

A TG/DTA STUDY ON THE EFFECT OF COAL BLENDING ON IGNITION BEHAVIOUR

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Abstract

Understanding the ignition behaviour of coal is of utmost importance for the design of boilers and control of the combustion process. In recent years there has been an increasing utilisation of coal blends for combustion, but information on the possible interactive effects during ignition of the individual components is scarce. In this work the ignition behaviour of a series of coal blends, made up from three coals of different rank, sub-bituminous, high volatile and low volatile bituminous, was studied. To this end a thermogravimetric analyser linked to a mass spectrometer for evolved gas analysis was used. Different ignition behaviour was observed for the coals studied; the sub-bituminous and low volatile bituminous coals ignited heterogeneously, while homogeneous ignition occurred for the high volatile bituminous coal. In the case of blends of the low and high volatile bituminous coals, different mechanisms of ignition were observed depending on the blends composition.

Keywords: coal blends, DTA, ignition, interactive effects, TG

Introduction

Coal blending is becoming a normal practice in large combustion plants, which utilise low-cost imported coals for blending with local coals, as operators attempt to increase the flexibility of fuel types, improve the combustion behaviour of their coals and meet the requirements of emission legislation. Although some aspects of the combustion behaviour of blended coals in power stations can be determined reasonably well from knowledge of the properties of the component coals in the blend and their respective mass fractions [1, 2], this is not a general rule and there are some important aspects that cannot be predicted, such as the ignition behaviour.

Ignition is considered as the process initiating the combustion phenomenon and it is a relevant step due to its influence on flame stability, pollutants formation and emission, and flame extinction. In practice, the ignition behaviour of coal can be decisive to identify the optimal location for their injection into industrial combustors.

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Ignition of coal particles can occur through homogeneous (i.e., gas phase ignition) or heterogeneous mechanisms [3, 4]. The heterogeneous reaction involves the direct attack of oxygen on the whole sample particle. In the homogeneous mechanism, the initial step is pyrolysis and subsequent ignition of volatiles, followed by ignition of the char.

It is well known that both the temperature and mechanism of ignition are not inherent properties of coal [5, 6]; they depend on the type and operating conditions of the test apparatus. Thus, the ignition temperatures are seen to decrease with increasing sample mass and with decreasing heating rate [5].

The use of small-scale tests for an initial evaluation of the reactivity of coals and blends is a far more rapid and cheaper method than pilot-scale testing. Thermogravimetric analysis has been extensively used for the ignition and reactivity characterisation of different materials and blends [7–11]. Although extrapolation to other devices at larger scale cannot be performed directly, thermogravimetric analysis is very useful from a fundamental viewpoint, and for comparison between samples. Non-isothermal thermogravimetric experiments can be used not only for providing information about the ignition process itself but also as a fast and simple ranking method of solid fuels with respect to their reactivity. The higher the ignition temperature, the lower the reactivity of the sample. Thus, it can be said that thermogravimetric analysis gives relevant information about ignition, not in absolute terms (i.e., temperature values) but in giving reliable ignition trends in a series of samples.

Nevertheless, no general consensus has been reached on the ignition mechanisms and very little information is available about the interaction between components of coal blends and how this influences ignition. Therefore, the main objective of this work was to study the ignition behaviour of different coals by thermogravimetric analysis and to assess the possible interactive effects induced by blending.

Experimental

Three coals of varying rank and different origin were selected and used for the preparation of binary blends in different proportions: a sub-bituminous coal from Chile (PE), a high volatile bituminous coal from USA (LK) and a low volatile bituminous coal from Spain (LD). The main characteristics of these coals are given in Table 1. As can be seen they present different volatile matter content, which exerts a strong influence on the ignition behaviour.

Temperature-programmed pyrolysis and combustion tests of the coals and blends selected were performed in a differential thermogravimetric analyser (Setaram TAG 24). Experimental conditions leading to consistent reproducible results were established from previous works [12, 13]. In all experiments, approximately 5 mg of sample were heated at $15^{\circ}\text{C min}^{-1}$ from room temperature to 850°C . A gas flow rate of $50\text{ cm}^3\text{ min}^{-1}$ was used; the inert gas for pyrolysis experiments was argon and air was used as the reactive gas for the combustion tests.

