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Pyrolysis configurations effects on scrap waste tires pyrolysis products

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Abstract—This paper presents End of Life Tires (ELT) pyrolysis results in two batch reactors with different configurations. The first setup is constituted of a pyrolyser with 17 cm of diameter and 17 cm of cylindrical height. An external electrical heater was used for heating the circumferential walls and the bottom of the pyrolyser. It can reach 400 Watts. The mass used was equals to 100 g. The second setup is bigger than the first one. It consists of a cylindrical fixed-bed reactor made of stainless steel with an internal diameter of 160 cm and a height of 250 cm. The reactor is placed in an enclosure heated by an electric furnace. The reactor heating power is controllable and may reach 5 kilowatts. It allows only the heating of the pyrolyser circumferential walls. We used 300 g. The heating rate was fixed to 10 °C/min and the Nitrogen N₂ flow rate to Q_{N₂} equals to 40 ml/min. The Thermo-Gravimetric analysis TGA shows that the maximal degradation temperature is approximately equals to 400 °C and the volatile yield (gases and liquid) is 60.35 wt.%. It is found that the End of Life Tires pyrolysis produce 30.53 wt.% of Tire Derivative Oil (TDO) using setup 1 and 34.37 wt.% using setup 2. The tire-derived oils properties i.e. the density, the viscosity and the higher calorific value HCV are measured and compared to other commercial oils.

Keywords— End of Life Tires (ELT), pyrolysis, energetic valorization, fuel, and Gas chromatography - mass spectrometry (GC-MS).

I. Introduction

Worldwide, the amounts of used polymer products are increasing by the year: most of them are used for automobile tires. According to reports from the largest associations of tire and rubber product manufacturers, the annual global production of tires is some 16.55 million tons, which corresponds to an estimated 17 million tons of used tires each year [1]–[3]. With population growing and economic and social development, tires are becoming a major waste produced by means of transport like motorcars, motorcycles, buses, trucks and bicycles. As tires are non-biodegradable and

not always recyclable, measures have to be implemented to reduce their negative impact on the environment. Landfill and incineration, which are the conventional ways to handle End of Life Tires (ELT), are no longer sustainable, as they can lead to environmental damages like soil impregnation, air pollution and water contamination.

Nowadays, thermal cracking, or pyrolysis, is one of the promising methods to treat the End of Life Tires (ELT). Pyrolysis involves heating of polymeric material under atmospheric pressure using inert atmosphere. The process is conducted at temperatures between 250-700°C and is useful to break down the ELT into three products, oil, gas and char [4].

The most common rubbers used for tires are : Natural Rubber (NR), Styrene-Butadiene Rubber (SBR) and Butadiene Rubber (BR). Sulfur is used to vulcanizing, steel and carbon black are used as reinforcing agents and aromatic extender oil is used to soften and enhance the workability of rubber. All of these components are 100% recyclable.

Many researchers have investigated pyrolysis of End of Life Tires (ELT). Aydın and al (2012) [5] used End of Life Tires (ELT) without steel and fabric, in a fixed bed reactor in nitrogen over the temperature range of 400–700 °C. They found that the liquid yield increased from 31 % at 400 °C to 40 % at 500°C. They investigated the influence of nitrogen flow rate on product yield and found only negligible differences in yield.

Kar (2011) [6] investigates the influence of pyrolysis temperature, used 10 g of End of Life Tires (ELT) batches in a fixed bed, nitrogen purged reactor at 10 °C/min heating rate in the range of temperature from 375 to 500 °C. He found that the maximum oil yield of 60.0 % oil was obtained at 425 °C. The oil yield decreased to 54.12 % at the higher temperature of pyrolysis, of 500 °C. When the temperature of pyrolysis was increased from 375 to 500 °C, the gas yield increased from 2.99 to 20.22 % and char yield decreased from 50.67 to 26.41 %.

