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Thermogravimetric analysis of the co-combustion of the blends with high ash coal and waste tyres

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Abstract

Incineration methods are becoming increasingly important from the view point of the need to minimize the environmental impact of waste tyre disposal. Combustion of waste tyre, one high ash coal and tyre-coal blends with 10, 30 and 50% waste tyre were investigated by means of thermogravimetric analysis (TGA) carried out at 20 K min^{-1} in the temperature range from ambient temperature to 1273 K. And effects of the mixed proportion between coal and waste tyre on the combustion process, ignition and burnout characteristics were also studied. The results indicate that the combustion of waste tyre is controlled by the emission of volatile matter, the regions are more complex for waste tyre (three or more peaks) than for coal (one peak). Also as compared with the case of burning only high ash coal, the incorporation of waste tyre can improve the combustion characteristics of high ash coal, especially the ignition performance and the peak weight loss compared with the separate burning of waste tyre and coal. Moreover, comparisons of the TG–DTG profiles between experimental and calculational results, it is indicate that there is a comparatively important difference, the co-combustion characteristics is the coupling effect between waste tyre and coal. The data resulting also showed that the co-combustion of waste tyre and low quanlitied coal as fuel is feasible.

Keywords: Waste tyre; High ash coal; Co-combustion; Thermogravimetric analysis (TGA)

1. Introduction

Considerable attention has been focused on the growing stockpiles of used automotive tyres, as these are non-biodegradable and create adverse environmental effects. The options presently available for disposing of tyres are landfilling/tyre dumps, mechanically processing the tyres, retreading, pyrolysis and rubber reclaim, energy recovery, etc., however, available landfill sites have been decreasing at an alarming rate and, thus, tipping fees are increasing. Storing tyres in tyre dumps poses a fire and health hazard, since fires are difficult to control therein and release large amounts of toxic pollutants.

Tyre dumps are also host to disease-carrying mosquitoes and rats.

The combustion of waste tyre and its blends with coal combines a number of advantages that are not found in other disposal methods [1–7]. These advantages include a large reduction of waste tyres volume as well as the thermal destruction of toxic organic compounds and pathogens. Moreover, these methods permit the recovery of the energetic value of this material replacing a non-renewable fuel. However, the co-combustion process may have some disadvantages, mostly related to the emissions of NO_x, trace elements and dioxins [8–10].

Due to the technological properties of waste tyres (volatile matter, ash and fixed carbon), unlike the coal, significant differences in the combustion profiles must be expected. This may have an important influence on combustion efficiency. Studies on thermogravimetric analysis (TGA) profiles contribute to enhance the knowledge of this process and, therefore, to establish the optimum operational conditions to develop it. Accordingly, several authors have studied the behaviour of the pyrolysis and combustion of coal, biomass, sewage sludge, refuse derived fuel (RDF) and others materials by TGA [11–14]. However, there are fewer literatures to study the co-combustion of high ash coal and waste tyres.

The objective of the presented study has been to investigate the combustion characteristics of separate burning of the waste tyres and co-burning of waste tyres and coal by thermogravi-

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metric analysis. Influences of the proportion of waste tyre on the combustion process, ignition and burnout performance were also determined, evaluating the interactions between the blend components. The data resulting may be used to enhance the understanding of the characteristics of waste tyres and also provide a useful basis for further designing and operating the combustion equipment with high-efficiency if the mixed-fuels were used in cement industries.

2. Experiments

The material whose thermal decomposition was studied consisted of scrap automobile tyre feedstock, coal and the mixed-fuel of waste tyre and coal. Waste tyre was prepared by the waste tyres which were shredded and grinded to 0.2–1.6 mm diameter particle size. The volatile of waste tyre reached to 65%. High ash coal was supplied by a cement plant, whose ash arrived to 44.2%. The blends containing 10, 30 and 50% waste tyre were prepared. The percentages of waste tyre refer to the weight of coal and were added to the mixing. The materials were stored in the laboratory under dry conditions.

