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混煤燃烧特性研究

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STUDY ON COMBUSTION CHARACTERISTICS OF BLENDED COALS

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ABSTRACT: Power Plants in China have to burn blended coal instead of design coal，so it is necessary to investigate the combustion of blended coals. Using the test rig with a capacity of 640MJ/h with an absolute milling system and flue gas online analysis system, the characteristics of some blended coals, such as burning out, slagging and pollution were investigated. The ratio of coke and slag as a method to distinguish coal slagging characteristic was introduced. Some kinds of blending of coal have some effect on NO_x but there is no obvious rule. The emission of SO_x can be reduced to blend coal, especially for the low sulfur coal in this investigation.

KEY WORDS: Blended coals; Combustion characteristic; Slag; NO_x; SO_x

摘要：由于国内电厂大量燃用混煤，因此，从技术经济角度出发，对混煤燃烧特性进行研究具有很大的必要性。文中利用一个具有在线烟气成分分析的 640MJ/h 热试验台，进行了几种混煤的燃尽、结渣和污染特性试验。焦炭和渣的比例被引入以区分煤的结渣特性。NO_x 的释放没有特别明显的规律，但研究中发现几种低硫煤混合后，SO_x 释放有所减少。

关键词：混煤；燃烧特性；结渣；NO_x；SO_x

1 INTRODUCTION

Because of decrease of washing coal, shortage of transport capability and the policy of bad coal combustion in power plant in China, power plant can not burn one coal and have to burn blended coals. According to the reports of power plant of Water and Electricity Ministry, blending ratio of power plant is 44% in 1982. In 1987, Harbin Whole Set Equipment Research Institute found that most of power plants are very difficult to burn design coal when they investigate the basic instance of 428 main power plants. At present, blended combustion is very common, even the design coal of some power plants are blended coals.

However, the blended coal is not a simple mechanical process—only some kinds of coal were blended. Because the difference of fractional coal constitution and combustion characteristic, the combustion condition can not be satisfied at one time. This may be lead to combustion instability and low efficiency etc[1-8].

In this paper, the burnout, slag and NO_x, SO_x emission of blended coals have been researched in a semi-industrial combustion facility. The blended coals are composed of four brown coals, namely Huolinhe coal, Yangcaogou coal, Fengguang coal and Meihe coal, which are often used by Shuangliao Power Plant.

The characteristics of the four brown coals are shown in table 1. The blending ratio of blended coals is shown in table 2. The size of coal particles is limited to about R_{90}=35%.

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表 1 煤的元素分析
Tab.1 The characteristics of coals

Properties	Coal			
	Huolinhe	Yangcaogou	Fengguang	Meihe
V_{daf}/%	48.53	46.31	60.83	49.25
FC_{daf}/%	51.47	53.69	39.17	50.75
A_d/%	27.82	25.28	56.23	24.1
C_d/%	52.30	54.01	29.26	55.51
H_d/%	3.07	4.84	2.65	4.30
O_d/%	15.42	14.53	10.88	12.88
N_d/%	0.82	0.80	0.79	1.46
S_d/%	0.57	0.53	0.19	1.75
$Q_{d,net}$/ (kJ/kg)	15919	12388	9249	19819

表 2 混煤比例
Tab.2 The blending ratio

Blended coal No.	Single coal ratio/%			
	Huolinhe	Meihe	Fengguang	Yangcaogou
1#	80	20	0	0
2#	70	30	0	0
3#	80	0	20	0
4#	70	0	30	0
5#	80	0	0	20
6#	70	0	0	30
7#	60	20	10	10
8#	70	10	10	10
9#	0	40	30	30

2 EXPERIMENT

This investigation were done at Combustion Research Facility (CRF), which is introduced from Canada. It's designed for a maximum coal feed rate of 20 kg/h medium sulfur coal at a firing rate of 640 MJ/h (as shown in figure 1). It has functions of advanced control system, on-line measurement and record of experimental result.

The test rig consists of five parts, which are the combustion system, data acquisition and control system, compressing air and cooling system, the system of sampling and analysis of flue gas as well as milling system. The furnace is a refractory-lined cylindrical chamber, composed of four identical modules, the bottom three with cylindrical cooling jackets. The height is 3.6m, and the diameter is 0.3m. The furnace temperature is measured by platinum- rhodium thermocouple. The flue gas that leaving the furnace is continuously monitored by O_2, NO_x, CO_2, CO and SO_2 analyzers. The slag is got in the cooling drawer at the bottom of the furnace and the fly ash is sampled at the bottom of ESP. The coal feed rate is 20 kg/h.

