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Full Length Article

Experimental research on combustion characteristics of coal gasification fly ash in a combustion chamber with a self-preheating burner

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ABSTRACT

Coal gasification fly ash (CGFA) is the by-product of coal gasification in a circulating fluidized bed (CFB) and is characterized by its low volatile-content, low carbon-content, and high ash-content, which can be used as a secondary fuel. In China, the annual output of CGFA is enormous; therefore, the realization of a highly efficient CGFA combustion method would be beneficial to achieve better overall coal utilization. Nevertheless, it is challenging to burn CGFA steadily with conventional technologies because of its low volatile content. However, the coal preheating combustion technique has been proven to be an effective method to burn semi-coke and anthracite, both of which are poorly flammable, and could also be applied to CGFA. We have used an advanced preheating combustion technique with a self-preheating burner and carried out experimental investigations into CGFA combustion in a 0.4-MW CGFA preheated combustion test rig. The results show that the preheated combustion system ran smoothly and the CGFA combustion efficiency reached 98.6% with NO_X emissions of 155 mg/m^3 (6% O_2). Therefore, the highly efficient and clean combustion of CGFA was realized, and the combustion of poorly flammable fuels using a self-preheating burner was shown to be feasible. The effects of the primary air ratio, secondary air ratio, and the position of the tertiary air inlet on the combustion characteristics and NO_X emissions of CGFA were also studied.

1. Introduction

Coal is the primary energy fuel in China, and coal gasification is considered an effective method to realize the highly efficient and clean utilization of coal [1]. Circulating fluidized bed (CFB) gasification technology is characterized by highly efficient heat and mass transfer, a uniform bed temperature, low operating costs, and adaptability to different grades of coal; therefore, it is an important technique with a market share that has increased sharply in recent years [2–5]. Coal gasification fly ash (CGFA) is the by-product derived from CFB coal gasification. Because the carbon conversion efficiency of CFB gasification technology is only 80%, plenty of energy remains in the CGFA, and the lower calorific value of CGFA is about 2000 to 4000 kcal/kg. It is estimated that the production of CGFA will reach thirty million tons in 2020. Thus, there will be enormous losses if CGFA is discarded because it contains a significant quantity of unburned carbon and could be used as a secondary fuel in China, especially when energy is short supply. Therefore, it is crucial to realize a highly efficient and clean combustion process for CGFA. However, studies have shown that the ignition, combustion stabilization, and burnout of CGFA are challenging because of its extremely low volatile content (0–5%), low carbon-content (20–40%), and high ash-content (40–60%) [6]. Furthermore, CGFA cannot be disposed of with conventional combustion technologies because a part of the fixed carbon has been graphitized.

Because of its advantages in flame stability and reducing NO_X emissions, high-temperature air combustion technology has attracted the attention of many researchers, and some studies of low-volatile-content solid fuels have been implemented. Suda [7] carried out many experimental investigations into high-temperature combustion, resulting in the stable combustion of anthracite coal. In that investigation, the combustion air was preheated to a high temperature by an electric or gas air heater placed outside the furnace; as a result, the fuels could be burned stably. However, the extra air heater required to maintain the high air temperature complicates the system and increases costs, especially when the heat capacity is increased and the combustion air volume increases significantly. To solve these problems, Zhang [8] designed a primary air enrichment and preheating (PRP) burner that can produce the high-temperature air necessary for the combustion of solid fuels without an additional air heater. With the specially designed burner, internal gas recirculation inside the chamber is possible, and

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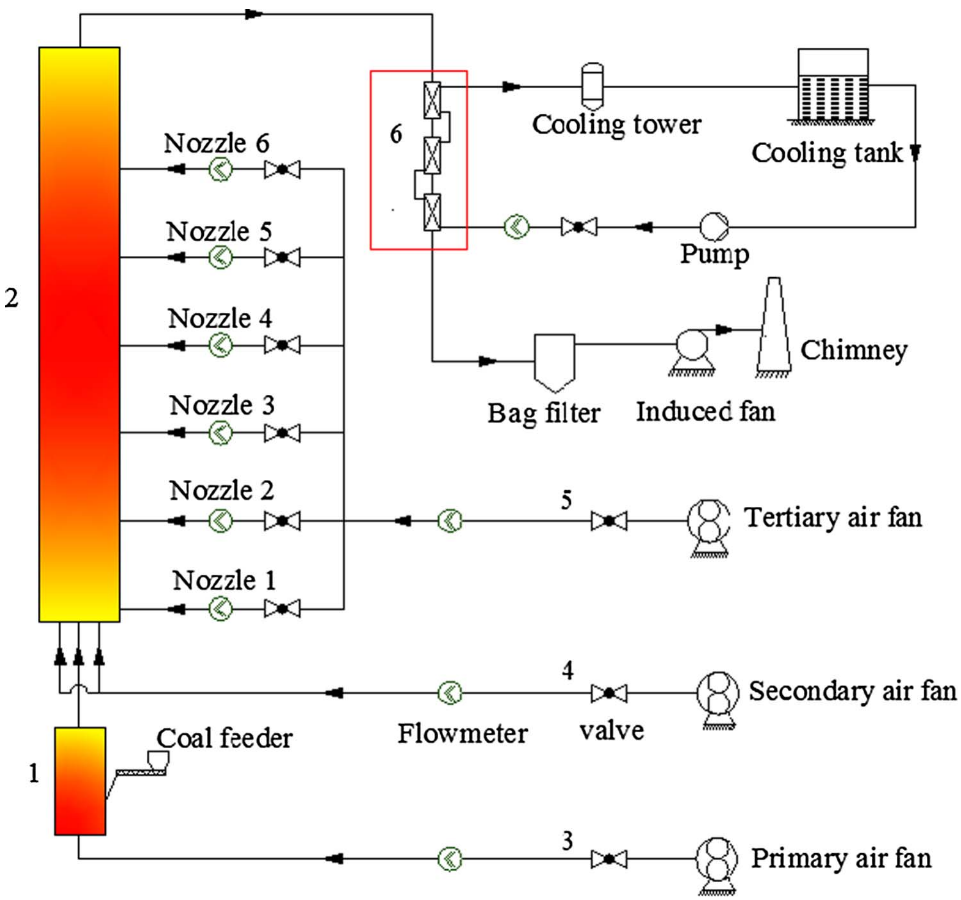

