



Research on the measurement method of fuel feeding temperature during circulating fluidized bed boiler's start-up

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Abstract

Circulating fluidized bed (CFB) boiler is a high-efficiency and clean combustion technology that has been developed rapidly in recent years. During the start process, only after the furnace temperature is heated up with fuel oil higher than the fuel feeding temperature, fuel can be fed into it, otherwise, it will easily lead to deflagration accidents in the furnace. While adding fuel too late will increase the unnecessary cost of fuel oil. There are three main methods for measuring fuel feeding temperature in the CFB boiler. The thermogravimetric analysis-derivative thermogravimetry (TG-DTG) method has the problem of a large gap between the measurement results and the actual boiler fuel feeding temperature. Although the measurement results in the CFB test rig are more accurate, its procedure is more complex and costly. The method of on-site debugging and measurement has disadvantages such as high measurement cost and poor measurement repeatability. For this reason, this paper designs a simple method to measure fuel feeding temperature in CFB boiler, which has standard operability and lower test cost. The measurement results of variable fuel types were compared with the measurement results of the above three methods, which prove that the results of all samples are close to those in the actual CFB boiler with error within 40°C. It is confirmed that this method can accurately measure the CFB boiler fuel feeding temperature, which is of great significance to the operation of the CFB boiler.

KEYWORDS

CFB boiler, fuel feeding temperature, measurement method, simple method, TG-DTG method

1 | INTRODUCTION

As a clean combustion technology with advantages of high combustion efficiency, low pollutant emission, fuel flexibility, and large turndown ratio, circulating fluidized bed (CFB) has been developed rapidly in the last

40 years.^{1–3} In 2009, the world's first 460-MW supercritical CFB boiler was put into commercial operation at Lagisza Power Plant in Poland. In 2013, the world's first 600-MW supercritical CFB boiler was put into operation in China. Currently, a 660-MW high-efficiency ultra-supercritical CFB boiler is under construction in China.



So far, China has become the largest CFB boiler market in the world.

The fuel relies on the heat exchange from the bed material to reach the ignition point and to burn in the CFB boiler. Therefore, during the boiler start-up process, the temperature of the bed material needs to be heated to the feeding fuel temperature a little higher than the ignition point (if the fuel is coal, it is also called as the feeding coal temperature), and then the fuel can be fed into the furnace. Fuel oil is commonly used to heat the bed material. If the fuel is fed when the bed temperature is lower than the feeding fuel temperature, the fuel entering the furnace will not only fail to ignite but also reduce the bed temperature. When the unburnt fuel accumulates too much, the concentration of volatiles in the furnace will rise sharply. Once the ignition temperature of the volatile is reached, the combustible gas such as carbon monoxide in the volatile will detonate, and the bed temperature is hard to control, which will cause agglomeration on the air grid. On the contrary, if the bed temperature is much higher than that of the feeding fuel temperature, the start-up time of the CFB boiler and the consumption of ignition fuel will increase.^{4–6} For large-capacity CFB boilers, this effect is more obvious because of more bed material. Therefore, the fuel feeding temperature during the CFB boiler start-up is an important parameter for the safe and economical operation of the boilers.

At present, the measurement methods of feeding fuel temperature in industrial applications mainly include the following three methods: measuring by thermogravimetric analysis-derivative thermogravimetry (TG-DTG), measuring by a CFB test bench, and determining by commissioning actual boiler. The TG-DTG method refers to determining the fuel ignition temperature by mathematical means according to the weight loss curve of the fuel (TG) and the corresponding weight loss rate curve (DTG). As shown in Figure 1, the steps of measuring the ignition temperature of a certain fuel by the TG-DTG method are elucidated. Drawing a vertical line through the peak value of the DTG curve, it intersects the TG curve at point A, then a tangent line to the TG curve is drawn through Point A, and a horizontal line is drawn across Point B, which is the beginning of weight loss. The temperature corresponding to the intersection Point C of the above tangent line and the horizontal line is defined as the ignition temperature.^{7,8} The allowable temperature raising rate of the TGA thermogravimetric analyzer is generally less than 20°C/min, while the temperature rising rate of the fuel feeding into the furnace in the actual CFB boiler is over 100°C/s.⁵ In addition, there is a very violent diffusion mixing process in the CFB boiler, but this process is limited in the TGA thermogravimetric

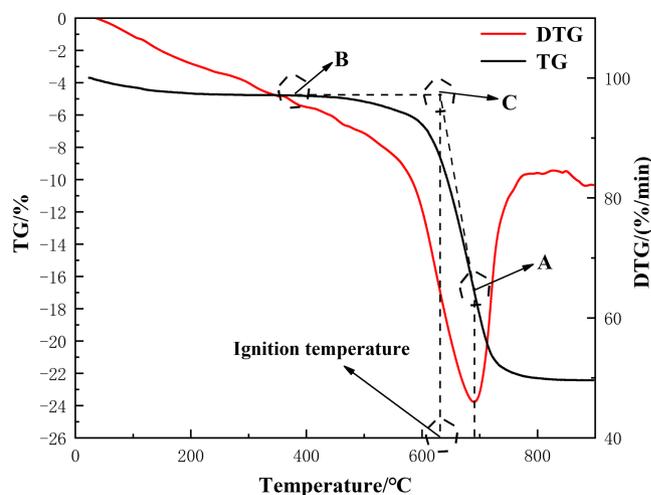


FIGURE 1 Determination of ignition temperature of a certain fuel by TG-DTG

analyzer. The measurement results by the TG-DTG have a large deviation from the actual fuel feeding temperature of the CFB boiler, and it is generally 100–150°C lower than the actual CFB boiler's fuel feeding temperature; in addition, the price of TGA thermogravimetric analyzer is relatively expensive,⁵ so it is generally only used for laboratory research. The CFB test bench measurement refers to recording the temperature change of the furnace, combined with the measurement of the oxygen content, and visually inspecting the flame and sparks.^{9,10} The combustion state of the CFB test bench is closer to the actual boiler, and the measurement results are also closer to the actual CFB boiler fuel feeding temperature. However, due to the need to build a small CFB test bench, the test process is more complicated. In addition, in the context of carbon peak and carbon neutral in China, it is constrained to carry out fossil fuel combustion tests in urban areas, so this method is not suitable for popularization. The method of on-site commissioning refers to the operator artificially determining the feeding fuel temperature by observing the combustion condition, such as bed temperature changing and oxygen changing in the furnace. Although the parameters determined by this method are relatively reliable, it requires many attempts on site and certain experience. There are problems such as higher test costs, complicated test procedures, and long test periods.

To sum up, the existing methods for measuring fuel feeding temperature in CFB boilers cannot meet the requirements of good measurement accuracy and low cost at the same time, so they cannot guide industrial applications conveniently and quickly. For this reason, this paper designs a simple method to measure the fuel feeding temperature. Laboratory experiments were



carried out for different fuels, and the test results were compared with the measurement values of the above three methods. It turns out that this method can accurately measure CFB boiler fuel feeding temperature, which provides an important basis for the economical and safe operation of the boiler.

2 | MEASURING DEVICE

In this paper, a simple method for measuring CFB boiler fuel feeding temperature is designed, and the measurement device is shown in Figure 2.

