Ignition characteristics of coal blends in an entrained flow furnace

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Abstract

Ignition tests were carried out on blends of three coals of different rank - subbituminous, high volatile and low volatile bituminous - in two entrained flow reactors. The ignition temperatures were determined from the gas evolution profiles (CO, CO₂, NO, O₂), while the mechanism of ignition was elucidated from these profiles and corroborated by high-speed video recording. Under the experimental conditions of high carbon loading, clear interactive effects were observed for all the blends. Ignition of the lower rank coals (subbituminous, high volatile bituminous) enhanced the ignition of the higher rank coal (low volatile bituminous) in the blends. The ignition temperatures of the blends of the low rank coals (subbituminous-high volatile bituminous) were additive. However, for the rest of the blends the ignition temperatures were always closer to the lower rank coal in the blend.

Keywords: Coal blending; Ignition behaviour; Entrained flow reactor

1. INTRODUCTION

The use of coal blends is now conventional practice in power stations that fire pulverised coal. This is due to strategic, economic, environmental reasons or in order to improve the combustion properties of the blended coal [1, 2]. Coal is the most abundant and widely geographically distributed fossil fuel. Thus, coal blending is an opportunity to diversify the range and to reduce the costs of using coal for power generation. Some aspects of the

combustion behaviour of blended coals, such as emissions of sulphur oxides, overall ash loading and thermal input, can be resolved reasonably well from a knowledge of the properties of the component coals in the blend and their respective mass fractions [3]. However, other aspects (i.e., ignition behaviour, slagging and fouling, NO_x emissions and burnout) cannot always be estimated from the behaviour of individual coals [4-6].

Furthermore, the ignition of coal particles is an important preliminary step in the coal combustion process, due to its influence on flame stability, the formation and emission of pollutants, and flame extinction. The reactivity and ignition behaviour of coal particles is of considerable importance for designing the boiler and controlling the combustion process. The ignition of coal particles may take place either homogeneously or heterogeneously. In the homogeneous ignition mechanism, the initial step involves the rapid release and subsequent ignition of volatiles which react in the gaseous phase surrounding the coal particles. This is followed by ignition of the char. The heterogeneous coal ignition mechanism involves the direct attack of oxygen on the whole coal particles and, in this case, the rates of heat generation due to combustion reactions are much higher than the rates of heat removal [7-9].

Several experimental techniques have been employed to study the ignition behaviour of coal. Visual flash has been used as an indicator of coal ignition [10-12]. Thermogravimetric analysis (TGA) is another technique commonly used to determine the temperature and mechanism of coal ignition [13-16]. The evolution of the gaseous products during coal ignition and burnout has also been employed to determine the ignition temperature of pulverised coal [17-20]. However, it is well known that the ignition temperature and mechanism are not inherent properties of coal [12, 21]. They depend on the type of test apparatus and the operating conditions employed. Therefore, the ignition temperature of a fuel should be determined under conditions similar to those in which it is to be used.

Although the operating conditions in an entrained flow reactor (EFR) are different to those in pf combustion, they are closer to industrial conditions than TGA. Furthermore, the EFR can assess coal ignition behaviour in a cheaper and more rapid way than tests carried out in pilot-scale plants. In a previous paper [19], the temperatures and mechanisms of coal ignition for different rank coals ranging from subbituminous to semianthracite, were determined in an entrained flow reactor (EFR). It was found that the mechanism of ignition changed from heterogeneous for subbituminous, low volatile bituminous and semianthracite coals, to homogeneous for high volatile bituminous coals.

In the present work the ignition temperature and the mechanism of ignition were determined for various binary coal blends by means of tests carried out in two entrained flow reactors. In the first EFR the change in the slope of the evolution curves of the gaseous products was used as an indicator of ignition and to determine the temperature of coal blends ignition. The second EFR was fitted with a slotted window to permit cinematographic observation. The methodology used in this work allowed us to assess the ignition behaviour of the coal and coal blends and to study the interactive effects in the coal blends.

2. EXPERIMENTAL

The tests to determine the temperatures and mechanisms of ignition were carried out in an electrically heated entrained flow reactor. Full details of the experimental set-up and procedure have been previously provided [19]. In brief, coal samples were ground to below 106 μm , and dry sieved to obtain a particle size fraction of 53–106 μm . The coals were fed in continuously at a rate of 0.5 g min⁻¹. The reactor was heated at 15 °C min⁻¹ from 500 to 800 °C. The experiments were conducted under stoichiometric conditions, in air, and 100% excess oxygen. A gas flow rate was chosen to ensure 2 seconds residence time at 500 °C. The criterion for determining the ignition temperature was based on the derivative curves of the

gases produced. The ignition temperature was taken as the temperature where the derivative curves, normalised with respect to the maximum derivative value, reached a value of 10% [19].