Islam and al. (2011) using a fixed bed reactor pyrolysed 750 g of End of Life Tires (ELT). They also found a high oil yield of 55% at 475 °C pyrolysis temperature, a char yield of 36 % and a gas yield of 9 % [7].

Kaminsky and al [8] reported in their paper that the pyrolysis of synthetic and natural rubber in fluidized bed process allowed to obtain high amounts of monomers like isobutene and isoprene.

Alkhatib and al (2015) studied the pyrolysis of End of Life Tires (ELT) in a fixed bed reactor at a low heating rate and reaching 500°C. They found a high oil yield of 53.49 % when the power is 1500 watt with a corresponding char and gas yield of 38.62 % and 7.89 % respectively. [9]

In this work, End of Life Tires (ELT) were chosen as a raw material with the objective to study the effect of heating reactor mode on the pyrolysis products. ELT pyrolysis was carried out in two different fixed-bed reactors with different heating modes, in order to investigate their effects on the products. Reactors were heated to a final temperature of 600°C, at a heating rate of 10°C/min and N₂ flow rate 40 ml/min. The physical properties and the chemical compositions of the pyrolytic oil were investigated.

II. Experimental

A. Materials and methods

The raw materials tested in this study are End of Life Tires (ELT) powders from passenger cars that have been brought from a Collection Company in France. Tires powder used did not contain all reinforced materials (wires, fibers). Tires powder dimensions ranged between 1 × 1 × 1 mm³ and 2 × 3 × 1 mm³.

The elemental analysis results in TABLE I show that End of Life Tires is rich in carbon C (≈ 81%) and oxygen O (≈ 11%) and has a low Nitrogen N (0.47 %) content. These results are interesting in the application of ELT in gasification and pyrolysis processes. The H / C and O / C ratios were 0.134 and 0.084 respectively. Therefore, the empirical formula of ELT is CH_{0.134}O_{0.084}N_{0.006}S_{0.013}.

TABLE I. END OF LIFE TIRES (ELT) CHARACTERIZATION.

Elemental Analysis (wt.%)					Ash (wt.%)	HCV(MJ/kg)
N	C	O	H	S		
0.47	80.82	6.79	10.81	1.11	11	32.57

B. Thermo-gravimetric analysis TG

Pyrolysis tests were carried out using thermo gravimetric analysis coupled with differential scanning calorimetric (SETARAM SETSYS Evolution-TG-DSC apparatus), equipped with a graphite furnace and a balance with a maximum capacity of 35 g and a resolution of 0.002 µg. An argon flow is passed through the head of the thermo balance to prevent corrosion of the microbalance from the produced and

introduced gases. The sample temperature was measured by a thermocouple placed in the reaction atmosphere, at 15 mm below the sample pan. About 20 mg of sample was pyrolysed using a cylindrical platinum crucible of 130 µl of volume and a very low height to diameter ratio (≈0.25). A flow of 100 ml/min of pure nitrogen was introduced to ensure an inert atmosphere during the pyrolysis of the sample which was heated from room temperature to 600 °C under atmospheric pressure and at a heating rate of 10 °C/min.

C. Pyrolysis setups with and without heating at the pyrolyser bottom

Two reactors were used in pyrolysis experiments. The first pyrolysis setup is shown in Fig. 1. It is constituted of: Nitrogen gas tank, Acquisition controller (2), Labview software (1), heating up resistance (4) which allows a heating at the bottom and the circumferential walls of the pyrolyser, reactor made of stainless steel (6), row material (5), pressure sensor (8), condenser (9), fuel receiving flask (12), non-condensable gases outlet (16). The reactor has as dimensions: 17 cm diameter and 17 cm height cylindrical. Glass Wool was used for the reactor heat insulation. An external electrical heater was used for heating. It can reach 400 Watts. The wall temperature is measured by a thermocouple (T₀, and controlled by a PID controller.

