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The experimental study of fly ash decarbonization on a circulating fluidized bed combustor

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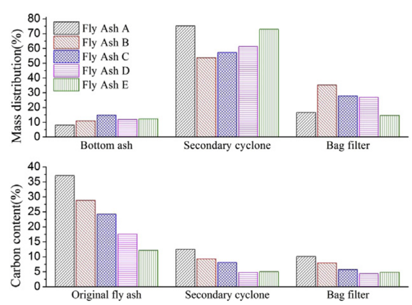
HIGHLIGHTS

- Fluidized bed combustor was designed on fluidization properties of the fly ash.
- Fly ash with different carbon content were used for decarbonization research.
- The furnace thermal load was calculated based on the power compensation effect.
- Decarbonization characteristics and performance of the test combustor were investigated.

GRAPHICAL ABSTRACT



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ABSTRACT

Fly ash is a by-product of coal-fired power plants, whose production is huge. As the coal resources are in short supply in recent years, most circulating fluidized bed (CFB) boilers in China burn hard coals, thus, the carbon content in the fly ash is much higher than expected. The high carbon content in the fly ash limits the potential utilization as building materials. At present, the decarbonization method of high carbon content CFB fly ash is mainly fly ash recirculation combustion (FARC). Because of the huge difference between original boiler operating conditions and fly ash ideal combustion state, the decarbonization effect is disappointed. Therefore, a series of fly ash decarbonization experiments were carried out on a bench-scale CFB combustor designed on fluidization properties of fly ash, and the decarbonization characteristics were discussed. Results show that fly ash requires a minimum sectional thermal load of 0.42 MW/m^2 for continuous and stable combustion in test combustor, corresponding to the critical carbon content in the fly ash is 18%. The maximum decarbonization efficiency of the test CFB combustor is approximately 75%, which is much higher than that of FARC.

1. Introduction

With the advantages of broad fuel flexibility and low pollutant emission, circulating fluidized bed (CFB) combustion technology has been developed rapidly in power generation over the past 20 years, which presently has become the most commercialization clean coal combustion technology and is moving towards the development of supercritical and large-scale [1–4]. Fly ash is a by-product of the coal-fired power plants. With the increased production of coal, the fly ash production is increasing largely year by year, which has become the largest single source of emissions of industrial solid waste in China and even in the world [5,6]. The conventional treatments of fly ash are yard storage and comprehensive utilization. The comprehensive utilization

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requires the carbon content in the fly ash not exceeding 15% and that of class-A fly ash is required no more than 5% further. The results of the investigation show that fly ash comprehensive utilization rate is less than 30% and that of CFB fly ash is much less than 10% in China [7]. Fly ash yard storage not only takes up a lot of land, but also causes great harm to the environment [8].

As the coal resources are in short supply in recent years, most CFB boilers in China burn hard coals such as anthracite, bituminous, low reactive coal residue etc. Moreover, coal resources in the power plants often deviate from the designed coal due to the variability and instability of coal supply. Thus, the carbon content in the fly ash is much higher than expected [9,10], especially for CFB boilers burning coals with low volatile and high value [11]. In addition, in the early operation stage of CFB boilers, fly ash with high carbon content are generally produced due to low cyclone efficiency and low furnace height [12]. Therefore, how to deal with the early high carbon content fly ash yard storage as well as avoid existing high carbon content fly ash accumulation have become an urgent problem to be solved.

At present, the decarbonization method of high carbon content CFB fly ash is mainly fly ash recirculation combustion (FARC) technology, which sends the high carbon content fly ash captured by the electrostatic precipitator (ESP) or bag filter back to the furnace directly by pneumatic conveying. Because of the huge difference between original boiler operating conditions and fly ash ideal combustion state, the residence time of fly ash is still very short in furnace and the decarbonization effect is disappointed [13–15]. At the same time, the residual limestone in the fly ash will increase the NO_X emissions. In addition, as the ESP or bag filter load increases, the dust emission concentration increases significantly. All these problems cannot be ignored absolutely [15–17].