Three coals were used in the tests; PE, subbituminous (20.7% ash, 39.8% VM, db), LK, hvb (6.2% ash, 35% VM, db), and LD, lvb (4.7% ash, 16.5% VM, db). To study the effect of blending on the ignition characteristics of the resultant blends, nine binary blends at percentages of 25, 50 and 75 wt%, were prepared from the three coals.

For the visual observations and video recording another entrained flow reactor was employed. It consisted of a quartz tube of 4 cm internal diameter located inside an electric furnace, capable of reaching a maximum temperature of 1200 °C. This EFR has a slotted window (1.5 cm wide, 4 cm high) which allows optical access to the reaction zone situated immediately behind the injection probe. The ignition tests recorded on a video camera were carried out both on the individual coals and their binary blends at a percentage of 50% wt. In these experiments the coal samples (53-106 μm) were introduced continuously into the reactor at a fixed temperature of 750 °C, and the residence time was set at 1 second.

3. RESULTS AND DISCUSSION

In the previous paper in which the ignition of individual coals was studied [19], the high volatile bituminous coal LK, presented a homogeneous ignition mechanism resulting in the sequential ignition of volatiles and char. This was reflected in the double peak in the evolution profiles of the gases emitted. By contrast, the low volatile bituminous coal, LD, and the subbituminous coal, PE, displayed a heterogeneous ignition mechanism resulting in the simultaneous ignition of volatiles and char. In the case of the subbituminous coal PE, this was explained by the high reactivity of its char, while for coal LD the heat generated by the

combustion of volatiles was not sufficient to ignite the LD char at temperatures lower than 700 °C.

In Figure 1 selected frames of the individual coals, captured from the video recording of the ignition experiments performed in the EFR, are shown. These images clearly confirm the conclusions extracted from the gas evolution profiles, i.e., it can be observed in Figure 1 that coal PE burned discretely, withstanding the formation of common flames. This is much more evident in the case of coal LD, where the particles burned individually, surrounded by faint flames occurring at a lower frequency than in the case of PE. Thus, the behaviour of PE and LD is in accordance with a heterogeneous ignition mechanism.

A totally different behaviour was observed for coal LK, as can be seen in Figure 1. The burning of LK resulted in a bright and common flame that occupied a large volume of the quartz reactor around its centre line. This behaviour is characteristic of a homogeneous ignition mechanism which involves the evolution and subsequent combustion of the volatiles that react in the gaseous phase surrounding the coal particles.

In the case of the blends of coals LK (hvb) and PE (sub), Figure 2 shows the CO evolution for the ignition experiments conducted in air. It should be noted that the rest of the gases analysed (CO_2 , NO, O_2), evidenced the same behaviour as that of CO. The evolution of CO and, consequently, the ignition temperatures shifted to higher temperatures with the increase in the proportion of LK in the blends, as might be expected. It can be inferred from this figure that the mechanism of ignition for LK as well as for the blend with 75 wt% LK (LK-75) is homogeneous, as reflected by the double peak in the CO profiles. For the other two blends, LK-50 and LK-25, the ignition mechanism is heterogeneous, with a single peak in the CO emissions.

Figure 3 shows the ignition temperatures determined for the blends LK-PE. It can be seen that the temperature of ignition decreases with the increase in the oxygen available for the coal

particles. Figure 3 also shows a linear trend for the tests in air, 100% excess oxygen and under stoichiometric conditions. This linearity may be interpreted as being the result of an interactive particle-to-particle effect between the coals. That is to say, if the coals ignited independently, then the temperature of ignition would be closer to that of coal PE for all the blends. As this is not the case, it seems that the ignition of PE was delayed by a competitive factor, i.e., the ignition of the LK volatiles which are competing for the oxygen available.

For the 50% blend of LK-PE a heterogeneous mechanism was deduced from the evolution of the gases. However, the images presented in Figure 4 for the 50% blend of LK-PE indicate that this blend exhibits a behaviour halfway between homogeneous and heterogeneous ignition. In some instants the coal particles burned discreetly with distinct enveloping flames, no flame to flame interactions being evident in this case. At other moments the formation of an enveloping elongated flame could be clearly observed. However, this was not a continuous process and the formation of a sustainable flame with time was not observed.

