

Original Article: Investigating the Chemical Mechanisms of CO₂ Absorption and Conversion

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ABSTRACT

In the present study, the chemical mechanisms of CO₂ absorption and conversion have been investigated. Today, it is widely assessed that greenhouse gas (GHG) emissions are one of the most challenging environmental issues and carbon dioxide is the largest source of human GHG. Greenhouse gas emissions have increased dramatically since the beginning of the industrial era until 2018: In 2018, average CO₂ concentrations were about 40% higher than in the mid-19th century, with an average growth of 2 ppm per year in the last 10 years 2 and even 3 ppm per year since 2015. Among human activities producing greenhouse gases, the combustion of fuels for electricity and heat is the largest source of carbon dioxide emissions, accounting for more than 42% of human CO₂ emissions, where 43% and 26% of these gases are respectively industrial and residential needs are allocated. Apart from energy production, direct emission of CO₂ caused by vehicle transportation (23%) and industrial processes (19%) are the main factors of CO₂ emission caused by human activities. In addition, global energy demand is expected to increase over the years and even double by 2050. Fossil fuel consumption remains dominant. A MEA-based CO₂ storage process is considered, and then the captured CO₂ is directly sent to the conversion unit for its catalytic conversion. As a result, the combination of the two units leads to a single linked unit, especially in the case of the reuse of heat provided by the exothermic reactions of methanol for the regeneration of the CO₂ storage solvent. An economic evaluation is proposed to estimate the operating and investment costs as well as the net present value, which shows that the economic feasibility strongly depends on the costs of electricity and H₂ production.

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Introduction

Carbon dioxide is a colorless and non-flammable gas at normal temperature and pressure. Its amount is lower than nitrogen and oxygen in the earth's atmosphere and it is one of the most important gases in the air [1]. The carbon dioxide molecule consists of three and two atoms of oxygen and carbon with a ratio of 2 to 1 and is written as CO_2 . This compound is a greenhouse gas that helps retain heat in the atmosphere and without it our planet would become a cold planet. This odorless gas is one of the four components of dry air [2-4].

The amount of carbon dioxide in the air is 400ppmv. This value is about 270ppmv before human industrial activities. This increase in concentration has led to an excessive increase in the earth's temperature and many damages to it. But how is carbon dioxide produced?

Carbon dioxide absorption has gained special importance in recent years. As you know, every year a large amount of carbon dioxide enters the atmosphere from different sources such as power plants, forest fires, fossil fuels, for example, the exhaust from power plants alone contains 12% of this substance [5]. The entry of this pollutant causes climate change, global warming, production of greenhouse gases and negative effects such as the melting of natural glaciers. Two significant natural sources of CO_2 in the Earth's atmosphere are volcanoes and wildfires. In addition, when you breathe in, carbon dioxide leaves your mouth and nose when you exhale [6].

Carbon dioxide absorption methods

Biological methods: Include the use of microorganisms to absorb carbon dioxide, produce renewable fuels such as biofuels, produce food and medicine. Eukaryotic and prokaryotic bacteria are organisms that can be useful in absorbing this material. One of the advantages of biological absorption is the

production of useful biological products such as bioplastics, pharmaceuticals, and biofuels. In this method, CO_2 removal occurs in chlorophyll, which is known as the process of photosynthesis. Chlorophylls are photosynthetic pigments that convert CO_2 into glucose in the presence of natural light (sun) or unnatural light [7].

Photosynthesis is a biochemical process that helps feed plants and some microbes. In this process, photosynthetic organisms combine water and oxygen and produce carbohydrates (sugar). The byproduct of this reaction is oxygen. Therefore, places like forests and oceans where photosynthesis takes place act as a source of oxygen and remove CO_2 from the atmosphere. In the beginning, the Earth's atmosphere had much more CO_2 . The photosynthesis of organisms led to the creation of oxygen in the air [8].

Classification of photosynthesis reactions:

The classification of photosynthesis reactions is light-independent and light-dependent. In the first stage, NADP^+ and ADP are converted into NADPH and ATP energy-carrying molecules under the influence of the light source. Light and in the next step when CO_2 is absorbed to produce biological products by the Calvin cycle is independent of light. In these stages, RuBisCo enzyme plays an important role in absorbing and stabilizing CO_2 , this enzyme has a low affinity for CO_2 . The weak performance of this enzyme increases with the doubling of oxygenation [9].