The whole measuring device consists of a crucible, thermocouple No. 1, thermocouple No. 2, a paperless temperature recorder, and a muffle furnace. To facilitate the test and save the test sample, the crucible is a boat-shaped crucible made of corundum, with a length of 40 mm, a width of 10 mm, and a depth of 8 mm. Since the crucible containing the test sample needs to be put into the muffle furnace, and the temperature in the muffle furnace needs to be kept constant during the test, a small hole with a diameter of 7 cm is opened on the front of the muffle furnace. Make sure the crucible can be reached without opening the muffle door. After the crucible is inserted, the small hole is blocked by fireproof insulation cotton to ensure the constant temperature in the muffle furnace. The No. 1 thermocouple is closely set on the sample surface, and the No. 2 thermocouple is set directly above the test sample, parallel to the No. 1 thermocouple. The paperless temperature recorder is used to record the real-time temperature information with a frequency of 1 s.

3 | MEASURING PRINCIPLE

Generally, fuel combustion is divided into four stages, heating and drying, volatilization and ignition, fixed

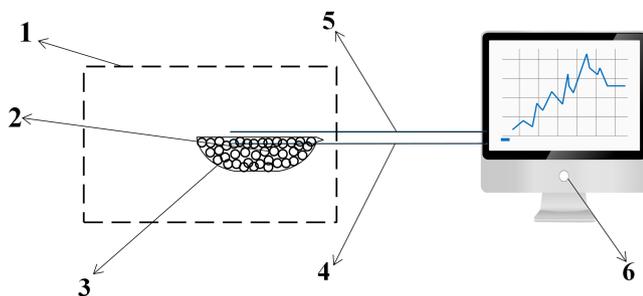


FIGURE 2 Measuring device 1-muffle furnace; 2-sample; 3-crucible; 4-thermocouple No. 1; 5-thermocouple No. 2; 6-paperless temperature recorder

carbon combustion, and burnout.¹¹ When the fixed carbon starts to burn, it means that the temperature in the furnace has met the temperature conditions for the stable combustion of the fuel. It is safe and reasonable to use the fixed carbon fire beginning temperature as the CFB boiler fuel feeding temperature. Therefore, this paper indirectly measures the fuel feeding temperature by measuring the fixed carbon fire beginning temperature. When the volatile in the surface of the test sample is released and burnt out under the influence of the external temperature, the fixed carbon in the surface layer of the test sample begins to fire, and the flame generated by the fixed carbon will cause the temperature of the No. 2 thermocouple to change abruptly, and this change will be recorded in time by the paperless temperature recorder. Taking the first-order derivation of the temperature data of the No. 2 thermocouple with time, the temperature change rate of the No. 2 thermocouple at each moment can be obtained. Figure 3 shows the measurement result of a certain fuel, which is used as an example to further illustrate the test principle. The last moment when the temperature change rate suddenly increases is defined as the measurement moment, which is caused by the burning of fixed carbon. The temperature of the No. 1 thermocouple corresponding to the measurement moment is exactly the temperature of the test sample when the fixed carbon in the surface layer of the test sample begins to burn. The last peak of the temperature change rate corresponds to the moment when the fixed carbon in the surface layer of the test sample is burned out. Since the data of the No. 1 thermocouple and the data of the No. 2 thermocouple are recorded simultaneously, corresponding to the measurement moment, the temperature at which the fixed carbon in the test sample begins to burn (i.e., the fuel begins to burn steadily) can

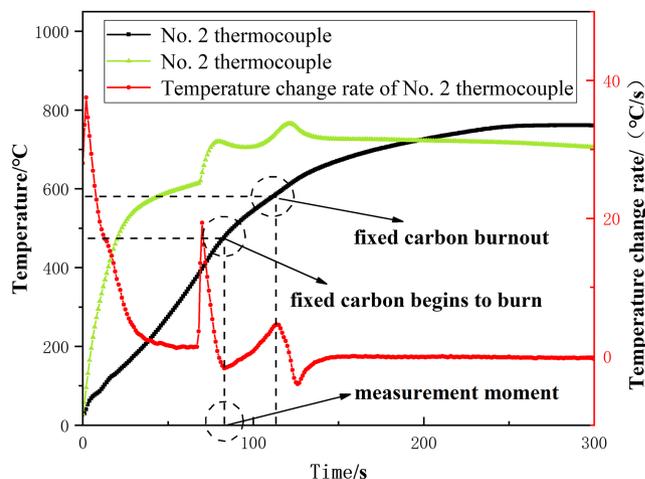


FIGURE 3 Measurement results of a certain fuel



be obtained from the temperature and time data of the No. 1 thermocouple.

It should be noted that the position of the thermocouple is related to the accuracy of the measurement results. When the crucible filled with the test sample is put into the muffle furnace to start the test, the temperature distribution of the test sample at different depths is not consistent due to heat conduction. The depth of free diffusion of air in the muffle furnace is limited, the lower part of the test sample in the crucible is insufficient contact with the air, so it will not burn. The sudden changes of the No. 2 thermocouple temperature are the result of the combined action of the muffle furnace radiation and the surface combustion of the test sample. When the No. 2 thermocouple response shows that the fixed carbon on the sample surface is starting to burn, the temperature of the lower part sample is lower to ignite the fixed carbon. Therefore, the temperature of the sample surface, measured by No.1, is the target that needs to be monitored. The No. 1 thermocouple should be as close as possible to the interface between the test sample and the air. Only in this way, the influence of heat conduction on the measurement results can be reduced maximumly to ensure that the actual measured No. 1 thermocouple temperature is comparable with the sample surface temperature. At the same time, it should be ensured that the No. 1 thermocouple is completely covered by the test sample; otherwise, the No. 1 thermocouple temperature probe will be affected by thermal radiation, resulting in a large deviation from the actual temperature of the test sample surface. Since the oxygen concentration in the muffle furnace cannot support the violent combustion of some low-volatile fuels, only a very weak flame can be seen during the test. Therefore, the No. 2 thermocouple should be as close as possible to the interface between the test sample and the air, but not in contact with the test sample, so that the temperature change caused by the weak flame can be collected.

4 | MEASURING STEPS

The measurement steps are shown in Figure 4.

To make the No. 1 thermocouple more convenient to arrange on the sample surface, the test samples selected in this paper are powders, the sample particle size ranges from 75 to 250 μm , and the median particle size is 150 μm . The sample mass for each measurement is 3.0 g.

The preset temperature of the muffle furnace is positively related to the heating rate of the test sample, and the heating rate directly affects the releasing rate of volatile and the ignition rate of fixed carbon in the test sample.^{12,13} The stable combustion temperature of

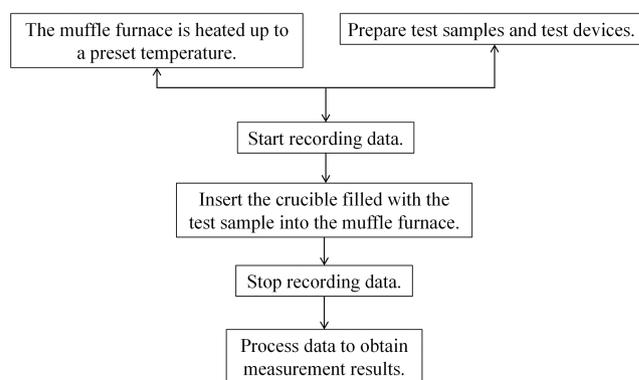


FIGURE 4 Measuring steps

high-volatile fuel is low, if the heating rate is too fast, the thermocouple cannot respond to the temperature change of the fuel in time, which will lead to deviation in the measurement results. Therefore, for test samples with high volatile content, the preset temperature of the muffle furnace should be appropriately reduced. However, the preset temperature cannot be too low; otherwise, the sample may be completely ashed before reaching the stable combustion temperature, and no combustion will occur. The stable combustion temperature of low-volatile fuel is high, so it is necessary to avoid an excessively low heating rate that will cause the surface of the test sample to be slowly and completely ashed other than burned, thereby failing to obtain accurate measurement results. Therefore, for test samples with low volatile content, the preset temperature of the muffle furnace should be appropriately increased. After repeated tests, it is determined that when the test sample is a high-volatile fuel, the preset temperature range is 650–800°C; when the test sample is a low-volatile fuel, the preset temperature range is 700–850°C. High-volatile fuels are defined as fuels with a volatile content of more than 30% as the dry ash-free base.

