PYROLYSIS OF END OF LIFE TYRES RECLAIMED FROM LORRY TRUCKS: PART I – OIL RECOVERY AND CHARACTERISATION

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ABSTRACT
About 1.5 billion tyre units are classed as a solid waste on an annual basis after their disposal. The carcass of end of life tyres encompass various petrochemical substances that could easily be recovered after thermally cracking the rubber fraction. 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. Oil recovered was extensively studies for its properties and fuel potential. Sulphur content was also determined reaching 2.92% for oil extracted at 500°C with elemental carbon estimated at 64.78%. Elevated temperatures of operation have also shown high potential of diesel fuel fraction (C_{10}-C_{19}) in the pyrolysis oil where it reached 80% for oil recovered at 800°C.
Keywords: tyres, pyrolysis, diesel, energy, waste.

1 INTRODUCTION

It is estimated that the European Union (EU) alone produces some 289 million tyre units on an annual basis and that end of life tyres (ELTs) are estimated to be in the range between 1.3 and 1.5 billion units each year [1]. Some 64% of this total number of tyres discarded as a special category waste or rubber solid waste is still diverted to landfill sites [2]. According to the United States Environmental Protection Agency (EPA), 9.16 million tonnes of rubber waste was generated in 2018 and only 1.67 million tonnes were recycled in the same year [3]. Furthermore, ELTs are known to resist degradation due to exposure and environmental factors. Therefore, landfilled ELTs and stockpiled ones present an immediate danger to the environment, as well as residents to the areas close by such sites. ELTs disposed of in improper manner can lead to fire ball hazards, rodent and insect infestation; and environmental pollution [4].

The carcass of a tyre consists of natural rubber (10–30 wt.%), styrene-butadiene rubber (30–50 wt.%), butadiene rubber (30 wt.%) and carbon black (30 wt.%). Other additives (inorganics and organic ones) and sulphur make up some 1% of its constituent [2]. This supports the fact that ELTs embody long chain hydrocarbons similar to the ones present in fuels produced from refineries and petrochemical complexes. According to Hita et al. [5], lorry (truck) tyres consist of about 30 to 50 wt.% of natural rubber depending on either US or European standard which is higher than passenger car tyres.

There exist three main routes for ELTs management nowadays that can provide numerous advantages both on operational and environmental fronts. The first route of ELTs treatment is material recovery whereby the tyre is mechanically grinded using various techniques to reduce its size to 1 cm (or below). The product could be used in civil engineering applications, roads and coastal purposes as well [6]. The second means of ELTs treatment is via combustion with the aim of energy recovery [7]–[9]. Lastly, ELTs could be valorised using the technique of pyrolysis whereby the tyres are treated under inert atmospheres for fuel and light gas recovery to recover valuable products competing with

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one produced from fossil fuels [10]–[13]. Potential products and their characteristics could be found in detail elsewhere [1].

The problem of ELTs stockpiling and their management extends the world over. Moreover, the Middle-East and namely in Kuwait, the largest ELTs grave yard is present with over 7 million units stockpiled in one location [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 oil (pyro-oil) quality properties and its potential as a fuel substitute. This part of the communication focuses on the oil extracted quality. The work presented herein can also pave the way for strategies in Middle-East and by extension other regions to have a circular economy basis 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 [12]. Oil yield was studied between 500 and 800°C as an average of the three bed temperatures used in the operation. Pyrolysis was conducted and the oil collection was achieved post condensation (<3 hours of pyrolysis time) using a heating rate of 5°C min^{-} throughout. 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. Samples were analysed using a Perkin Elmer CHNS/O elemental analyser 2,400 organic elemental analyser with a MAS auto-sampler. Flash point was determined using a Koehler Closed Cup Rapid Flash Tester. The GCMS analysis was carried out using an Agilent 8,860 GC and an Agilent 5977B MSD. The samples went through a Solid Phase Extraction (SPE) procedure before being injected in the GC, in order to extract the chemicals of interest and avoid column contamination and saturation with heaviest chemicals. The fuel range chemicals were determined and categorised as per the following: Petrol (C_4-C_9), diesel (C_{10}-C_{19}) and wax (C_{19}+).

3 RESULTS AND DISCUSSION

Fig. 1 shows the yield obtained as an average of the experimental runs conducted. The oil was produced at a maximum (84 g) when 500°C operating temperature was used and decreased gradually reaching 68 g at 800°C. This could be attributed to the low temperature providing more residence time whereby the carbon content in the material is cracked more towards primary hydrocarbon oil formation. No waxes were produced throughout the experimental runs. This indicates that primary reaction was complete for all polymeric content in the ELTs carcass for the intermediate stages of products [15]–[17].

Fig. 2 shows the estimated CV as a function of the operating temperature in this work. It is quite clear that the CV was increasing incrementally as a function of the reactor's bed temperature from 41.2 to 42.1 kJ g^{-1}. The CV as an average falls within the range of previous reports by other authors using various reactor set-ups [1], [18], [19]. It is quite

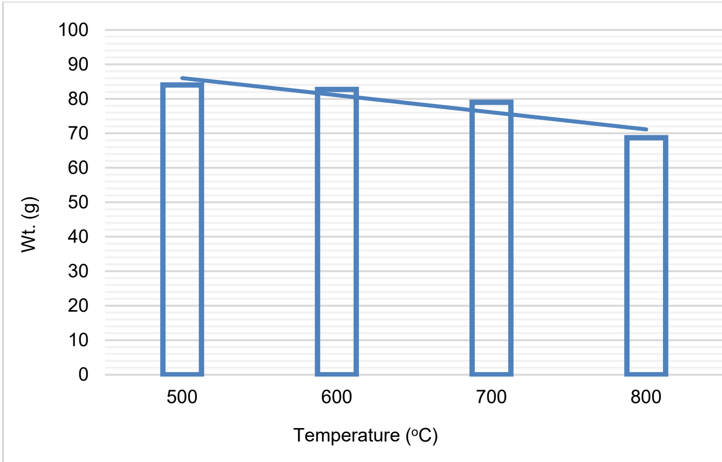

Figure 1: Oil yield (g) as a function of reactor temperature (°C).