Advantages of using microorganisms to absorb carbon dioxide

The use of microorganisms in the biological absorption method includes the following advantages:

- ✓ Fast production;
- ✓ High photosynthetic conversion rate;

- ✓ High capability for environmental treatment, such as bio fixation of CO₂;
- ✓ High capacity for wide production of products;
- ✓ An easy method of genetic improvement;
- ✓ Industrialization potential [10].

Chemical methods: In this method, chemical solvents are used to absorb CO₂, for example, in the gas sweetening unit, which has the task of removing sour gases such as H₂S and CO₂, the carbon dioxide absorption unit (absorption unit) usually uses alkanolamines to absorb CO₂.

The gas containing CO₂ is passed through a liquid or solid absorbent that has the ability to absorb carbon dioxide, and then the loaded absorbent is transferred to another container, where after heating and reducing the pressure, the absorbed carbon dioxide is released and the adsorbent resulting from the regeneration step goes to the previous step for further absorption in a periodic process. Today, most adsorbents in commercial use are based on liquid systems or soluble adsorbent compounds. This means that for the separation of gas streams, in the first place, the viscosity of the liquid phase is very important (Figure 1).

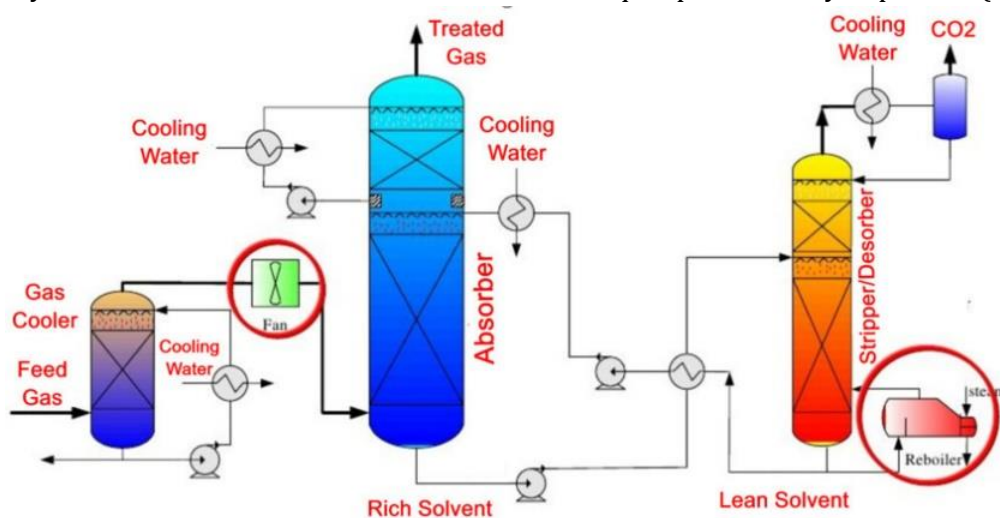


Figure 1. Chemical methods, in this method, chemical solvents used to absorb CO₂, for example, in the gas-sweetening unit, which has the task of removing sour gases such as H₂S and CO₂, the carbon dioxide absorption unit (absorption unit) usually uses alkanolamines to absorb CO₂.

Adsorbents used in the chemical method: In general, different adsorbents are used in the absorption unit, which can be divided as follows:

- ✓ Amine solvents (such as mono ethanolamine and di ethanolamine;
- ✓ Dimethyl ether polyethylene glycol (dialkyl ether alcohol);
- ✓ Alkyl carbonate;
- ✓ Cold ammonia [11].

In addition to the above, new complex solvents and solid adsorbents are being developed that

are specifically designed to absorb carbon dioxide, including liquid activated carbons and ionic polymers. The adsorbents mentioned above are used in this method due to features such as low energy requirement, low volatility and high stability, suitable selectivity in absorption, chemical resistance against impurities and low production cost [12].

✓ **Post-Combustion Capture:** This method involves separating CO₂ after the combustion of fossil fuels. In this process, exhaust gases from chimneys, which contain CO₂, come into contact

with a liquid solvent such as amines, and the CO_2 is absorbed into the solvent. Then this CO_2 is separated from the solvent and stored in compressed form.

✓ **Pre-Combustion Capture:** In this method, fossil fuels are converted into a combined gas including hydrogen and CO_2 before combustion. Then CO_2 is separated from this gas and stored. This method is mostly used in hydrogen production plants and some heavy industries [13].