Table 1 Main characteristics of the coals used

| Coal | PE | LK | LD |
|--|-----------------------|-----------------------|-----------------------|
| Proximate analysis | | | |
| Ash/mass%, db | 20.7 | 6.2 | 4.7 |
| V.M./mass%, daf | 50.2 | 37.3 | 17.3 |
| Ultimate analysis/mass%, daf | | | |
| C | 71.2 | 85.1 | 88.0 |
| H | 5.3 | 4.9 | 3.8 |
| N | 1.1 | 1.6 | 1.6 |
| S | 0.6 | 0.8 | 3.5 |
| O (by difference) | 21.8 | 7.6 | 3.1 |
| Calorific value/kJ kg ⁻¹ , db | 2.268 10 ⁴ | 3.326 10 ⁴ | 3.324 10 ⁴ |
| Rank | sb | hvb | lvb |

db: dry basis; daf: dry ash free basis; sb: sub-bituminous; hvb: high volatile bituminous; lvb: low volatile bituminous.

A quadrupole mass spectrometer, QME 125 from Balzers, was coupled to the thermobalance for analysing the evolved gases. The ionisation was performed by an axial beam ion source (100 eV). The ions, separated according to their mass-to-charge ratio, were detected by a Faraday collector. The optimisation of the coupling system has been described elsewhere [14].

Results and discussion

Individual coals

The evaluation of the ignition behaviour was performed from the analysis of the TG and DTA profiles of the samples studied. The ignition indicator is the deviation of mass loss in inert vs. oxidising gas. In this evaluation the assumption is that pyrolysis depends only on the particle temperature, and that oxidation of the particle surface leads to an additional mass loss [5]. Figure 1 shows the mass loss profiles during pyrolysis and combustion tests of the three coals studied.

It can be observed that the pyrolysis and combustion profiles of each coal coincide until a minimum temperature of 250°C. Only in the case of coal PE there is a significant mass loss before this temperature (10% of the initial mass approximately), which was due to the release of moisture. This was corroborated by the MS profiles, shown in Fig. 2, where the main gaseous products of the combustion tests are presented. As can be seen, at temperatures lower than 250°C, only water is released.

From the comparison of the pyrolysis and combustion profiles of each coal presented in Fig. 1, the ignition temperatures and the mechanism of ignition can be deduced. In the case of LK, a noticeable initial mass loss takes place in the same way, both in pyrolysis and combustion conditions. This means that the volatiles are re-

