

Study on the Combustion Characteristics and Kinetic Parameters of the Blended Coal Treated with Different Grinding Methods

Wang Boping^{1,*}, Liu Liang¹, Wang Xun¹, Fang Xunzhou², Hou Qinjia¹, Liu Zenghui¹, Wang Kailun¹

¹School of energy and power engineering, Changsha University of Science and Technology, Changsha, 410114, China

²Huadian Fuxin Guangzhou Energy Co., Ltd., Guangzhou, 100031, China

* Corresponding author: Wang Boping (1994 -), School of energy and power engineering, Changsha University of Science and Technology.

Abstract The presented investigation focused on the combustion characteristics and kinetic parameters of the coals blended using different grinding methods (separated and mixed grinding), via Thermogravimetric analyser. According to the thermogravimetric experiments, with the increase of the proportion of Yangcheng coal, the combustion characteristics of the coal treated with the mixed grinding method are increasingly better than those of the coal treated with the separated grinding method (under the same mixing ratio). Additionally, the methods of Coats-Redfern were applied to calculate kinetic parameters, which indicated that when the proportion of Yangcheng coal is 30%, the activation energy values of the coal treated with two grinding methods are similar; when the proportion of Yangcheng coal is below 30%, the activation energy values of coal treated with the separated grinding method is lower than that of the coal treated with the mixed grinding method; when the proportion of Yangcheng coal is above 30%, the activation energy values of the coal treated with the mixed grinding method is lower than that of the coal treated with the separated grinding method.

1 Introduction

The diversity of coal quality is a major issue in thermal power stations at the current stage. To ensure the stable and economical operation of pulverized coal furnaces, power coal blending is often used to satisfy the needs of boilers at power stations. Many domestic scholars have studied coal blending techniques. For example, Cao ^[1] used a thermogravimetric analyzer to study the combustion characteristics, NO_x emission laws, and slagging conditions of Mongolian coal and its blended coal by means of separated grinding and blending combustion. Fu ^[2] et al. carried out optimization research on coal blending for coal-fired power stations, which can provide guidance for related operations. Wu ^[3] et al. studied the influence of different pyrolysis temperatures and rates on the combustion characteristics of the semi-coke jetted by blast furnace by adopting the thermogravimetric analysis method. Xia ^[4] et al. established an optimized practical coal miller combination model so as to improve the coal blending decision-making system for a coal-fired power plant. Zhang et al. ^[5] found that when the proportion of easily grindable coal reached about 40%, the Hardgrove grindability index (HGI) of the blended coal increased significantly. Ma ^[6] et al. found that for out-of-furnace blending combustion, lower proportion of bituminous coal could lead to greater promotion effect between the blended coals, thus improving the burnout rate; with the

increase of this proportion, the suppression effect would be gradually strengthened, which is not conducive to the burnout of the blended coal.

Researchers at home and abroad have conducted a series of studies on blending combustion and models of the blended coal as well as the characteristics of particle composition ^[7-8] and combustion. Compared with raw coal, the blended coal changes significantly after blending, so simple superposition cannot help to accurately predict the combustion characteristics of the blended coal sample. This paper conducts thermogravimetric experiments by taking the blended coal with different proportions as the material and by adopting the two methods of mixed coal grinding (mix coal before grinding) and separated coal grinding (mix coal after grinding). This paper explores the influence of blending methods on the combustion characteristics and kinetic parameters of the blended coal, aiming to find a suitable method for coal blending.

2 Experiment

2.1. Sample preparation

This experiment adopts the 5E-MAC3 industrial analyzer and the NETZSCH STA449 thermal analyzer (TG) and takes two commonly used coals (anthracite in Yangcheng, Shanxi Province and bitumits in Zhengzhou, Henan Province) as the materials. Untreated raw coal briquettes

taken before the experiment were ground into qualified coal powder according to the experimental needs.

We adopted two methods of mixed grinding and separated grinding to prepare 10 blended coal samples (1:9, 3:7, 5:5, 7:3, 9:1), plus two unblended coal samples (a total of 12 samples). For the sake of convenience, we numbered them in sequence as #1, #2, #3, #4, #5, #6, #7, #8, #9, #10, #A, #E (see Table 1). The industrial analysis of coal is shown in Table 2.