The combustion characteristics of high ash coal, waste tyre and the mixture of coal and waste tyre were determined in a NETZSC STA-449C thermogravimetric analyzer. The combustible mass of the samples was kept at 20 mg. In an air flux of 20 mL min^{-1}, the furnace temperature was increased from ambient temperature to 1273 K at 20 K min^{-1}. The weight of sample was monitored continuously as a function of temperature. The TG, DTG and DSC experiment of coal, waste tyre and the mixed fuel are completed.

3. Results and discussion

3.1. Co-burning process of blends of waste type and coal

The co-burning profiles of different blends had been compared with the profiles of high ash coal and waste tyre. Fig. 1(a)–(c) shows the TG and DTG profiles of the blends, high ash coal and waste tyre. The characteristic parameters were obtained from the burning profiles, as shown in Table 1.

It was found from Fig. 1 that the coal shows the typical combustion profile of high ash coal with a main peak comprised between 400 and 700 °C with a maximum weight loss rate at 590 °C, the result of thermal decomposition and loss of volatiles as well as char gasification [5]. Also, combustion of the volatile matters is inconspicuous and a net weight gain was observed that is due to oxygen chemisorption before the onset of combustion. However, the waste tyre combustion interval can be divided into five stages, the stages at 250–350 °C, 360–420 °C and 420–480 °C can be considered combustion process of the volatile matters, with a total weight loss contribution of about 42%, and fixed carbon combusts at 520–600 °C and 650–800 °C. Also a net weight loss was observed that is due to the quick emission of the volatile matters at the onset of combustion, which differ from that of the pure coal. Consequently, there is an obvious difference of combustion characteristics between waste tyre and coal, the coal combustion is due to the combustion of fixed carbon, but the waste tyre combustion attributes to the emission and combustion of the volatile matters.

The profiles of blends samples comprise a number of peaks and vary depending on the characteristics of the content of waste tyre. The curve of each blend lies between the curves of the reference materials, and the contributions of waste tyre and coal to these profiles can be clearly appreciated. Thus, the 10 wt.% blends behave similarly to coal although showing some differences, such as the practical disappearance of the chemisorption stage and fixed coal combustion. It is also indicated from Fig. 1 and Table 1 that the maximum weight loss rate of the blends are higher than that of the pure coal, and the corresponding temperature and time decrease after waste tyre blended with coal. Also, for the 10, 30 and 50 wt.% blends, the peak weight loss rate decrease with the increase of waste tyre in the blends, it is indicated that combustion processes of the blends are more complex, which could be mainly attributed to the interaction combustion between waste tyre and high ash coal, so when waste tyre is used to replace partially coal, the appropriate content must be optimized according to the physical and combustion performance of waste tyre and coal.

Suppose there is no interaction between high ash coal and waste tyre when the blends combust, thus the following equations can be obtained

$$W_{mix}(T) = f_A W_A(T) + f_B W_B(T)$$

$$f_A + f_B = 1$$

where $W_{mix}(T)$, $W_A(T)$ and $W_B(T)$are the mass of blends, coal (A) and waste tyre (B), respectively. f_A and f_B are the mass fraction of the individual components in the blends.

Fig. 2(a)–(c) demonstrates the experimental and theoretical TG–DTG curves of the blends with the raise of temperature.