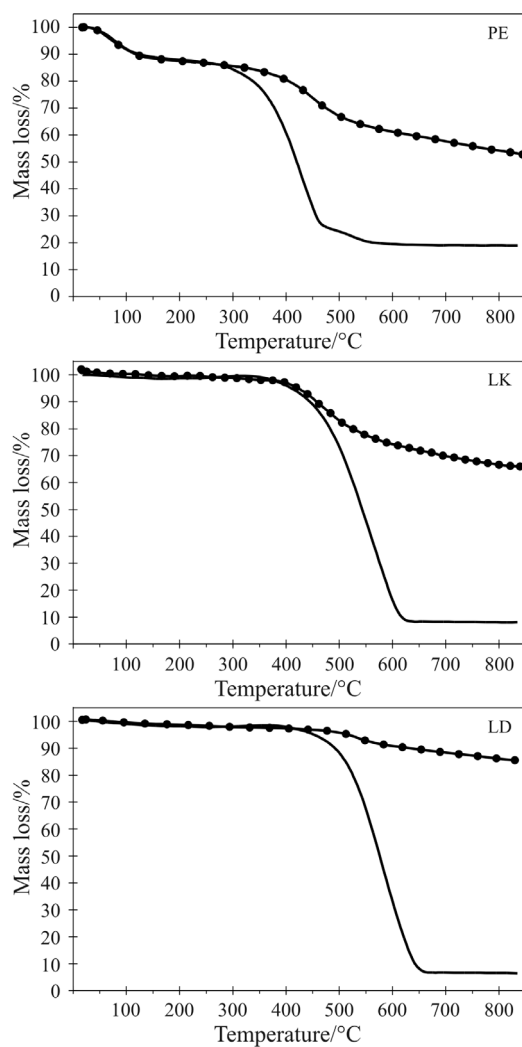


Fig. 1 TG profiles of the coals studied. • – pyrolysis; — – combustion

leased due to the increase of temperature, independently of the nature of the atmosphere. In the presence of oxygen the volatiles ignite and a significant increase of mass loss is observed. This process corresponds to a homogeneous ignition mechanism. However, the other two coals, PE and LD, present a mass loss during the first step of the pyrolysis process very different than that during combustion, indicating that the ignition mechanism is heterogeneous, the whole coal particle burns at the same time (volatiles and char).

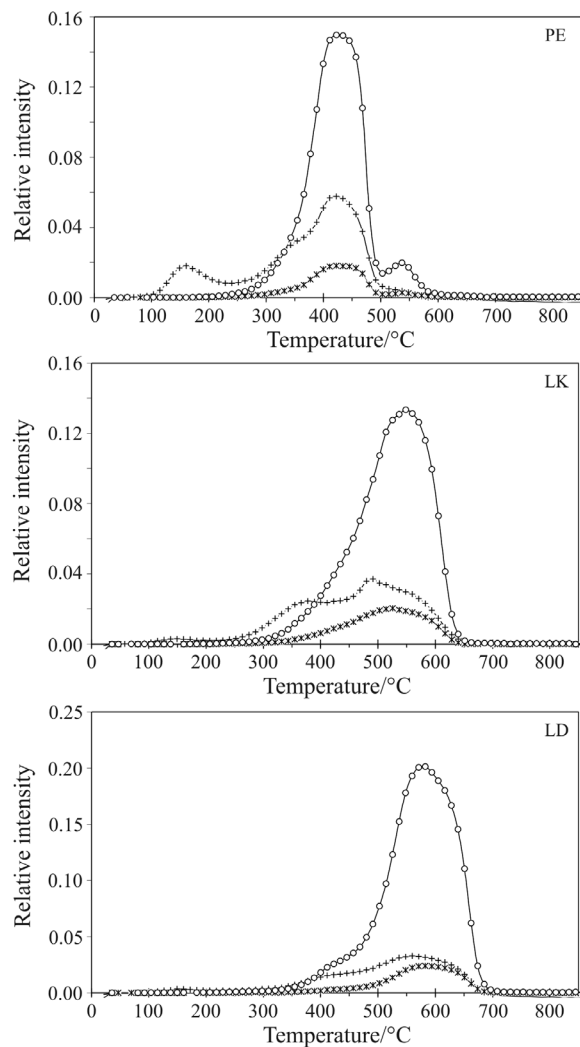


Fig. 2 Gas evolved analysis by MS during temperature-programmed combustion tests in the TG for the coals studied. \circ – CO_2 ; $+$ – H_2O ; $*$ – CO

In the case of coals PE and LD (heterogeneous mechanism) the ignition temperature, T_i , corresponds to the temperature at which the combustion profile separates from the pyrolysis one (284 and 416°C, respectively). However, for the LK coal the ignition temperature should be the volatile ignition temperature and this does not correspond to the deviation point (i.e., 399°C) but to the maximum of the lower temperature peak in the DTA profile (i.e., 376°C) [7, 15].

The coincidence in the ignition mechanism of PE and LD does not imply that they have similar reactivity. It is well known that the higher the burnout temperature,

T_c , defined by the end of the combustion profile, the lower the reactivity of the coal. These temperatures increase from PE to LK and LD (Table 2) indicating a decreasing trend of reactivity.