After the fixed carbon on the surface of the test sample is completely burnt, the temperature of the No. 2 thermocouple will not change much. After the temperature remains unchanged for a preset time, it can be determined that the combustibles on the sample surface have been completely burnt, the measurement time has passed, all the required measurement data have been obtained, and the data recording can be stopped at this time. The above-mentioned preset duration of time can be selected in the range of 200–300 s.

5 | TEST SAMPLES

Three typical fuels, coal, biomass, and petroleum coke, were selected as test samples. Due to the small difference



in the proportion of volatile components of different types of biomasses, rice husk was selected as the representative of biomass fuel in this paper. The proximate analysis and ultimate analysis data of the test samples are shown in Table 1.

6 | RESULTS AND DISCUSSION

All test samples were tested under three different preset temperature conditions, listed in Table 2. The characteristics of the measurement result curves of the test samples with different volatile content are different. To better describe the measurement results, the test samples are divided into low-volatile content fuels and high-volatile content fuels, the results are discussed, respectively. All the temperature change rates in the paper refer to the temperature change rate of the No. 2 thermocouple.

6.1 | Low-volatile fuels

Figures 5–7 show the measurement results of petroleum coke, No. 1 coal, and No. 2 coal under different preset temperature conditions, respectively. No. 1 Thermocouple was covered by the test sample, while No. 2 thermocouple was exposed to the air atmosphere. Due to the existence of conduction thermal resistance, the temperature of the No. 1 thermocouple was always lower than that of the No. 2 thermocouple in the early stage of the test. In the later stage of the test, the temperature of the No. 1 thermocouple will exceed that of the No. 2 thermocouple. This is because the fuel on the sample surface was completely burnt after contacting with the air, once the combustion flame disappeared, and the temperature of the No. 2 thermocouple gradually approached the preset temperature of the muffle furnace.

But, at this time, the test sample at the crucible bottom is still in the process of slow ashing, and the heat released during this process makes the temperature of the No. 1 thermocouple continue to rise, and finally exceeds the temperature of the No. 2 thermocouple. After the test sample at the crucible bottom is completely ashed, the temperature of the No. 1 thermocouple also gradually tends to the preset temperature of the muffle furnace.

There are two peaks on the temperature rate curve of the No. 2 thermocouple. Taking Figure 5a as an example, the first peak is due to the fact that after the thermocouple was transferred from the room temperature environment to the high-temperature environment of the muffle furnace, the thermocouple probe sensed the high-temperature environment, and the temperature change rate increased rapidly from 0. Then, as the temperature difference between the probe temperature of the No. 2 thermocouple and the preset temperature of the muffle furnace becomes smaller and smaller, the temperature difference of convective heat transfer decreases, and the temperature change rate of the No. 2 thermocouple gradually decreases. When the No. 2 thermocouple is close to the preset temperature of

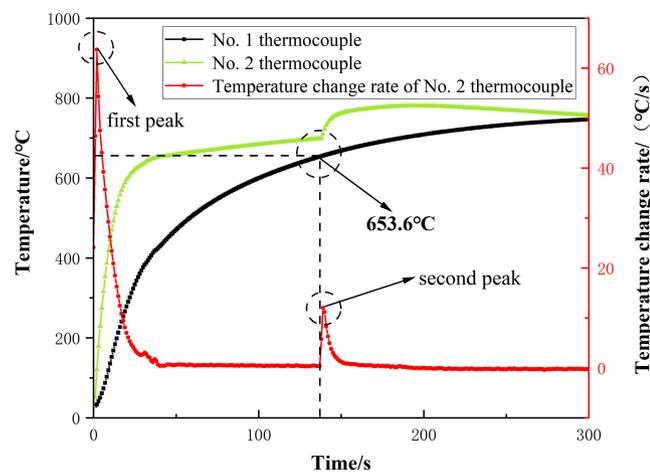
TABLE 2 Test conditions

Sample name	Preset temperature/°C
No. 1 coal	750/800/850
No. 2 coal	700/750/800
No. 3 coal	700/750/800
No. 4 coal	700/750/800
No. 5 coal	700/750/800
No. 6 coal	700/750/800
Petroleum coke	650/700/750
Rice husk	700/750/800

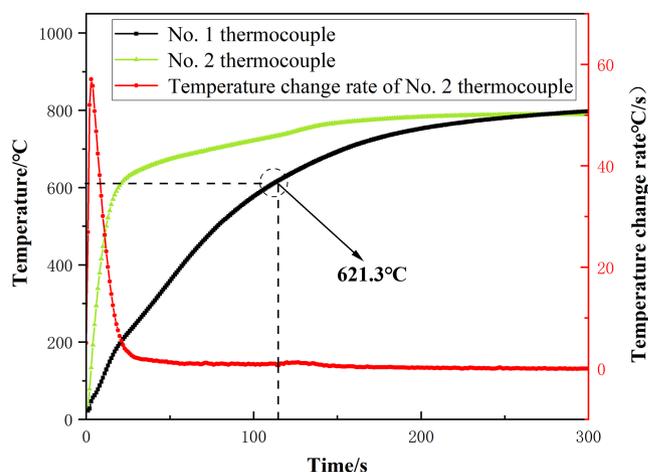
TABLE 1 Proximate analysis and ultimate analysis of test samples

Sample name	Proximate analysis (%)			Ultimate analysis (%)					(MJ/kg) Q _{net, ar}
	M _{ar}	A _{ar}	V _{daf}	C _{ar}	H _{ar}	O _{ar}	N _{ar}	S _{ar}	
No. 1 coal	5.44	46.34	14.05	43.57	1.19	1.90	0.76	0.81	15.74
No. 2 coal	2.15	49.37	21.38	40.60	2.17	0.33	0.70	4.84	16.44
No. 3 coal	1.43	36.81	33.29	55.78	4.03	0.63	0.65	0.68	23.03
No. 4 coal	5.42	31.89	36.42	49.76	3.50	8.67	0.94	0.49	19.45
No. 5 coal	5.40	40.80	39.44	46.39	3.29	2.11	0.99	1.02	18.86
No. 6 coal	16.01	14.98	44.87	52.24	3.80	11.75	0.89	0.33	19.98
Petroleum coke	0.35	0.92	10.36	85.92	2.94	1.79	0.72	7.32	32.75
Rice husk	6.00	16.92	67.44	30.02	4.41	25.80	0.99	0.06	11.76

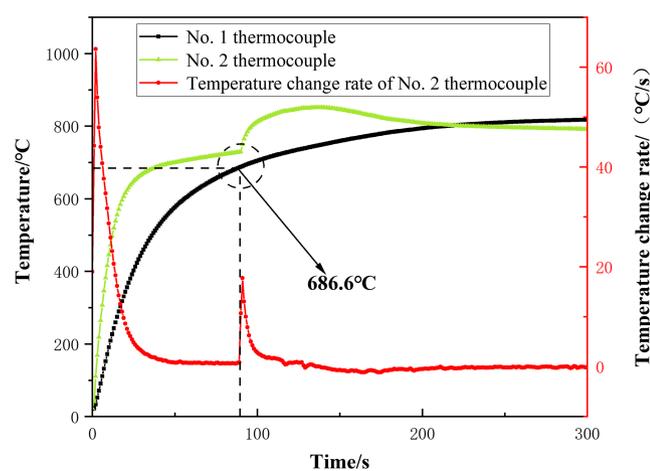
Note: Subscript “ar” means received base; subscript “daf” means dry ash-free base; “Q_{net, ar}” means a low calorific value as the received base.