3 RESULTS AND DISCUSSION

3.1 Burnout properties of brown-blended coals

In this investigation, the slag is got in the water-cooling drawer at the bottom of the furnace, the fly ash is sampled at the bottom of ESP. The coke adhered to furnace wall. The coke is scratched from wall after test. Also, the loss of solid unburnout from the furnace is used to judge the burnout properties of blended coals. Generally, the loss of solid unburnout q_l is calculated as follows

$$q_l = \frac{32825A_{ad}}{Q_r}\left(\frac{a_{fh}c_{fh}}{100-c_{fh}}+\frac{a_{lz}c_{lz}}{100-c_{lz}}\right)\% \qquad (1)$$

Where Q_r is heat quantity input to the furnace, kJ/kg; A_{ad} is the content on the air-dry basis; A_{fh} is the quota of fly ash in the amount of fuel ash; A_{dz} is the quota of ash forming the slag in the amount of fuel ash; C_{fh}, C_{dz} are respectively contents of combustible matter in fly ash and slag.

The precondition, in which the equation is used, is $a_{fh}+a_{lz}=1$.When most of the coal ash forms the fly ash and slag, the quota of ash forming the coke in the amount of fuel ash is very little. So the existence of coke can be omitted. In this condition, the equation (1) can correctly describe the burnout property of coal. Additionally, it is difficult to get the quota of coke in the conditions of the real boilers in power plants. Therefore the equation (1) is often adopted when calculating the solid un-burnout loss of pulverized-coal combustion of the real boilers. But at the conditions of this experiments, the quota of coke is very large and varies from the range of 10.70~40.48%, so, the loss of solid un-burnout caused by the coke cannot be neglected. So the loss of solid un-burnout is defined as follows:

$$q_l = \frac{32825A_{ad}}{Q_r}\left(\frac{a_{fh}c_{fh}}{100-c_{fh}}+\frac{a_{lz}c_{lz}}{100-c_{lz}}+\frac{a_{lj}c_{lj}}{100-c_{lj}}\right)\% \qquad (2)$$

Where a_{lj} is the quota of the ash forming the coke in the amount of fuel ash; c_{lz} is the content of combustible matter in the coke, %.

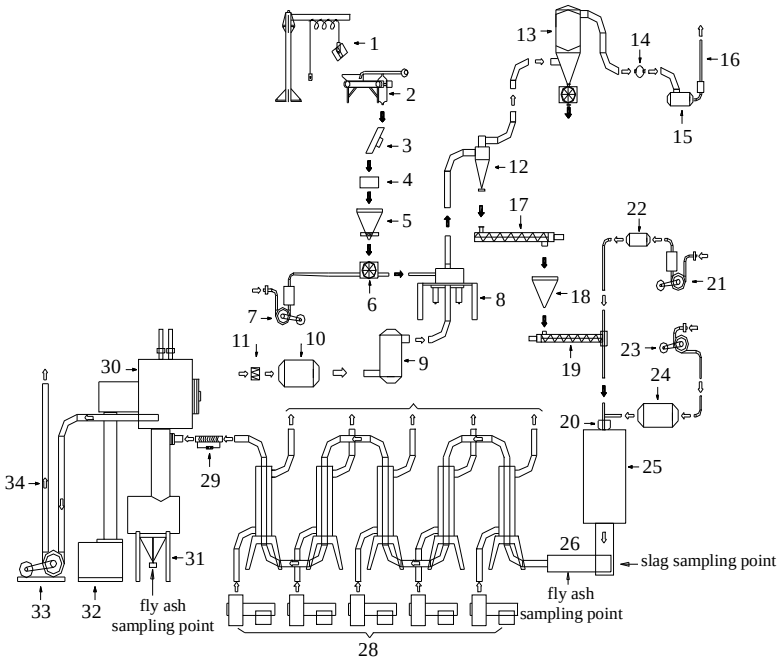
The result according to the equation (2) is shown in table 3. Because of the ash quantity is very great,

the single Fengguang coal combustion is not well. For the three single brown coals, the burn-off rate of Meihe coal is the highest and that of Yangcaogou coal is the lowest. For the blended coals, the burnout property of 2# (3M+7H) is better than that of 1# (2M+8H), and the burnout property of 6# (3Y+7H) is worse than that of 5#(2Y+8H). The burnont property of Yangcaogou coal is better than that of Fengguang coal, then the burnout property of 5# (8H+2Y) is better than that of 3# (8H+2F). So it can be found that when two types of coals are mixed, the higher percentage that good burnout coal accounts for, the better the burnout properties of blended coals is. F is the Fengguang coal, as shown in Fig. 1 and Fig.2.