Table 1
The characteristics parameters of the blends, coal and waste tyre profiles

No.	$((dw)/(dt))_{max}$ (mg s^{-1})	T_p (°C)	T_e (°C)	t_p (s)	t_e (s)	t_f (s)	T_f (°C)	TG-end (%)	D_i ($\times 10^{-3}$)
1	4.77	588	458	27.8	21.2	40.7	845	41.77	8.1
2	6.72	523	450	24.4	20.7	34.6	721	37.1	13.3
3	6.35	531	428	24.6	19.2	34.2	725	30.22	13.5
4	6.07	531	378	24.8	17.1	34.8	726	24.35	14.3
5	8.55	447	350	20.5	15.8	35.0	724	11.14	26.4

Notes: 1–100% coal, 2–90% coal + 10% waste tyre, 3–70% coal + 30% waste tyre, 4–50% coal + 50% waste tyre, 5–100% waste tyre, T_p is the corresponding temperature of $((dw)/(dt))_{max}$, T_e is the ignition temperature, t_f and T_f is the burnout time and the corresponding temperature, TG-end is the ultimate leftovers; D_i stands for the ignition index.

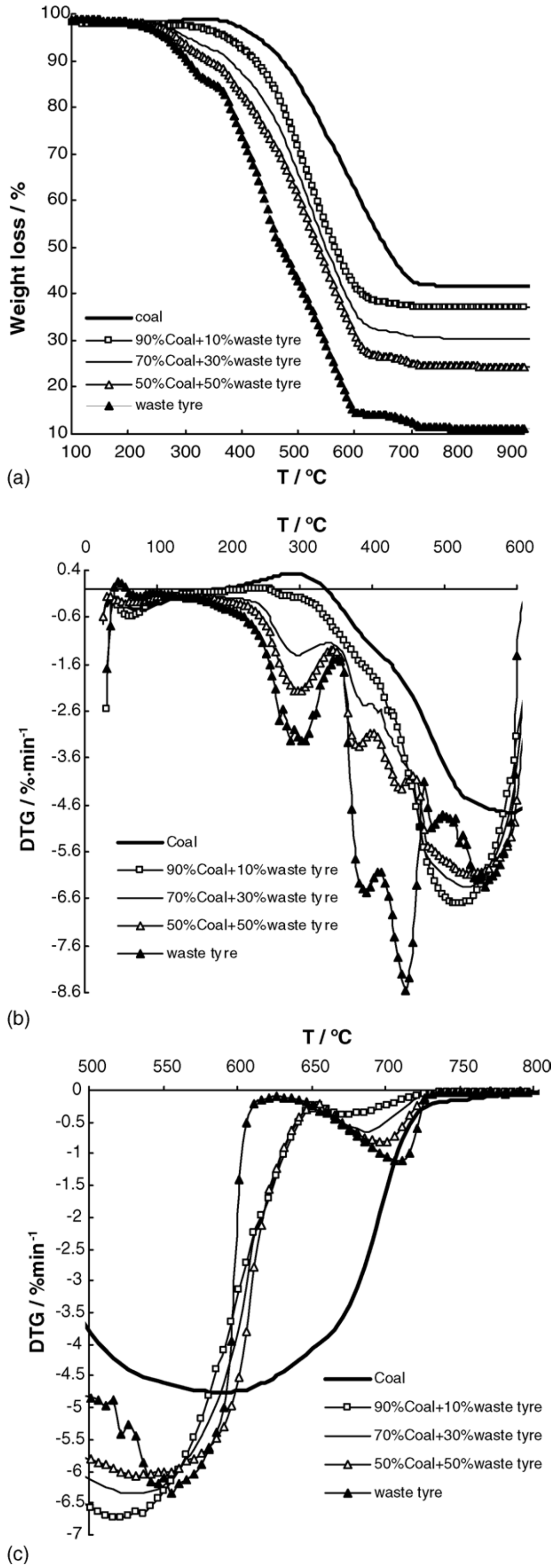

Fig. 1. TG and DTG profiles of the blends, coal and waste tyre: (a) TG curves, (b) DTG curves (0–600 °C); (c) DTG curves (500–800 °C).