Table 1 Sample number

Samples	Number
Mixed grinding A:E=1:9	#1
Mixed grinding A:E=3:7	#2
Mixed grinding A:E=5:5	#3
Mixed grinding A:E=7:3	#4
Mixed grinding A:E=9:1	#5
Separate grinding A:E=3:7	#7
Separate grinding A:E=5:5	#8
Separate grinding A:E=7:3	#9
Separate grinding A:E=9:1	#10
A	#A
E	#E

Table 2 Industrial analysis of samples

Number	Mad	Aad	Vad	FCad
#1	0.89	28.87	18.43	51.81
#2	1.81	16.24	13.93	68.02
#3	2.82	17.02	6.14	74.02
#4	1.83	23.64	9.57	64.96
#5	1.85	33.02	16.12	49.01
#6	1.12	16.32	16.34	66.22
#7	1.78	8.94	10.81	78.47
#8	1.87	18.79	6.45	72.89
#9	1.78	27.42	12.26	58.54
#10	1.84	36.41	18.74	43.01
#A	2.5	22.02	10.99	64.49
#E	1.92	38.59	19.86	39.63

2.2 Conditions of thermogravimetric experiment

Sample mass: 10.0 mg ± 0.5 mg;

Heating rate: 20°C/min;

Temperature range: 25°C < T < 1000°C;

Experimental atmosphere: air;

Air flow: 100 mL/min.

2.3 Evaluation index of combustion performance

Ignition temperature T_i : obtained by TG-DTG method (as shown in Figure 1);

Burnout temperature T_f : the temperature when the weight loss rate of the TG curve exceeds 98%;

Maximum burning rate (dw/dt) max;

Peak temperature T_m : the temperature corresponding to the maximum value of DTG;

Average burning rate (dw/dt) mean;

Comprehensive combustion characteristic index S_N :

$$S_N = \frac{(dw/dt)_{max} dw/dt_{mean}}{T_i^2 T_f} \quad (1)$$

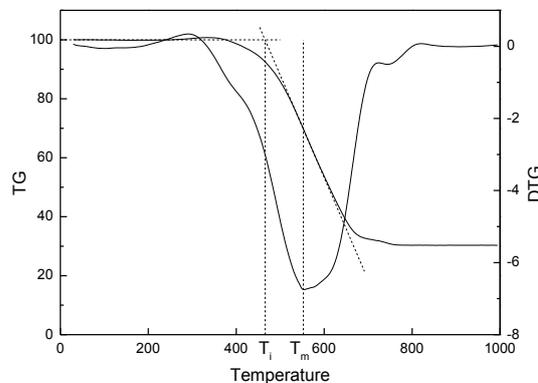


Figure 1 Schematic diagram of ignition temperature

2.4 Obtaining activation energy values and mechanism functions

According to Arrhenius Equation [9] and the effective collision theory of chemical reactions, when the activation energy value is lower, the reaction is easier to occur, and vice versa. [10] This paper uses the Coats-Redfern first-order equation [11] to calculate the kinetic parameters of the coal combustion process ($T_i < T < T_f$). The final equation can be expressed as:

$$\ln \left[\frac{-\ln(1-\alpha)}{T^2} \right] = \ln \left(\frac{AR}{\beta E} \right) - \frac{E}{RT} \quad (2)$$

In the formula:

α —mass conversion rate at time t ;

$\alpha = \frac{m_0 - m_t}{m_0 - m_\infty}$ (m_0 is the initial mass of the sample; m_t is the sample mass at time t ; m_∞ is the mass at the final sample temperature);

A—pre-exponential factor, 1/min;

E—reaction activation energy values, kJ/mol;

R—gas constant, 8.314J/(K · mol);

β —heating rate, K/min;

T—thermodynamic temperature, K.

Since $\ln \left(\frac{AE}{\beta R} \right)$ in the formula does not change with temperature, $\ln \left[\frac{-\ln(1-\alpha)}{T^2} \right]$ and $\frac{1}{T}$ are in the functional relationship of $Y = aX + b$ ($Y = \ln \left[\frac{-\ln(1-\alpha)}{T^2} \right]$, $X = \frac{1}{T}$, $a = -\frac{E}{R}$, $b = \ln \left(\frac{AR}{\beta E} \right)$). The corresponding conversion rate α at any temperature T in any temperature interval can be calculated according to the TG curve, based on which Y and X values can also be calculated. The author took multiple X and Y points in the combustion area of the 12 samples (the ignition temperature-burnout temperature was selected as the analysis interval) for fitting by adopting the data analysis software and obtained the activation energy values E and the pre-exponential factor A according to the function expression. [12-14]

