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The influence of the pyrolysis conditions in a rotary oven on the characteristics of the products

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ABSTRACT

The pyrolysis of 1:1 blends of reinforcing fibre (RF) from tyre wastes with low rank bituminous coal was carried out in a rotary oven. The pyrolysis conditions were modified in order to study their influence on the yield and characteristics of the char and oil obtained. The variables studied were as follows: rotation speed, final pyrolysis temperature, N_2 flow and heating rate. The textural characteristics of the char were studied by means of N_2 adsorption at 77 K, whereas the oil composition was studied by infrared spectroscopy and gas chromatography. Modification of the variables did not have any effect on the composition or textural properties of RF/coal char. However, an increase in the nitrogen flow, rotary speed and a decrease in the heating rate led to a higher oil yield with more oxygenated groups and less aromaticity. These conditions also caused an increase in the contribution of the light oil to the oil yield. Moreover, an increment in the final temperature also resulted in a higher percentage of light oil, a greater amount of aromatic compounds and smaller number of oxygenated groups.

1. Introduction

The economic and environmental problems associated with the generation of scrap tyres are increasing due to the remarkable growth in the number of vehicles worldwide. For these reasons, the management of used tires represents a serious technological, economic and ecological challenge [1,2]. In recent years, the combustion, gasification and pyrolysis of wastes derived from tyre rubber have been studied in order to find a use for the huge amount of waste [3–12]. These technologies were considered the most appropriate for exploiting a waste which contains a high amount of carbon and has a high calorific value [13].

Pyrolysis essentially involves the decomposition of the wastes derived from tyre rubber at high temperatures (300–900 °C) in an atmosphere of an inert gas such as nitrogen at atmospheric pressure, into three products: gas, pyrolytic oil and char. The composition of each fraction depends on the pyrolysis conditions used and on the composition of the tyre [7]. The main advantage of the process is that it deals with wastes, which would otherwise be difficult to dispose of and creates reusable products.

Pyrolysis has also been referred to as reverse polymerisation, thermal depolymerisation or polymer cracking whose main reactions are dehydration, cracking, isomerisation, dehydrogenation, aromatisation and condensation [14]. Depending on the ultimate objective of the pyrolysis, it is necessary to establish the optimal conditions since the characteristics of the products will depend on the configuration of the oven. Several studies have been performed to investigate the influence of temperature, pressure, heating rate and the residence time of the volatiles and solids on the product yields and characteristics using different types of reactors [14,15].

Pyrolysis of the tyres has been carried out by means of different experimental procedures, in laboratory and commercial scale plants using autoclaves, rotary kilns, screw conveyors (auger), fixed, spouted, entrained and fluidised beds, rotating cone, vortex reactors, melting vessels, plasma reactors, free-fall, tubing bomb reactors, vacuum pyrolysis and the ablative process, in addition to other techniques. Such studies have been focused on different aspects of the pyrolysis process and the results obtained have then been related to the feedstock, operating conditions used for the experiments, and the specific characteristics of the system used: type of reactor, efficiency of heat transfer, etc. [16,17]

All the reactors/configurations have advantages and disadvantages in terms of technical, economic and ecological parameters and are used for various energy applications such as generation of heat or electricity and the production of liquid fuels and char.

Rotating drums are extensively used in chemical industries as kilns, mixers, dryers and reactors. The rotary reactor prevents agglomeration and ensures a good mixing of the particles because of the rotation of the reactor.

The aim of the present work is to study the pyrolysis of 1:1 blends of tyre waste reinforcing fibre (RF) with low rank bituminous coal in order to establish the influence of the variables of the rotary reactor on the yields and characteristics of the products.

2. Experimental

The raw materials used for the pyrolysis experiments were fluff/fibres (RF) obtained as a waste during the grinding and shredding of

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Table 1
Experimental pyrolysis conditions.

Pyrolysis conditions	Final pyrolysis temperature (°C)	Rotary speed	Nitrogen flow (ml/min)	Heating rate (°C/min)
850-L-400-5	850	Low	400	5
850-H-400-5	850	High	400	5
850-M-400-5	850	Maximum	400	5
950-L-400-5	950	Low	400	5
850-L-600-5	850	Low	600	5
850-L-100-5	850	Low	100	5
850-L-400-1	850	Low	400	1

scrap tyres from the processing of car and truck tyres [5,13]; and a low rank coal (volatile matter = 36.2 wt.% db, ash content = 6.4 wt.% db) used in blast furnaces for pulverised coal injection.

The pyrolysis experiments in the rotary oven were carried out with a 1:1 blend of the RF and coal. A constant mass of sample of 40 g was used in all the experiments. A cold trap and a column filled with amberlite resin allowed the recovery of the condensable products, i.e. heavy oil and light oil respectively. The char and liquid product yields were calculated relative to the starting material, while the gas yield was calculated by difference. A diagram showing the configuration of the oven has been published previously [13]. For the pyrolysis experiments the coal was ground to a size smaller than 1.18 mm while RF was used, as received. The variables studied were: three rotation speeds (low = 8.2 rpm, high = 13.8 rpm and maximum = 15.1 rpm); final pyrolysis temperature (850 and 950 °C), nitrogen flow (100, 400 and 600 ml/min) and heating rate (1 and 5 °C/min). The following notation has been used throughout the text: 850-L-400-1 indicates a pyrolysis experiment carried out to a final temperature of 850 °C at a low rotary speed, a N_2 flow of 400 ml/min and a heating rate of 1 °C/min. This experiment was considered as a basis for comparison with the rest. Table 1 shows the conditions used for each experiment.