The second pyrolysis setup is shown in Fig. 2. It consists of a cylindrical fixed-bed reactor made of stainless steel (internal diameter of 160 cm and a height of 250 cm (Almost 10 * Diameter of the setup 1, 250/17 = 14.7 * the height of the setup 1). The reactor is placed in an enclosure heated by an electric furnace and which can reach a maximum temperature of 1000 °C, the reactor heating power is controllable and may reach 5 kilowatts. It allows only the heating of the pyrolyser circumferential walls. The wall temperature is measured by a thermocouple (T_{reg}), and controlled by a PID controller.

For both of them, the reactors were purged using a high Nitrogen flow for 4-6 min before the beginning of each experiment to make sure that the system is filled with inert gas (pyrolysis conditions). This was verified by micro-Gases Chromatography analysis. The oxygen percentage was less than 1% before heating. We used 100 g in the setup 1 and 300 g in setup 2 as it is bigger than setup 1. The produced volatile gases are evaporated out of the reactor into a water-cooled counter-current condenser. The condensable liquid products produced during the pyrolysis are condensed in a heat exchanger cooled by water at a temperature of 10 °C and collected in a flask, the non condensable gases are discharged to atmosphere. The collected liquid in the receiving flask (12) is characterized by viscosity, density and higher Calorific Values (HCV).

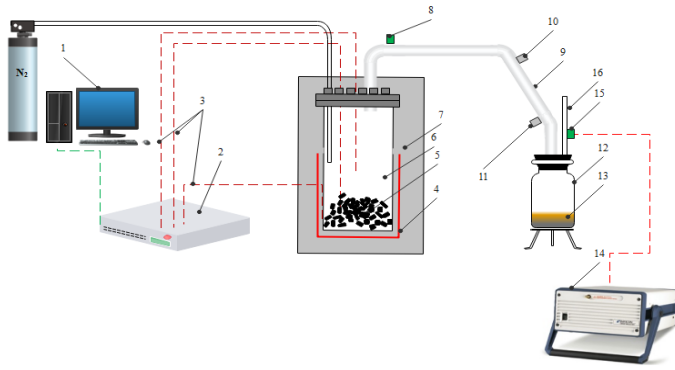


Fig. 1. First pyrolysis setup with a heating system at the bottom and the circumferential walls of the pyrolyser.

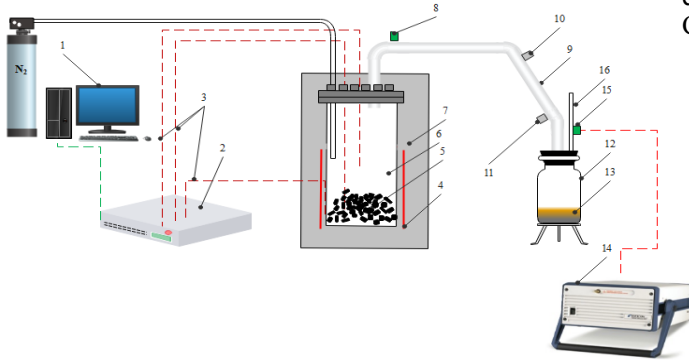


Fig. 2. Second pyrolysis setup with a heating system only on the circumferential walls of the pyrolyser.

D. Gas chromatography-mass spectroscopy (GC-MS)

In order to quantify the dominant chemical compounds of the pyrolytic oils, samples were analyzed using GC-MS spectrometer coupled with flame ionization detector FID. An agilent SLB-5MS column (30mx 0.250mm; 0.25 μ m film thickness) was used with a helium flow rate 1 ml/min. The temperature program began with a hold at 70°C for 1 min followed by an increase at 12°C/min to 180°C, then 12°C/min to 330°C, which was held for 1min. the temperature of FID was fixed at 275°C. Injections of 0.5 μ l of oil samples were realized with a split ratio of 10:1:5 mg of products were dissolved in 1 ml of heptane. Identification of chromatographic peaks was established from MS data, which was matched to the NIST spectral library.

