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Note

Studying the mechanisms of ignition of coal particles by TG–DTA [1]

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Abstract

The mechanisms of ignition of coal of different quality, such as anthracite, bituminous coal and lignite, were studied by thermogravimetry (TG) and differential thermal analysis (DTA). Experiments on coal ignition were carried out at a low heating rate (10 K min^{-1}) with particle sizes ranging from 37 to 4000 μm.

It is concluded from this experimental work that

(1) ignition measurement by TG–DTA is an excellent method for accurate determination of the ignition temperature of coal particles;

(2) with increasing coal quality from lignite through bituminous coal to anthracite, the type of ignition changes from homogeneous ignition through hetero–homogeneous ignition to heterogeneous ignition, and the ignition temperatures also increase;

(3) with increasing coal particle size, the type of ignition of Kaipin bituminous coal changes from hetero–homogeneous to homogeneous ignition, and ignition of the char separates from that of the volatile matter and shifts to a higher temperature, whereas both types of ignition of Loy Yang lignite coal and Hongay anthracite coal are not effected by particle size.

Keywords: Anthracite; Bituminous coal; Coal particles; Heterogeneous ignition; Homogeneous ignition; Ignition mechanism; Lignite; Particle size; TG–DTA

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1. Introduction

The ignition of coal particles is an important preliminary step in the coal combustion process. It is, therefore, necessary to study the mechanisms of ignition of coal particles for designing the coal combustor, controlling combustion process efficiently, and estimating the self-ignition and explosion of coal stockpiles. Extensive research on the mechanism of ignition of coal particles has classified ignition into three types:

(1) homogeneous ignition, or the ignition of the volatile matter released from coal;
(2) heterogeneous ignition, or the ignition of the coal particle surface; and
(3) hetero–homogeneous ignition, which results from simultaneous ignition of the volatile matter and the coal particle surface.

Thus, these types of ignition depend on coal quality, particle size and the volatile matter content. Essenhigh et al. [1] have indicated that large (greater than 100 μm) coal particles can be ignited homogeneously by prior pyrolysis and subsequent ignition of the volatile matter at a low heating rate (less than $100\,K\,s^{-1}$). They also found that small coal particles can be ignited heterogeneously by direct attack of oxygen on the whole coal particle at a high heating rate.

However, the effect of coal quality on the ignition mechanism still has not been discussed. Accordingly, this work was aimed at investigating the ignition mechanisms and the effect of particle size on the ignition. Experiments were carried out on coal of three different qualities, lignite, bituminous coal, and anthracite by using TG and DTA at low heating rates and coal of various particle sizes.

2. Experimental

2.1. Ignition temperature measurements

To determine the ignition temperature of coal, various experimental techniques have been proposed, such as: the pulse ignition technique [2, 3], TG ignition measurement [4], the modified DTA technique [5], direct measurement of particle temperature at ignition using a thermocouple [6], laser induced-ignition [7] and ignitability test [8].

In this study TG–DTA, combined TG ignition measurement and DTA was adopted. The principle of this technique is based on the fact that when the sample is ignited homogeneously, two exothermic peaks appear in front of and at the back of a turning point where the TG combustion curve and the TG pyrolysis curve are separated. The first peak is caused by the combustion of volatile matter released from the coal and the second peak is caused by burning of the residual char. For heterogeneous ignition, on the other hand, only one strong exothermic peak appears on the DTA curve, as a result of burning of the whole coal particle. However, in the case of hetero–homogeneous ignition, after release of part of the volatile matter, one strong exothermic peak appears on the DTA curve with a remarkable weight loss on the TG curve.

2.2. Samples

Three different qualities of coal, Loy Yang coal (lignite), Kaipin (bituminous) coal and Hongay coal (anthracite) were employed. Proximate and ultimate analyses of these coals were performed by means of an electric furnace (1200PKP, Motoyama) and CHN-corder (MT3, Yanaco). The data obtained are shown in Table 1. Coal samples were air-dried at 383 K for 24 h before the TG–DTA ignition measurement.