The chars obtained were characterised by elemental analysis, which was carried out in a LECO CHN-2000 for C, H and N, a LECO S-144 DR for sulphur and a LECO VTF-900 for direct oxygen determination. The ash content was determined by thermogravimetric analysis using a TA Instruments SDT 2960 thermoanalyser.

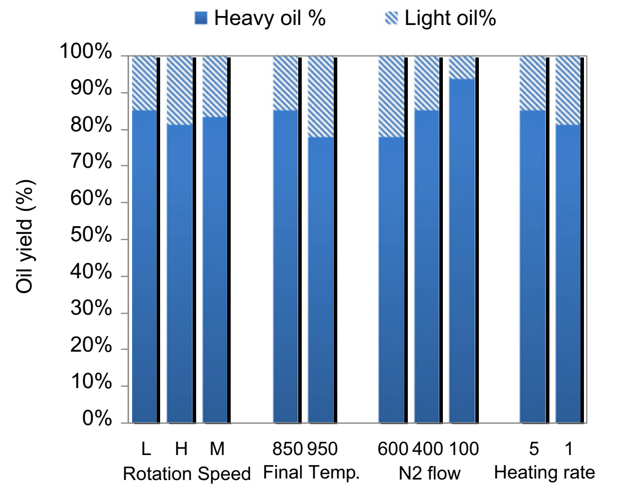

Fig. 2. Distribution between heavy oil and light oil depending on the pyrolysis conditions.

The textural properties of the chars were studied by means of N_2 adsorption at 77 K on a Micromeritics ASAP 2420 apparatus. The software package provided with the equipment was used to determine the textural characteristics. The specific surface area (S_{BET}) was calculated by means of the BET method. The total pore volume (V_T) was measured at $P/P_0 = 0.97$. The micropore volume was determined by applying the Dubinin equation to the lower relative pressure zone of the N_2 isotherm. The mesoporosity was calculated as the difference between the total pore volume (V_T) and the micropore volume.

The elemental composition of the oils was determined using the same procedures as in the case of the chars. The calorific value was measured in an adiabatic IKA-Calorimeter C4000, Analysentechnik Heitersheim apparatus. Fourier transform infrared spectroscopy (FTIR) spectra were recorded on a Nicolet Magna-IR560 spectrometer equipped with a DTGS detector. Gas chromatographic analyses of oils were carried out on an Agilent-7890A gas chromatograph equipped with flame ionisation and mass spectrometry detectors (GC-FID-MS). The separations were performed using a fused-silica capillary column

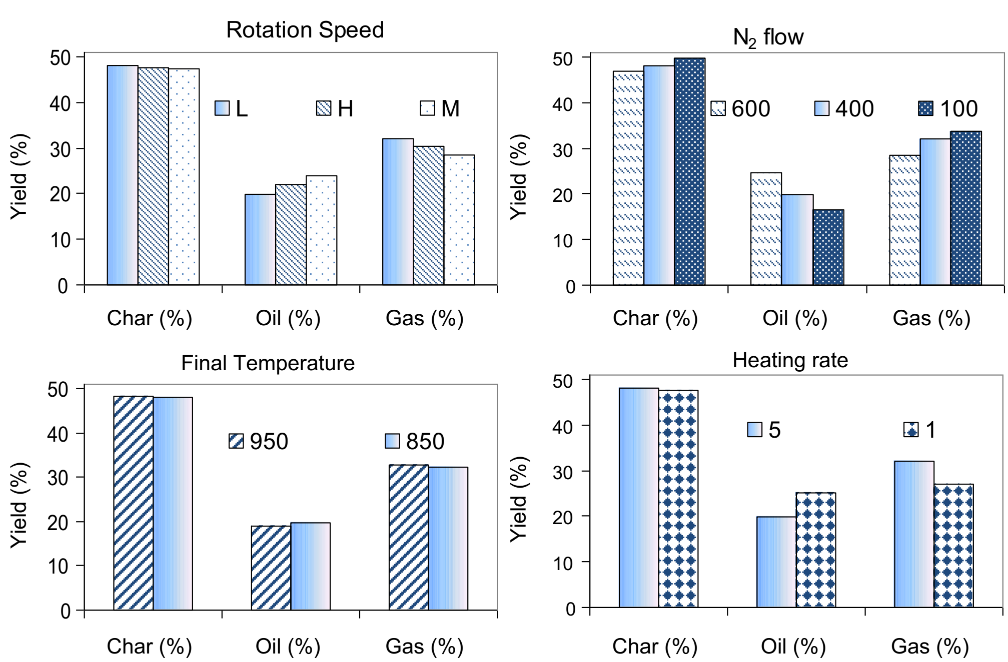

Fig. 1. Mass balance of the pyrolysis experiments with different conditions.