# Research progress on the source, adsorption treatment and conversion technology of CO2

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**Abstract.** As an important greenhouse gas, the increase in emissions of carbon dioxide ($CO_2$) has become one of the main drivers of global climate change. This paper systematically discusses the source, adsorption treatment method and conversion technology of $CO_2$. First of all, the sources of $CO_2$ are divided into two categories: natural processes and human activities. Among them, $CO_2$ generated by human activities is the main cause of environmental problems such as global warming. Subsequently, the article introduces the adsorption method as an important means of $CO_2$ treatment, covering the adsorption principle, common adsorbent types, adsorption process and adsorption regeneration methods. Finally, this paper focuses on the conversion technology of $CO_2$, including thermal catalytic conversion, photocatalytic conversion and electrocatalytic conversion. Each method has unique advantages and challenges, and provides different ideas and solutions for the effective conversion and utilization of $CO_2$.

## 1 Introduction

With the acceleration of global industrialization and the continuous growth of energy demand, the problem of $CO_2$ emissions is becoming more and more serious. As a major greenhouse gas, excessive $CO_2$ emissions not only lead to global warming, but also cause a series of environmental problems and ecological disasters. Therefore, finding efficient and sustainable $CO_2$ conversion technology and converting $CO_2$ into valuable chemicals or fuels has become a hot topic for global researchers. This paper aims to explore the way of catalytic conversion of $CO_2$, and to provide new ideas and methods for the efficient conversion and utilization of $CO_2$.

## 2 Sources of $CO_2$

$CO_2$ comes from a variety of sources, covering two aspects: natural processes and human activities.

### 2.1 Natural processes

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There are a wide range of sources of $CO_2$ in nature. Animal and plant activity is the main cause of $CO_2$. The respiration process of animals and plants produces $CO_2$. The respiration of underground microorganisms will release $CO_2$, which may dissolve in groundwater and penetrate into the surface or atmosphere. Organic matter such as animal and plant carcasses, feces and humic acid will release $CO_2$ under the decomposition of microorganisms. In addition, some geological activities also produce $CO_2$. Natural phenomena such as volcanic eruptions will release a large amount of $CO_2$ into the atmosphere [1].

### 2.2 Human activities

$CO_2$ generated by human activities is the root cause of some environmental problems such as global warming [2]. In the fields of electric power production, industrial manufacturing, transportation and residential life, the combustion of fossil fuels such as coal, oil and natural gas produces a large amount of $CO_2$. In addition to the direct combustion of fossil fuels, some industrial production processes (such as cement manufacturing, steel smelting, etc.) also release a large amount of $CO_2$. In addition, deforestation, agricultural activities (such as the oxidation of methane from rice cultivation to $CO_2$) and urbanization will change the way of land use, thus affecting the emission and absorption of $CO_2$.

From the perspective of human behavior, the main sources of $CO_2$ emissions can be further refined into the following sectors. The first is the power and thermal energy production sectors, whose total $CO_2$ emissions account for a large proportion of global greenhouse gas emissions, mainly due to the combustion of fossil fuels. Secondly, in various industrial manufacturing processes, the fuel combustion of automobiles, aircraft, ships and other vehicles is an important source of $CO_2$ emissions in the transportation sector. The $CO_2$ emissions in the construction industry mainly come from the production of building materials, energy consumption in the process of building operation and the treatment of construction waste [3].

## 3 $CO_2$ adsorption treatment

### 3.1 Adsorption principle

The adsorption method selectively absorbs $CO_2$ molecules to the surface of another material through weak van der Waals force (physical adsorption) or strong covalent bonding force (chemical adsorption), thus achieving the purpose of enriching $CO_2$. Physical adsorption is mainly based on the physical interaction between the adsorbent and $CO_2$ molecules, such as van der Waals force, while chemical adsorption involves the chemical reaction between the adsorbent and the $CO_2$ molecule to form a chemical bond.

