Review on carbon capture technology of Oxy-fuel combustion in coal fired boiler

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Abstract. In China, the total amount of energy resources is huge, the types are rich, but the per capita share is small, the resource structure is unreasonable, and the distribution space is uneven. Compared with the global average level, China's energy mineral resources richness is about 60% higher, which is one of the countries with higher global energy mineral resources richness [1]. However, China's per capita share of energy resources is very limited, only half of the world level, and the structure of energy resources is unreasonable. The proportion of oil and gas is only 2.3%, far from the world average of 21%. Therefore, carbon capture and storage technology is the most effective way to reduce carbon dioxide (CO2) emission of coal fired on a large scale, and can reduce the CO2 emission of coal fired by more than 90%. This paper reviews the most promising carbon capture technology of the Oxy-fuel combustion in coal fired boiler.

1. Introduction
At present, the concentration of greenhouse gases in the atmosphere has risen to a record level, pushing the temperature of various places to a more dangerous level. Climate problems, especially global warming caused by greenhouse effect, have seriously threatened human survival and development. Greenhouse gases produced by human activities are considered to be one of the direct causes of climate warming. Since the industrial revolution, human activities have increased the volume fraction of CO2 in the atmosphere by 25% - 30% and methane by 100%. Cumulative carbon emissions have increased the global average temperature by 1.5°C [2]. The greenhouse effect will lead to the retreat of glaciers, the rise of sea level, the northward movement of climate belt, and a series of ecological problems.

In China, energy is mainly provided by fossil fuels. Fossil fuel is the main part of primary energy. Coal fired power generation has always been the main power source in the world, contributing more than 40% of the power generation in the long term [3]. Coal fired power generation is to convert the chemical energy of fuel into heat energy through combustion, then heat energy into mechanical energy, and finally the mechanical energy is transformed into electrical energy, covering the key links of fuel, combustion, heat transfer, power cycle, cold end and so on. Therefore, fossil fuel consumption is a major source of increased CO2 emissions. Since 2003, coal consumption has been the largest source of CO2 emissions. In 2019, CO2 emissions from coal, oil and natural gas consumption will account for 45%, 43% and 22% of the total emissions respectively. The power industry is the largest carbon emission industry, accounting for 38% of the total emissions. In China, coal-fired power plants generate more than 50% of the total emissions of all industries [4]. Therefore, the development of fossil fuel greenhouse gas control technology, especially coal-fired CO2 emission reduction
technology, is of great significance to my country's commitment to greenhouse gas emission reduction and the development of a low-carbon economy.

2. CO₂ capture technology for coal-fired power plants
Carbon capture and storage (CCS) technology is the most effective way to reduce CO₂ emissions from coal combustion on a large scale, which can reduce CO₂ emissions from coal combustion by more than 90%. According to the estimation of the International Energy Agency (IEA), under the background of controlling the global temperature rise at 2°C in 2050, CCS technology will reduce carbon emissions by 13%, becoming the single technology with the largest share of emission reduction. At present, there are three main ways to capture CO₂: Pre-combustion, Oxy-fuel combustion and Post-combustion [5].

2.1. Post-combustion capture
Pre-combustion capture technology is based on integrated gasification combined cycle power generation (IGCC) technology. The main technical route is to generate syngas rich in carbon monoxide (CO) and hydrogen (H₂) through coal gasification or partial oxidation, and then oxidize CO to CO₂ through water gas shift reaction, so as to improve the CO₂ concentration in syngas. Then CO₂ in syngas is separated by physical adsorption or chemical absorption method, and the obtained H₂ is used as fuel to organize combustion in the boiler. The technology can remove C element, S element and other elements in coal before combustion, which can obtain higher concentration of CO₂ and reduce the emission of pollutants. However, the biggest problem of this technology lies in the complexity of the system and the high cost of investment and operation [6].

2.2. Post-combustion capture
Post-combustion capture technology is to enrich and capture CO₂ in coal-fired flue gas by physical adsorption, chemical absorption or membrane separation. The technology has high maturity, and can be directly applied to the existing coal-fired power plants, so the transformation is less difficult. However, due to the relatively low concentration of CO₂ in coal-fired flue gas, the amount of flue gas to be treated by the capture device after combustion is large. Meanwhile, the physical adsorption method has low CO₂ recovery and limited adsorption capacity [7]. The regeneration energy consumption of chemical adsorption method is large and the operation cost is high. The membrane separation method is not mature, so it is difficult to carry out large-scale industrial application.

2.3. Oxy-fuel combustion capture
Oxy-fuel combustion (O₂/CO₂ Combustion) capture: Oxy-fuel combustion technology is one of the most technologically and economically advantageous CO₂ capture technologies for coal-fired power plants.

