Study on the combustion characteristics of high temperature activation gas-solid binary fuel

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1 Abstracts

Circulating fluidized bed (CFB) units have problems such as fluidization deterioration, combustion efficiency decline, uneven combustion reaction and elevated pollutant emissions at low loads, therefore their deep peaking capacity is limited. To solve these problems, this paper proposes a coupled combustion technology of preheating and Circulating fluidized bed (Pre-CFB), which can convert room-temperature granulated coal fuel into high-temperature activated gas-solid binary fuel and improve the reaction kinetic characteristics of the fuel to enhance the low-load combustion performance of the CFB boiler, through the addition of a preheating combustion device in front of the CFB. The results of the thermal test carried out on a 2MW Pre-CFB experience system show that The particle size of granular coal is reduced by 30.5% after preheating and the pore structure on the surface is more developed. The ignition temperature of the solid fuel is lowered by 98℃. The high-temperature solid-phase fuel and high-temperature gas enter the furnace chamber together and then combust in a graded manner, which improves the temperature uniformity of the furnace chamber by 42% and reduces the NO*x* emission 67.6%. It is also found that high-temperature gas-solid binary fuels can be used in the CFB boiler banked-fire process, and that a preheating load of 3.5% can extend the stable operation of the CFB boiler at near-zero load by 100%.

2 Background

Circulating Fluidized Bed (CFB) combustion technology has been widely used in the fields of power generation, biomass utilization and waste treatment due to its advantages of wide fuel adaptability, high combustion efficiency and low pollutant emission [1]. However, with the rapid increase in the proportion of renewable energy power generation, traditional thermal power units need to frequently participate in grid peaking, resulting in CFB boilers need to operate at low load for a long time [2]. Under this condition, the gas-solid flow, combustion stability and heat transfer characteristics in the furnace deviate significantly from the design conditions, which leads to many technical challenges [3].

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At low loads, CFBs are mainly subject to the following challenges in combustion: deterioration of combustion reaction kinetics, impeded release of volatile matter, difficulty in coke burnout, and reduced combustion stability due to the overall reduction in furnace temperature; uneven mixing of materials and imbalance in combustion zones due to deterioration of fluidization; and exceeding of pollutant emission standards [4-6].

This paper presents a new idea based on CFB combustion from the combustion side. By constructing a Pre-CFB combustion system, the room temperature coal fuel can be effectively modified into a high temperature gas-solid binary fuel, and the reaction kinetic properties of the fuel can be improved.

3 Purpose of the experiment

(1) Obtaining the effect of preheated combustion on the combustion characteristics and emission characteristics of CFBs on a macroscopic scale.

(2) Explaining the changes experienced by fuels before and after preheating on a microscopic scale. Explain the reaction mechanism of gas-solid binary fuels

(3) Validation of the feasibility of extended banked-fire time with a high-temperature gas-solid binary fuel at near-zero load.