III. RESULTS AND DISCUSSION

A. TG and DTG analysis of ELT

TG analysis is a thermal analysis technique that measures the material weight evolution as a function of temperature and time, in a controlled environment. TG was applied to study End of Life Tires (ELT) thermal degradation in various temperature ranges.

From the TG-DTG curves shown in Fig. 3, the End of Life Tires (ELT) thermal degradation evolution represents two peaks indicating that there are two degradation steps where the conversion takes place. The degradation starts at 200 °C.

Then, with the temperature rise, the degradation rate increases until reaching its maximum at 420 °C. The ELT thermal degradation was completed at 500 °C for the heating rate 10 °C/min and a Nitrogen flow rate of 40 ml/min T_{max} at which the conversion is maximum is about 420 °C as shown in Fig. 3. The volatile yield materials are around 60 %. The results obtained by J. H. Chen and al [4] who used a Nitrogen flow rate fixed at 50 ml/min, a heat rates $\beta= 5, 10, 20$ and 30 K/min, show that in this condition, the initial temperature varied from 209°C to 248 °C for the passenger car tire of and from 185°C to 238 °C for truck tire. The final temperature varied from 501 to 548 °C for the tire of passenger car and from 493 to 553 °C for truck tire. The T_{max} temperature is in the range [396 – 425 °C] and [392 – 430 °C] respectively. In this work we used End of Life Tires (ELT) from passenger cars. The thermal degradation ranges obtained agree with J. H. Chen and al 's work [4].

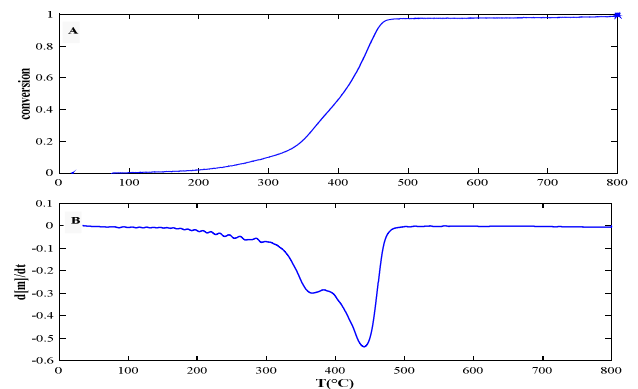


Fig. 3. TG and DTG curves of End of Life Tires (ELT) a: TG, b:DTG.

B. ELT pyrolysis products characteristics

1) ELT pyrolysis products yields

The ELT pyrolysis products were classified into three groups: gas, liquid (Tires Derived Oil TDO) and solid.

TABLE II shows the yields pyrolysis products distribution. With setup 1, the pyrolysis products' yields are respectively 30.81 wt.% for the liquid, 17.85 wt.% for the gas and 51.60 wt.% for the solid for the experiments' conditions used. While when using setup 2, the liquid yield increases to 34.37 wt.%, the solid yield passed to 54.59 wt.%, and the gas yield decreases to 11.04 wt.%. With comparison to the Aydin et Ilkiliç work [5] who used a Nitrogen flow rate varied from 150 ml/min to 350 ml/min and a heating rate of 12 °C/min, the authors found that at 500 °C, the liquid yield decreases from 39.85 % to 38.8 % while increasing the flow rate from 150 to 350 ml/min. While, for the same previous conditions, the gas yield increases from 12.03 wt.% to 14.9 wt.%. Thus, our liquid and gas yields obtained for a Nitrogen flow rate of 40 ml/min and a heating rate of 10 °C/min without maintaining the maximum temperature during supplementary heating seems to be good energetic experiments' conditions as they allow to reduce the nitrogen flow rate used and the energetic costs related to heating. Comparing to H. Aydin and C. Ilkiliç's work[5], they found that the yields were 40.26 wt.%, 47.88