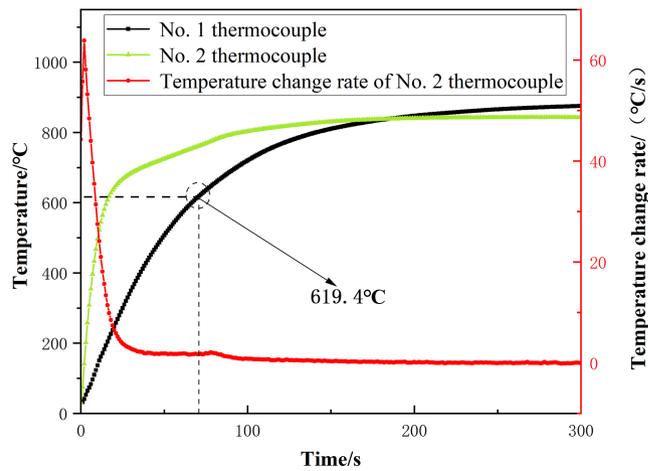
(a) 700°C



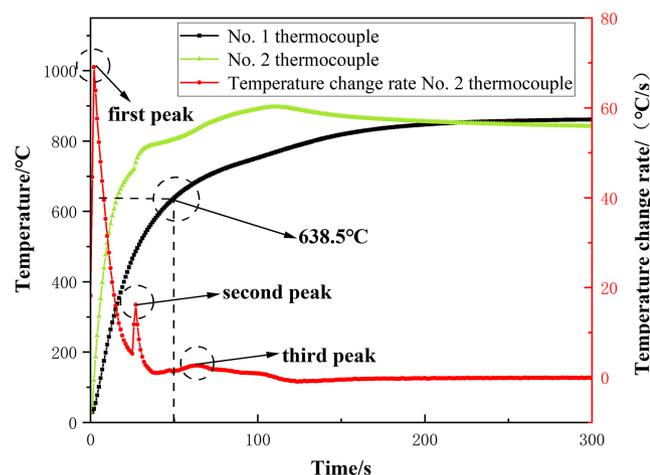
(a) 750°C



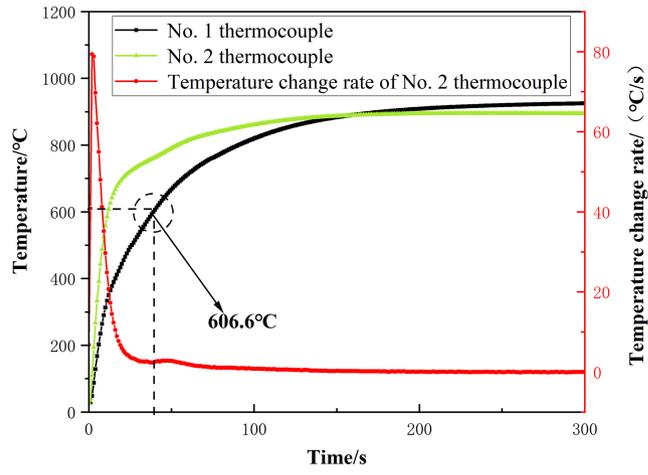
(b) 750°C



(b) 800°C



(c) 800°C



(c) 850°C

FIGURE 5 Measurement results of petroleum coke

the muffle furnace, the temperature change rate of the No. 2 thermocouple also tends to 0 because the convection heat transfer temperature difference is almost zero. The second peak is caused by the combustion of fixed

FIGURE 6 Measurement results of No. 1 coal

carbon on the sample surface. The flame generated by the combustion causes the temperature of the No. 2 thermocouple to rise suddenly, and the temperature change rate also increases. After the flame

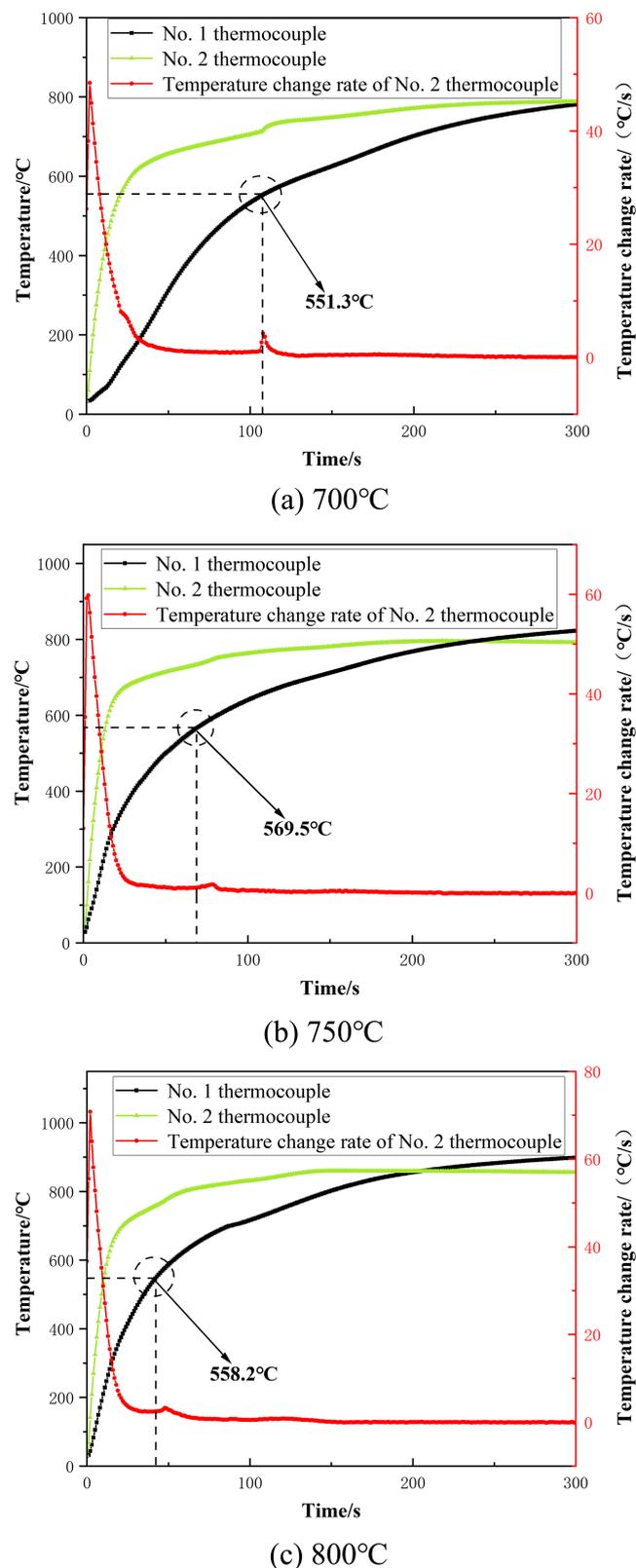


FIGURE 7 Measurement results of No. 2 coal

disappears, the temperature change rate gradually decreases after the fixed carbon burns completely.