✓ **Direct Air Capture:** This advanced technology involves the absorption of CO_2 directly from the ambient air. This method is done using special chemicals that have the ability to absorb CO_2 and can potentially be effective in reducing atmospheric CO_2 levels.

✓ **Bio sequestration:** This method includes the use of plants and microorganisms to absorb CO_2 from the air and store it in biomass or soil. Forestry and smart agriculture are among the ways of biological absorption of CO_2 [14].

Using cylinders containing carbon dioxide gas can be used to supply the required carbon dioxide. This is done by opening the gas valve a little and releasing it into the greenhouse. Every hour, for 100 square meters of greenhouse area, about 1.5 liters of pure oil or half a liter of liquid gas must be burned in order to produce the required amount of carbon dioxide in the greenhouse environment. According to research, providing 300 ppm of carbon dioxide is sufficient for the growth and development of greenhouse plants. But this amount does not apply to all plants and some plants require more [15].

The effect of carbon dioxide injection on products

According to research, plants react to the CO_2 injection system when its concentration in the atmosphere is greater than 300ppm. In many plants, it has been seen that the concentration of 2000 PPM caused them to grow more, which

of course depends on the natural and hereditary conditions of the plant in the past, and maybe the plant was used to this amount in the past. According to the experiments conducted on plants in different latitudes. It shows that by increasing the concentration of dioxide up to 1000-1500 ppm, the plant has shown a positive reaction. Of course, it should also be taken into account that high concentrations of dioxide have a negative effect on the plant due to its toxicity and cause the leaves to die and the yield to decrease. The threshold of carbon dioxide change is different among plants. For example, tomatoes need a carbon dioxide level of 2200ppm and cucumber needs 1500ppm. In general, increasing the level of carbon dioxide by 1600ppm increases production by 31% [16].

Factors that simultaneously increase the concentration of dioxide affect the increase of the product

Light is also an important factor in plant photosynthesis. In other words, when the amount of light is low, photosynthesis also decreases. Even if the concentration of carbon dioxide is sufficient and the CO_2 generator is working properly. But if the light is not strong enough, there will be a disturbance in the process of photosynthesis and plant growth. The concentration of carbon dioxide can be increased when the light intensity is 5500lux. Light intensity less than this amount will not be economical. Increasing temperature is also considered an important factor to increase plant growth. By increasing daily temperature along with increasing carbon dioxide concentration, it leads to better plant growth.

How the carbon dioxide injection system works?

Because the injection of carbon dioxide takes time to become effective. which is ready for photosynthesis. Therefore, it should be injected

from sunrise to one hour before sunset, and the air conditioning valves should be completely closed. Normally, the CO₂ injection system takes place from mid-November to mid-April according to the latitude of the region and the location of the greenhouse [17]. The method of carbon dioxide injection is usually done by burning oil or natural gas in the environment of the greenhouse by generating devices that hang from the ceiling in the middle of the greenhouse [18].

Effective parameters in improving CO₂ absorption by nano fluids

The parameters that are effective in improving CO₂ absorption by nano fluids are:

- ✓ **Changing the PH of the solution:** By adding nanoparticles and making the solution more alkaline, the absorption of CO₂ acid gas (which takes place through the acid-base reaction) is improved.
- ✓ **Increased contact surface:** Nanoparticles suspended in the base fluid have a high ratio of contact surface to volume, which increases the active sites of absorption on solid nanoparticles and increases the absorption capacity. On the other hand, with the shortening of the penetration path in nanoparticles compared to bulk particles, the speed of absorption also increases significantly [19].
- ✓ **Contactors type:** Contactors used for contact between two liquids (adsorbent nano fluid) and gas (carbon dioxide) phases include a wide range of contactors. Bubble towers, tray towers and hollow fiber membranes (HFMC) are examples of such contactors. Choosing the right contactor improves the mass transfer

between two phases and is effective in CO₂ absorption.

What is the effect of impurity in the gas flow entering the purification unit?

- ✓ An increase in the viscosity of the adsorbent, which increases the work required for pumping;
- ✓ Absorption capacity and efficiency of the process decreases [20];
- ✓ It causes problems such as foaming and sediment formation in the mass transfer tower;
- ✓ Materials resulting from the destruction of absorbents increase the corrosion of equipment.