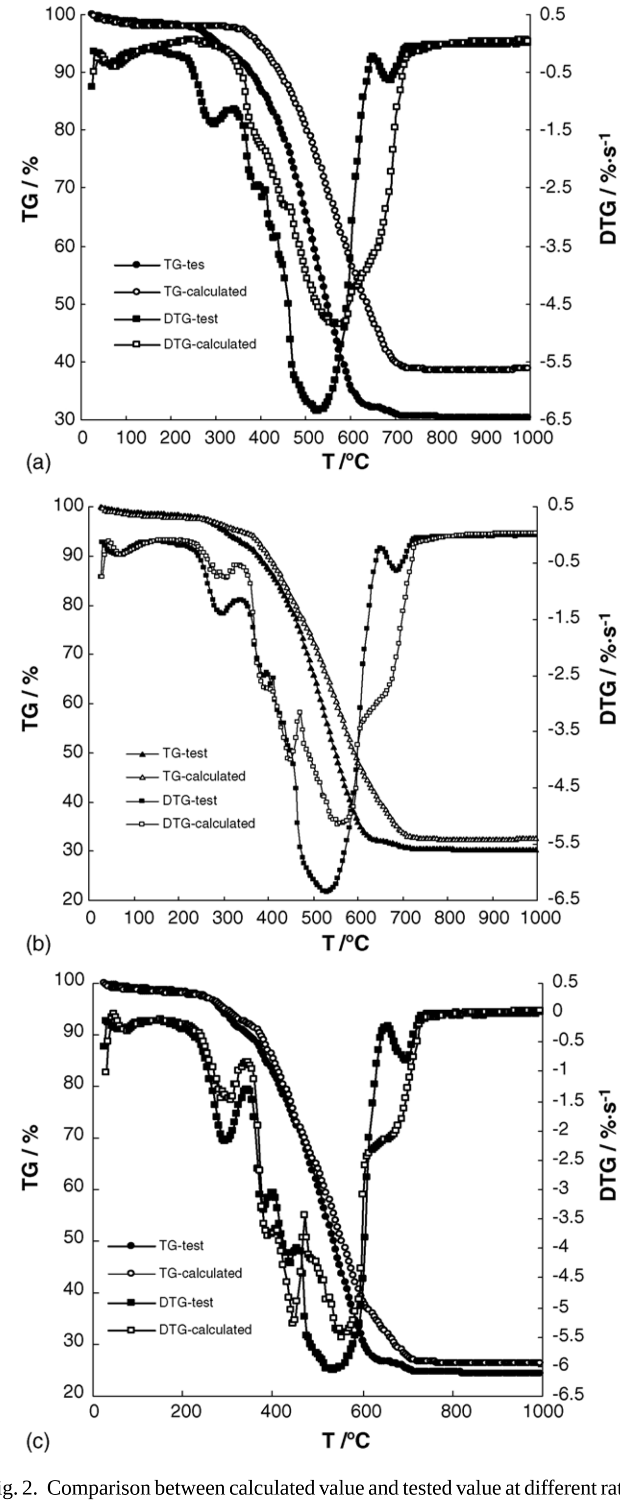

Fig. 2. Comparison between calculated value and tested value at different ratios: (a) coal: waste tyres = 9:1; (b) coal: waste tyres = 7:3; (c) coal: waste tyres = 1:1.

The theoretical results for no interaction in the mixture have been calculated from the addition of the mass of the individual components.

As can be seen in TGs of Fig. 2, for blends of coal and waste tyre, no interactions between blend components are observed, since both profiles, experimental and calculated from the weighted sum of the blend components, are coincident. However, for DTGs, it is indicated that a comparatively important

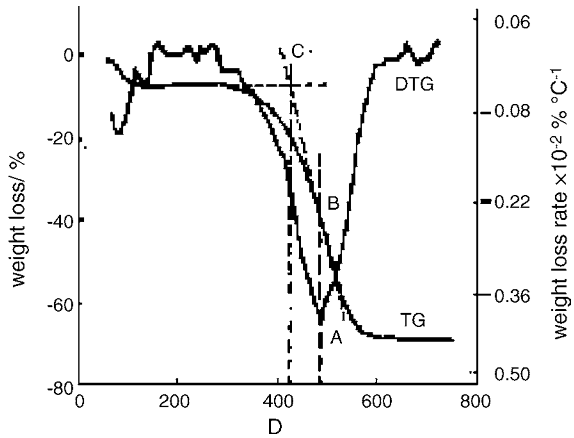

Fig. 3. Ignition temperature (T_e) definition sketch.