When considering the blends of LD (lvb) and PE (sub) a different behaviour was observed in comparison to that of LK-PE, both in the mechanism and the temperatures of ignition of the blends. Although the ignition temperatures of coals LD and PE were markedly different, the two coals presented an heterogeneous mechanism of ignition. The results corresponding to the ignition temperatures of the blends are displayed in Figure 5. In this figure it can be seen that in all cases (air, 100% excess oxygen or under stoichiometric conditions) the temperatures of the blends are much closer to that of coal PE. The low volatiles content of coal DI means that they do not compete for the oxygen available and they do not interfere with the ignition of PE. However, the ignition of coal PE exerts a strong influence on the ignition of the low volatile bituminous coal DI. This effect can even be observed in the test conducted in air for the blend with 90% LD. The temperature of ignition in this case is 638 °C, in comparison to 583 °C and 707 °C for PE and LD, respectively. Likewise, from the gas evolution curves only one

ignition event was observed. Clearly, there is an interactive effect since the ignition of coal PE favours the concurrent ignition of coal LD. Some representative still pictures shown in Figure 6 extracted from the video observations confirm that a heterogeneous ignition mechanism took place in the case of the 50-50 PE-LD blend, and that it occurred as a one-step ignition event. In Figure 6 it can be seen that the blend burns as isolated particles without the formation of a stable flame.

The last series of samples was composed of binary blends of LK (hvb) and LD (lvb), which presented a heterogeneous and homogeneous ignition mechanism, respectively. The results displayed in Figure 7 indicate that the ignition temperatures are closer to the temperature of coal LK. It should be noted that these blends formed bright common flames. The flame wakes were also more pronounced and much longer than in the case of those formed by the ignition of LK (cf Figure 2). The elongated flames corresponding to the 50-50 LK-LD blend are shown in Figure 8. These flames are up to two times higher than those of LK; this effect is clear evidence that the ignition of the higher volatile level component of the blend, LK, enhances the ignition of the lower volatile coal, LD, leading to a stable and sustained flame, as can be seen in Figure 8. It should be noted that, although blending coals of differing volatile composition may lead to average an flame stability behaviour, the burnout of coal blends could be better or worse than the average.

4. CONCLUSIONS

By means of ignition tests carried out in two entrained flow reactors under continuous feeding it was possible to determine the temperatures of ignition and to elucidate the mechanisms of ignition of coal blends, constituted by binary mixtures of different volatile matter content coals. For blends of a subbituminous coal, PE, (homogeneous ignition), and a high volatile bituminous coal, LK, (heterogeneous ignition), the mechanism of ignition is determined by

the coal with the predominant proportion in the blend. The ignition temperature in this case is a mean value of those of the individual coals, indicating that there is interaction between the volatiles of LK and PE.

When the individual coals presented a heterogeneous mechanism, the blends displayed the same mechanism. This was the case of the subbituminous coal, PE, and the low volatile bituminous coal, LD. The temperatures of ignition, however, were much closer to those of the lower rank coal in the blend, PE.

It was demonstrated that under the experimental conditions employed, the ignition of the lower rank coals (PE, subbituminous, and LK, high volatile bituminous) enhanced the ignition of the higher rank coal, LD (low volatile bituminous).

However, the inclusion in a blend of a coal which has a high volatile heat release cannot be assumed to lead to an enhanced char burnout in a higher rank coal. The availability of oxygen is a competing factor which may result in burnouts of coal blends being higher or lower than the burnout calculated from the average weight of the individual coals.

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List of figures

Figure 1. Representative still pictures of the ignition of the PE, LK and LD coals.

Figure 2. CO evolution profiles of the LK-PE blends during the tests in the entrained flow reactor.

Figure 3. Variation of the ignition temperatures of the LK-PE blends.

Figure 4. Representative still pictures of the ignition of the 50-50 LK-PE blend.

Figure 5. Variation of the ignition temperatures of the PE-LD blends.

Figure 6. Representative still pictures of the ignition of the 50-50 PE-LD blend.

Figure 7. Variation of the ignition temperatures of the LK-LD blends.

Figure 8. Representative still pictures of the ignition of the 50-50 LK-LD blend.

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