On the basis of comprehensive analysis of the problems caused by FARC, a fly ash fluidized bed combustion system with heat self-balance for decarbonization was put forward and applied for a patent. For a comprehensive understanding of decarbonization characteristics of the system, the fluidized bed combustion system was designed on fluidization properties of fly ash and the decarbonization characteristics were studied by using five types of CFB fly ash with different carbon content.

2. Experimental study

2.1. The test system introduction

As shown in Fig. 1, the experiments were carried out in a bench-scale CFB combustion system, which consists of the combustor, the feeding system, the air supply system, the electric heating system, the water cooling system and the measurement system. The furnace was built by silicon carbide with a rectangle cross-sectional dimension of 150 mm × 150 mm and 3000 mm in height. In order to extend the residence time of fly ash in furnace, the cyclone was designed according to the particle size distribution of fly ash to ensure the cut size $d_{50} \leq 10$ μm. Fly ash was fed into furnace by the screw feeder, which could be quantificationally adjusted by the control motor. Most of the fly ash particles were separated by the cyclone and then returned back to furnace through the *U*-valve. In order to know the separation effect of the cyclone, a quartz glass tube with a length of 300 mm was installed in the middle of the riser for observation. The electric heating system was used for ignition and steady combustion under low boiler load, which consists of the air heating system and the furnace heating system. The water cooling system consists of two groups of serpentine tubes.

Ten temperature measuring points and three pressure measuring points were evenly arranged along the furnace height direction. Wind box, cyclone and *U*-valve at the important components were also allocated with temperature and pressure measuring points. The temperature and pressure data were collected and monitored by the monitor and control generated system (MCGS). A "MGA5" infrared gas analyzer (oxygen measurement accuracy is 0.2%) was employed to monitor the online gas concentrations at the outlet of cyclone.

2.2. Experimental methods

The facility was started up with spend bed materials according to different working conditions, corresponding to the static bed height ranges from 120 mm to 400 mm. The bed materials were real boiler bed materials received from a 300 MW CFB boiler with a particle size distribution of 0–0.3 mm after screening. When the combustor started for ignition, the air generated from the air

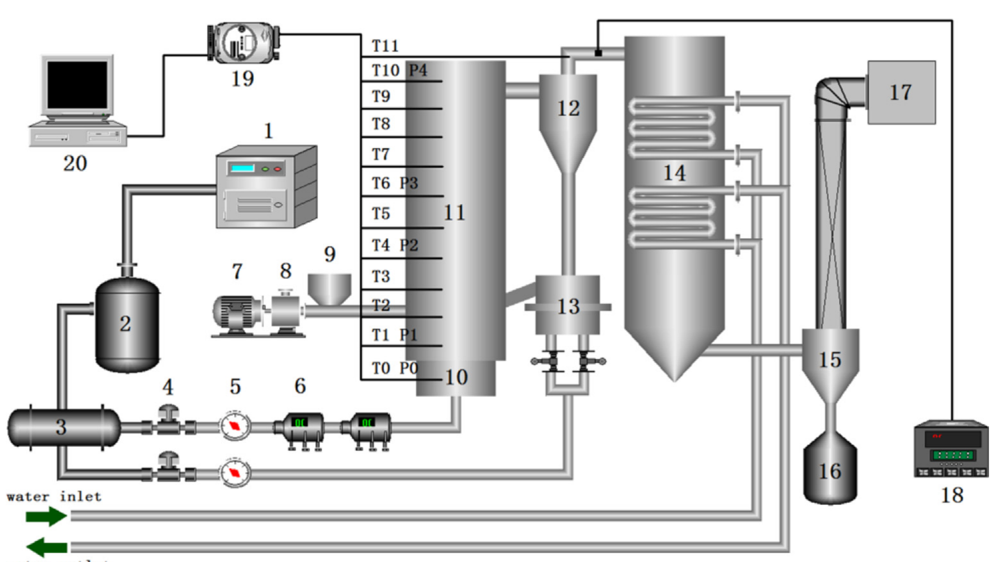

Fig. 1. Schematic diagram of the experimental system.