PYROLYSIS OF END OF LIFE TYRES RECLAIMED FROM LORRY TRUCKS: PART II – ANALYSIS OF RECOVERED CHAR

SULTAN MAJED AL-SALEM
Environment & Life Sciences Research Centre, Kuwait Institute for Scientific Research, Kuwait

ABSTRACT
Annual production (and subsequently disposal) of tyres is taking place growing proportionally to the increase in population. Pyrolysis has proven to be a good thermos-chemical conversion method that can convert end of life tyres (ELTs) into valuable products namely solid char. In this work, experimental studies were carried out on end of life tyres (ELTs) reclaimed from lorry trucks which are known to be quite resilient to environmental exposure. The cracking took place between 500 and 800°C in a pyrolysis operation of fixed bed reactor type. The char recovered was extensively analysed in this study. Average particle size analysis showed that majority of the recovered char was >4 mm (36.2%) and the moisture content was somewhat low around 1 wt.% determined by thermogravimetry. On the other hand, the gross calorific value (GCV) was determined to be higher than 28 $kJ \cdot g^{-1}$ pointing towards possibility of using this product as a source of energy.
Keywords: tyres, pyrolysis, diesel, energy, waste.

1 INTRODUCTION

End of life tyres (ELTs) represent a major component of solid waste (SW) that requires special attention. This is due to the fact that ELTs don't degrade with environmental exposure and can cause major environmental pollution when stockpiled. Various countries around the world have started implementing regulations and enforce environmental legislations to protect their environments from ELTs accumulation. In a European context, the *Vehicle Life Cycle End* Directive enforces 40% (as a minimum) of ELTs to be valorised and redirected from landfill sites [1].

ELTs are composed of various elastomers and rubbers that are typically bound together with carbon black fillers [2]. Evans and Evans [3] have shown that passenger vehicles and lorry truck tyres contain the following in their composition (wt.%): Rubber (45–47%), carbon black (21.5–22%), metal (16.5–21.5%), textiles (5.5%), zinc oxide (1–2%), sulphur (1%) and additives (5–7.5%). The composition of ELTs encourages the valorisation of the rubber constituents to produce value added products such as fuel oil and gases. To do so, pyrolysis presents itself as a solution that can reduce the volume of tyre waste and extract valuable products from it. Pyrolysis is defined as a thermo-chemical conversion method that can treat feedstock using inert atmospheres in a temperature range between 350 and 900°C [4]. Pyrolysis produces fuel in the form of oil that can be used as an added product to refinery blends or directly as a fuel. Gases from ELTs pyrolysis can be used as a heating gas to the process itself since it comprises C_1 to C_4 chemicals. Furthermore, the third and last product of the process (i.e., solid char) can be used as a solid fuel or upgraded as activated carbon [2].

The yield of pyrolysis char varies significantly with respect to the type of reactor used and operating conditions. Fixed bed reactors implementing a temperature range between 300 and 1,000°C have been reported to produced pyrolysis char from ELTs in the range from 30 to ≈48 wt.% [5]–[12]. On the other hand, fluidised bed reactors (FBRs) have been reported to produce char in the range from 35 to 48.5 wt.% in temperatures that range

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between 450 and 780°C [13], [14]. In this work, lorry (truck) ELT grade was studied using a fixed bed reactor to achieve pyrolysis conditions with the aim of studying the pyrolysis char (pyro-char) quality. This part of the communication compliments the first part which reports the oil properties extracted from the same experimental set using the same feedstock. The work presented herein can also pave the way for strategies in Middle-East and by extension other regions to have a circular economy using ELTs as a potential feedstock material with value added products recovered.

2 EXPERIMENTAL

ELTs carcasses (10 kg) were acquired from Al-Essa Company (Kuwait) which were reclaimed ensuring similar make and model of each tyre grade. The ELTs were of lorry truck type reclaimed originally from Al-Maillam group dealership (315/80R22.5). Each tyre was firstly air blown to remove any dust particles and then subjected to shredding using ELDAN (Denmark) at 60°C. The obtained samples (manually measured) were 1.22 cm in size. The samples were stored in laboratory conditions (≈ 22°C) using sealed plastic containers. Feedstock in the amount of 200 g was placed in the fixed bed as a charge with Alumina packing of a 5 mm diameter (average bulk density of 700 kg·m^{-3}) was used in the amount of 120 g. For operation and reactor specifications, the readers are referred to Al-Salem [4].