Table 2 Characteristic temperatures of the coals studied and comparison between experimental and theoretical (calculated assuming linear behaviour) values for the blends selected

| Sample | Blend composition | Experimental $T_i/^\circ\text{C}$ | Theoretical $T_i/^\circ\text{C}$ | Experimental $T_c/^\circ\text{C}$ | Theoretical $T_c/^\circ\text{C}$ |
|--------|-------------------|-----------------------------------|----------------------------------|-----------------------------------|----------------------------------|
| PE | | 284 | | 569 | |
| LK | | 376 | | 613 | |
| LD | | 416 | | 642 | |
| LK:PE | 1:3 | 294 | 307 | 590 | 580 |
| | 1:1 | 329 | 330 | 596 | 591 |
| | 3:1 | 329 | 353 | 609 | 602 |
| LD:PE | 1:3 | 284 | 315 | 613 | 587 |
| | 1:1 | 335 | 350 | 623 | 606 |
| | 3:1 | 352 | 383 | 631 | 624 |
| LD:LK | 1:3 | 376 | 386 | 629 | 620 |
| | 1:1 | 396 | 396 | 632 | 628 |
| | 3:1 | 396 | 406 | 632 | 635 |

T_i : ignition temperature; T_c : burnout temperature

The reasons for heterogeneous ignition mechanisms of coals PE and LD are different. On one hand, the more stable volatile compounds of LD evolve at high temperatures where the char can react and thus the whole particle burns together. On the other hand, the char of coal PE is very reactive and it tends to react at low temperatures, where the combustion of the volatiles also takes place.

The temperature range from the beginning of the tests up to the ignition temperature determines the initial heating and volatile release (zone A in Fig. 3). In the zone B from the ignition point to the end of reaction, a sharp exothermic peak is observed due to the combustion process. The PE profiles present an endothermic peak at around 100°C due to the loss of moisture. The area under the exothermic peak in zone A is also different between coals. Only LK presents a bimodal peak. This is due to different stages of volatiles and char ignition, according to the homogeneous ignition mechanism already deduced from Fig. 1.

Ignition of coal blends

Ignition is the transition from a slow fuel oxidation rate to a rapid oxidation of either the volatiles or the solid matrix [10]. This requires that the heat loss is balanced by the heat generated at the ignition temperature. Therefore, it is important to note that

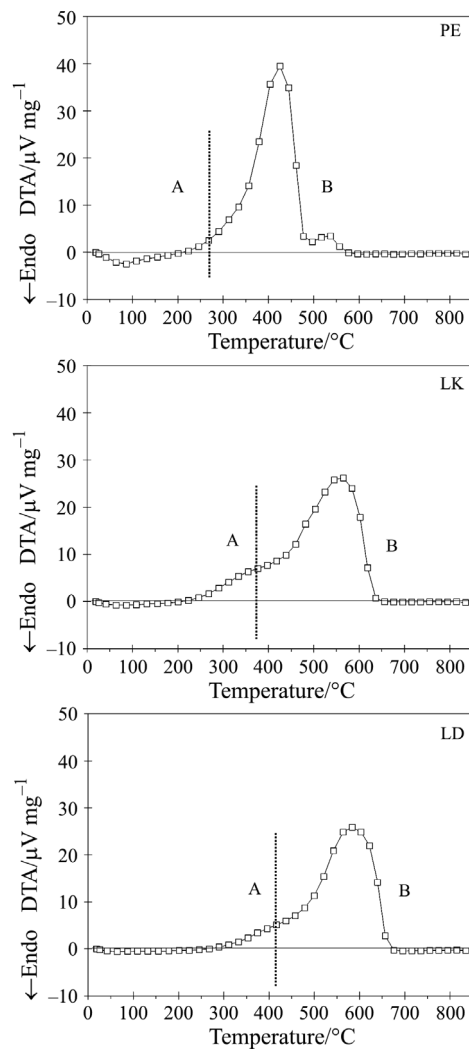


Fig. 3 DTA curves during temperature-programmed combustion tests in the TG for the coals studied

two coals with the same proximate analysis may not have the same ignition characteristics. This occurs because ignition depends on early heat release, not necessarily early volatile release. This increases the difficulty of evaluating the performance of blended coals. When coal blends are burnt the ignition temperature would be, a priori, closer to that of the coal with the lower ignition temperature. This is true if the coals act independently, and the non-ignited coal is not too large a heat sink for the ignited coal [16].