表 3　混煤的燃尽率

Tab.3　Burn-off rate of blended coals

Serial number	Solid unburnout loss/%	Blended Coals
1	2.35	5#(8H+2Y)
2	2.39	3#(8H+2F)
3	2.54	2#(7H+3M)
4	2.775	9#(4M+3F+3Y)
5	3.47	Meihe
6	4.09	4#(7H+3F)
7	4.14	1#(8H+2M)
8	4.17	7#(6H+2M+1F+1Y)
9	4.83	Huolinhe
10	5.23	6#(7H+3Y)
11	6.45	8#(7H+1M+1F+1Y)
12	10.24	Yangcaogou



1—jig crane; 2—belt conveor; 3—magnet; 4—roller crusher; 5—crusher coel feed hopper; 6-variable sppe blow through feedel; 7—feed blower; 8—coal puvlverizer; 9—sliencer; 10—air heater; 11—filter; 12—cyclone; 13—pulse jet dust collector; 14—explosion barrier; 15—vortex-type vacuum pump; 16—vent to atmosphere; 17—screw conveyor; 18—pulverized coal feed hopper; 19—volumetric screw feeder; 20—burner; 21—primary air blower; 22—primary air heater; 23—secondary air blower; 24—secondary air heater; 25—furnace chamber; 26—flue; 27—air-cooler heat exchangers; 28—blower; 29—flue gas trace heater; 30—electrostatic precipitator(ESP); 31—flyash hopper; 32—transformer; 33—exhaust blower; 34—chimney

图 1　CRF 试验台

Fig. 1　CRF test rig

3.2　Slagging of blended coals

Slagging is a complex physical and chemical process. It is not only related to the composition of coal ash, but also is influenced by the type of burners, the structure of furnace, the temperature level in furnace, the aerodynamic field of furnace and atmosphere in furnace. At present, there are some methods to predict and estimate the slagging of pulverized-coal combustion, such as ash fusion, ash composition and ash viscosity, but none of them is accurate enough to predict correctly in practice.

On the basis of the test rig, the ratio of coke attached to the wall over the amount of slag on the bottom of the furnace were got. It is used as a parameter of slagging and used to evaluate the extent of slagging in furnace in this paper. The bigger the ratio is, the easier the slagging is. Table 4 showed the result of the ratio of coke to slagging. From table 4 it

can be found, the tendency of slagging of Meihe coal and 5#(2Y8H) coal are obvious. However, there is no difference to the Huolinhe coal. It agrees with the slagging tendency in boilers of Shuangliao Power Plants on the whole. The ratio of coke to slagging is a reasonable discriminant parameter of slagging. From slagging characteristics of Meihe coal, 2# coal, Yangcaogou coal, 1# coal, 6# coal, Huolinhe coal, the results showed that the slagging characteristics of blended coals are among fractional coals. The slaggings characteristic of coal that slagging badly was changed by the blended coal that not easy slagging, so the slagging can be lightened.

表 4 在炉底附着的焦炭和渣的比例

Tab.4 The ratio of the coke attached to furnace wall over the slag on bottom of furnace

Serial number	Blended Coals	Coke/slag
1	9#(4M+3F+3Y)	2.92
2	Meihe	1.89
3	2#(7H+3M)	1.84
4	5#(8H+2Y)	1.44
5	Yangcaogou	1.27
6	7#(6H+2M+1F+1Y)	1.12
7	1#(8H+2M)	1.17
8	6#(7H+3Y)	1.11
9	3#(8H+2F)	0.97
10	8#(7H+1M+1F+1Y)	0.96
11	4#(7H+3F)	0.53
12	Huolinhe	0.39

According to table 4, the slagging property of 5#(2Y8H) coal is more serious than that of Huolinhe coal and Yangcaogou coal. It showed, when the blending of a coal that has high slagging potential with another coal with low slagging potential, the trouble of slagging get worse. The reason is that the eutectic phenomenon of ash composition makes the ash fusion of the mixed coal lower than that of any of the coals used in the blending. So, improper blending of coals will cause serious slagging. F is the Fengguang coal, as shown in Fig. 1 and Fig. 2.