wt.% and 11.86 wt.% respectively for the liquid, the solid and the gas for a heating rate of 12 °C/min until 500 °C and 200 ml/min of N₂ flow rate. However, they have used small tires pieces after cutting them to slices and removing steel wires and fabric fibers. Our gas and solid yields obtained are higher than those of H. Aydin and C. Ilkiliç's work [5] when using setup 1. However, our liquid yield for the two reactors was less than theirs. The yields values found by S. Boxiong et al [10] were 32.1 wt.%, 35 wt.% and 25 wt.% respectively for the liquid, the solid and the gas for a heating rate of 10 °C/min until 500 °C. They used a tire material shredded and crumbed without steel. Their liquid yield is equals to our liquid yield when using setup 1, for a heating rate of 10 °C/min until 500 °C and is lesser than our liquid yield when using setup 2. Tire pyrolysis is strongly dependent on type of inter- and intra-molecular bonding that exists among the polymers that makes up the tires and tire composition [11] this can be a reason to the difference between this result and other previous results.

TABLE II. PRODUCTS YIELDS OBTAINED FROM END OF LIFE TIRES (ELT) PYROLYSIS BY SETUP 1 AND 2.

	Setup 1	Setup 2
Product yield (%)		
liquid	30.81	34.37
gas	17.85	11.04
solid	51.60	54.59

2) GC-MS of the TDO

The identification of liquid compounds was carried out using gas chromatography-mass spectrometry GC-MS analysis. The peaks with P80% mach quality were considered valid, that their provisional assignments were consistent with published GM / MS data of similar products [12–14].

The derived oil (TDO) Chromatograms obtained from End of Life Tires (ELT) using setup 1 is shown in Fig. 4 and TABLE III. It is obvious that TDO products consist mainly of a variety of aromatic compounds with few aliphatic compounds.

TABLE III shows the TDO compounds, its retention times and its weight percentages. It can be seen that TDO is a very complex mixture of C₅–C₁₆ organic compounds with high concentration of unsaturated compounds. The total concentrations of aromatic and aliphatic compounds were 16.51 and 15.73 wt.%, respectively.

The Chromatograms of TDO obtained from setup 2 is shown in Fig. 5. Compound name, its formula, its retention time and it weight percentage are shown in TABLE IV.

It is clear from Fig. 4 that the main products obtained in setup 1 are the D-limonene, benzene derivatives and very small amounts of other aliphatic/aromatic compounds. While TDO obtained from setup 2, contains a very wide and complicated range of aliphatic/aromatic compounds.

In Fig. 4 and Fig. 5, D-limonene (C₁₀H₁₆) is the dominant compound with more aliphatic compounds and single ring aromatic. D-limonene is a favorable product because of its wide important uses as a feedstock in many industries [15], [16]. Production all over the pyrolysis process of D-limonene indicates that dehydrogenation /cyclisation/ aromatization reactions always take place during the pyrolysis as D-limonene is produced [17].

In pyrolytic oil obtained using setup 2, the most important components are aromatics (1-Methyl-naphthalene, 1H-Indene....), followed by alkanes (Limonene) and non-hydrocarbons (Benzothiazole, 2-Methoxy-4-(1-propenyl)-phenol...) which confirmed by previous literatures [17].

Benzothiazole, a nitrogen- and sulphur-containing compound (C₇H₅NS), was also determined at a concentration of 1.27 wt%. The presence of this compound may be explained by thermal degradation of the accelerators used for the vulcanization of rubber which are frequently sulphur and/or nitrogen based organic compounds, such as 2-mercaptobenzothiazole and benzothiazole, disulphide[17].

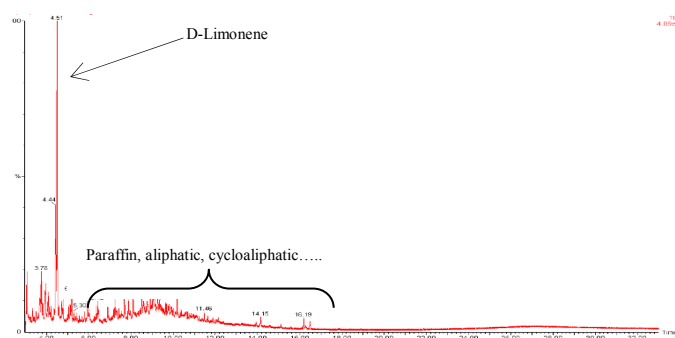


Fig. 4. GC/MS of TDO setup 1.