2.3. Experiment operation

Fig. 1 shows a schematic diagram of the TG–DTA system (TAS-100, Rigaku). To measure the ignition temperature of coal particles, the experiments were carried out in air and nitrogen. In preliminary experiments, the effects of heating rate on the coal combustion test and the reproducibility of the experiment were examined. Fig. 2 shows a typical examination with heating rates changing from 5 to 20 K min^{-1}. It was found that as the heating rate increases, the type of coal ignition was not affected, although the ignition temperature was shifted to a slightly higher temperature. The reproducibility of TG–DTA curves of the three types of coal is shown in Fig. 3. It can be seen that the system sensitivity and the reproducibility of the TG–DTA experiment are excellent.

Throughout all the experimental runs, the gas flow rate and heating rate were kept at 70 cm^3 min^{-1} and 10 K min^{-1}, respectively. The particle size of the coal samples ranged from 37 to 4000 μm.

3. Results and discussion

3.1. Ignition mechanisms of coal of different quality

Fig. 3 shows the results of experiments performed to determine the ignition temperature of Loy Yang coal, Kaipin coal and Hongay coal. For Loy Yang coal (Fig. 3(a)), two exothermic peaks can be found on the DTA curve at temperatures of about 573 K and 688 K, as a result of the combustion of volatile matter (VM) and residual char, respectively. Moreover, the weight loss on the TG curve between the initial point and the turning point at 663 K, where the TG combustion curve is separated from TG

Table 1
Properties of the three coals

Coal	Location	Approximate analysis (dry basis)/wt%			Ultimate analysis (d.a.f.)/wt%			
		FC	VM	Ash	C	H	N	S+O (by diff.)
Loy Yang	Australia	46.3	51.3	2.4	66.1	4.3	0.7	28.9
Kaipin	China	55.1	32.0	13.0	76.8	4.6	1.0	17.6
Hongay	Vietnam	73.8	9.8	16.4	74.8	2.3	0.9	22.0

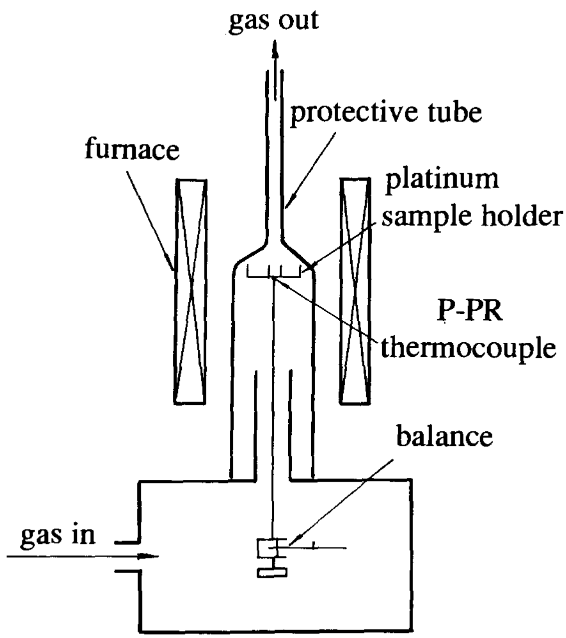

Fig. 1. Schematic diagram of apparatus.