Fig. 1. Schematic diagram of the 0.4-MW CGFA preheated combustion test rig: 1, self-preheating burner; 2, combustion chamber; 3, primary air pipeline; 4, secondary air pipeline; 5, tertiary air pipeline; and 6, flue gas cooler.

primary air can be preheated by the hot flue gas. Semi-coke and anthracite were used as the experimental fuels, and de-NO_X emissions were realized. Lu [9] also studied high-temperature air combustion technology and proposed a new method based on CFB, resulting in the construction of a novel combustion system. In the system, the high-temperature combustion air is generated from the combustion with a high excess air ratio in the CFB.

Coal preheating technology has also been found to be an effective method to burn poorly flammable fuel and can be operated efficiently. It is different from high-temperature air combustion because the fuel is preheated instead of the combustion air; thus, the processes of volatile release and coal pyrolysis are separate, and small, flammable gas molecules are generated in the preheating process. Because the high-temperature flammable gas ignites easily, it is considered to be a promising technology for low-volatile-content fuels. A gas fire coal preheating (GFCP) technique was developed by the All-Russian Thermal Engineering Institute and is considered a clean-combustion technology [10–12]. In the GFCP method, fuel is heated to a high temperature by the hot flue gas from gas combustion, resulting in low NO_X emissions and improved thermal efficiency. However, the combustion system is complicated, and the operating costs are high because natural gas is used to preheat the fuel. Niu [13] studied the effect of coal preheating on NO_X reduction in a 4-kW drop-tube furnace, and the results show that the reduction in NO_X emissions is 30%, even for meager coal. All the methods mentioned above are effective for dealing with poorly flammable fuels, such as anthracite coal, semi-coke, and petroleum. However, combustion technology for CGFA or experimental research into CGFA has not been reported, and it is difficult to choose an appropriate technology to burn out the CGFA.

Recently, a self-preheating burner based on CFB was proposed by the Institute of Engineering Thermophysics, Chinese Academy of Sciences [14], and a 30-kW test rig was constructed with the self-preheating burner placed on the top of the furnace; hence, the preheated fuel was sent into the combustion chamber from the top and flowed down. Based on this technique, the temperature of the fuel can be preheated above 800 °C by partial pyrolysis, gasification, and the combustion of the fuel itself without external heat input, and the preheating temperature can also be controlled by adjusting the amount of fuel and air [15]. Many experiments have been implemented, and the results show that highly efficient and clean combustion of poorly flammable fuels including anthracite and semi-coke can be achieved [16–18]. It is speculated that the stable, clean, and highly efficient combustion of the CGFA also can be realized by using a self-preheating burner. Nevertheless, there are many ways to arrange the self-preheating burner around the combustion chamber. For example, it can be arranged at the top of the combustion chamber or at the bottom. The arrangements are related to many factors such as the characteristics of fuels and the boiler capacity, and different arrangements require different operational approaches and result in different combustion features. Generally, the installation of the burner at the bottom of the combustion chamber is appropriate because installation at the top of the burner results in high costs when the combustion system is enlarged, although it is easier to discharge the ash in this configuration.

To verify whether the self-preheating burner can be applied to the combustion of CGFA and investigate the combustion characteristics of CGFA with the self-preheating burner at the bottom of the combustion chamber, a special self-preheating burner was designed, a 0.4-MW CGFA preheated combustion test rig was constructed, and a series of experiments were carried out. This paper outlines the performance characteristics of the system and discusses the combustion characteristics and NO_X emissions of the burning of CGFA under different operational conditions.