Physical methods (carbon dioxide surface absorption)

The physical method is one of the easy absorption methods that has a low operating cost. These methods include gas-liquid contactor and series flasks for solvent reduction. The use of membranes is one of the methods of carbon dioxide absorption, which is a subset of physical absorption. Membranes are special materials that have the selectivity to pass a certain substance [21], the choice of membrane is based on the nature of the substance. The gas flow passes through the membrane with a pressure difference, usually high pressure flow is preferred for membrane separation. Physical absorption is usually considered when the partial pressure of CO₂ is greater than 3.5 bar. Other components in the gas stream are absorbed in the solvent depending on their concentration and solubility (Figure 2).

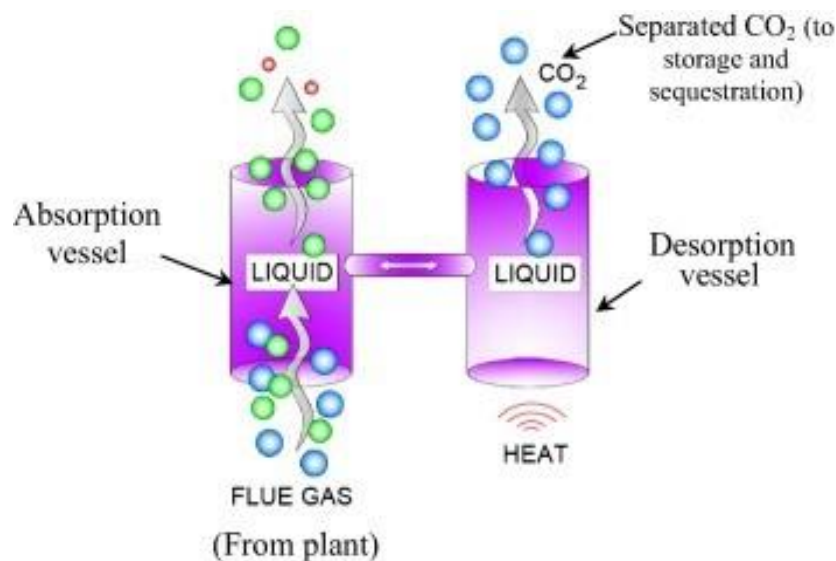


Figure 2. Physical methods (carbon dioxide surface absorption)

Advantages of using the physical absorption method

- ❖ One of the most important advantages is relatively low operating cost;
- ❖ It is not necessary that the equipment and pipelines be made of steel. Because the solvent is not corrosive and this also reduces costs;
- ❖ There is no need for external heat for the absorption process and the only energy required is the energy of the pump and compressor [22];
- ❖ Solvent regeneration is easily done by reducing the pressure;
- ❖ The important feature of physical absorption is selectivity against H_2S and it can absorb other substances such as COS and mercaptans without destroying the solvent;
- ❖ Absorption of CO_2 without any chemical reaction [23].

CO_2 capture and storage steps

Finally, the absorption and storage of carbon dioxide can be considered to include three stages as follows:

- ✓ **Absorption of carbon dioxide:** Three states before combustion, after

combustion, oxygen combustion occurs; The absorption of carbon dioxide coming out of the chimney, which is produced by the combustion of fossil fuels in the air, is placed in the post-combustion absorption category. In this case, the goal is maximum absorption of carbon dioxide (90%) in power plants. If pure oxygen is used instead of air in fuel combustion, then the oxygen combustion method is stated, in which the flame temperature is too high, but H_2O and CO_2 can be recovered in this method. In the absorption of carbon dioxide before combustion, there is a reaction between oxygen in the air with synthetic gas CO and hydrogen. Carbon monoxide reacts with steam in a catalytic reactor to produce carbon dioxide and hydrogen.

- ✓ **Transporting carbon dioxide:** Pipelines are one of the most common ways to transport carbon dioxide, CO_2 gas is compressed at a pressure higher than 8 mega Pascal's, so transportation becomes easier and less expensive. Another method of CO_2 transfer is liquid transfer in ships, roads or railways.
- ✓ **Carbon dioxide storage:** The absorption and storage of carbon dioxide in geology is

actually a technology to reduce climate change and global warming. This can be done in three ways, including:

- ✓ Underground storage;
- ✓ Gas or liquid storage in oceans.

For example, parts of the oceans that are drained oil or gas fields are considered suitable places for this. The choice of oceans is because this gas is dissolved and stored to form hydrate for thousands of years. But this work can endanger aquatic life and increase the PH level of ocean water. Another method is storage at a depth of less than 800 meters. Of course, these areas must have a rocky crust so that this gas does not leak out. For example, coal beds or deep salt marshes are suitable for this. Always, the place that is considered for carbon dioxide storage must have high safety, have little connection with the environment and conform to geological standards.

