Study on Test Method of Energy-saving Performance for Coal additives in Slime

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Abstract. Adding coal additives in civil water heating coal furnace can effectively reduce coal consumption and has great economic benefits, but there is no standard method for testing energy-saving performance of coal additives in slime. Referring to GB/T 16155-2018 "Test Method for Performance of Civil Water Heating Coal Furnace", this paper developed a measuring device for energy-saving performance of coal additives, and proposes a detection method based on the temperature of effluent and backwater as a measuring scale for heating capacity of slime combustion. The experimental results show that the energy-saving effect of coal additives on clean briquette is not obvious when it is sprayed on clean briquette and burned by dry clean briquette, while in wet mixed combustion, the cumulative heat of slime with coal additives increases by up to 50% compared with that of ordinary slime.

1. Introduction

In 2016, about 3 billion people around the world use solid fuels such as wood, rice straw and coal as their main energy sources for cooking and heating, while coal is the main energy source in China [1]. In order to improve the energy consumption and high pollution of civil water heating coal furnace, the use of sulphur fixing agents, energy saving agents to improve combustion efficiency, improve energy efficiency, energy saving and emission reduction has become an important development direction for the scientific and environmental protection of coal combustion in the conventional field [2]. In view of the variety of coal additives, it is necessary to test their energy-saving performance. At present, the testing methods of coal additives are all based on the testing standards of civil furnaces. Most of the methods used the principle of boiling water temperature measurement [3-5]. There is no standard method for testing the energy-saving performance of coal additives in slime.

GB/T 16155-2018 "Test Method for Performance of Civil Water Heating Coal Furnace" [6] prescribes the test method for thermal performance of civil coal-fired heating furnace. The test system consists of thermometer, inlet and outlet pipeline, switch valve, throttle valve and coal-fired furnace. The test method stipulates that the furnace should be in full load combustion state. The testing process has the characteristics of high combustion temperature, fast combustion speed, large temperature difference between inlet and outlet water (about 55 °C) and fast heat transfer. This method can be used to test the thermal efficiency of civil heating furnaces, but it cannot detect the heating capacity of furnaces used slime at start burning. The reason is that the slime burns slowly, the strength decreases, the time prolongs, and the outlet water temperature reaches 75~80°C for a long time. Especially, it
takes a long time for the coal furnace to heat the fresh room temperature water to 75~80°C after the start of the water discharge, and it still heats the normal temperature water to the 75~80°C hot water accumulatively within 90 minutes. It is obvious that water measurement cannot completely measure the actual heating capacity of coal stove, or even cannot carry out continuous combustion test.

For this reason, this paper presents a test method for coal-saving performance of coal additives based on GB/T 16155-2018 "Test Method for Performance of Civil Water Heating Coal Furnace", and builds a parallel experimental platform to verify the coal-saving effect of coal additives through combustion heat transfer effect.

2. Experimental device and test method

2.1. Experimental Device

The energy-saving efficiency of coal additives is usually measured by 24-hour combustion cycle. If a coal stove is used, the heating quantity is measured by two ways, ordinary coal-burning and coal-burning with coal additives, according to their respective suitable methods. In view of the long operation cycle and large process error, the scientific and accurate detection data cannot be guaranteed. For this reason, a test-bed for the performance of combustion-supporting agent is built as shown in Figure 1. The test device is a computer-centered left and right symmetrical two test loops (a and b), which are connected with the coal stove respectively. In each test loop, there are outlet water thermometer, circulating water pump, heat exchanger, backwater thermometer and flowmeter. In addition, a thermometer used to measure the furnace temperature is installed on the body of coal stove.

The detection device has a computer control system, including data acquisition module and data processing module for processing data collected by data acquisition module. The data acquisition module is connected with two test circuit outlet thermometers, backwater thermometers and flowmeters to realize data acquisition and recording. The measuring accuracy of the measuring instruments used in the experimental device is shown in Table 1.

![Figure 1. Schematic diagram of combustion-supporting agent performance test device](image)

Table 1. Parameter accuracy of measuring instruments for test devices

| Name of parameter | temperature | Instantaneous flow rate | Cumulative flow rate | Accumulated heat |
|-------------------|-------------|-------------------------|----------------------|-----------------|
| Indexing value    | 0.1°C       | 0.001L/s                | 0.001L/s             | 0.1kcal         |

1. coal stove a, 2. water outlet pipe a, 3. water outlet thermometer a, 4. circulating water pump a, 5. heat exchanger a, 6. backwater thermometer a, 7. flowmeter a, 8. water tank a, 9. chimney a, 10. backwater pipe a, 11. furnace temperature thermometer a, 12. coal stove b, 13. water outlet b, 14. water outlet thermometer b, 15. circulating water pump b, 16. heat transfer Exchanger b, 17. backwater thermometer b, 18. flowmeter b, 19. water tank b, 20. chimney b, 21. backwater pipe b, 22. furnace temperature thermometer b, 23. computer
2.2. Testing Method
The temperature measured by the outlet water thermometer is the outlet water temperature of the coal furnace, and the temperature measured by the backwater thermometer is the inlet water temperature of the coal furnace. The circulating water is cooled by heat exchanger, and the instantaneous flow rate and cumulative flow rate of the circulating water are detected by the flowmeter. The relationship curves of test time, circulating water temperature and flow rate are drawn in real time. Timely detection and collection of all heating data of water-heated coal stove ensures that the heat supply can be collected, recorded and calculated in time at low temperature and smoldering state. By comparing the test data on both sides of adding coal additives and not adding coal additives, the energy-saving efficiency test of coal additives can be realized.