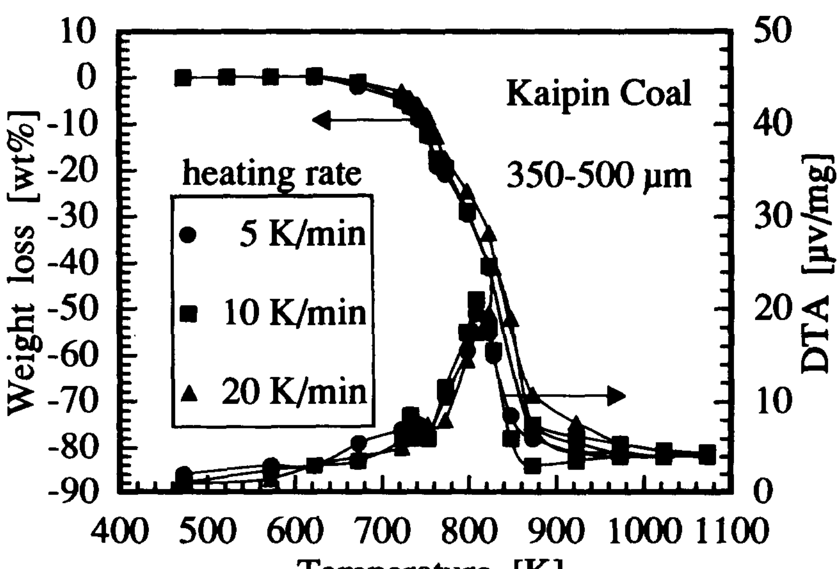

Fig. 2. Effect of heating rate on TG–DTA curve.

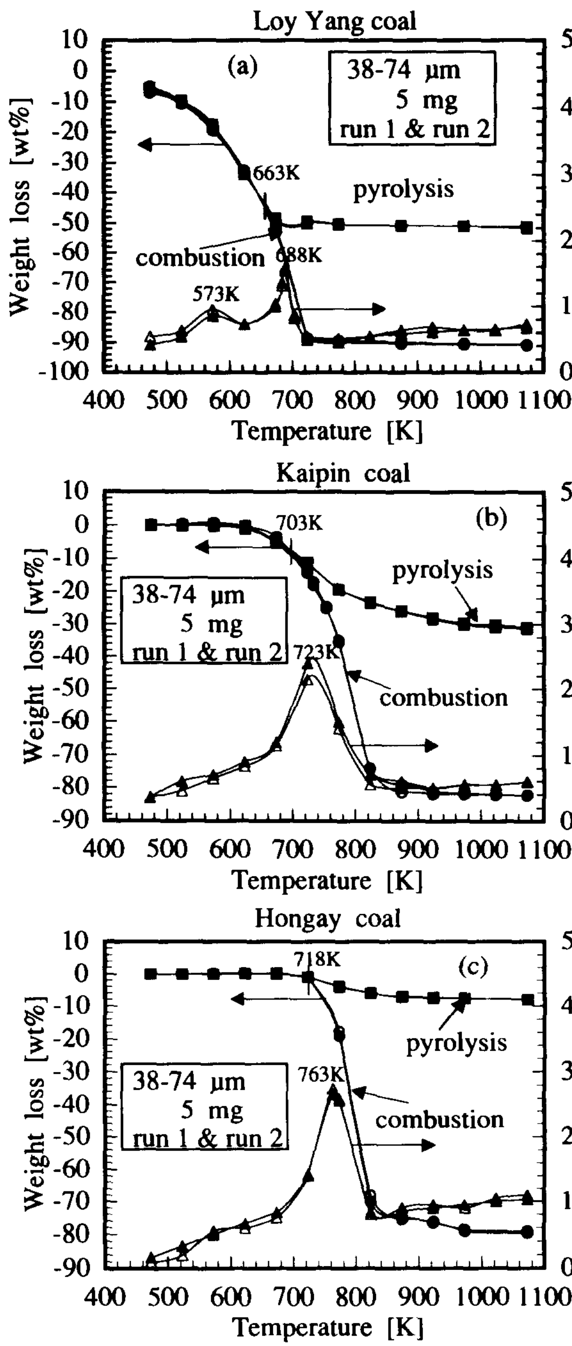

Fig. 3. Determination of ignition temperature.