Measurement of carbon dioxide dissolved in water

There are many methods for measuring dissolved carbon dioxide in water. Titration is a common field method for measuring this gas in water systems. To begin with, you need to take 23 ml of the sample. Then add a drop of phenolphthalein indicator to it. Next, add the sodium hydroxide solution drop by drop and shake the container well to mix. Continue adding the sodium hydroxide solution until the color of the solution changes and remains pale pink for 30 seconds. Each drop of sodium hydroxide solution is equivalent to 1.25 milligrams per liter of carbon dioxide.

Investigating the absorption process of carbon dioxide gas by amine solvents in microchannel

A microchannel is a device whose at least one dimension has a micrometer scale. Today, the use of micro channels is considered due to the more precise control of operating conditions

and better mixing. According to the research results, among the alkanolamine solvents, MEA 30% by weight has the highest efficiency with the carbon dioxide gas absorption rate of 94.99%. It was also found that increasing the temperature up to 40°C has a positive effect on the absorption flux.

Nano fluid stability

The stability of nano fluids used in the absorption of carbon dioxide gas is very important. By reducing the size of nanoparticles and increasing the viscosity of the base fluid, it is possible to reduce the settling speed of nanoparticles and have a more stable nano fluid. On the other hand, the preparation method of nano fluid affects its stability.

As mentioned, most of the gas absorbent nano fluids are prepared in a two-step method, the two-step method is prone to sediment formation and particle accumulation, which is sometimes solved by adding surfactants. But it should be noted that as the concentration of nanoparticles increases, the adhesion of nanoparticles increases. Therefore, the effective contact surface is reduced and the mass transfer rate is reduced. On the other hand, with an increase in the concentration of nanoparticles, the viscosity of the nano fluid will increase and the rate of mass transfer in the liquid phase will also decrease. The improvement factor is defined as the CO₂ mass transfer rate in the presence of nano fluid compared to the mass transfer rate in the base fluid:

Mechanisms of improvement of CO₂ absorption by nano fluids

- ✓ **Brownian motion:** The random movement of nanoparticles in the solution causes a disturbance and subsequently a micro convection in the fluid. This micro convection increases the mixing between

gas-liquid two phases and improves mass transfer;

- ✓ **Bubble break:** Stable nanoparticles suspended in the liquid collide with CO₂ gas bubbles in the solution (in tray towers, bubble towers and other absorption towers that operate based on direct contact between two phases), and break them into smaller bubbles. As a result of this action, the contact surface between the two phases increases;
- ✓ **Hydrodynamic effect:** Brownian motion of nanoparticles in the solution causes turbulence in the boundary layer of mass transfer between liquid-gaseous two phases and reduces the thickness of the boundary layer of mass transfer. Decreasing the thickness of the boundary layer of mass transfer reduces the resistance to mass transfer and improves the rate of mass transfer;
- ✓ **Shuttle effect:** Due to their Brownian motion, nanoparticles are able to come to the liquid-gas contact surface and absorb gas molecules. The particles that have absorbed the gas return to the fluid mass and expel the absorbed gas. In this way, the liquid-gas contact surface is constantly refreshed;
- ✓ **Gas absorption on the surface of nanoparticles:** Nanoparticles used to improve CO₂ absorption mainly have a functional surface where CO₂ gas can be directly absorbed on these surfaces. Another possible mechanism to explain the improved mass transfer rate in nano fluids is the Marangoni effect. The accumulation of nano fluid suspended nanoparticles in the liquid-gas contact surface causes a decrease in surface tension on this surface and creates a surface tension gradient. This surface tension gradient causes confusion and mixing of two phases.

A new technology was invented to capture CO₂

New carbon dioxide capture technology capable of producing carbon monoxide and synthetic natural gas could help fight the climate crisis. New research by researchers at the University of Surrey demonstrates a new technology that could allow scientists to both capture carbon dioxide and convert it into useful chemicals in a circular process. The end result is an efficient way to produce byproducts such as carbon monoxide and synthetic natural gas. Dr. Melis Doyar, Senior Lecturer in Chemical Engineering at the University of Sari, says: "Absorbing CO₂ from the surrounding air and converting it directly into useful products is exactly what we need to approach carbon neutrality in the chemicals sector." This method could very well be a turning point in the steps we need to reach the goal of zero carbon production by 2050. He added: "We need to move away from our current thinking about how chemicals are produced, because current practices rely on fossil fuels, which are not sustainable." With this technology, we can deliver chemicals with a much lower carbon footprint and look at replacing fossil fuels with carbon dioxide and renewable hydrogen as the building blocks of other important chemicals. The new invention uses a patent-pending technology called dual-functional switchable materials (DFM). DFMs absorb carbon dioxide and accelerate its direct conversion to chemicals.