Char yield was studied between 500 and 800°C as an average of the three bed temperatures used in the operation. A Tarsus F3 TGA from NETZSCH was used for the thermal decomposition properties of the samples and for the determination of the moisture content. The TGA unit is externally calibrated and the analysis was conducted as per ISO 11358 directions using a 10 mg sample weight. A CAL3K Advanced bomb calorimeter was used for gross calorific value (CV) determination of the oil samples as per ISO 1928:20 using 0.5 g specimens. Average particle size was measured on the char samples as they were supplied using the sieve analysis method. Sieves of mesh sizes 10 mm, 4 mm, 2 mm, 1.60 mm, 1 mm, 0.850 mm and 0.125 mm were stacked in order of highest to the lowest size and assembled on a sieve shaker A sample mass of about 90 g was taken from each char sample and poured on the topmost sieve (mesh size 10 mm).

3 RESULTS AND DISCUSSION

Fig. 1 shows the char yield as a function of the reactor bed temperature. The amount of char reduced from 91 to 85 g between 500 and 800°C, respectively. Lower residence time in the pyrolysis reactor can influence such a behaviour. The higher the final temperature the longer the material will degrade. The char represents some 45% of the total charge of the feedstock which falls in the range previously mentioned in the introduction section of past reports. The moisture content ranged between 0% and 2.16% depending on the pyrolysis temperature used to produce the char with an average of all samples around 1 wt.%. Past reports showed that pyrolysis char had a moisture content as high as 3.57 wt.% [2]. The calorific value was estimated for the char and is depicted in Fig. 2.

The char consists mainly of the original carbon black present in the feedstock [15]. Char derived from pyrolysis is considered a primary reaction product, given that it accounts for 30–40% of the original tyre mass and is mainly made up of carbon black and a significant quantity of inorganic ash containing most of the sulphur and Zn used in the tyre manufacturing [16]–[19]. Antoniou and Zabaniotou [20] showed that the higher heating value (HHV) of the char derived from ELTs pyrolysis between 450 and 600°C was 29.75 MJ/kg which made them determine it as a good fuel for potential upgrading. All

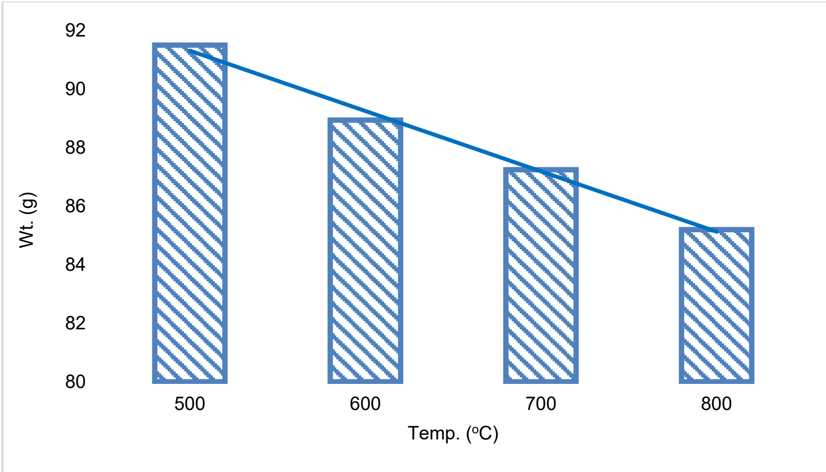


Figure 1: Pyrolysis char calorific yield (g) as a function of the operating temperature (°C).