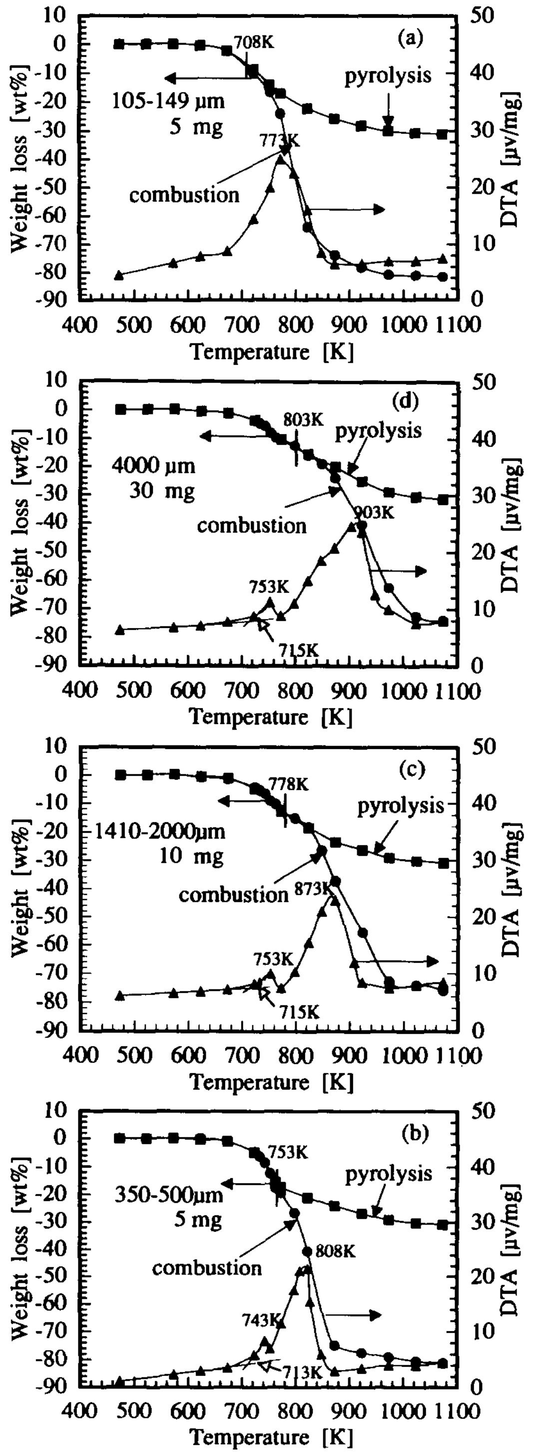

Fig. 4. Effect of particle size on the ignition of Kaipin coal.

pyrolysis curve, is almost equal to the volatile matter content of the coal. Therefore, the ignition of Loy Yang coal is concluded to be homogeneous ignition.

The data for Kaipin coal (Fig. 3(b)) indicate that the TG combustion curve is separated from the TG pyrolysis curve when part of the volatile matter has been released from the coal. Moreover, before the turning point at 703 K, an exothermic DTA peak can be found. Thus, it is concluded that the ignition of Kaipin coal is hetero–homogeneous.

For Hongay coal (Fig. 3(c)), the particles are ignited heterogeneously by direct attack of oxygen on the whole particle rather than the char, since the volatile matter has not released from the coal before ignition. This is because of the low VM content of the coal [9].

From the above results, it is found that three different qualities of coal show different types of ignition, and the ignition temperatures increase as the quality of the coal increases. On the basis of these results it is considered that they have different chemical structures owing to increasing aromatic rings content and a reduction in the number of bridges with increasing coal quality from lignite through bituminous to anthracite. Further, it was also found that with increasing coal quality, release of volatile matter from the coal during the heating process becomes increasingly difficult.

3.2. *Effect of particle size on ignition temperature*

Because Loy Yang coal ignites homogeneously even for smaller particles at low heating rates, it is estimated that its ignition type is not changed with increasing particle size.