4 Methods

4.1 Experimental system

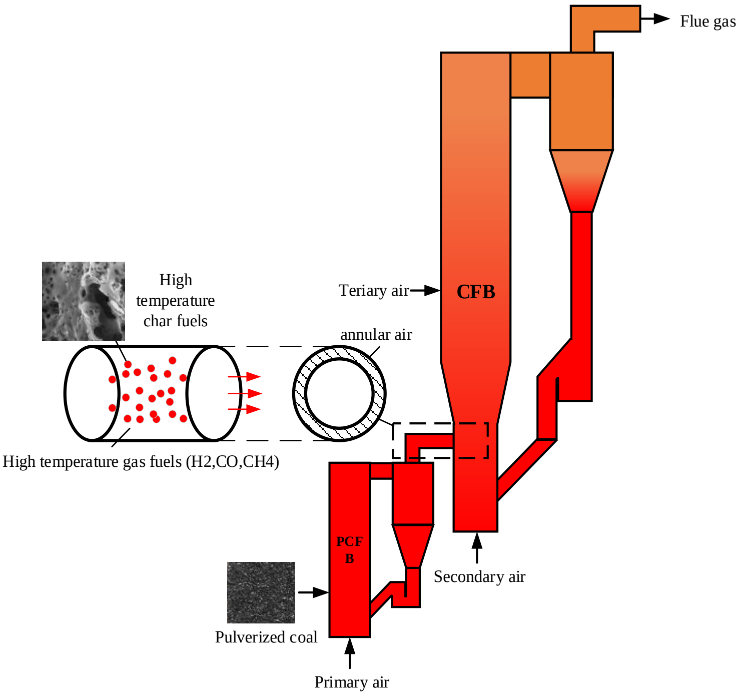

Figure1: Formation and conversion processes of gas-solid binary fuels

The experimental system is a Pre-CFB system with a rated power of 2 MW. In the experience, according to the designed coupling method, part of the pulverized coal is first fed from the feed port of the PCFB, and the primary air is passed from the bottom of the PCFB to maintain the air equivalence ratio in the PCFB at about 0.2. Under the low air equivalence ratio, the pulverized coal is converted into high temperature gas-solid binary fuel, which enters the CFB for secondary combustion. Some pulverized coal is also fed into the bottom of the CFB to ensure that the total operating load is around 30%. In addition, secondary air, tertiary air and annular air are fed from different heights of the CFB to ensure complete combustion of the Fuel in CFB. The air equivalent ratio of the whole system should be maintained at about 1.3, which corresponds to about 5% oxygen in the tail.

4.2 Thermal state tests on a 2MW Pre-CFB experimental system.

The commonly used coal from circulating fluidized bed power plants, referred to as Datong coal, is used in this experiment. Datong coal is characterized by high ash and volatile content. In the experiment, pulverized coal with a particle size of 0-200 um was passed into the PCFB, and granulated coal with a particle size of 0-4 mm were passed into the CFB. The results of elemental and industrial analysis of Datong coal are shown in Table 1 below.

Table1: Elemental and industrial analysis results of Datong coal

Name	Elemental Analysis					Industrial analysis				Low calorific value
	wt%					wt%				MJ/kg
	C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}	M_{ar}	FC_{ar}	V_{daf}	A_{ar}	$Q_{net,ar}$
Datong coal	45.6	2.91	8.90	0.89	0.36	2.40	36.27	22.40	38.93	17.061

Table2 below shows the basic operating parameters of PCFB and CFB when operated at 30% load with different coupling methods.

Table2: Operating parameters for different coupling methods at 30% load

Number	**Acronyms**	**PCFB Load**	**CFB load**	**Tem of PCFB**	**Tem of CFB**	**Primary air volume**	**secondary wind**	**tertiary air**	**annular airflow**
		%	%	℃	℃	Nm^3/h	Nm^3/h	Nm^3/h	Nm^3/h
1	10%PCFB+20%CFB	9.5	19.9	908	800	55	353	45	68
2	15%PCFB+15%CFB	16	18.3	923	841	63	331	62	68
3	20%PCFB+10%CFB	19	11.8	914	771	75	373	72	68
4	30%PCFB	33	0	919	758	135	397	53	68

Observe the experimental phenomena and compare the operating process curves and temperature distributions of PCFB and CFB under different coupling methods.

Figure 2-5 below shows the operating process curves of the Pre-CFB system with different coupling methods.