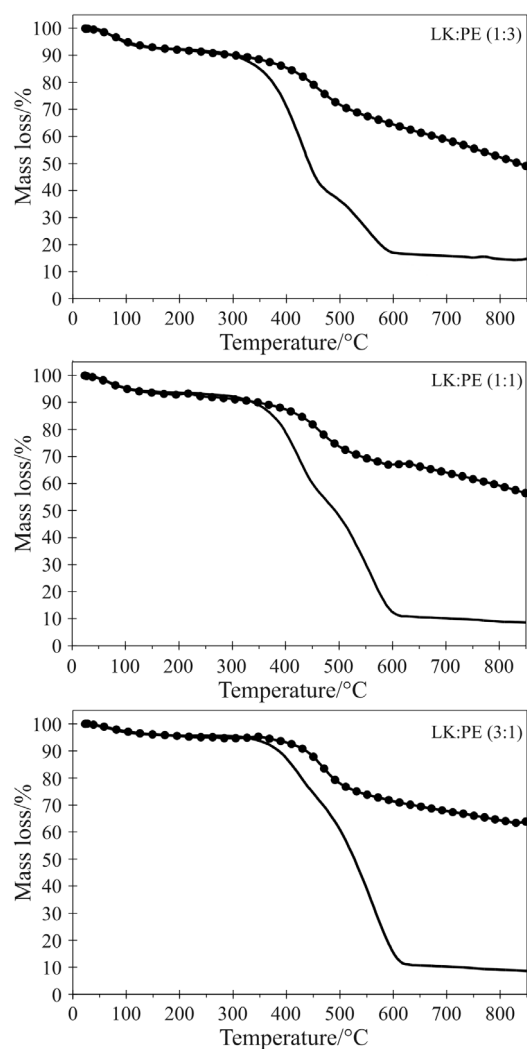


Fig. 4 TG profiles of the LK:PE blends. • – pyrolysis; — – combustion

In this work different binary blends were studied in order to evaluate the interaction between coals and its influence on ignition. Figure 4 shows the TG profiles of the three blends selected from LK and PE coals. It can be observed that for the three blends the mechanism of ignition is heterogeneous, the mass loss during pyrolysis does not coincide with the combustion profile. The blend with the higher content of coal LK, LK:PE (3:1), presents the closest profiles indicating the influence of coal LK on blend ignition behaviour. The ignition temperatures of the blends are presented in Table 2. It can be observed that the T_i values are slightly lower than the theoretical ones, calculated by the additive rule. The burnout temperatures, T_c , are