Figs. 4(a) to 4(d) show the TG–DTA curves of Kaipin coal of various particle sizes. It may be observed that the TG–DTA curve shifts to higher temperature levels with increasing particle size. The shape of DTA curve is also changed by changing the

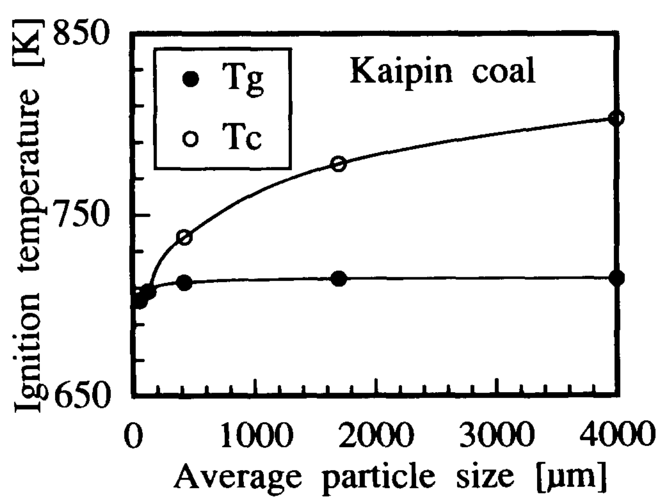

Fig. 5. Relationship between particle size and ignition temperature of char and volatile matter for Kaipin coal.

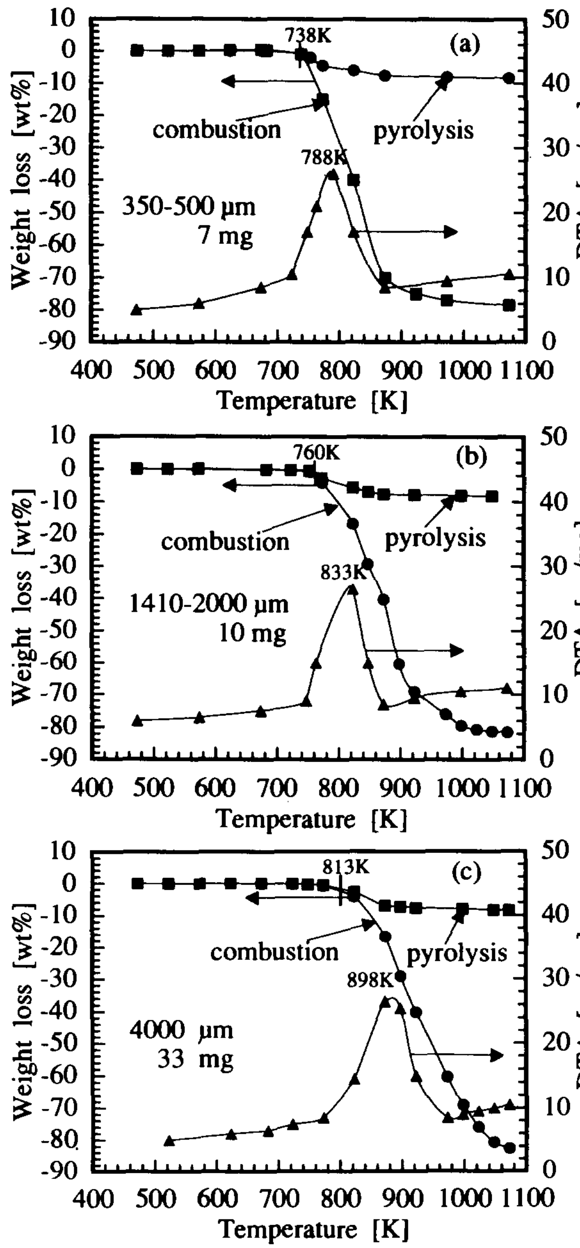

Fig. 6. Effect of particle size on the ignition of Hongay coal.

particle size. For particles with diameters of 105–149 µm, the shape of DTA curve is similar to that from particles of 37–74 µm diameter. However, for particles with diameters of 350–500 µm, the exothermic peak is divided into two and the TG combustion curve is also composed of two stages. As the particle size increases further,