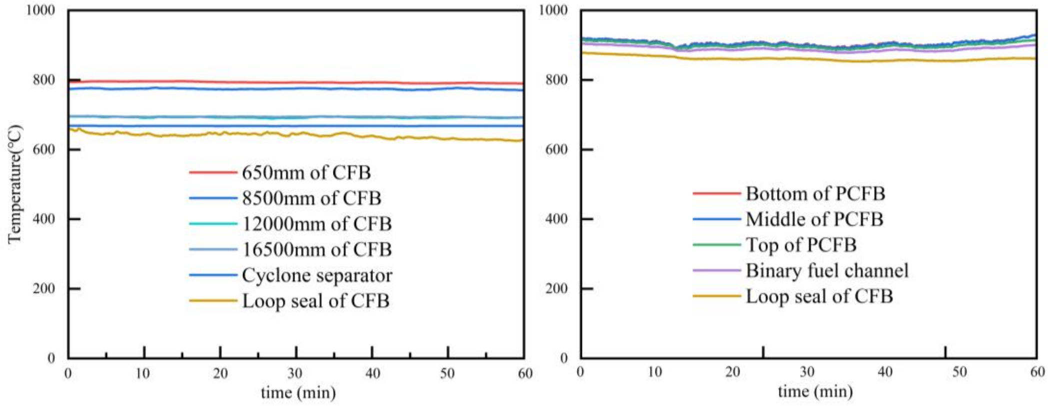

Figure2: Temperature variation curve in operation mode of 10%PCFB+20%CFB

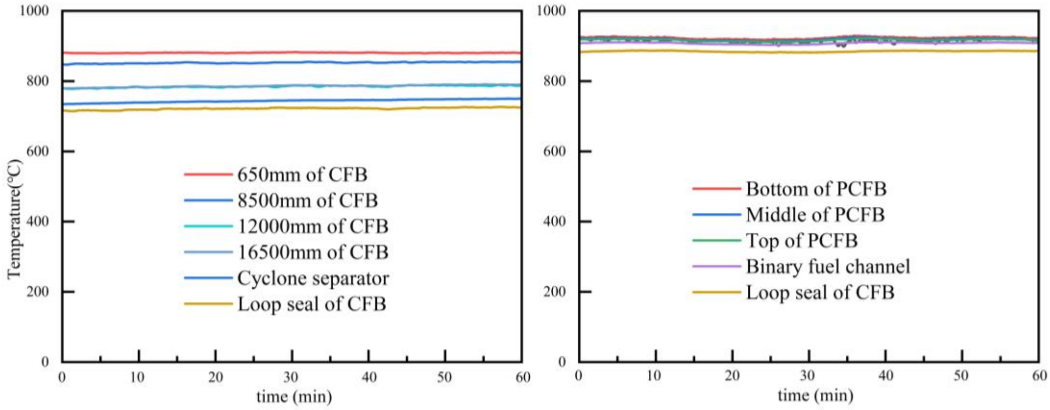

Figure3: Temperature variation curve in operation mode of 15%PCFB+15%CFB

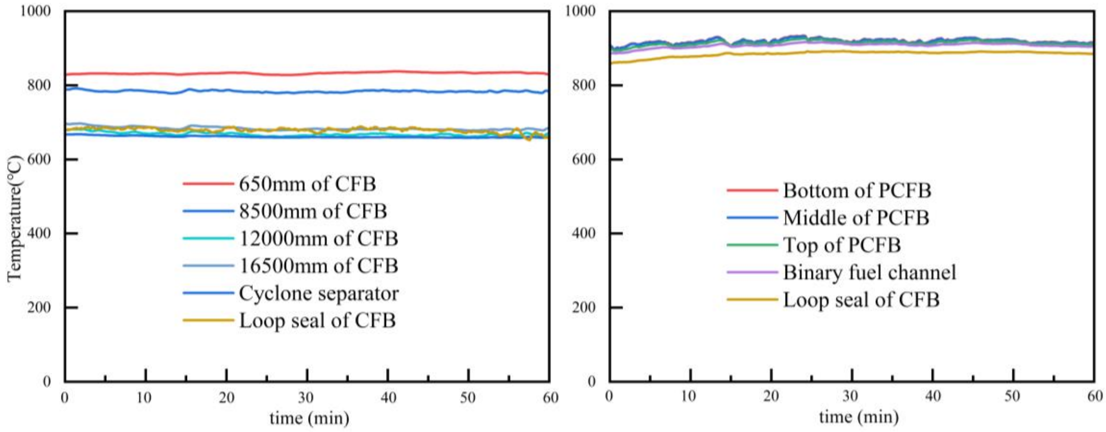

Figure4: Temperature variation curve in operation mode of 20%PCFB+10%CFB

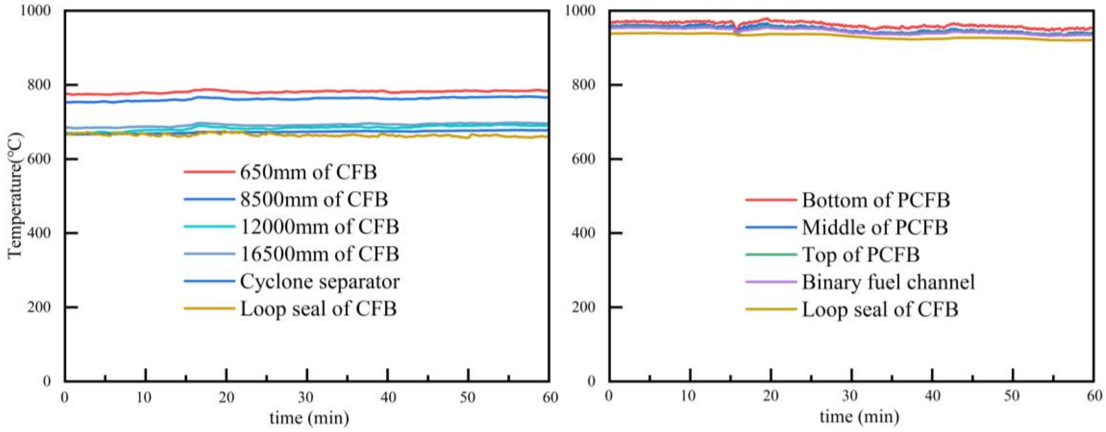

Figure5: Temperature variation curve in operation mode of 30%PCFB

4.3. Characterization of high temperature gas-solid binary fuels

In the experiment, gas and solid samples were taken from the connection of PCFB and CFB, and the solid fuel was analyzed for industrial analysis, elemental analysis, particle size analysis and SEM analysis to analyze the composition and calorific value of the gas phase fuel.

The results of the relevant analyses are shown as figuer6 and figure7, some of the results are still being compiled and are not listed at this time.