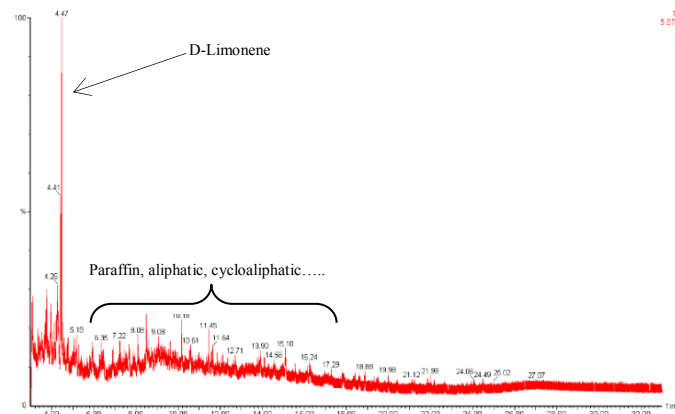


Fig. 5. GC/MS of TDO setup 2.

TABLE III. RETENTION TIMES (RT) OF CHEMICAL COMPOUNDS IN THE TDO FOR SETEP 1.

RT	compound	Formula	%
3.071	p-Xylene	C ₈ H ₁₀	1.59
3.766	Benzene, 1-ethyl-3-methyl-	C ₉ H ₁₂	1.566
3.962	2H-Indeno[1,2-b]oxirene, octahydro-, (1aà,1bá,5aà,6aà)-	C ₉ H ₁₄ O	2.82

4.446	Benzene, 1-methyl-4-(1-methylethyl)-	C ₁₀ H ₁₄	3.65
4.528	D-Limonene	C ₁₀ H ₁₆	11.84
4.789	1H-Cycloprop[c]inden-7-ol, octahydro-	C ₁₀ H ₁₆ O	1.359
5.195	1-Phenyl-1-butene	C ₁₀ H ₁₂	1.48
5.398	Benzene, 1-(1,5-dimethylhexyl)-4-methyl-	C ₁₅ H ₂₄	1.19
5.929	Hydrocinnamic acid, o-[(1,2,3,4-tetrahydro-2-naphthyl)methyl]-	C ₂₀ H ₂₂ O ₂	1.63
6.36	1H-Indene, 2,3-dihydro-1,2-dimethyl-	C ₁₁ H ₁₄	0.82
6.463	Pentamethylbenzenesulphonamide	C ₁₁ H ₁₇ NO ₂ S	1.11
6.901	Benzothiazole	C ₇ H ₅ NS	1.27
7.232	7-(1-Hydroxy-cyclohex-2-enyl)-2,2-dimethyl-hept-5-en-3-one	C ₁₅ H ₂₄ O ₂	0.76
7.674	Hydrocinnamic acid, o-[(1,2,3,4-tetrahydro-2-naphthyl)methyl]-	C ₂₀ H ₂₂ O ₂	1.86
8.087	7-(1-Hydroxy-cyclohex-2-enyl)-2,2-dimethyl-hept-5-en-3-one	C ₁₅ H ₂₄ O ₂	1.14
8.493	Benzoic alcohol, 2,6-difluoro-5-methyl-	C ₈ H ₈ F ₂ O	0.81
10.15	1H-Indole, 4-(3-methyl-2-butenyl)-	C ₁₃ H ₁₅ N	0.32
10.577	2,5-Octadecadiynoic acid, methyl ester	C ₁₉ H ₃₀ O ₂	0.22
11.432	Limonen-6-ol, pivalate	C ₁₅ H ₂₄ O ₂	0.15
12.091	5,8,11,14-Eicosatetraynoic acid	C ₂₀ H ₂₄ O ₂	0.09
13.89	1-Heptatriacotanol	C ₃₇ H ₇₆ O	0.08

TABLE IV. RT OF CHEMICAL COMPOUNDS IN THE TDO FOR SETEP 2.