Oxy-fuel combustion technology is to use the mixture of O₂ and part of circulating flue gas obtained by air separation instead of air and fuel to organize combustion, so as to improve the concentration of CO₂ in flue gas. This technology can adjust the combustion temperature by circulating flue gas, meanwhile, the circulating flue gas can replace N₂ in the air to carry heat to ensure the heat transfer and thermal efficiency of the boiler. Relevant research shows that the purity of CO₂ in dry flue gas can reach more than 95%, which is very beneficial to capture CO₂. This system adds air ion separation system, which can not only provide high purity oxygen for combustion, but also produce nitrogen, argon and other gas products, reducing the power consumption of oxygen production. And the system has a small amount of exhaust gas, and the exhaust gas temperature can be reduced appropriately, which can make use of the latent heat of steam gasification in the flue gas [8]. In addition, Oxy-fuel combustion has other advantages, such as high combustion efficiency, promoting complete combustion of fuel, less exhaust volume and low NOx emission compared with air combustion. The most important thing is that the research of Argonne National Laboratory in the
United States has proved that the Oxy-fuel combustion technology can be used only by proper transformation of conventional boilers. Therefore, the initial investment of the system is relatively small, and the system can be operated on a large scale when the technical conditions are mature. Therefore, Oxy-fuel combustion technology is one of the most effective CO₂ emission reduction technologies.

3. Application status of Oxy-fuel combustion technology in coal fired boilers in China

In recent years, the application of Oxy-fuel combustion in coal-fired boiler mainly includes traditional pulverized coal boiler and circulating fluidized bed (CFB) boiler.

3.1. Traditional pulverized coal boiler

In 2011, Huazhong University of Science and Technology built the first 3MWth Oxy-fuel combustion carbon capture test platform in China, and the test platform achieved the goal of more than 80% CO₂ concentration in boiler flue gas.

In 2015, Huazhong University of science and technology built another 35MWth Oxy-fuel combustion engineering demonstration platform. The system includes air separation and oxygen generation system, CO₂ circulating combustion system, flue gas dust removal and desulfurization system, flue gas dehumidification system, reserved CO₂ compression and purification and underground storage system, developed Oxy-fuel combustion pulverized coal boiler, burner and other key equipment. Finally, the CO₂ concentration in flue gas reaches 82.7%, which lays a solid foundation for the promotion of Oxy-fuel combustion technology [9].

3.2. Circulating fluidized bed boiler

CFB is a clean combustion technology with high efficiency and low cost. It has the advantages of high combustion efficiency, strong fuel adaptability, wide load regulation ratio, convenient and fast load regulation, less pollutant emission, less no generation due to low temperature combustion, low cost desulfurization in furnace with limestone as desulfurization additive, and easy comprehensive utilization of ash. The schematic diagram of CFB boiler is shown on picture 1. Due to these advantages, vigorously developing CFB combustion technology is an important direction for the development of clean coal combustion technology in China, and has also attracted the attention of many foreign scientific research institutions.

Southeast University has built the world's first 50kWth CFB combustion test platform which can realize warm flue gas circulation, and cooperated with B&W company to build a 2.5MWth CFB Oxy-fuel combustion experimental device. Institute of Engineering Thermophysics, Chinese Academy of Sciences has established a 1MWth CFB device. In recent years, the carbon capture technology of pressurized Oxy-fuel combustion is gradually emerging, which increases the pressure of the combustion chamber to 0.5-1.0 MPa, avoids the process of pressure rise pressure drop pressure rise in the combustion system, inhibits the air leakage of the system, fully recovers the enthalpy of water.
vapor in the flue gas, and reduces the carbon capture cost. American technology company has carried out pilot study of 1MW CFB pressurized Oxy-fuel combustion. In China, pressurized Oxy-fuel combustion is still in the relevant basic research and 20/50 kW level pilot study. In Generally, there is a lack of research on pressurized Oxy-fuel combustion at home and abroad, and the research on megawatt level is just beginning[10].

4. Conclusion
In China, fossil fuels, especially coal, still occupy an important position in energy consumption. According to statistics, China consumed about 2.74 billion tons of standard coal in 2018, accounting for 59.1% of total energy consumption, while coal-burning carbon dioxide emissions accounted for 76.8% of total man-made carbon dioxide emissions. The development of fossil fuel greenhouse gas control technology, especially coal-fired CO2 emission reduction technology, is of great significance to China's commitment to greenhouse gas emission reduction and the development of a low-carbon economy. Oxygen-enriched combustion technology is the most promising in-combustion carbon capture technology for industrial applications, but its cost, safety and reliability are the key difficulties for the promotion and application of this technology.

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