difference can be seen that may be related to a certain degree of interaction between the components. The co-combustion characteristics are the coupling effect between waste tyres and coal, and with the decrease of the dosage of waste tyre the difference will be more obvious, which was due to the fast emission of volatile matters of waste tyre. Consequently, the co-combustion of coal and waste tyre cannot be expressed by addition of individual components of the waste mixtures. These results do not agree with those obtained by other authors [15], who observed no interactions during blend combustion.

3.2. Ignition performance of waste type blends

As shown in Fig. 3, the ignition temperature (T_e) was defined as following [16]: firstly through the DTG peak point A, a vertical line was made upward to meet the TG oblique line at point B; secondly a tangent line to TG curve was made at point B, which met the extended TG initial level line at point C; thirdly another vertical line was made downwards through point C, which met the cross axle at point D. The corresponding temperature of point D was defined as T_e.

Also the ignition index D_i is determined by the equation as follows:

$$D_i = \frac{(dw/dt)_{max}}{t_p t_e}$$

where $((dw)/(dt))_{max}$ is the maximum combustion rate, t_p is the corresponding time of the maximum combustion rate and t_e is the ignition time.

The ignition temperatures (T_e) of the blends and individual waste tyre were obtained and shown in Table 1.

It is indicated from Table 1 that the ignition temperature T_e of high ash coal is higher by 108 °C than that of pure waste tyre. The ignition temperature T_e of the blends decreases gradually with the increase of the content of waste tyre, and the ignition temperature of the blends with the addition of 50% waste tyre is close to that of waste tyre. These may be due to a large amount of volatile matter in waste tyre and the rapid emission of the volatile matter under lower temperature, which attribute to accelerate the ignition of the blends. Also compared with the ignition index D_i of the blends, it is shown that D_i of the blends increase with the increase of waste tyre content, which agree with the results of ignition temperature. That is to say, the ignition performance of high ash coal was improved owing to the incorporation of waste tyre and the interaction of the component 1ignites.

3.3. Burnout performance of waste type blends

Burnout temperature of the samples was identified the corresponding temperature of no weight loss in TG–DTG curves. It is shown from Fig. 2 and Table 1 that the influences of waste tyre on the burnout temperature and the corresponding time are slight. However, for TG curve, the TG curves are backed off and the needed temperature increase under the same weight loss with the increase of the content of high ash coal, the ultimate leftovers of the blends decrease with the increase of waste tyre. These may be due to the difference of the content of ash in coal and waste tyre, that is to say, co-combustion of coal and waste tyre can improve the burnout efficiency of high ash coal to a certain degree.

4. Conclusions

Several comprehensible differences mainly due to the "rank" differences of the materials were found between the combustion profiles of high ash coal and waste tyre samples. In general: (1) the regions of the volatile matter combustion of waste tyre shift to lower temperatures than the corresponding ones for coal; (2) the temperature ranges of these regions are broader for waste tyre than coal; and (3) these regions are more complex for waste tyre (three or more peaks) than for coal (one peak).

For blends of coal and waste tyre, no interactions between blend components are observed in TGs. However, for DTGs, it is indicated that a comparatively important difference can be seen that may be related to a certain degree of interaction between the components. The co-combustion of coal and waste tyre cannot be predicted from the weighted sum of the blend components.

The incorporation of waste tyre can improve the combustion characteristics of high ash coal, especially the ignition performance and the peak weight loss compared with the separate burning of waste tyre and coal, which indicate that the co-combustion of waste tyre and low quanlitied coal as fuel is feasible.

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