Dual functional replaceable materials

DFMs are called "Switchable" because of their ability to produce multiple chemicals depending on the operating conditions or the reactant composition added. This means that the technology is highly adaptable to changes in demand for chemicals as well as the availability of renewable hydrogen as a reactant. Master's student Lucia-Pantzcrola Mercuri, who led the

research at the University of Surrey, says the new innovation could help fight climate change. He says: This research not only shows a suitable solution for the production of carbon-free fuels and chemicals, but also provides an innovative approach to combat the ever-increasing emission of CO₂ that contributes to global warming. In June 2022, Britain's largest carbon capture plant became operational in Cheshire, North West England. This factory is one of the largest producers of sodium carbonate, salt and sodium bicarbonate in Europe. These chemicals are vital components of a wide range of everyday items from glass to detergents, while also being used for water treatment, in animal feed, human food products and also for medicinal purposes. Later that month, Climeworks AG, a Swiss company specializing in Direct Air Capture technology, established the newest and largest direct carbon capture and storage center in Iceland called Mammoth. The construction of the center is expected to take 18 to 24 months. After operation, this facility will have a nominal capacity of absorbing 36 thousand tons of carbon dioxide per year.

Discussion

Absorption and control of CO₂ gas using MXene nano plates

85% of gas emissions containing carbon dioxide (CO₂) are caused by fossil fuels. Carbon pollution in the air causes warming of the earth, heavy rains, forest fires. Therefore, the purification and de carbonization of gases produced by machines, factories and power plants is highly needed to prevent human and environmental damage. Until now, there have been various researches related to the absorption of carbon dioxide in the air with different absorbent methods and materials, the results of which were all positive, but the important point is the operational capability of these methods and materials on an industrial

scale. In a comprehensive research conducted this year (2023), researchers have been able to absorb the CO₂ contained in gaseous pollutants using a new material called MXene nano plates, so that the technique used can also be industrialized.

MXene nano plates and their ability to absorb and control CO₂

Carbon dioxide in the air is the main cause of climate change, which itself leads to the formation of phenomena such as drought, flood, sea level changes, erosion, global warming. Such climate changes are dangerous in the long run and will affect the lives of future generations. In 2022, the concentration of carbon dioxide in the air was measured to be about 417 ppm, which if such a high concentration of carbon dioxide increases at the same rate, the global temperature will increase by more than 1.5 degrees Celsius in the next decade. These results show that an excessive increase in the amount of carbon dioxide in the air will bring great problems and therefore it is necessary to reduce and control its amount. Until now, various methods have been used to reduce the amount of carbon dioxide through its absorption, which can be introduced as an example of the direct air capture method. In this method, the ambient air is sucked by a device and then with the help of special absorbent materials, the carbon dioxide in the air is separated and stored. Until now, various absorbent materials such as zeolite, silica gel, and activated carbon have been used to absorb CO₂. But this method and other methods used in carbon dioxide removal are not able to be operated on a large scale due to the high price, non-reusability and non-availability of CO₂ absorbing materials. The lack of methods and adsorbent materials provided for absorbing carbon dioxide has made researchers always look for newer solutions and materials, less expensive and

with high scalability. During the last two decades, a new nanomaterial called MXene nano plates, which are in the category of nanomaterials with a two-dimensional (2D) structure, was discovered and introduced. MXene nano plates have special mechanical, electrical, chemical, electronic and photocatalytic properties, all of which have a direct and positive effect on the performance of this material in absorbing carbon dioxide [24].

Absorption and control of carbon dioxide (CO₂)

Carbon dioxide absorption is done in three ways as follows:

1. Pre-combustion absorption: In this method, before the carbon in the fuel turns into CO₂ during combustion, it is removed by the adsorbent. The amount of CO₂ reduction in this method is higher than other methods. In this method, the fuel is passed through a membrane containing MXene nano plates and the carbon contained in the fuel is separated by the nano plates [6].