3 Experimental results and discussion

3.1 Analysis of combustion characteristics based on TG-DTG curve

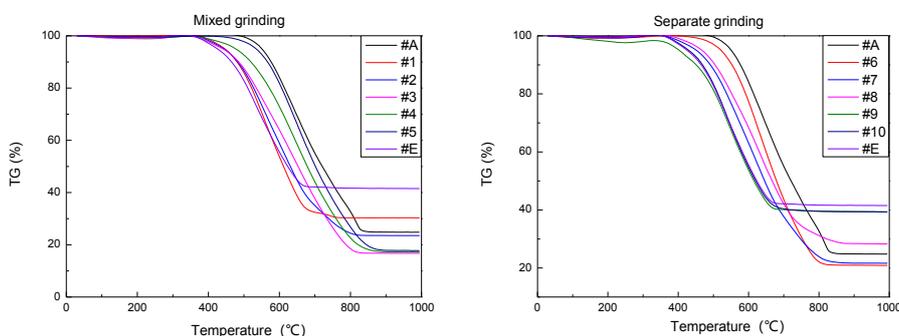


Figure 2 TG-temperature diagram of sample

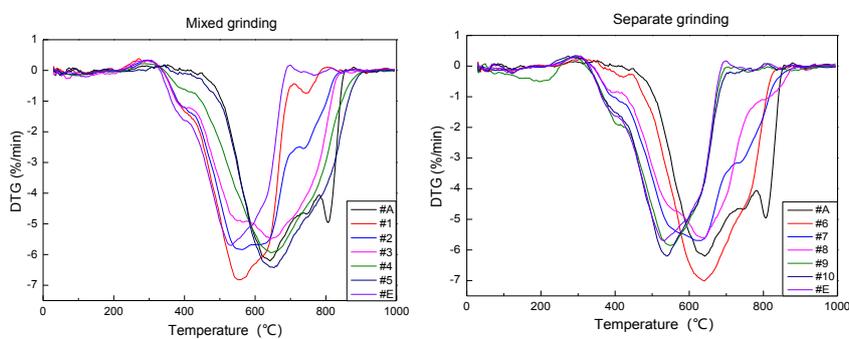


Figure 3 DTG-temperature diagram of sample

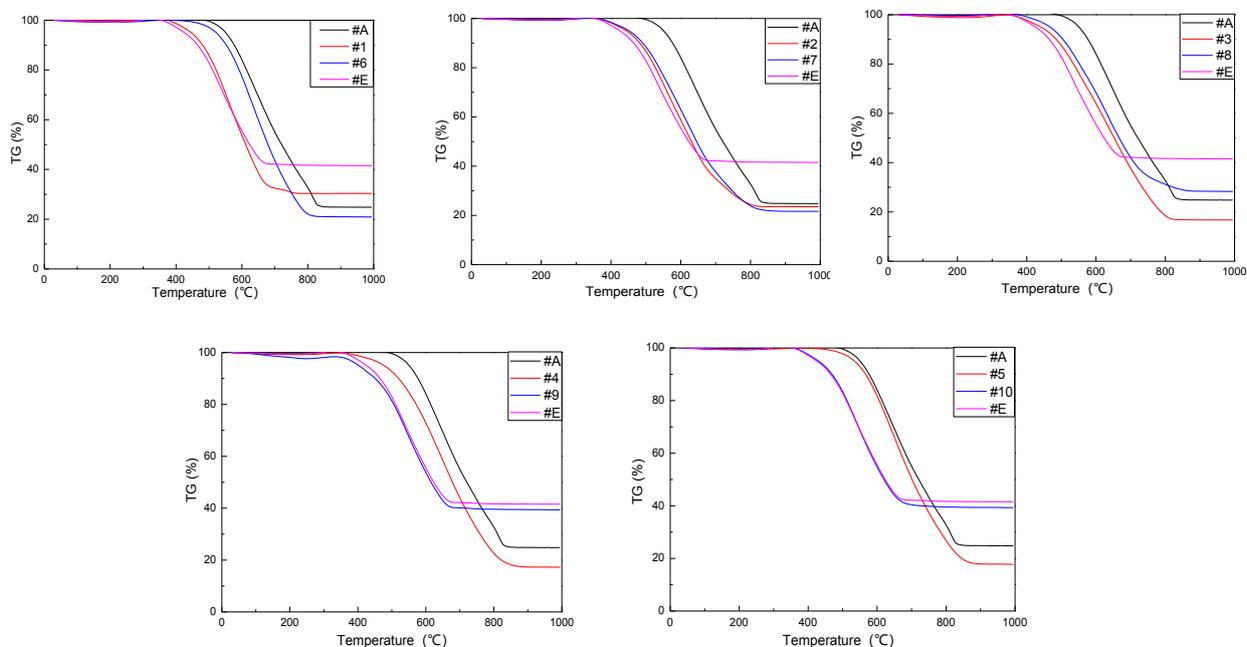


Figure 4 TG-temperature diagram of samples with the same proportion and different grinding methods