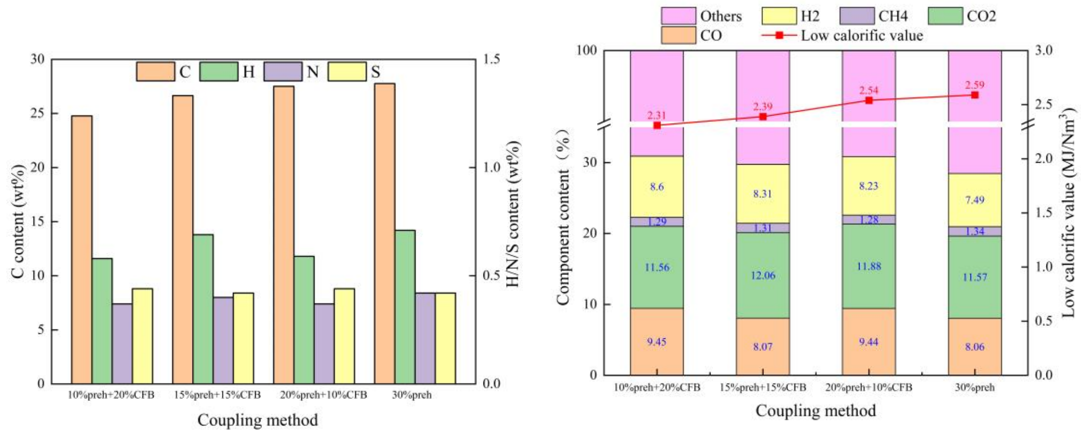

Figure6: Gas-solid fractions under different coupling methods

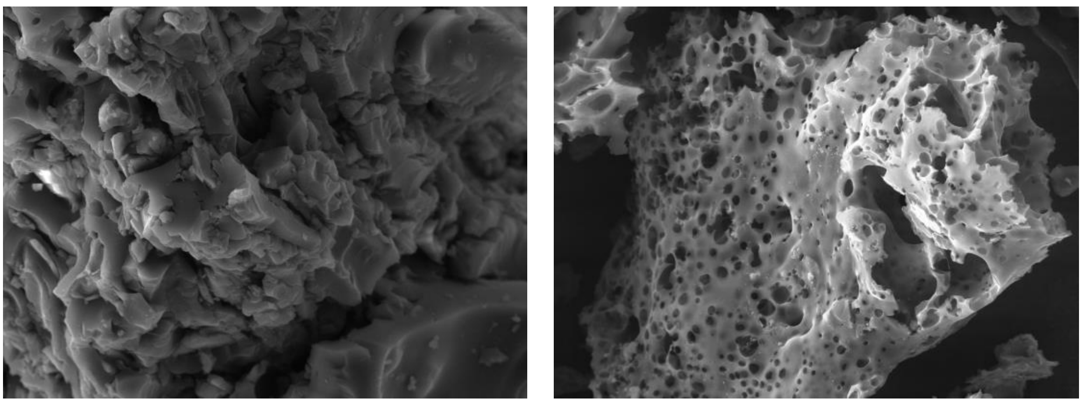

Figure7: Changes in surface micro-morphology of solid fuels before and after preheating at 30% PCFB-load

4.4 NO*x* emission analysis

The flue gas was examined at the exit of the tail flue of the CFB and the NO*x* emission concentrations were compared under different coupling methods.

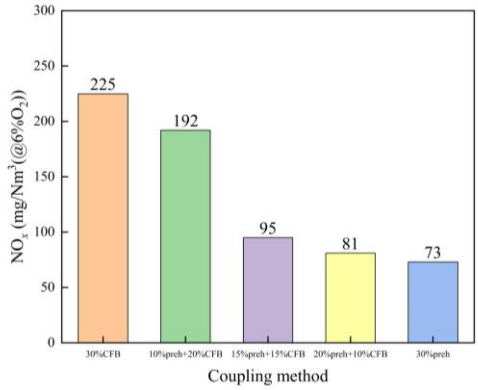

Figure8: NO*x* emissions under different coupling methods

Raw coal is first preheated and modified in PCFB and then combusted in CFB, which can effectively reduce NO*x* emissions. The reduction increases with the increase of the preheating ratio, and the NO*x* reduction effect is best with pure preheating combustion when operating at 30% load. NOx emissions can be reduced by up to 67.6 % in the 30% PCFB mode of operation.

4.5 Banked fire process analysis

In order to investigate the long-time operation mode of CFB at near zero load, three banked fire tests were carried out on a 2MW Pre-CFB experience system, and the relevant working condition parameters are shown in the table3 below.

Table3: Banked fire condition parameters

Number	**Acronyms**	**Operational state of PCFB**	**Initial banked-fire temperature**	**Bed material quality**	**Preheating load**	**Preheating load ratio**	**Excess air factor**
			℃	**kg**	**kW**	**%**	**/**
5	Preheating bankedfire	On	846.7	292.3	70	3.5	1.2
6	Conventinal bandedfire1	Off	839.7	302.6	0	0	0
7	Conventinal bandedfire2	Off	768.6	182.9	0	0	0

The bed temperature variation curve and heat power losses corresponding to the three banked fire conditions are shown below.