### 3.2 Type of adsorbent

Adsorbents are the core of adsorption technology. Common adsorbents include activated carbon, molecular sieve, hydrotalc, cage hydrate, metal organic skeletons (MOFs), etc. These adsorbents have different physical and chemical properties and are suitable for different adsorption scenarios. For example, activated carbon is widely used for the adsorption of $CO_2$ due to its large specific surface area and microporous structure; molecular sieve is favored for its specific pore size and shape selectivity [4].

### 3.3 Adsorption process

The adsorption process can be carried out in many ways, the two most common of which are the filling bed and the fluidized bed. In the filling bed, the adsorbent is loaded into the tower, and the gas mixture flows through the gap between the fixed adsorbent particles [5]. In the fluidized bed, the gas flows at a higher speed, causing the adsorbent particles to be suspended in the airflow. As the adsorption process progresses, the adsorbent gradually saturates. At this time, regenerative measures need to be taken to release the adsorbed $CO_2$ and restore the adsorption capacity of the adsorbent [6].

### 3.4 Adsorbent regeneration method

According to different regeneration methods, the adsorption method is often divided into variable pressure adsorption (PSA), variable vacuum adsorption (VSA) and variable temperature adsorption (TSA). PSA refers to the regeneration of adsorbents by changing the pressure of the system. In the process of adsorption, the system maintains a high pressure to promote the adsorption of $CO_2$. While in the process of regeneration, the pressure of the system is reduced, so that the adsorbed $CO_2$ is detached and released. VSA is similar to PSA, but it is usually vacuumed to further reduce the system pressure, thus improving the regeneration efficiency. TSA is usually regenerated by changing the temperature of the adsorbent. During the adsorption process, the adsorbent is kept at a low temperature to adsorb $CO_2$. In the process of regeneration, the adsorbent is heated to a higher temperature, so that the adsorbed $CO_2$ is detached and released [7].

## 4 $CO_2$ conversion

$CO_2$ conversion is an important research field. It involves a variety of methods and approaches aimed at transforming $CO_2$, a greenhouse gas, into a valuable chemical or energy source. The following is a detailed introduction of the main methods of $CO_2$ conversion.

### 4.1Thermal catalytic conversion

The thermal catalytic conversion of $CO_2$ is an important chemical process. This method uses thermal energy to drive the catalyst to promote the chemical reaction between $CO_2$ and reactants (such as hydrogen) to generate valuable chemicals or fuels.

The thermal catalytic conversion method activates $CO_2$ with thermal energy, and converts it into CO, $CH_4$, methanol and other high-value-added products under the conditions of the presence of hydrogen sources or other reducing agents, which is easier to achieve. Typical technologies include $CO_2$-$CH_4$ reforming reaction and thermal hydrogenation and reduction of $CO_2$. $CO_2$-$CH_4$ reforming syngas is a typical $CO_2$ utilization technology, which makes $CH_4$ and $CO_2$ CO and $H_2$ under the action of high-temperature systems, water vapor, oxygen and catalysts. Syngas can be used to produce various products, for example, the production of advanced alkanes and oxygen compounds through the Feto synthesis method. The method is simple and low-cost, but it requires an operating temperature of 800 ~ 1,000 ℃ to achieve the high-equilibrium conversion of methane and $CO_2$ to $H_2$ and CO, and carbon deposition will cause catalyst inactivation [8]. Thermal hydrogenation and reduction of $CO_2$ also requires the activation of $CO_2$ in a high-temperature environment. At present, the research mainly focuses on the selection and utilization of high-efficiency catalysts. The catalysts of Fe, Co, Cu, Zn and other metals are loaded on carriers with large specific surface area and high thermal stability. They are used for $CO_2$ hydrogenation to produce low-carbon olefins [9], and the preparation process is continuously improved. Cu-based catalysts and Pd, Pt, Au and other precious metal catalysts are widely used in $CO_2$ addition. Hydrogen to methanol [10], methanol is more than 80% selective. At present, $CO_2$ hydrogenation to methanol technology has entered the stage of industrialization.

