based MOF (Me₂NH₂)[In(ABDC)₂], SHF-61, which shows selective adsorption of CO₂ and Methane CH₄ depending on the 'breathing status' of the material. The CO₂ adsorption capacity of this MOF was reported to be 2.4 mmol per gram of MOF material.⁸⁶ MOF-74 type analogs exhibit high CO₂ adsorption performance due to the open metal sites in the hexagonal channels aligned along the c-axis.⁸⁷

We should consider when developing new adsorbents and recovery processes, with emphasis on material processing, capture capacity, selectivity, regeneration cyclicality, and cost.⁸⁰ This perspective focuses on the investigation of pure MOF membranes and MOF-based composite membranes for CO₂ capture applications such as post-combustion (CO₂/N₂) and pre-combustion CO₂ separation (CO₂/H₂), and natural gas purification (CO₂/CH₄).⁸⁸

The ability of other adsorbent to adsorb CO₂ described by Osman,⁸⁹ grapheme-type materials show CO₂ adsorption capacity of 0.07 mol/g. Activated carbon (AC), kaolinite (KAO) and kaolinite-activated carbon

(KAC) composite adsorbent characterized was evaluated for CO₂ adsorption. The maximum amounts of AC, KAC and KAO adsorbed were found to be 28.97 mg CO₂/g, 18.54 mg CO₂/g and 12.98 mg CO₂/g, respectively.⁹⁰The synthesized mesoporous carbon obtained CO₂ adsorption of 9.916 mmol/g and the activated carbon of 3.84 mmol/g for on 3.5 hours of adsorption.⁹¹Capacities qualitatively scale with surface area and range from 3.2 mmol/g for MOF-2 to 33.5 mmol/g (320 cm³(STP)/cm³, 147 wt %) for MOF-177, the highest CO₂ capacity of any porous material reported.⁹²

The addition of aerosil to CuBTC (CuBTC-A-15) enhanced the sorbed CO₂ amount by 90.2% and the addition of biochar (CuBTC-BC-5) increased adsorbed the CO₂ amount by 75.5% in comparison to pristine CuBTC obtained in this study, by the addition of montmorillonite (CuBTC-Mt-15) increased the adsorbed amount of CO₂ by 27%. CuBTC-A-15 and CuBTC-BC-5 are considered to be the most perspective adsorbents, capturing 3.7 mmol/g CO₂ and showing good stability after 20 adsorption-desorption cycles.⁹³ Ni-MOF-74 shows the highest adsorption of CO₂ with 12.35mmol/g compared to other metals.⁹⁴This work has a guiding significance for developing and synthesizing new materials by ligand functionalization of high surface area MOFs which are promising in carbon capture technology.⁹⁵In the year 2021 about 27 commercial carbon capture utilization storage (CCUS) facilities are currently under operation with a capture capacity of up to 40 Mt of CO₂ per year.²¹

VII. CONCLUSION

The cycle of CO₂ stream in environment resulted positive, negative or neutral conditions that is depend on the flow of input and output of CO₂ stream into atmosphere. Recently, the atmosphere has saver from the positive stream of CO₂, It's showed that the increasing atmosphere temperature continuously, it's indicated that concentration CO₂ in atmosphere also increase. Removing CO₂ concentration in atmosphere have been removed by many ways.It's can be done by naturally and human efforts. Naturally removed mainly done by photosynthesis, and also land and ocean absorption of CO₂ from atmosphere, but that is not enough to remove CO₂ return back to the era before industrial age. Human efforts encouraged to remove CO₂ from the atmosphere, at least to slow down the increase of CO₂ concentration in atmosphere. Invented appropriate adsorbent such MOFs would speed up removing of CO₂ from atmosphere. Hopefully, the concentration of CO₂ in atmosphere can be maintained in the appropriate level.

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