RT	compound	Formula	%
3.064	p-Xylene	C ₈ H ₁₀	0.94
3.349	Tricyclo[3.2.2.0]nonane-2-carboxylic acid	C ₁₀ H ₁₄ O ₂	0.54
3.51	Cyclohexanol, 2-methyl-5-(1-methylethenyl)-, (1 α ,2 α ,5 α)-	C ₁₀ H ₁₈ O	0.54
3.752	Benzene, 1,2,4-trimethyl-	C ₉ H ₁₂	0.56
3.955	3-Methylene-bicyclo[3.2.1]oct-6-en-8-ol	C ₉ H ₁₂ O	1.15
4.421	Benzene, 1-methyl-4-(1-methylethyl)-	C ₁₀ H ₁₄	1.66
4.489	D-Limonene	C ₁₀ H ₁₆	3.25
4.774	1H-Cycloprop[c]inden-7-ol, octahydro-	C ₁₀ H ₁₆ O	0.63
5.12	Benzene, 1-methyl-4-(1-methylethenyl)-	C ₁₀ H ₁₂	0.51
5.398	Benzene, 1-(1,5-dimethylhexyl)-4-methyl-	C ₁₅ H ₂₄	0.55
5.932	4-Methyl- α -methyl- α -nitrostyrene	C ₁₀ H ₁₁ NO ₂	0.88
6.36	Hydrocinnamic acid, o-[(1,2,3,4-tetrahydro-2-naphthyl)methyl]-	C ₂₀ H ₂₂ O ₂	0.35
6.467	Benzene, (1,1-dimethyl-2-propenyl)-	C ₁₁ H ₁₄	0.53
6.894	Benzothiazole	C ₇ H ₅ NS	0.82
7.233	N-Methyltomatidine	C ₁₅ H ₂₄ O ₂	0.49
7.678	Hydrocinnamic acid, o-[(1,2,3,4-tetrahydro-2-naphthyl)methyl]-	C ₂₀ H ₂₂ O ₂	0.64
8.088	7-(1-Hydroxy-cyclohex-2-enyl)-2,2-dimethyl-hept-5-en-3-one	C ₁₅ H ₂₄ O ₂	1.15
8.498	Oct-3-ene-1,5-diyne, 3-t-butyl-7,7-dimethyl-	C ₁₄ H ₂₀	0.71
9.078	Naphthalene, 1,3-dimethyl-	C ₁₂ H ₁₂	0.45
10.173	Naphthalene, 2,3,6-trimethyl-	C ₁₃ H ₁₄	1.48
13.914	Morphinan-4,5-epoxy-3,6-di-ol, 6-[7-nitrobenzofurazan-4-yl]amino-	C ₂₆ H ₂₇ N ₅ O ₆	0.86
15.108	1-Heptatriacotanol	C ₃₇ H ₇₆ O	1.29

3) Char characterization

In order to characterize the remaining solid of pyrolysis, some analyses were done for the coal such as HCV and EA. The elemental analyzes were carried out on the pyrolytic products including the carbonaceous residue from each pyrolysis experiments. The results of these analyses are

summarized in the TABLE V. The results show that the composition of the char issued from setup 1 had a higher carbon (80.5 wt.%) and sulfur (2.1 wt.%) weight percentages. While using setup 2, the chars contains 79 wt.% of carbon and 2.14 wt.% of sulfur. According to Williams [18] chars have high sulphur contents reported to be between 1.9 wt.% and 2.7 wt.% and high carbon contents of up to 80.3 wt.% and 90 wt.%. Thus our results agree with Williams [18] ones. The results revealed that the ash content are equal to 14 wt.% for both setups. This high values of ash can be related to the additive mostly zinc, added in the formulation of the tire and dirt material found on End of Life Tires (ELT). This values are in conformity with [18] results who found percentages 8.27 and 15.33 wt.%.