In the way of using coal additives and coal mixed combustion, it is divided into dry mixed combustion and wet mixed combustion. Dry mixed combustion is the direct mixing of solid coal additives and coal. The liquid coal additives can be sprayed onto the surface of coal, and then burned in accordance with the normal natural dry combustion mode of the coal stove. Wet mixed combustion is a kind of wet combustion in which coal additives are mixed with water and coal to form slime, which is added to the coal furnace.

The specific test methods of wet mixed combustion are as follows:
1) Set the flow rate of the flowmeter from 0.2 ~ 5m³/h, and the data acquisition frequency is 1 time/s.
2) Clean briquette is mixed with coal additives. The water solution of coal additives is composed of 1:50, 1:80 and 1:100 mass ratios of coal additives and water, respectively.
3) When the effluent temperature reaches a certain temperature, such as 50~60℃, a certain amount of slime is added to the furnace to carry out the smoldering test. When the difference between the effluent thermometer and the backwater thermometer is less than 2~3℃, it means that the external heating capacity of the coal furnace tends to be exhausted, and the combustion process has entered the tail stage, or the effluent temperature is less than 33℃. The furnace cannot heat water.

Accumulated heat can be calculated according to formula 1.

\[ Q = \int_{\tau_1}^{\tau_2} 10^{-3}C \times \rho \times q_v \times (t_i - t_o) d\tau \]  

where, \( Q \) is cumulative heat, kcal; \( C \) is specific heat, kcal/(kg. C); \( \rho \) is density, kg/m³; \( q_v \) is volume flow rate, L/s; \( t_i \) is water inlet temperature, ℃; \( t_o \) is backwater temperature, ℃; \( \tau_1 \) is starting time, s; \( \tau_2 \) is termination time, s.

3. Test results and analysis

3.1. Comparison of Dry Mixed Combustion with Direct Combustion of Raw Coal
The performance of the coal stove is tested in two loops a and b on the performance test device of coal additives, which is added in a loop and not added in b loop. Because they are all dry fuels, the test is performed according to GB/T 16155-2018. 1 kg clean briquette is added per hour, and the cumulative coal addition is 6 kg. The experimental results are shown in Table 2. From Table 2, it can be seen that when coal-fired stove uses dry mixed combustion of coal additives and briquette mixture, compared with briquette combustion test, the increase of heat supply data is not obvious. The main reason is that the volatilization of the effective components of the product is fast, and the combustion process of coal is not changed obviously, so it is difficult to reflect the energy-saving effect. Therefore, the use of coal additives must adopt wet mixed combustion mode.

Table 2. Comparison of experimental data of dry mixed combustion with direct combustion of coal

| Items                  | Unit | Dry Mixed Combustion | Direct Combustion of Coal |
|------------------------|------|-----------------------|----------------------------|
| Experimentation time   | h    | 5.5                   | 5                          |
| Water inlet temperature| ℃    | 47.5(low)             | 49.5(low)                  |
| Backwater temperature  | ℃    | 95.0(high)            | 87.1(high)                 |
|                        |      | 45.5(low)             | 46(low)                    |
3.2. Comparisons between Wet Mixed Combustion and Ordinary Slime Smoulder

In order to eliminate the difference of working conditions between coal furnaces, parallel tests of heating with or without coal additives were carried out in two water-heated coal furnaces. Contrast combustion test was carried out by two coal stoves used slime. Coal additives and slime was used in loop a and ordinary slime was used in loop b. The same primer of about 0.85 kg firewood, 4 kg of clean coal were used, and two coal stoves were started ignition at the same time. Adjust the two stoves to the same operating parameters (the circulating water flow rate is 0.2~0.3m³/h), and same combustion. The system is set to zero when the temperature of water supply collected by the test system is higher than 32℃. Then the heat supply is collected and recorded. The total amount of coal added should be no more than 7 kg. The experimental results are shown in Table 3. From Table 3, it can be seen that the combustion time of slime with coal additives is obviously prolonged by about 2 hours compared with that of ordinary slime, and the cumulative heat of coal additives is 50% higher than that of ordinary slime.

Table 3. Comparison of experimental data of wet mixed combustion and ordinary slime smoulder

| Items               | Unit | Wet Mixed Combustion | Ordinary slime smoulder |
|---------------------|------|-----------------------|-------------------------|
| Experimentation time| h    | 11.5                  | 9.5                     |
| Water inlet temperature | ℃   | 40.6(low)             | 42.0(low)               |
| Backwater temperature | ℃   | 48.9(high)            | 45.9(high)             |
| Cumulative flow     | L    | 2986                  | 2218                    |
| Accumulated heat    | Kcal | 10718                 | 7130                    |

4. Conclusion

1) A detection device and method were proposed for measurement energy-saving efficiency used coal additives in slime. The energy-saving efficiency of coal additives was tested by single-stage contrast test and double-stage parallel test using coal additives or not in coal stove.

2) Coal additives can promote the combustion of coal, improve the heating effect of civil heating coal stove and reduce coal consumption, but energy-saving effect of coal additives is not obvious in dry mixed combustion.

3) The experiment of wet mixed combustion with coal additives shows that the combustion time of slime with coal additives is obviously prolonged by about 2 hours than that of ordinary slime, and the cumulative heat of coal additives is 50% higher than that of ordinary slime.

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