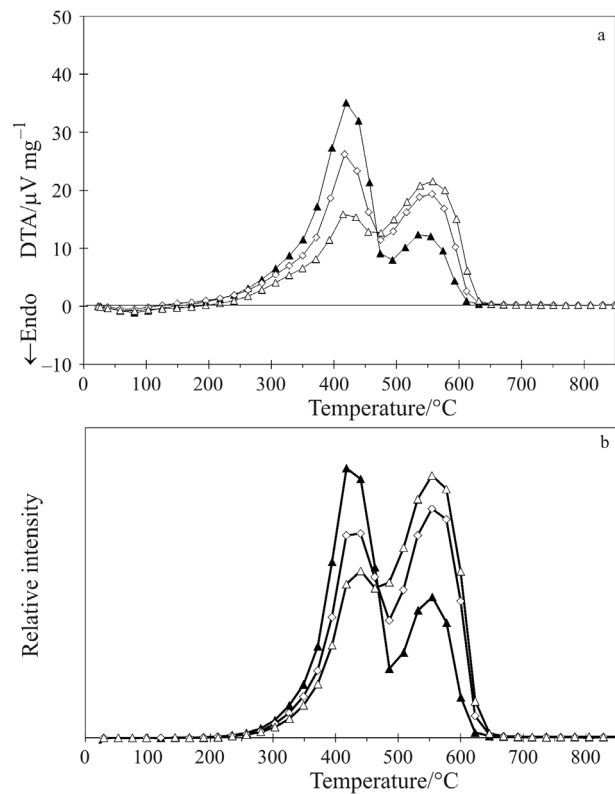


Fig. 5 a – DTA curves during temperature-programmed combustion tests in the TG of the LK:PE blends; ▲ – LK:PE (1:3); ◇ – LK:PE (1:1); △ – LK:PE (3:1),
 b – CO₂ evolution profiles during temperature-programmed combustion tests in the TG of the LK:PE blends; ▲ – LK:PE (1:3); ◇ – LK:PE (1:1); △ – LK:PE (3:1)

slightly higher than the theoretical values. It is clear that the lower rank coal (PE) influences on the T_i while the higher rank coal (LK) influences on the T_c of the blends. The DTA curves (Fig. 5a) show two well defined peaks, corresponding to the separate combustion of the two chars. The CO₂ evolution profiles (Fig. 5b) present the same behaviour. Thus it can be said that no interaction between LK and PE was observed in the experiments performed in this work.

Figure 6 presents the TG profiles from the pyrolysis and combustion tests of the LD:PE blends. The two individual coals presented heterogeneous ignition mechanisms, and so do the three blends studied. The ignition and burnout temperatures of the blends (Table 2) are clearly lower and higher, respectively, than the theoretical ones calculated by assuming the additive rule. This clearly indicates that the components burn separately, PE being the coal that determines the T_i of the blend, whilst LD is the coal that influences more on the T_c of the blends.

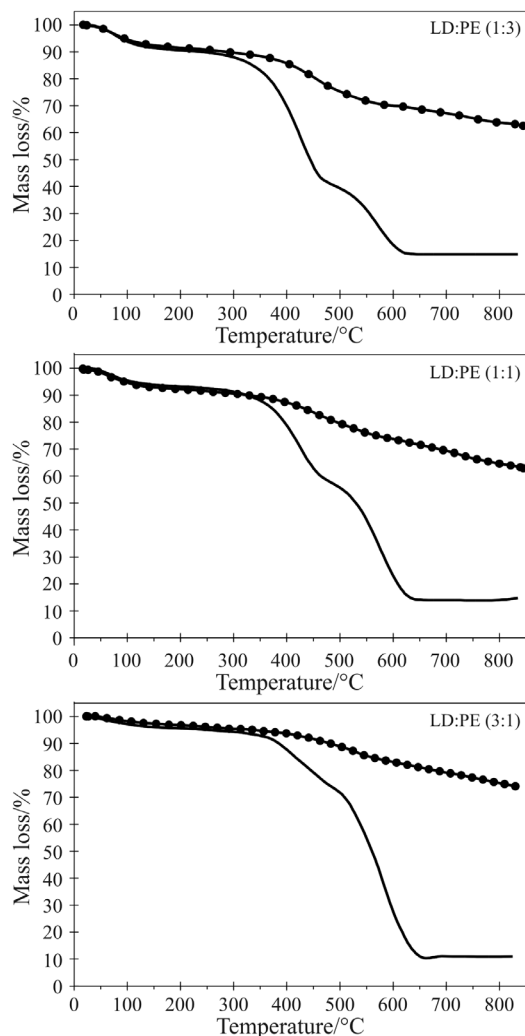


Fig. 6 TG profiles of the LD:PE blends. • – pyrolysis; — – combustion

Figure 7 shows the three binary blends LD:LK studied. The LK coal presented individually homogeneous ignition mechanism, and LD showed heterogeneous one. It was observed that in the corresponding blends the mechanism of ignition changes from heterogeneous to homogeneous as the percentage of LK increases in the blend. Thus, for the sample LD:LK (3:1) the mechanism is heterogeneous, for LD:LK (1:3) it is homogeneous and for the blend LD:LK (1:1) the mechanism seems to be a mixture (Fig. 7). It has to be remarked that in the case of the blends LD:LK no inflexion point was observed in the TG profile during combustion, and according to the shape of the curves the blends burn as a single coal. This is corroborated by the DTA curves presented in Fig. 8. The ignition temperatures were calculated in the same way as for

