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Analysis on the status of carbon utilization

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Abstract. Although a number of new types of clean energy are appearing gradually, it cannot be denied that fossil fuels are still the main source of energy at present, and they will remain their status in the following decades. As the most common product of fossil fuel combustion, abundant CO_2 is produced and emitted into the atmosphere every year. Among them, only little is utilized. Others that stay in the atmosphere and can pass through the sun's short-wave radiation, and absorb the ground's long-wave radiation, so that the lower atmosphere can maintain a suitable temperature, this is the so-called "greenhouse effect". However, because of the excessive fossil fuel combustion, the content of CO_2 in the atmosphere gets higher than the normal value, causing global warming. To solve this problem, Carbon Capture, Utilization and Storage (CCUS) has been considered one of the key technologies to combat global warming. This paper summarizes some alternative ways of carbon utilization. To be more specific, Enhanced Oil Recovery (EOR), CO_2 conversion and Supercritical CO_2. The paper may provide a reference for those who first hear about CCUS.

Keywords: CO_2, CCUS, carbon utilization, EOR.

1. Introduction

Realizing the significance of CCUS, scientists take efforts in this topic and different ways of utilization have been invented. Among these different methods, some of them have already come into use in some specific areas, but most of them have drawbacks that cannot be ignored. As a result, although having developed for approximately 40 years, the CCUS industry is still in the early stages of commercialization. From the technical point of view, there are mature technologies for reference in all the links involved, but with the restriction of the economic cost, it is not yet ready for large-scale use.

In addition, with the increase in population, the demand for energy supply also increases. According to the National Bureau of Statistics report published in 2018, the total emissions of CO_2 worldwide have raised from 24,689.9 million tons in 2000 to 36,138.3 million tons in 2014 [1]. As more and more CO_2 is being emitted, a method is urgently needed to cope with the CO_2.

The Intergovernmental Panel on Climate Change (IPCC) especially stressed the importance of achieving net zero CO2 emissions in the middle of this century in its Special Report on Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development [2], and proposed that carbon removal is a necessary measure to achieve net zero emissions. Most scenarios that do not exceed 1.5 °C involve the extensive application of CCS technology. The only scenario that does not require CCS would require the most fundamental shift in human behaviour. CCS is therefore important for achieving global climate goals. Different from CCS, CCUS also involves the utilization

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of CO_2. CCUS technology will purify the captured CO_2 and put it into the new production process for recycling and reuse, and recycle CO_2. It can not only achieve carbon emission reduction, but also generate economic benefits, so it is more practical. This paper mainly focuses on carbon utilization and introduces some common ways.

2. Three main methods of carbon utilization

2.1. Enhanced Oil Recovery (EOR)

Enhanced Oil Recovery (EOR) refers to a procedure in which a substance is injected into a reservoir to repressurize rock formation and to release any oil that may have been trapped in the formation [3]. It is one of the most mature technologies, and has already been taken into use in some areas, especially in the US and the Middle East.

EOR can be classified into 4 types: Chemical flooding, Gas flooding, Thermal recovery and Microbial Enhanced Oil Recovery. Among them, gas flooding is the most widely used one. The gas used in the process can be CO_2, N_2 and some hydrocarbon gases. CO_2 is the most common one because of its relatively high efficiency and low cost.

During the process, CO_2 is injected and mixed with the oil trapped in the formation, which reduces the viscosity of crude oil and has a certain effect to relieve congestion. This stream is then pumped to the surface, and CO_2 can be separated and reused. With EOR, 30% to 60% or more of the original oil in the reservoir can be extracted.

2.2. CO_2 conversion

Known as one of the best ways of CO_2 utilization, CO_2 can be converted. The mainstream of this technology is through hydrogenation. Here are some of the products.

Water gas and CO:

$$CO2 + H2 \rightarrow CO + H2O \tag{1}$$

CO, carbon monoxide, plays an important role in CO_2 conversion, for it is the feedstock of many subsequent syntheses. Thus, the reverse water-gas shift (RWGS) reaction which can produce water gas from CO_2 has become one of the most important processes in carbon utilization. With a specific catalyst, usually C_u, A_u and N_i [4], CO_2 can be converted into CO through RWGS. The product, also known as water gas or syngas, can be directly used as fuel.

Alkanes and alkenes:

$$nCO2 + (3n + 1)H2 \rightarrow CnH2n + 2 + 2nH2O \tag{2}$$

Fischer–Tropsch synthesis (FTS):

$$(2n + 1)\,H2 + nCO \rightarrow CnH(2n + 2) + nH2O \tag{3}$$

As the main ingredients of petroleum, Alkanes can be produced through the process of hydrogenation. It is also noteworthy that there is a specific way to produce long-chain alkanes (C_5-C_{20}) called Fischer–Tropsch synthesis (FTS). Among them, C_5-C_{11} is the main ingredient of gasoline, C_8-C_{16} is the main ingredient of jet fuels, and C_{10}-C_{12} is the main ingredient of diesel fuels. We can easily figure out that CO is used, and here comes the significance of the RWGS reaction. The CO obtained in the RWGS process can be separated and used as a feedstock in the FTS. It is considered one of the most promising methods of CO_2 conversion.