#### *4.1.1 Photocatalytic transformation*

$CO_2$ photocatalytic conversion is a technology that uses photocatalysts to promote the conversion of $CO_2$ into other valuable chemicals under light conditions. This technology has the advantages of green environmental protection and sustainability, so it has received widespread attention and research.

The photocatalytic conversion method uses photosensitive semiconductors to generate electrons and holes under the action of light, and electrons reduce $CO_2$ to CO, formic acid and other products, which is also known as artificial photosynthesis. The study found that finding high-efficiency photocatalysts is the key to strengthening artificial photosynthesis.

The basic principle of semiconductor photocatalytic reduction $CO_2$ is shown in Figure 1 [11]. As can be seen from Figure 1, (1) under the irradiation of a certain wavelength of light (hv≥Eg), the electrons on the semiconductor catalytic material price band (VB) are excited to jump to the conduction band (CB), producing photoelectron-hole pair. (2) Photoelectron-hole separation and migration to the surface of the photocatalytic material. At the same time, photoelectron-holes may be compounded in the body center or on the surface. (3) Photoelectrons and holes migrate to the surface to participate in the redox reaction respectively, where $CO_2$ reacts with photoelectrons and $H^+$ in water to form organic compounds ($CO_2+H^+ +e^- \rightarrow$ organic compounds Matter), the photohole on the surface of the photocatalytic material reacts with water to generate ·OH and $H^+$, that is: $H^+ + H_2O \rightarrow \cdot OH+H^+$, thus completing the photocatalytic reduction $CO_2$ reaction. In the reduction process, the reaction conditions and catalytic materials are different, and the reduction products obtained are also different, such as HCOOH, CO, HCHO, $CH_3OH$ and other hydrocarbons. The reaction formula and reaction electrode potential are as follows:

$$2H_2O+4H^+ \rightarrow O_2+4H^+ \qquad +1.23\ eV \tag{1}$$
$$2H^++2e^- \rightarrow H_2 \qquad 0\ eV \tag{2}$$
$$CO_2+e- \rightarrow CO_2^- \qquad -1.49\ eV \tag{3}$$
$$CO_2+2H^++2e^- \rightarrow HCOOH \qquad -0.19\ eV \tag{4}$$
$$CO_2+2H^+ +2e^- \rightarrow CO+H_2O \qquad -0.19\ eV \tag{5}$$
$$CO_2+4H^+ +4e^- \rightarrow HCHO+H_2O \qquad -0.06\ eV \tag{6}$$
$$CO_2+6H^+ +6e^- \rightarrow CH_3OH+H_2O \qquad +0.03\ eV \tag{7}$$
$$CO_2+8H^+ +8e^- \rightarrow CH_4+H_2O \qquad +0.18\ eV \tag{8}$$

From the above principle, it can be found that photocatalytic reduction of $CO_2$ needs to meet two basic conditions: first, the photon energy must be greater than or equal to the band gap. Second, the conductive band potential is more negative than the surface electron receptor potential, and the valence band potential is more correct than the surface electron body potential. In this way, the reaction process of photocatalytic reduction of $CO_2$ can be realized [11]. Compared with the thermal catalytic conversion method, photocatalytic reduction $CO_2$ can be carried out at room temperature and pressure, which obviously has a wider application prospect. However, the cheap and efficient photocatalyst has not been developed. At present, there are still problems of low light utilization efficiency and low yield [12].