For petroleum coke, shown in Figure 5, and coal shown in Figures 6 and 7, the second peak in the rate of

temperature change exhibits different characteristics. Petroleum coke is a by-product produced in the process of refining light oil. It has the characteristics of low volatile content, low ash content, and high fixed carbon content. Compared with low-volatile coal, it has larger porosity and specific surface area, which is more conducive to the combustion process.¹⁴ Taking the petroleum coke sample used in this experiment as an example, its specific surface area is 12 m²/g, which is larger than that of low-volatile coal of the same particle size. Therefore, although the proportion of volatile as the dry ash-free base of petroleum coke is lower than that of No. 1 and No. 2 coals, the combustion is more intense than that of No. 1 and No. 2 coals. During the test, it was found that No. 1 and No. 2 coals only had a weak blue flame when burning, while the petroleum coke showed a clear yellow flame when burning, and the flame length was longer. This also explains why the second peak of the temperature change rate is more obvious than that of No. 1 and No. 2 coals. Comparing Figures 6 and 7, it can be seen that the second peak of the temperature change rate in the measurement results of No. 2 coal is more obvious than that of No. 1 coal under the same preset temperature conditions. This is because No. 2 coal has higher volatile and is easier to burn.

As shown in Figure 5c, When the preset temperature is 800°C, in the measurement results of petroleum coke, three peaks appear in the temperature change rate curve. The first peak is caused by the thermocouple responding to the change of external environment temperature, the second peak is caused by the combustion of volatile, and the third peak is caused by the combustion of fixed carbon. The amount of volatile released is positively correlated with the heating rate of the test sample,¹⁵ and the volatile combustion flame will not appear until the volatile concentration reaches a certain level. The proportion of volatile in petroleum coke is relatively low, and only when the heating rate is fast enough, the concentration of the released volatile meet the conditions for a combustion flame to appear. Compared with 700°C and 750°C, the volatile released by petroleum coke at a preset temperature of 800°C is higher, and the combustion of volatiles leads to an increase in the temperature change rate, which makes the second peak appear in the temperature change rate curve. At 700°C and 750°C, as shown in Figure 5a,b, the releasing of volatiles is low, and the volatiles combustion is not obvious, so there are only two peaks in the temperature change rate curve. At 800°C, in the measurement results of No. 1 and No. 2 coals, as shown in Figures 6c and 7c, there are also only two peaks in the temperature change rate curve. This is because the source of petroleum coke determines that the combustible component of petroleum coke volatile is relatively

high. However, the combustible components in the volatile of No. 1 and No. 2 coals are relatively low, so the volatile combustion of No. 1 and No. 2 coals is not obvious.

6.2 | High-volatile fuels

The measurement results of high-volatile fuel are shown in Figures 8–12.

Figures 8–12 show the measurement results of No. 3 coal, No. 4 coal, No. 5 coal, No. 6 coal, and rice husk, respectively. It can be seen that there are 3 or more peaks on the temperature change rate curve of the No. 2 thermocouple when measuring high-volatile fuels. Taking Figure 12a as an example. The first peak is also caused by the change of the external environment temperature induced by the thermocouple, the last peak is caused by the combustion of the fixed carbon on the sample surface, and all other peaks in the middle are caused by the combustion of the volatile in the test sample. Due to the high-volatile components in fuels, the combustion of volatile components is strong, so the peaks in the middle are more obvious. Some fuels have more than one peak in the middle because the volatile release and ignition are carried out in a certain temperature range, and not all are released at a certain temperature. When the temperature range of volatile release and ignition is narrow, the process from volatile release to complete volatile release and combustion will be completed in a very short time, and only one peak will appear on the temperature change rate curve; otherwise, when the temperature range of volatile release and ignition is wide, volatiles will be released in stages, and volatile combustion will also be carried out in stages, and there will be multiple peaks on the temperature change rate curve.

It should be emphasized that the last rising stage on the temperature change rate curve of the No. 2 thermocouple does not completely represent the combustion of fixed carbon on the sample surface, and it needs to be further judged according to whether there is a falling stage of the temperature change rate. For example, in Figure 11c, after the last rising phase on the temperature change rate curve, there will be a falling phase, in this case, it can be considered that this rising phase is caused by the combustion of fixed carbon on the sample surface, on the contrary, as shown in Figure 12c, after the last rising phase on the temperature change rate curve, there is no falling phase. If the rising phase is caused by the combustion of the fixed carbon on the sample surface, when the fixed carbon on the sample surface is completely burned, the effect of the combustion flame is suddenly lost, and there must be a falling phase of the temperature change rate. In Figure 12c, before the last