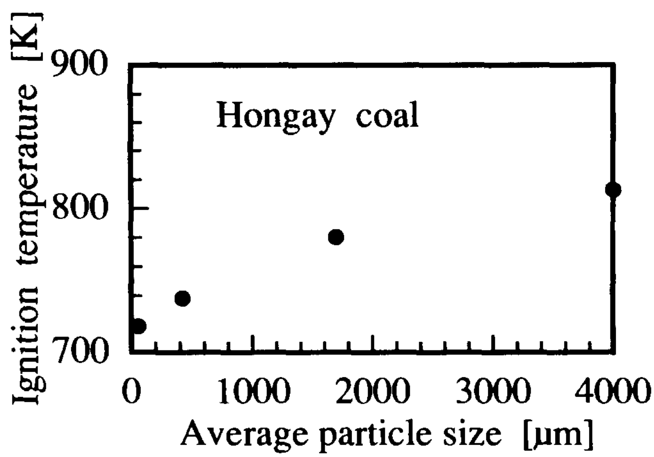

Fig. 7. Relation between ignition temperature and particle size for Hongay coal.

two exothermic peaks on the DTA curve and two stages on the TG combustion curve become more clearly apparent. It can, moreover, be seen from Fig. 5 that the ignition temperature of the volatile matter (T_g) is almost unchanged at all particle sizes; the ignition temperature (T_c) of the residual char shifts, however, to higher temperature levels with increasing parcile size.

The reasons for the observations above are that as the particle size increases:

(1) the rate of heating of the particle surface becomes slower than the rate of evolution of the volatile matter;

(2) the combustion of the volatile matter prevents reaction of the char by screening the solid from access by oxygen.

Figs. 6(a) to 6(c) and Fig. 7 show the effect of particle size on the ignition of Hongay coal and the relationship between the ignition temperature and particle size. It is found that heterogeneous ignition is still observed with increasing particle size, although the ignition temperature shifts to higher temperature levels. It is, therefore, concluded that the Hongay anthracite coal always ignites on the particle surface (heterogeneous ignition), and that its ignition type is not effected by particle size.

4. Conclusion

The following results were obtained by ignition experiments on three qualities of coal of various particle sizes.

(1) TG–DTA ignition measurement is an excellent method for accurate determination of the ignition temperature of coal particles.

(2) As coal quality increases from lignite through bituminous coal to anthracite, ignition type changes from the homogeneous through the hetero–homogeneous to heterogeneous ignition.

(3) As the coal particle size increases, the ignition type for Kaipin bituminous coal changes from hetero–homogeneous to homogeneous, and char ignition is separated from volatile ignition and shifts to higher temperature levels. The ignition types of both Loy Yang lignite coal and Hongay anthracite coal are not effected by particle size.

References

[1] R.H. Essenhigh, M.K. Misra and D.W. Shaw, Combust. Flame, 77 (1989) 3.
[2] T.F. Wall, R.P. Gupta, V.S. Gururajan and D.K. Zhang, Fuel, 70 (1991) 1011.
[3] D.K. Zhang, T.F. Wall, D.J. Harris, I.W. Smith and B.R. Stanmore, Fuel, 71 (1992) 1239.
[4] L. Tognotti, A. Malotti, L. Petarca and S. Zanelli, Combust. Sci. Technol., 44 (1985) 15.
[5] R.P.V. Venkatesh, R.M.R. Josyula, K.S.R. Balisagar and A.T. Mandayam, Fuel, 61 (1982) 634.
[6] J. Tomeczek and J. Wojcik, 23rd Int. Symp. Combustion, The Combustion Insitute, Pittsburgh, 1990, p. 1163.
[7] D.K. Zhang, Combust. Flame, 90 (1992) 134.
[8] M. Rostam-Abadi and J.A. DeBarr, Proc. 20th NATAS, Minneapolis, MN, 1991 418.
[9] D.L. Carpenter, Combust. Flame, 1 (1957) 63.