Figure 2 to Figure 4 show the thermogravimetric experimental data of 12 coal samples. The overall trends of the TG and DTG curves of the samples are generally similar, and the combustion characteristic temperatures of

different samples are not completely consistent. It can be seen from Table 3 that the ignition temperature T_i , the burnout temperature T_f , and the peak temperature T_m of the 10 blended coal samples are basically within the range

of the corresponding characteristic temperatures of the two unblended coals.

As shown in Figure 5, the comprehensive combustion characteristic index S_N of the blended coal treated with the mixed and the separated grinding methods decreases with the increase of the proportion of Yangcheng coal. S_N of the blended coal treated with the separated grinding method is basically in a linear relationship with the proportion of Yangcheng coal, while S_N of the blended coal treated with the mixed grinding method is not, indicating that the mixed grinding method promotes the complicated internal interaction of the blended coal more

significantly^[15], which affects the combustion characteristics. When the proportion of Yangcheng coal is 30%, S_N of two grinding methods are similar; when the proportion of Yangcheng coal is lower than 30%, S_N of the blended coal treated with the separated grinding method is higher; when the proportion of Yangcheng coal is higher than 30%, S_N of the blended coal treated with the mixed grinding methods higher. At this time, the Yangcheng coal with a higher hardness has an obvious comminution effect on the Zhengzhou coal with a lower hardness.

Table 3 combustion characteristic parameters of samples

Number	The proportion of Yangcheng coal (%)	Ignition temperature T_i (°C)	Burnout temperature T_f (°C)	Average burning rate $dw/d\tau$ mean	Maximum burning rate $(dw/d\tau)_{max}$ (mg/min)	Peak temperature T_m (°C)	Flammability index C_b ($\times 10^{-6}$ mg/(min·K ²))	Combustion stability index G ($\times 10^{-6}$ mg/(min·K ²))	Comprehensive combustion characteristic index S_N ($\times 10^{-10}$ mg ² /(min·K ²))
#A	0	440	686	0.142	0.686	545.62	1.350	1.176	2.006
#1	10	464.765	763	0.150	0.733	549.44	1.346	1.208	1.958
#2	30	459.52	826	0.175	0.647	568.04	1.206	1.051	1.925
#3	50	465.53	828	0.187	0.611	667.27	1.120	0.880	1.902
#4	70	510.61	884	0.192	0.667	641.82	1.085	0.930	1.802
#5	90	545.66	897	0.180	0.725	638.97	1.082	0.971	1.669
#6	10	534.775	822	0.180	0.791	632.23	1.212	1.081	2.003
#7	30	466.23	820	0.169	0.646	560.12	1.182	1.049	1.944
#8	50	491.38	874	0.170	0.703	638.45	1.203	1.009	1.791
#9	70	435.96	688	0.125	0.643	567.74	1.278	1.078	1.669
#10	90	448.45	780	0.127	0.644	536.04	1.237	1.103	1.502
#E	100	549.28	848.48	0.166	0.706	638.88	1.044	0.942	1.546

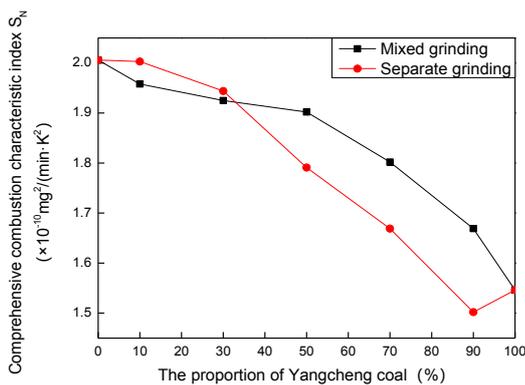


Figure 5 change trend of S_N with the proportion of Yangcheng coal

3.2 Combustion kinetics analysis

This paper conducts the kinetics of the blended coal from ignition to burnout using the C-R method. The results are shown in Table 4.