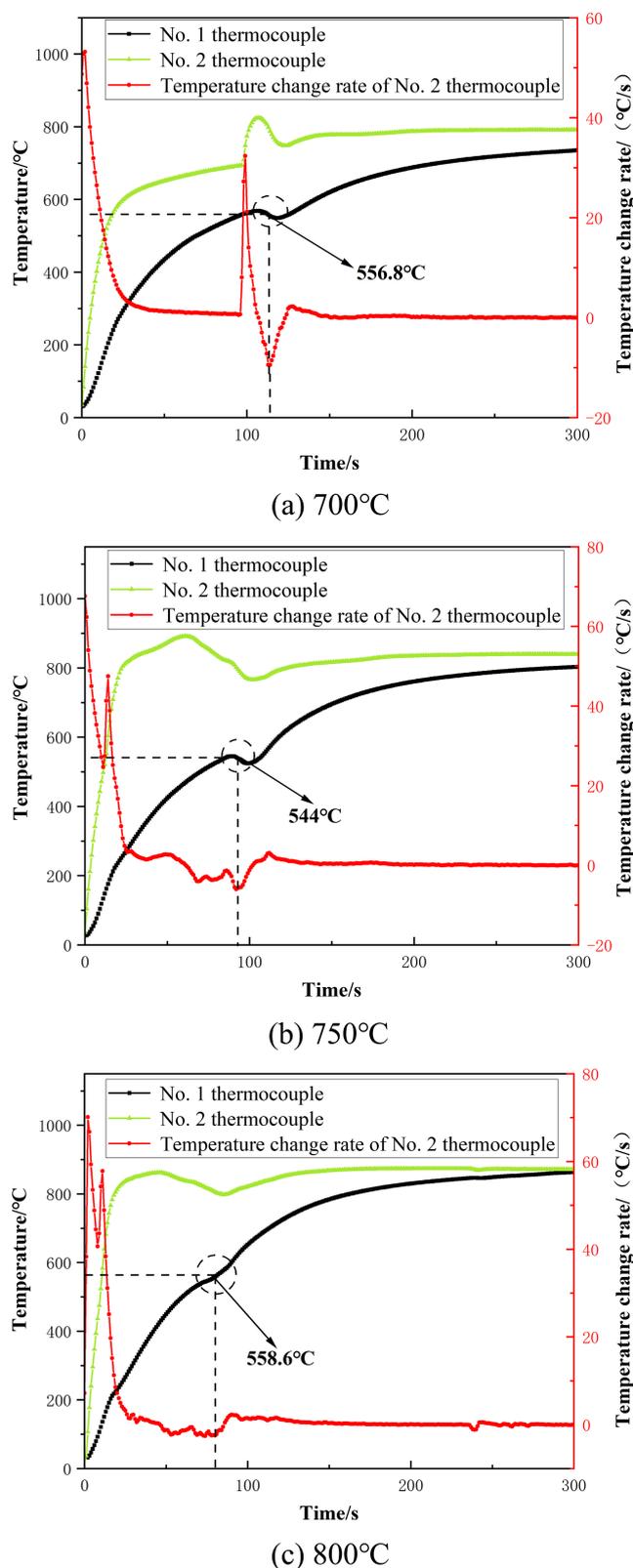
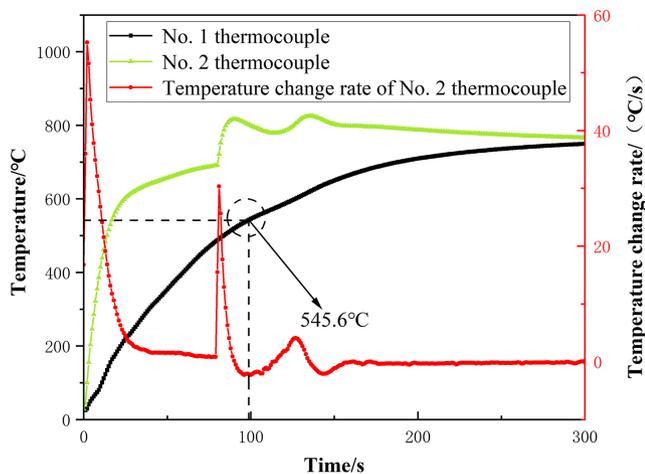
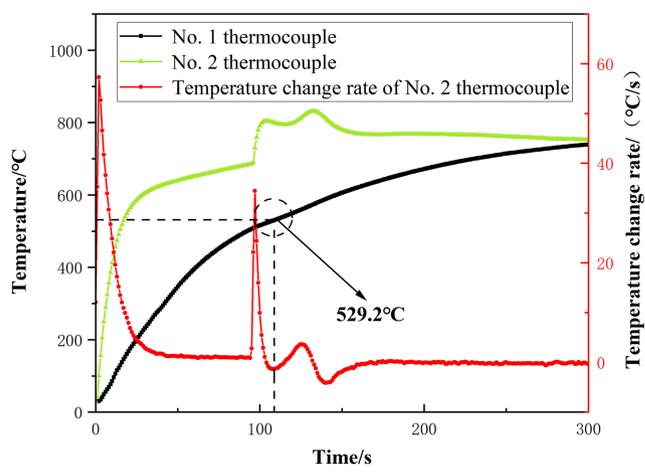


FIGURE 8 Measurement results of No. 3 coal

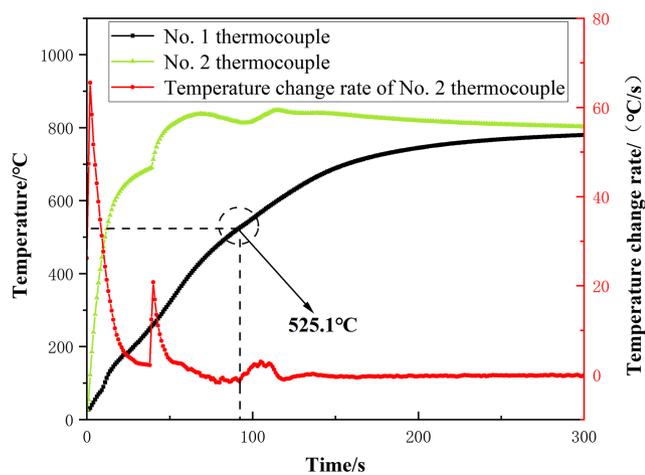
temperature change rate rising stage begins, due to the burning flame, the temperature of the No. 2 thermocouple is already greater than the preset



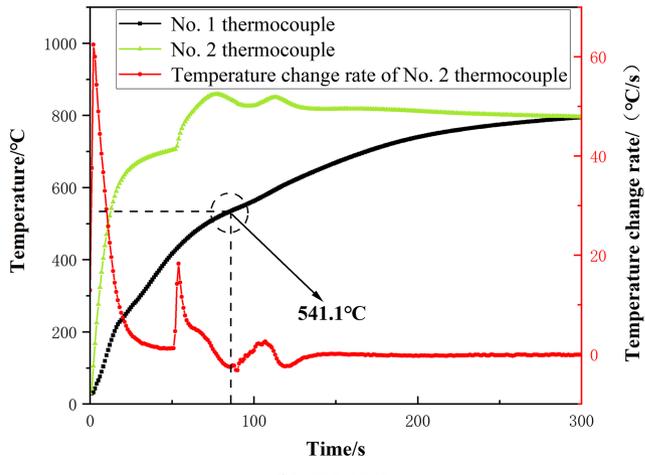
(a) 700°C



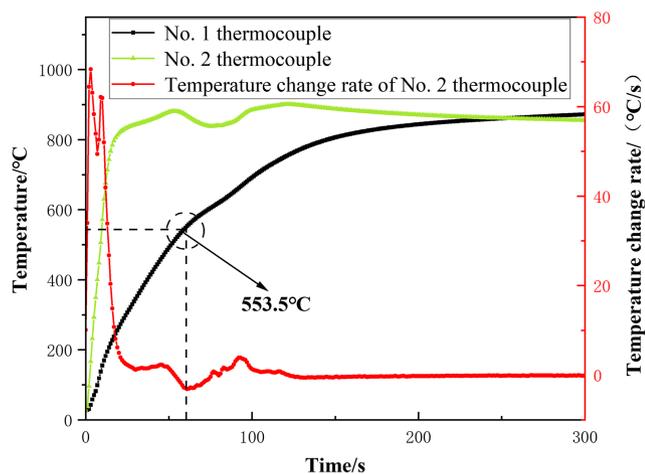
(a) 700°C



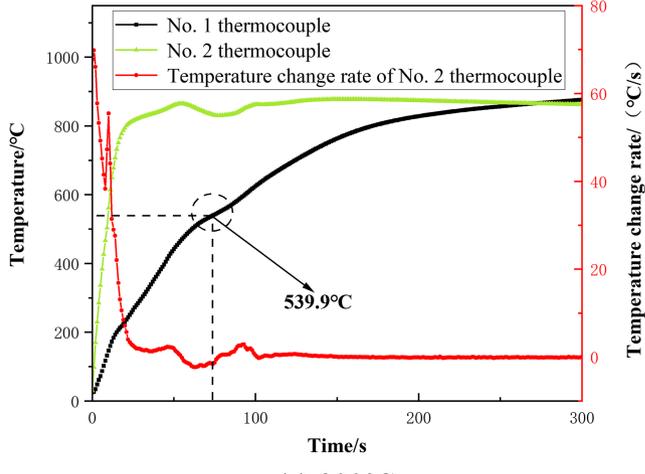
(b) 750°C



(b) 750°C



(c) 800°C



(c) 800°C

FIGURE 9 Measurement results of No. 4 coal

FIGURE 10 Measurement results of No. 5 coal

temperature of the muffle furnace, and the last temperature change rate rising stage is only a process in which the temperature of the No. 2 thermocouple gradually approaches the preset temperature of the muffle furnace.