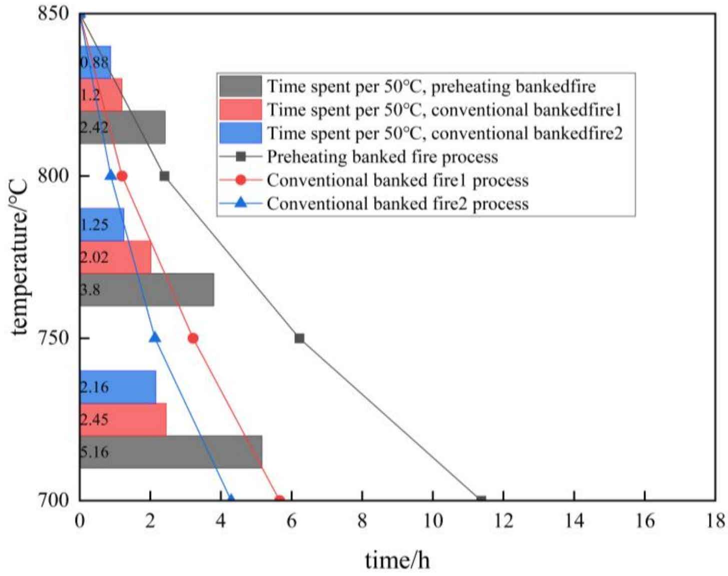

Figure9: Bed temperature variation curve under different banked fire conditions

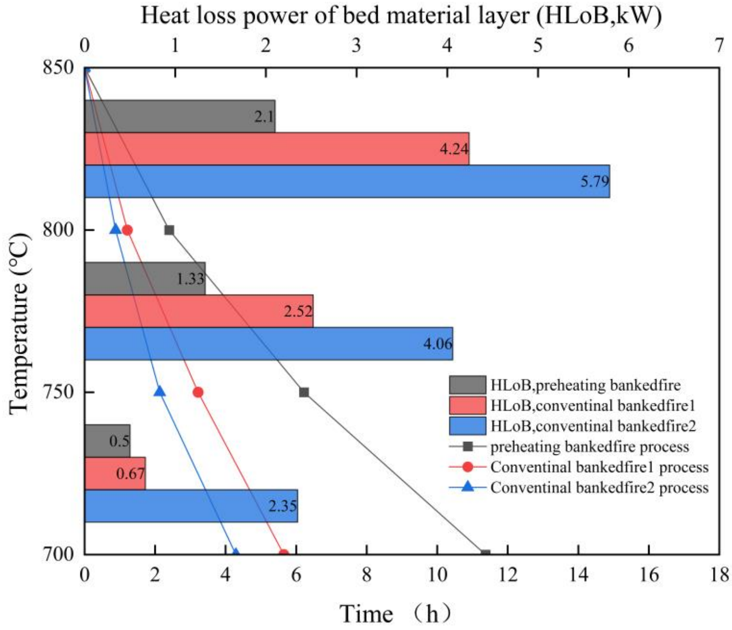

Figure10: Heat loss power of bed material layer under different banked fire conditions

During the CFB banked fire heat preparation, the PCFB was operated at a heat load of 3.5%, which could effectively reduce the temperature reduction rate of the CFB boiler bed material layer, thus maintaining the bed temperature during the CFB banked fire. Taking 850-700°C as the temperature interval of CFB banked fire heat preparation, the preheat banked fire method can extend the banked fire heat preparation time of CFB boiler from 5.67h to 11.38h, which is an increase of 100%.

5 Conclusions

1. By preheating and modifying the raw coal, high-temperature gas-solid binary fuels can be produced to improve the combustion performance of CFB boilers at ultra-low loads (⩽30%), increase the overall CFB temperature distribution uniformity, and reduce the NO*x* emission concentration.

2. Preheating can modify the raw coal into semi-coke with a richer pore structure, which helps to lower the ignition point of the fuel and increase the specific surface area.

3. Under near-zero load conditions, CFB boilers can only operate in hot banked fire standby mode. However, the limited thermal storage capacity within the furnace chamber results in extremely short duration of this standby state. PCFB can generate high-temperature gas-solid binary fuel during near-zero load operation. Supplemental combustion of high-temperature gas-solid binary fuels in the CFB unit greatly extends the hot standby time of the CFB boiler, providing a viable solution for CFB peaking operation through long periods of near-zero load.

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