2. Post-combustion absorption: In this method, when the fuel is combusted, the carbon dioxide gas produced by the absorbent material is removed. In this technique, the gas flow containing CO₂ is passed through a membrane containing MXene nano plates so that the CO₂ molecules are absorbed by the nano plates and separated from the gas flow.

3. Absorption by Direct Air Capture (DAC): In this method, the ambient air is sucked by a device and then the carbon dioxide in the air is separated and stored with the help of MXene nano plates. Despite the fact that the concentration of CO₂ in the air is lower than the gas flows resulting from fuel combustion in factories and power plants, the amount of energy and cost spent to remove carbon dioxide is more than the previous two methods. So far, more than 40 MXene nano plates with various chemical compounds have been

synthesized and introduced. The results of various studies conducted on these nanomaterials have shown that MXene nano plates have a significant performance and efficiency in CO₂ removal. In addition, additional studies on the synthesis of these new nanomaterials have been carried out on an industrial scale, and the obtained results indicate that these materials have the ability to be mass produced. According to the results obtained from the performance of MXene nano plates and their mass production capability, it can be said that the emergence of these new nano materials is a great achievement in the direction of removing and controlling carbon dioxide with low cost and high efficiency [4].

Unveiling of a catalyst to convert CO₂ to methane

Materials scientists at Rice University have developed copper-based catalysts to help speed up the rate at which carbon dioxide is converted to methane. Technologies for removing carbon from the atmosphere continue to improve, but solutions for what to do with the carbon after it's absorbed are more difficult. The hydrogen atoms created methane - a valuable fuel and industrial feedstock. This method based on electrolysis and catalysts created by bonding isolated copper atoms on two-dimensional polymer templates. "Electricity-based carbon dioxide conversion can produce a wide range of industrial fuels and feed stocks through different pathways," explained a research scientist in Ajayan's lab. However, the conversion of carbon dioxide to methane involves an eight-step pathway, which poses significant challenges for selective and efficient methane production. "Overcoming such issues can help close the artificial carbon cycle on a meaningful scale, and the development of efficient and cost-effective catalysts is a key step towards achieving this goal."

"We found that adjusting the distance between the copper atoms reduces the energy required for key reaction steps, thereby speeding up the chemical transformation," he noted [12]. The catalysts developed by him and his co-workers enabled one of the fastest and most efficient electrolysis-based conversions of carbon dioxide to methane known so far, helping to advance the conversion process both in terms of fundamental scientific insight and performance. Jingjie Wu, associate professor of chemical and environmental engineering at the University of Cincinnati, said, "If energy efficiency and carbon conversion can be addressed at the system level [18], inexpensive and efficient materials like these can help accelerate the industrial transformation of electrochemical carbon dioxide reduction technology. However, carbon storage (CCS) techniques and the application of carbon capture differ greatly in terms of the absolute amount of CO₂ they can deal with, and the respective targets need to be defined.

As presented in the IPCC mitigation scenarios, CCS from large CO₂ emitters (such as power plants, cement or steel) could jointly contribute to a reduction of CO₂ emissions above 25% by 2100. CCS can therefore be considered as a means of mitigating climate change even if the low carbon tax inhibits the creation of a business case for CCS technologies [9].

On the other hand, CCU techniques propose to replace carbon raw materials used in chemical processes by CO₂ in order to produce fuel or high value-added chemicals. In fact, they generally do not allow CO₂ storage because the carbon-based product releases its CO₂ into the atmosphere after a short period (e.g. liquid fuels). Carbon mineralization is mainly the only CCU technique that can be considered for long-term carbon sequestration [25].

As a result, the potential of CCU to reduce CO₂ emissions is relatively low, and even very optimistic estimates currently assume that the

total amount of CO₂ for CCU may reach about 180 Mt for chemicals and eventually 2 Gt for fuels, compared with 37 Gt of which emit CO₂. As a result, CCU techniques do not significantly contribute to climate change mitigation, but should be considered as a strong component in a further mitigation strategy program, including reducing the use of fossil fuels [15]. To this extent, innovative chemical processes are investigated for years to propose efficient alternatives that are able to capture carbon dioxide as carbon raw material sources and convert/store it in chemically valuable compounds. Power-to-Liquid (PTL) systems are so far envisioned as one of the most advanced technologies to respond to this problem by converting industrial CO₂ into liquid fuels that are more suitable for transportation, safety, and infrastructure considerations [2].