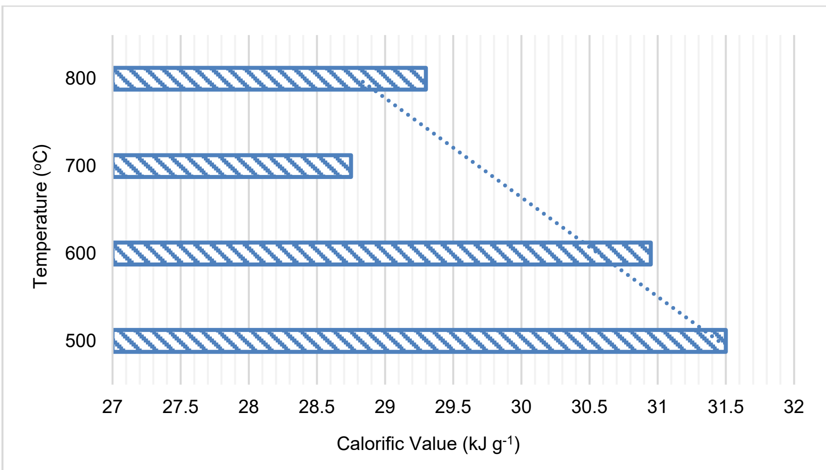
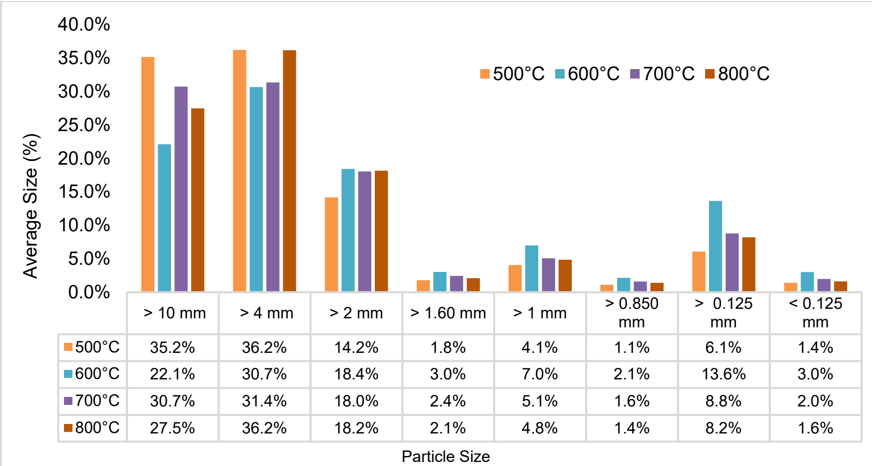


Figure 2: Pyrolysis char calorific value (kJ g^{-1}) as a function of the operating temperature (°C).

results in this work determining heating value were higher than the aforementioned ranged which promotes the pyro-char as a god candidate for fuel use. Therefore, it is recommended to pyrolyse tyres in Kuwait for potential char as pyro-char fuel. Antoniou and Zabaniotou [20] have also shown that char was at large a macroporous material (>50 nm, IUPAC classification). Based on the above, ELT char can be used as a solid fuel, or as a precursor for porous material production [21]. Further upgrading could be achieved for the char (to eliminate ash and residues) as well via acidification/basification treatments [21]. This is due to the fact that majority of the char analysed is larger in size than 4 and 10 mm (Fig. 3).



	> 10 mm	> 4 mm	> 2 mm	> 1.60 mm	> 1 mm	> 0.850 mm	> 0.125 mm	< 0.125 mm
500°C	35.2%	36.2%	14.2%	1.8%	4.1%	1.1%	6.1%	1.4%
600°C	22.1%	30.7%	18.4%	3.0%	7.0%	2.1%	13.6%	3.0%
700°C	30.7%	31.4%	18.0%	2.4%	5.1%	1.6%	8.8%	2.0%
800°C	27.5%	36.2%	18.2%	2.1%	4.8%	1.4%	8.2%	1.6%

Figure 3: Average (%) and particle size and as a function of the operating temperature (°C).

4 CONCLUSION AND FUTURE WORK

The pyrolysis char investigated in this work showed potential for future use as a solid fuel source of a size that exceeds macroporous materials with a calorific value ranging between 29.3 and 31.2 kJ·g^{-1}. To fully investigate the potential of this material, future analysis at this stage is required. Firstly, the sulphur content of the material should be assessed. This will indicate the potential of using it as a potential environmental source of energy in the future. The density of the char should also be considered in the future to compare it with other common solid fuels (e.g., refuse derived fuel). In addition, there should be a somewhat comparable database possessed with governments and interested parties showing the potential of products from various feedstock use (ELTs). This will truly provide a platform for future use in integration platforms with oil and gas industries to reduce fossil fuel dependence.

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