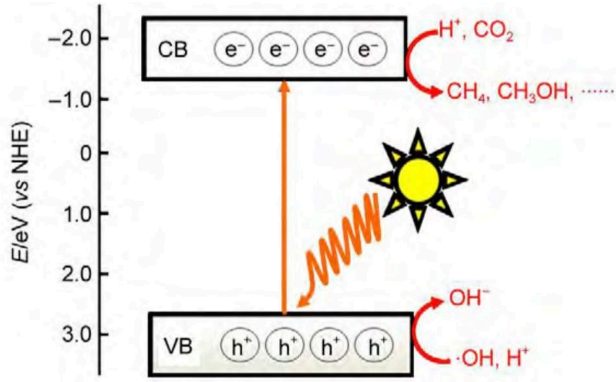


**Fig. 1.** The basic principle of semiconductor photocatalytic reduction $CO_2$.

### *4.1.2 Electrocatalysis*

The electrocatalytic conversion method converts $CO_2$ into a high-value-added product through the potential difference between the two electrodes. This method has low requirements for the reaction medium (gas and liquid phase conditions can occur). It can be carried out at room temperature and pressure. The products are rich, and the selective synthesis of products can be achieved by controlling the application of electrocatalytic conditions such as potential and electrode materials, which makes the electrocatalytic reduction of $CO_2$ become the forefront of today's $CO_2$ transformation research.

Electrocatalytic $CO_2$ reduction is the process of reducing electrons obtained from the surface of the electrode by $CO_2$ molecules or $CO_2$ solventized ions in solution. From the perspective of thermodynamics, $CO_2$ conversion will undergo different multi-electron transfer reactions at different potentials. Water or solvents (electrocatalytic processes in non-water environments) also undergo redox reactions on the electrode surface, providing protons for the $CO_2$ reduction process. At present, the main products of reported $CO_2$ electrochemical reduction include carbon monoxide (CO), formic acid (HCOOH), methane (CH4), ethylene ($CH_2CH_2$), ethanol ($CH_3CH_2OH$) [13], methanol ($CH_3OH$) [14], formaldehyde (HCHO) [15], acetate ($CH_3COO^-$) [16] and other products. The electrocatalytic $CO_2$ reduction in aqueous solution is generally accompanied by the hydrogenation reaction of the side reaction. At present, the catalyst for $CO_2$ electrochemical reduction reaction has expanded from traditional metals and metal oxides to a wide range of nanomaterials. These new nanomaterial electrocatalysts show a unique ability to adsorb and activate $CO_2$, and promote $CO_2$ electrochemical reduction at a high rate under the condition of low energy supply (low over potential).

Electrode materials, catalysts, electrolytes, etc. of electrocatalytic conversion will affect the selectivity of reaction products. If it is to be widely used in $CO_2$ conversion, it is necessary to develop efficient electrical catalysts to reduce the overelectric potential of the reaction and improve the efficiency of electric energy utilization. Otherwise, excessive power consumption will not be worth the loss.

## 5 Conclusion

The treatment and utilization of $CO_2$ has become a key issue in dealing with global climate change. Through the systematic analysis of the source of $CO_2$, adsorption treatment technology and its conversion methods, this paper emphasizes the importance of multi-channel response to $CO_2$ emissions. As an effective means of $CO_2$ capture, the adsorption method shows a variety of application scenarios. Activated carbon, molecular sieve and other adsorbents show excellent adsorption performance under specific conditions. However, the regeneration process of adsorbents still has problems such as high energy consumption and low efficiency. In the future, research should be committed to developing more efficient and renewable adsorption materials and optimizing the regeneration process to improve the overall processing efficiency. The conversion technology of $CO_2$ provides new possibilities for its resource utilization. The thermal catalytic conversion method can react $CO_2$ with reducing agents such as hydrogen to produce high-value-added products such as syngas or methanol, but it is limited by high-temperature operation and catalyst inactivation. Photocatalysis and electrocatalytic conversion technologies are carried out at room temperature and pressure, with broader application prospects. However, at present, the light utilization efficiency of the photocatalyst is low, the yield is not high, and the power utilization efficiency of the electrocatalytic process also needs to be improved.

Generally speaking, the effective treatment and transformation of $CO_2$ requires the coordinated development of multiple technologies. Future research should focus on the following aspects: developing efficient and low-cost adsorbents and catalysts; improving the energy utilization efficiency of the conversion process; and combining a variety of technologies to realize the integration of $CO_2$ capture and conversion. Through these efforts, we can achieve the efficient use of $CO_2$ resources while reducing $CO_2$ emissions and help achieve the global sustainable development goals.

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