3.3 NO_x emission

3.3.1 Distribution of NO_x concentration along the furnace

NO_x is always the concern of coal combustion because it is harmful to environment[9-13]. However, there are few investigation done on blended coals at presert. The distribution of NO_x concentration along the furnace fired with a single type of coal and blended coals shown in Fig. 2. It can be found, the concentration of NO_x at the beginning of ignition is larger, and owing to the coke reduction at the burnout stage, the NO_x concentration getting less. Furthermore, the distribution of NO_x concentration of blended coals which has two peaks is different from that of single coal with only one peak. The reason is that when two types of coals are mixed, the sequence of volatile matter liberation of the two types of coals differs from each other and the volatile matter of the two types of coals interacts.

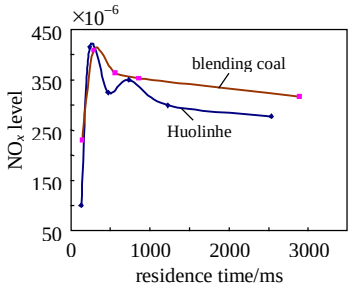


图 2 沿炉膛 NO_x 浓度分布

Fig2 The distribution of NO_x concentration along the furnace

3.3.2 Influence of the content of N on NO_x emission

As Fig.3 showed, with the content of N of coal increasing, the amount of NO_x emission is increased. Because NO_x emission during pulverized-coal combustion process is mainly produced by fuel NO_x, under the same conditions, the increment of the content of N of coal contributes to the NO_x production[14].

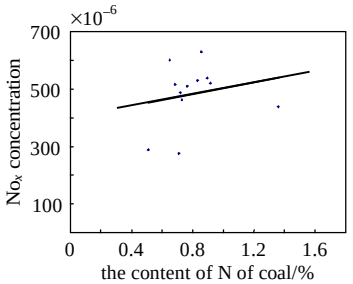


图 3 NO_x 与煤中含 N 量关系

Fig. 3 NO_x level with different content of N of coal

3.3.3 Influence of the fineness of coal on NO_x emission

The NO_x concentration in the conditions of the different fineness of coal particles is showed in Fig.4. The fineness is that R_{90}=22.5% and R_{200}=2.3%. The coarseness is that R_{90}=35% and R_{200}=4.1%. It showed

that when the fineness of coal particles is different, NO_x concentration is different. With the fineness of coal increasing, NO_x concentration increases. One reason is that the increment of the fineness of coal makes the liberation of N from coal easier; the other is that the increment of the fineness of coal makes the mixture of pulverized-coal with air better.

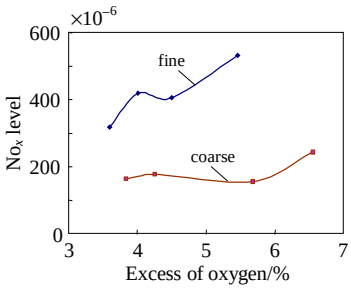


图 4　NO_x 与氧量关系
Fig.4　NO_x level with excess of oxygen

3.3.4　Influence of the oxygen on NO_x emission

Fig.5 showed the influence of the oxygen on NO_x emission. It can be found the influence is obvious, more excess oxygen more NO_x. The main reason is that the middle production NH_1 and HCN are easily transformed to N_2 in low oxygen condition. They will transform to NO_x in high oxygen condition. So, the way of reducing excess oxygen is a good method to reduce NO_x emission, even the unburned loss not be increased.

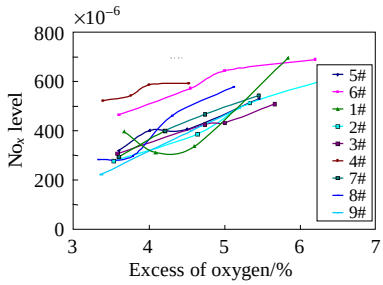


图 5　NO_x 与炉膛出口氧量关系
Fig.5　NO_x level with different oxygen

3.3.5　NO_x emission of fractional coal and blended coals

Tab.5 showed the NO_x emission of fractional coal and blended coals when the excess air coefficient is 1.4. F is the Fengguang coal, as showed in Fig.1 and Fig.2. It showed that the NO_x emission of 1# blended coals is higher. The NO_x emission of 4# blended coals is the lowest. Although there are some relationships between fractional coal and blended coals, there are no obvious rules to NO_x emission. Maybe the factors is complex, such as content of N of coal, excess oxygen, pulverized coal fineness.