As a result, one of the most promising fuels is methanol due to its liquid state in environmental conditions and a wide range of applications in the chemical and energy sectors. In fact, methanol is one of the most important building blocks of the chemical industry, which is used as a raw material for the production of acetic acid, MTBE, DME and formaldehyde. Methanol can replace petroleum derivatives and be used directly as a fuel for heat engines and fuel cells due to its high octane rating, which increases the compression ratio and more efficient combustions [11].

Absorbing 99% of carbon dioxide from the air with a new method

Tokyo Metropolitan University researchers have developed a new carbon absorption system that absorbs carbon dioxide directly from the Earth's atmosphere and has extraordinary performance. The most important challenge of carbon absorption systems from air (DAC) is their efficiency,

especially in the atmospheric air processing process [19].

Due to different concentrations of carbon dioxide, their chemical reactions are carried out with very slow absorbers. On the other hand, there are challenges in removing carbon dioxide in an environmentally friendly way and in cycles of absorption and elimination, which are likely to consume a lot of energy. Even in progressive efforts to build DAC units that use potassium hydroxide and calcium hydroxide, efficiency is faced with new problems, and on the other hand, the cost of regeneration is very high. For this reason, the need to discover new processes is very vital [26].

In the meantime, a group of researchers led by Professor Seiji Yamazu from Tokyo Metropolitan University investigated a type of DAC technology called liquid-solid separation phase systems. In many of these systems, an air bubble is created through the liquid, and on the other hand, a chemical reaction occurs between the liquid and carbon dioxide. During the reaction, its product is concentrated in the liquid. As a result, subsequent reactions become slower and slower. Liquid-solid phase separation systems provide an ideal solution in which the product of a chemical reaction is insoluble and in solid form. In this way, the material resulting from the reaction does not accumulate in the liquid and the speed of subsequent reactions does not become slower. This group of researchers focused on liquid amine compounds, modifying their structure to improve reaction speed and efficiency at different concentrations of carbon dioxide in the air [11].

In fact, they showed that in order for the solid substance in the solution to completely release the absorbed carbon dioxide, it must be heated to 60 degrees Celsius and then it turns into a liquid state. The carbon dioxide removal rate is twice as fast as DAC laboratory systems. In this way, the system developed by Japanese

researchers is the fastest carbon dioxide absorption system in the world against the processing of small concentrations of this substance in the air [25-27].

Conclusion

Nowadays, due to the increasing problems caused by the phenomenon of global warming, many methods have been proposed by researchers to reduce the polluting gas carbon dioxide. The processes of absorbing and storing carbon dioxide (CCS) or converting carbon dioxide into useful products are among these methods. In the meantime, photocatalytic conversion processes of CO₂ into valuable chemicals and hydrocarbon fuels, in addition to reducing concerns for the accumulation of this polluting gas, have created a new path for the production of compounds derived from carbon dioxide gas. The results of this study show that different reducing agents go through different reaction paths and eventually lead to the production of various products such as methanol, methane, formic acid, formaldehyde and carbon monoxide. In the following, in order to create favorable conditions for directing the reaction towards the distribution of the desired product with maximum efficiency, the reactions performed in the presence of these three reducing agents have been compared with each other. The selectivity of the conversion reaction in the presence of liquid water is higher than that of methanol, and methanol is produced at a higher rate. While most of the products of the photocatalytic reduction reactions of carbon dioxide in the gaseous phase and in the presence of water vapor are hydrogen gas, methane gas and carbon monoxide.

Most methods of CO₂ separation are based on physical or chemical absorption of this substance in a suitable solvent, since in physical absorption, the efficiency of the process depends a lot on the amount of CO₂ in

the gas entering the process, and with the decrease in the amount of CO₂, the amount of absorption decreases. This method cannot be effectively used to separate CO₂ from air, whose amount often does not exceed a few percent. Global warming caused by the accumulation of greenhouse gases in the atmosphere is one of the major environmental threats of the 21st century. As concerns spread, research on converting carbon dioxide into valuable compounds is increasing. In recent decades, scientific consensus has grown for carbon dioxide capture, fixation, and recycling technologies. Today, the production of methanol as one of the most widely used hydrocarbons in various industries that can replace crude oil derivatives has gained great importance. Photocatalytic conversion of carbon dioxide gas into valuable compounds, in addition to reducing the concern about the accumulation of this pollutant, opens a new path for the production of synthetic compounds derived from carbon dioxide gas.

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