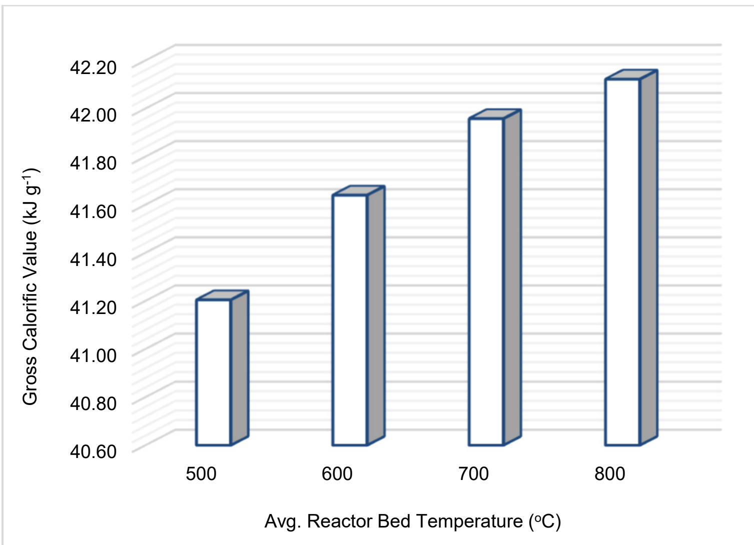

Figure 2: Calorific value (kJ kg^{-1}) as a function of reactor temperature (°C).

essential at this stage to point out the fact that the pyrolysis oil obtained herein are comparable to diesel fuel with almost similar CV [5]. The elemental analysis of the pyrolysis oil shows that the elemental carbon was at maximum for the 600°C (80.83%) whilst the sulphur was maximum for the 500°C (2.44%). De-sulphurisation is essential in this case since the sulphur content is quite high and requires to be reduced to 0.1% [20].

The flash point ranged between 40.1 and 42°C. The flash point indicates the flammability of the liquid as the lowest temperature which the substance is ignited with air [21]. Generally, pyrolysis oil has a lower flash point when compared to gas oil, kerosene or diesel [1]. Past reports on pyrolysis oil extracted from ELTs has ranged between 17 and 65°C [21]–[24]. The flash point of the pyrolysis oil extracted from truck tyres in this work has crossed the mark of kerosene. Fig. 3 shows the diesel fuel range estimated in the oil samples as a function of the operating temperature.

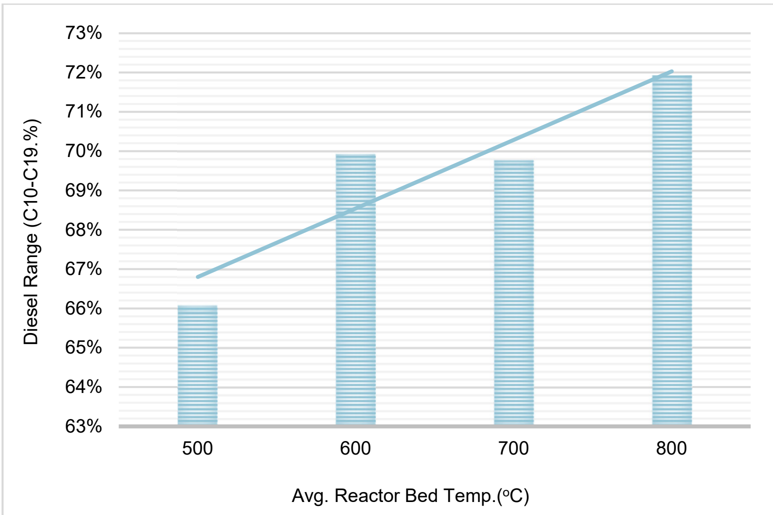

Figure 3: Diesel fraction (%) as a function of reactor temperature (°C) in oil samples studied in this work.

The diesel fuel was increasing incrementally from 66% at 500°C to 72% at 800°C. This shows that the majority of the chemical present are represented by diesel fuel herein. It also points towards the fact that tars are cracked within the primary reaction to produce this range of chemicals [15].

4 CONCLUSION

The thermal pyrolysis of end of life tyres was achieved and studied in the temperature range between 500 and 800°C. The yield was at a maximum at 500°C (44%) which was expected giving the material a longer residence time for complete cracking and evolution to tars vis-à-vis oils. The calorific value was increasing incrementally as a function of the reactor bed temperature reaching 42 kJ kg^{-1}. Furthermore, about 72% of the oils extracted were in the diesel fuel range. The findings herein can be of immense importance for providing a circular economy platform for countries that have a major environmental problem faced with stockpiling ELTs. The pyrolysis oil is associated with a better environmental performance when compared with combustion and incineration of to provide heat. Therefore, it is quite important to consider the fact that reducing the sulphur content and physical blending of such products can provide a platform for integration with oil and gas industries that can be of economic and environment benefit.

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