Table 4 Dynamic parameters of combustion stage of mixed coal sample

Sample	Temperature range	Fitting equations	Activation energy values	Correlation coefficient
	T (°C)		E_a (kJ·mol ⁻¹)	
#1	464-763	$Y=-8286.34X-0.22814$	68.89	0.98384
#2	459-826	$Y=-8634.72X-4.47136$	71.79	0.95755
#3	465-828	$Y=-8758.7X-4.47066$	72.82	0.96969
#4	510-884	$Y=-9299.78X-3.68272$	77.32	0.97683
#5	545-897	$Y=-10102.4X-2.90513$	83.99	0.96584
#6	534-822	$Y=-7778.06X-0.32095$	64.67	0.96764
#7	466-820	$Y=-9448.76X-3.5614$	70.34	0.95567
#8	491-874	$Y=-8460.88X-4.12884$	76.49	0.95745
#9	435-688	$Y=-9200.03X+0.8447$	81.52	0.97932
#10	448-780	$Y=-10818.1X-1.3366$	89.94	0.95554
#A	549-848	$Y=-11685.5X-2.02445$	97.15	0.95027
#E	440-686	$Y=-7078.32X+1.2658$	58.85	0.97078

It can be seen that for all fitting equations, $0.95 < R^2 < 1$, indicating a high fitting degree. The activation energy values of the blended coal during combustion is influenced by the grinding method and the proportion of Yangcheng coal. As shown in Figure 5, when the proportion of Yangcheng coal is 30%, the activation energy values of the coals treated with two grinding methods are similar; when the proportion of Yangcheng coal is below 30%, the activation energy values of the coal treated with separated grinding method is lower; when the proportion of Yangcheng coal is higher than 30%, the activation energy values of the coal treated with mixed grinding method is lower. This is because the middle coal particles of the Yangcheng coal with higher hardness cannot be crushed in time; on the other hand, the crushing force is transmitted is transferred to the middle coal particles of the Zhengzhou coal with lower hardness and crushed them. At this point, the middle coal particles of Yangcheng coal acts as the crushing medium, promoting the crushing of Zhengzhou coal. Due to the friction, Yangcheng coal exerts ashear-squeeze impact on Zhengzhou coal [5]. The pulverized coal powder that are in better contact with air is more likely to react, thus lower activation energy values.

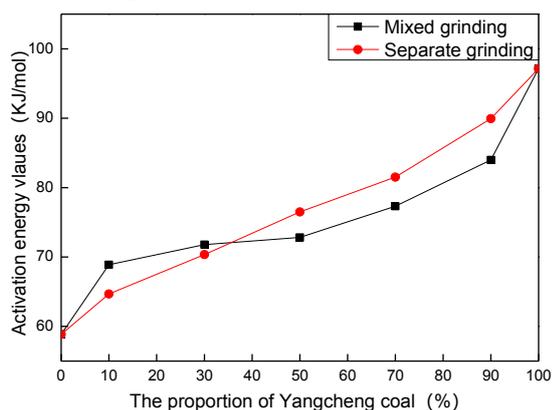


Figure 6 change trend of activation energy values with the proportion of Yangcheng coal

4 Conclusion

The combustion characteristic parameters of the blended coal are basically within the range of those of the two unblended coals. The comprehensive combustion characteristic index S_N decreases with the increase of the proportion of Yangcheng coal. S_N of the blended coal treated with the separated grinding method is basically in a linear relationship with the proportion of Yangcheng coal, while S_N of the blended coal treated with the mixed grinding method is not, indicating that the mixed grinding method affects the combustion characteristics of the blended coal.

When the proportion of Yangcheng coal is 30%, the combustion characteristics of the two coal grinding methods are similar; when the proportion of Yangcheng coal is less than 30%, the combustion characteristics of the coal treated with separated grinding method are better; when the proportion of Yangcheng coal is higher than

30%, the combustion characteristics of the coal treated with mixed grinding method are better.

When the proportion of Yangcheng coal is 30%, the activation energy values of the two coal grinding methods are similar, which indicates that the blended coal is more likely to react in the combustion area at this proportion. However, when the proportion of Yangcheng coal is less than 30%, the activation energy values of the coal treated with separated grinding method is lower; when the proportion of Yangcheng coal is higher than 30%, the activation energy values of the coal treated with mixed grinding method is lower.

In this experiment, as the proportion of Yangcheng coal increases, the coal with higher hardness (Yangcheng coal) will exert a more significant crushing effect on the coal with lower hardness (Zhengzhou coal). Therefore, as the proportion of Yangcheng coal increases, the mixed grinding method, which can produce particles with gradually higher fineness than the separated grinding method, will help to produce the coal with gradually better combustion characteristics.

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