6.3 | Comparison of different methods

To verify the accuracy of the measuring method, combined with the relevant data in the literature,^{16–19} the

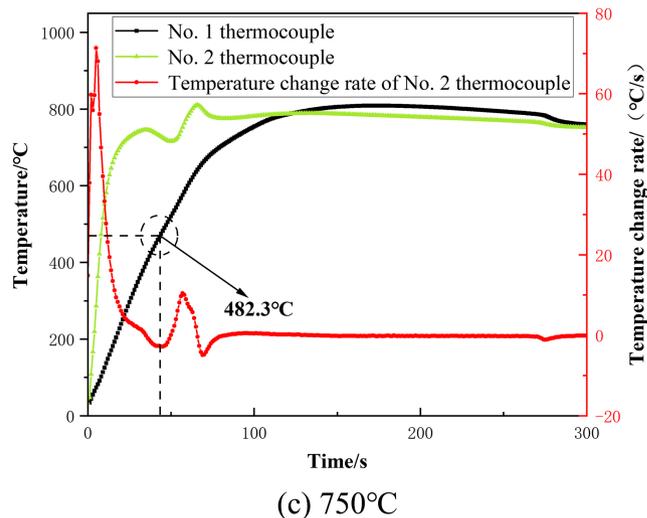
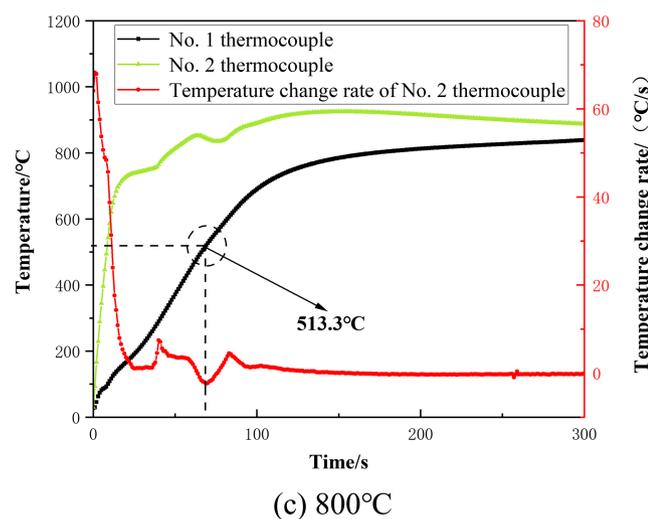
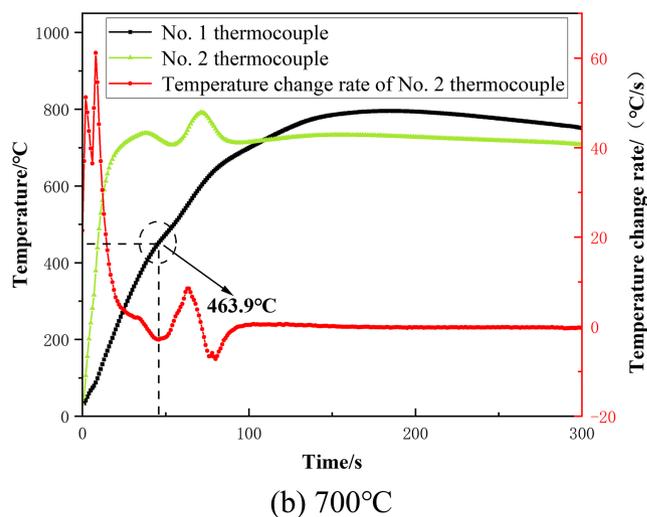
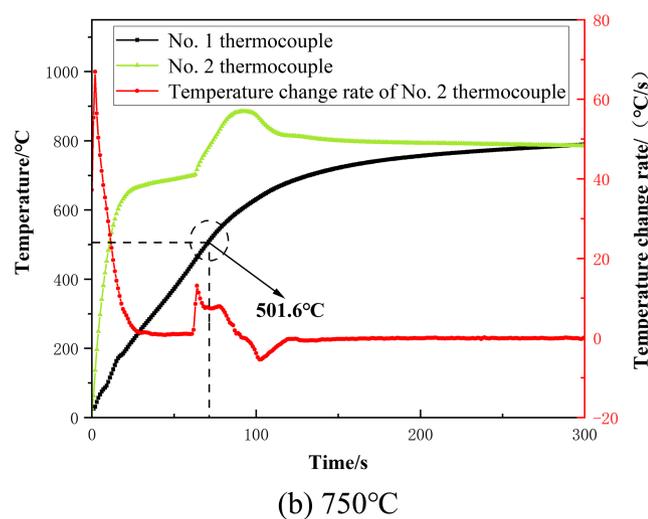
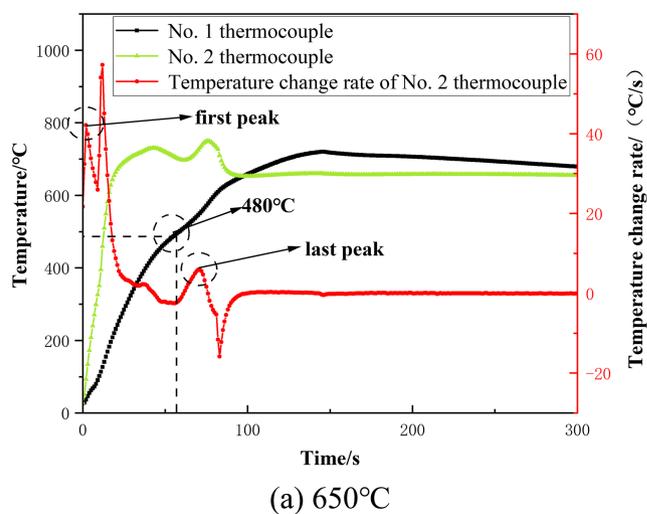
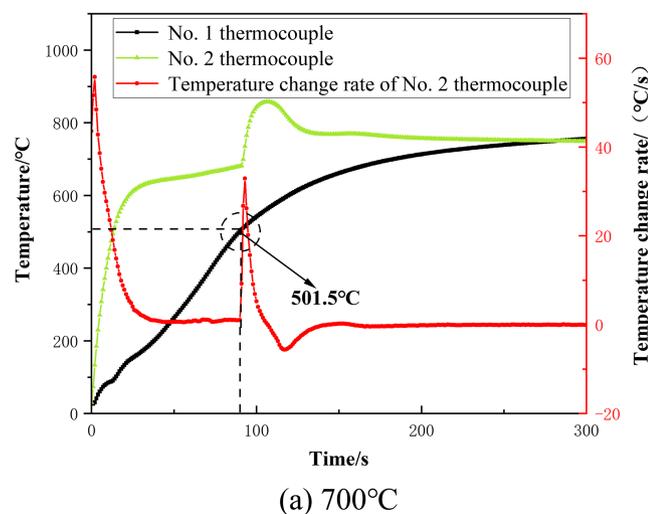


FIGURE 11 Measurement results of No. 6 coal

FIGURE 12 Measurement results of rice husks

measurement data as the average of three repeated measuring are compared with those measured by traditional methods for CFB boiler fuel feeding temperature. The comparison result is shown in Figure 13.