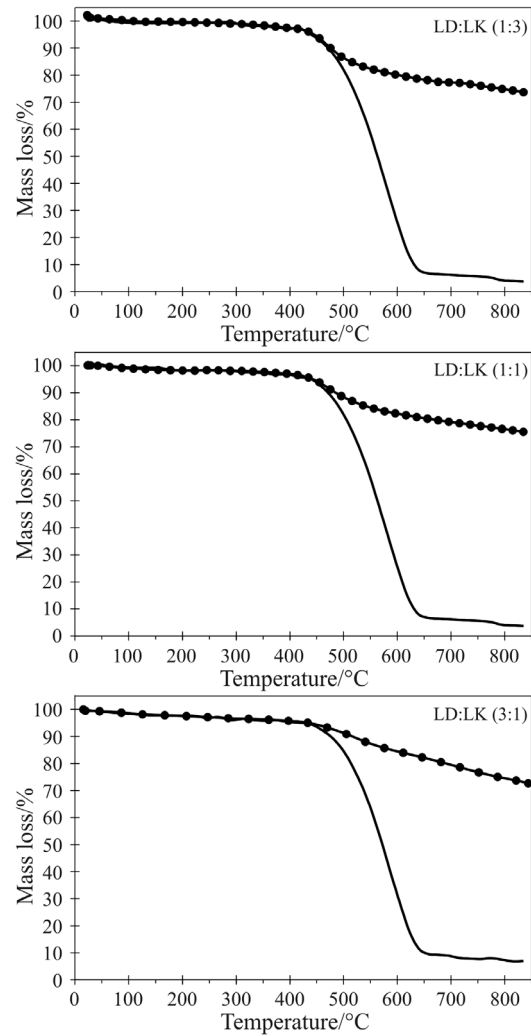


Fig. 7 TG profiles of the LD:LK blends. • – pyrolysis; — – combustion

the LK coal, that is from the maximum peak temperature of the first peak in the DTA curve. Table 2 shows the values obtained, and it can be observed that both T_i and T_e experimental values are very close to the theoretical ones.

In summary, it can be said that volatile matter content influences on the ignition temperature but not on the mechanism of ignition, the latter not being correlated with any of the typical parameters obtained from coal chemical analysis. In the case of blends of the low and high volatile bituminous coals, different mechanisms of ignition were observed depending on the blends composition. From the results obtained it can be said that it is not possible to predict blends behaviour from that of the individual components.

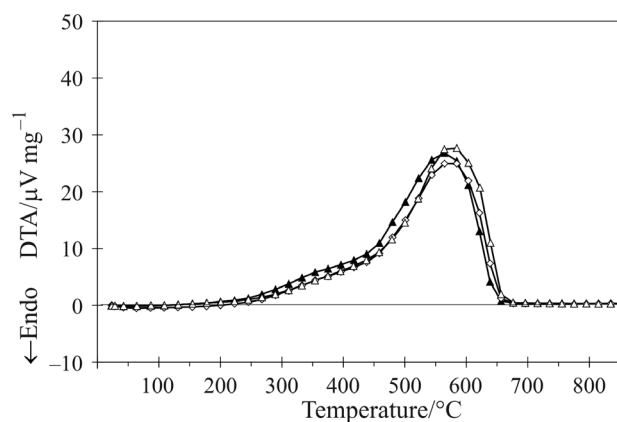


Fig. 8 DTA curves during temperature-programmed combustion tests in the TG of the LD:LK blends; ▲ – LD:LK (1:3); ◇ – LD:LK (1:1); △ – LD:LK (3:1)

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