表 5　几种煤与混煤 NO_x 释放量
Tab.5　NO_x emission of fractional coal and blended coals

Serial number	Coal	NO_x emission×10^{-6}
1	1#	630
2	6#	600
3	9#	537
4	7#	529
5	2#	520
6	5#	516
7	8#	510
8	3#	487
9	Huolinhe	463
10	Meihe	439
11	Yangcaogou	290
12	4#	276

3.4　SO_x emission

Because of the action of the alkalescence oxide of ash, some sulfur oxide of flue gas will be reacted. So, it has a sulfur emission coefficient. This work adopts the concept as follows:

K_e=sulfur emission of flue gas/ the content of sulfur of coal

The influence of K_e is the alkalescence oxide of ash mostly, such as Na_2O, K_2O, they are steady compounds, have not reaction to SOx. CaO, MgO, Al_2O_3 and Fe_2O_3 have sulfur retention effect. Especially, the sulfur reaction effect of CaO and MgO is the greatest. K_e reflects the sulfur retention effect of alkalescence oxide of ash in a certain extent. Tab.6 showed the SO_2 emission of coals vs the excess oxygen is 1.4.

From Tab.6, it can be found that the sulfur of the fractional coal is lower except Meihe coal. The reduction sulfur of all blended coals is less than 0.2%, and they are all low sulfur coal. So, the SO_x emission is lower. The sulfur emission coefficient of fractional coal and blended coals is between 0.6 and 0.85. The SO_2 emission is reduced greatly when blended low sulfur coal Huolinhe with high sulfur coal Meihe. Such as 1# blended coals and 2# blended coals. The 1# blended coals (20%Meihe+80%Huolinhe) makes the SO_2 emission reduce from 1189×10^{-6} of single Meihe coal combustion to 510×10^{-6}. In three fractional coals, the K_e of Meihe coal is the largest,

that of Yangcaogou is the least. In nine blended coals, the K_e of 5# is the largest, then it is 9#, 6#, 8#, 2#, 1#, 7#, 4# and 3# in turn. The SO_2 emission of blended coals, the 9# is the largest, then it is 2#, 1#, 5#, 7#, 8#, 6#, 4# and 3# in turn. F is the Fengguang coal, as showed in Fig. 1 and Fig.2.

表 6 几种煤与混煤 SO_2 释放量

Tab.6 SO_2 emission of fractional coal and blended coals

Coal	[s]/%	$[s]_Z$/%	K_e	$[SO_2](\times10^{-6})$
Meihe	1.64	0.3486	0.82	1189
Huolinhe	0.5	0.1315	0.70	376
Yangcaogou	0.34	0.1183	0.67	291
1#	0.726	0.1749	0.68	510
2#	0.839	0.1966	0.71	600
3#	0.43	0.1215	0.47	236
4#	0.39	0.1165	0.60	290
5#	0.47	0.1289	0.94	489
6#	0.44	0.1275	0.83	420
7#	0.56	0.1686	0.73	457
8#	0.68	0.1469	0.65	476
9#	0.79	0.1994	0.92	819

The symbol: [S]—sulfur of coal, S_{ad}, %; $[S]_c$—reduction sulfur , $[S]_Z=[S]_{ad}\times4186/Q_{ad,net}$,; K_e — SO_2 emission coefficient; $[SO_2]$ — concentration of SO_2 in flue gas, 10^{-6}.

From Tab.6, we can find that the SO_x emission of some blended coals that are composed of two single coal with different proportion is near fractional coal, such as 1# and 2# blended coals. The SO_x emission is reduced with the reduction of the ratio of high sulfur coal. The SO_x emission of some blended coals is higher than fractional coal, such as 5# and 6# blended coals. Many researchers of USA studied the SO_x emission rule of blended coals, they considered that the SO_x emission of blended coals is the linearity connection to fractional coal[15-16]. This paper considers that the SO_x emission of blended coals has not better rule. The reason is complex. It must be carried through experimental study in factual application.

4 CONCLUSION

In this paper, the experimental research on the properties of burnout and slagging of blended coals and the emission characteristic has been done. The loss of solid unburnout q_l is corrected and is used to judge the burnout properties of blended coals. It is considered that when two types of coals are mixed, the high percentge the coal which has the good burnout characteristic accounts for, the better the burnout properties of blended coals are.

The ratio of the coke attached to the wall of furnace over the slag on the bottom of the furnace is presented as a discriminant parameter of slagging. It were found, when the coal that has high slagging blended with the coal that has low slagging potential, the condition of slagging will get worse.

The characteristics of NO_x emission of blended coals have been studied. The result is that with the increasing of oxygen and the content of N of coal and fineness of pulverized coal the amount of NO_x emission increases.

The characteristics of SO_x emission of blended coals also have been studied. The result is that the SO_x emission of blended coals has not better rule. It must be carried through experimental study in factual application.

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