It is generally believed that the result measured by the on-site commissioning method is the CFB boiler fuel feeding temperature. Therefore, the measurement results of this method are used as a benchmark to analyze the

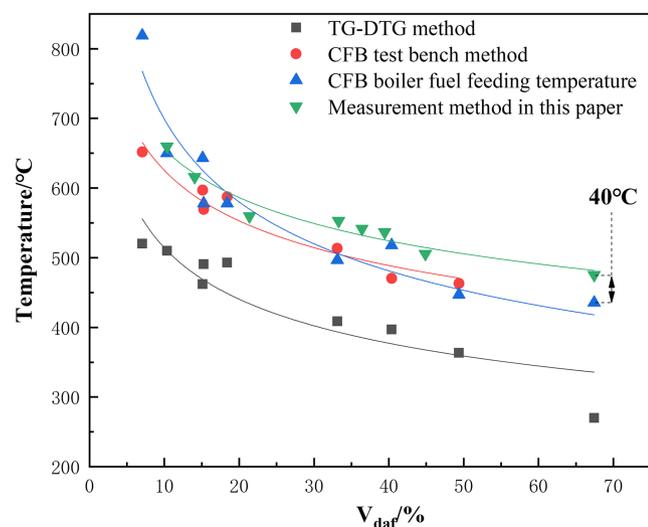


FIGURE 13 Comparison of measurement results of various methods. “ V_{daf} ” means the volatile fraction of dry ash-free base

accuracy of other measurement methods. It can be seen from Figure 13 that only the results measured by the TG-DTG method are quite different from the actual fuel feeding temperature. The results obtained by other methods, including the measurement method designed in this paper, are close to the CFB boiler fuel feeding temperature. The TG-DTG method measurement result is essentially the ignition temperature of the fuel, which is the minimum temperature condition for fuel combustion, but the determination of the fuel feeding temperature not only needs to ensure that the fuel can be burned, but also needs to consider the effect of heat exchange in the CFB furnace on the combustion. Thus, during the start-up of a CFB boiler, the feed temperature is often greater than the ignition temperature of the fuel. For fuels with low volatile content and high carbon content, due to their high ignition temperature, the power plant generally adopts a relatively conservative principle, so the actual fuel feeding temperature is significantly higher than the results obtained by the test bench.¹⁶

The determination of the actual CFB boiler feeding fuel temperature takes into account the bed material heated by the combustion of volatiles, the furnace temperature is still lower than the fixed carbon burning temperature when the fuel is fed into the furnace, and the heat released by the combustion of volatile components will make the furnace temperature quickly reach the temperature conditions required for the combustion of fixed carbon, thereby ensuring the stable combustion of the fuel. However, the measurement method designed in this paper cannot fully consider this effect. The heating effect of volatile combustion on the bed material increases with the increasing of volatile proportion in the

fuel. Therefore, for fuels with lower volatility, the results measured by the present paper have a small deviation from the actual CFB boiler fuel feeding temperature. With the increase of the volatile proportion of the fuel, the deviation between the results measured in this paper and the actual CFB boiler fuel feeding temperature shows an increasing trend, and the former is always greater than the latter. However, taking rice husks as an example, the difference between the results measured by the measurement method designed in this paper and the actual CFB boiler fuel feeding temperature is only 40°C, which is negligible in the actual CFB boiler operation. Therefore, the measurement method designed in this paper can accurately measure CFB boiler fuel feeding temperature.

7 | CONCLUSIONS

The traditional method of measuring the fuel feeding temperature of different fuels in the CFB boiler cannot take into account the measurement accuracy and measurement cost at the same time, and it is difficult to popularize and use in the industry.

In this paper, a simple and accurate method for measuring the fuel feeding temperature of the CFB boiler is designed. The temperature at which the fixed carbon in the fuel starts to ignite is taken as the CFB boiler fuel feeding temperature.

Using the method designed in this paper, measurements were carried out on six different volatile content ratios of coal, rice husk, and petroleum coke at three different preset temperature conditions. The measurement results show that for the fuel with low volatile content, the difference between the results measured by the present paper and the actual CFB boiler fuel feeding temperature is very small; for fuels with higher volatile content, the difference is slightly larger, but the maximum difference is only 40°C. It is confirmed that the measurement method designed in this paper can accurately measure the fuel feeding temperature of the CFB boiler.

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REFERENCES

- Guangxi Y, Junfu L, Peng X, et al. The up-to-date development and future of circulating fluidized bed combustion technology. *China Electric Power*. 2016;49:1-13.



2. Yuansheng H, Mengshu S, Chen Z. What are the resource benefits of circulating fluidized bed power generation technology? Take some key thermal power units in China as an example. *Int J Energ Res*. 2020;44(6):4687-4702. doi:10.1002/er.5251
3. Hwang IS, Jeong HJ, Hwang J. Effects of vortex finder length on flow field and collection efficiency of cyclone in an industrial-scale circulating fluidized bed boiler: numerical study. *Int J Energ Res*. 2020;44(9):7229-7241. doi:10.1002/er.5430
4. Wenbin H, Hairui Y, Junfu L, Guangxi Y, Jiansheng Zhang. Study on ignition properties of coals by using thermogravimetry. *Power Station System Eng*. 2005;2:8-9+12.
5. Hairui Y, Lei X, Yuanxiong G, Junfu L, Guangxi Y. Ignition characteristics of coal in CFB boiler. *Combustion Sci and Technol*. 2005;3:236-240.
6. Lei X, Hairui Y, Guangxi Y, Yidao J, Jiling L, Rushan B. Ignition characteristic of coal in fluidized bed boiler. *Coal Transformation*. 2004;2:51-53.
7. Qiumei Y, Yajun P, Hongguo C. Discussion on the determination method of ignition point in coal combustion test. *North China Electric Power Technol*. 2001;7:9-10+50.
8. Xiaojie Z, Qihong N, Shaozeng S, et al. Experimental study on ignition of coal blends. *Power Plant System Eng*. 1999;6:41-44.
9. Baiqian L, Wenxue G. Study of coal particle ignition in fluidized bed combustor. *J North China Electr Power Univ*. 1996;3:47-50.
10. Hao L, Jidong L, Zhijie L, Lidan Y. Study on ignition of lignite in fluidized bed. *J Huazhong Univ of Sci and Technol*. 1995;4:120-123.
11. Baxter LL, Mitchell RE, Fletcher TH, Hurt RH. Nitrogen release during coal combustion. *Energ Fuel*. 1996;1(1):188-196. doi:10.1021/ef9500797
12. Jingying Z, Bo F, Chuguang Z. Ignition and combustion stability of pulverized coals. *Coal Transformation*. 1997;3:63-68.
13. Wen L, Baoqing L. Study on the combustion property of coal char using thermogravimetry. *Coal Conversion*. 1996;3:76-81.
14. Yong L, Junfu L, Jiansheng Z, et al. Reactivity measurement and combustion experiments on CFB rig for petroleum coke. *Combustion Sci and Technol*. 2001;1:81-84.
15. Yingchun L. *Research on the synergistic mechanism and optimization of coal blending and tobacco rod co-firing under oxygen enrichment*. Kunming University of Sci and Technol; 2021.
16. Chunmei L, Lizhen W, Yanling S, Shiqing C. Determination of coal ignition temperature and flammability index by thermogravimetric method. *Shandong Electric Power Technol*. 1994;2:68-71.
17. Zhiwei W, Chaoyang Z. Experimental research of igniting characteristics in circulating fluidized bed. *Combustion Sci and Technol*. 2002;5:468-471.
18. Chuangqi S, Mudi T, Lirong L. Experimental study on the combustion characteristics of petroleum coke and coal. *Guangdong Chem Ind*. 2017;44:41-42.
19. Yuren F. *Experimental and kinetics study on combustion characteristics of biomass and coal*. Yanshan University; 2020.

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