Converting CO_2 into alcohol is also an alternative way for carbon utilization. Alcohol plays an important role in the chemical industry. It can be used to produce other types of organic compounds, or be used as a disinfectant. Among all the alcohol products transferred from CO_2, methanol (CH_3OH) is the most important C_1 alcohol, for it can be further converted into various chemical products. The process can be done with the presence of different catalysts [5], and Cu-based catalysts are considered one of the most commercial ones.

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2.3. Supercritical CO_2

If a gas is kept being cooled and pressurized, it will get into a state between gas and liquid. This state is named as supercritical state, in which CO_2 will exist as a mixture of liquid and gas. Compared with other supercritical materials, supercritical CO_2 has its own advantages:

First, it is non-toxic, which means it can be used in many fields, especially the food industry.

Second, the conditions to make supercritical CO_2 is not that strict and the requirements for equipment are not that high. When at 0℃, the pressure should be 3.1atm and when at -10℃, the pressure should only be 2.1atm.

Third, CO_2 is chemically inert, non-flammable, generally does not participate in the reaction. So it is relatively safe in operation.

Fourth, because of the little surface tension, supercritical CO_2 is a very good solvent. What's more, when substances are dissolved in supercritical CO_2, it is easy to separate the solvent from the solute, especially for those substances that do not tolerate high temperature.

Fifth, CO_2 in both the gaseous and supercritical states is very fluid, and the transition between the two states is very sensitive and convenient, so it can be used as a recycled medium.

Because of these excellent physical properties, supercritical CO_2 is very useful in the chemical industry.

One of the most common uses for supercritical CO_2 is that it plays an important role in the field of extraction. When extracting vegetable oil, the solvent should have a great solubility for oil. What's more, it should be non-toxic. Considering all the restricts, supercritical CO_2 is then recognized as the best choice. In additon, supercritical CO_2 can not only be used to collect, but also to remove. As what is known to all, caffeine cannot be intaken too much for one person once. Here comes the value of supercritical CO_2. Using supercritical CO_2 to remove caffeine from tea and coffee is a reliable way since there are no chemical residue.

Another use for supercritical CO_2 is dry cleaning. Because of the material used in some specific clothes, it is impossible to use the water to clean. Then supercritical CO_2 cannot be a better choice. As supercritical CO_2 have great solubility, it can dissolve most of the stain, including oil. As a result, the dry cleaning shop will use supercritical CO_2 to dissolve the stain and then evaporate them. There will be no remain.

2.4. Comparison

All the above three methods have their own advantages and disadvantages. A common shortage for all these three methods which directly makes CO_2 difficult to really come into use is the high cost. Although all the three methods can make some money, it is still too little, especially when compared with the cost. The cost for CO_2 conversion is between $280 and $300 per ton, and the cost for EOR is between $40 to $60 [6].

For EOR, it is one of the most mature technologies among all the carbon utilization methods, which has already been taken into use in parts of the world, especially in the Middle East and USA. But the lack of available statistical resources and systematical analysis hinder the understanding of the latest status and progress of different EOR technologies [7].

For CO_2 conversion, the biggest problem is the catalyst. Because CO_2 is a thermodynamically stable compound, its reduction necessitates the use of high energy substances or electroreductive processes. CO_2's inert property, along with its lower reactivity in various reactions, is most likely one of the main reasons why CO_2 conversion has not yet gained popularity. As a result, to reduce the cost of the process, a catalyst is needed. There are numerous catalysts, and a lot more researches and experiments are needed to find the optimal one [8].

There are some drawbacks to using supercritical CO_2 in the food industry. The lack of continuous systems for extracting solid substrates places severe capacity constraints on installed equipment. Because continuous processes cannot be used for solid substrates, SFE may be more appealing for refining conventional extracts than for treating solid substrates directly from an economic standpoint. The cost of the high-pressure equipment, however, is the most significant constraint on SFE. At the

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moment, only high-cost low-volume products are processed, but in the future, the technique could be economically competitive for larger volume products, though the process's expansion is limited by available patents [9].

3. Conclusion

In recent years, CCUS projects have shown an obvious trend of scale and cluster development. According to the statistics of the Global Carbon Capture and Storage Institute, by October 2022, the number of commercial CCUS facilities in operation and planning in the world has increased to 196, and the carbon dioxide capture capacity will reach 244 million tons per year upon completion. There are as many as 24 CCUS industrial clusters in planning and operation worldwide. Facing a great number of opportunities, the utilization of CO_2 is facing equivalent challenges as well. Only when overcome theses difficulties can CCUS have a brighter future.

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