Considering that the original tire sample contained 1.11 wt.% of sulphur and that the solid yield was about 51 wt.%, thus about 60% of the tire sulphur was left in the solid residue and the rest remained in the liquid fraction mainly as benzothiazole as illustrated on TABLE III and TABLE IV. Owing to the high C content of the char (80 wt.%) , its HCV (30 MJ/kg), is greater than coals one.

The char (solid) residue from End of Life Tires (ELT) pyrolysis may have potential applications such as filler in road bitumen, active carbon (using chemical or physical activation), carbon black for manufacture (as raw material to rubber) or solid combustion [19].

TABLE V. CHAR PROPRIETIES .

	Elemental Analysis (wt.%)					Ash (wt.%)	HCV(MJ/kg)
	N	C	O	H	S		
Setup 1	0.18	80.5	0.75	1.48	2.1	14	30
Setup 2	0.12	79.4	0.84	1.44	2.14	14	31.2

4) Estimation of diesel fraction

In order to characterize the obtained oils from ELT pyrolysis in terms of fuel properties, pyrolytic oils were compared with diesel fuel (TABLE VI).

The HCVs of both TDO products are similar but lower than diesel HCV. However, the viscosities and densities are different. Compared to R. Alkhatib and al [9] results's who used waste shredded tires as raw material without any catalyst, they found that the liquid HCV values were respectively equal to 43.43, 43.47 and 43.4735 MJ/kg for heating powers respectively of 750, 1500 and 3000 W.

The Low Calorific Value LCVs of both TDO products are similar equal to 40.712 and 40.148 MJ/kg respectively for setup 1 and 2 but lower than diesel LCV (43.1 MJ/kg).

Li et al (2004) used a pilot scale rotary kiln reactor to pyrolysis tires over a range of temperatures from 450 to 650 °C [20] The tires derived oil (TDO) produced during pyrolysis of used tires with setup 1 is lighter than the tires derived oil (TDO) obtained with setup 2 and close to diesel ones. The density values of TDO with setup 1 (0.87 g/ml) are close to the density value obtained by M. Ambrosewicz-walacik and M.

Walacik, [21]. The tires derived oil (TDO) viscosities for setup 1, setup 2 and diesel are equal to 1.51, 2.3 and 2.14 (mPa.s) at 40 °C respectively. This can be explained by the effect of the reactor configuration and the weight of the raw material. It is clear that each pyrolytic liquid has higher density and lower HCV values than diesel ones. Comparing both setups, setup 2 has a higher potential of oil production than setup 1. The oil obtained from setup 2 has a higher density compared to diesel.

TABLE VI. TDO AND DIESEL PROPERTIES, *LCV (LOW CALORIFIC VALUE).

Properties/fuel	TDO of Setup 1	TDO of Setup 2	diesel
Viscosity at 40°C (mPa.s ⁻¹)	1.51	2.3	2.14
HCV (MJ/Kg)	43.213	42.649	45.95
LCV (MJ/kg)	40.712	40.148	43.1
Flash point (°C)	<30	<30	>60
Density (g/ml)	0.87	0.92	0.826

IV. Conclusion

Pyrolysis of ELT to produce diesel-like fuels has been studied using two different setups. Tires powder used did not contain all reinforced materials (wires, fibers). Tires powder dimensions ranged between $1 \times 1 \times 1 \text{ mm}^3$ and $2 \times 3 \times 1 \text{ mm}^3$.

The elementary analysis results confirmed that the H / C and O / C ratios were 0.134 and 0.084 respectively. Therefore, the empirical formula of ELT is $\text{CH}_{0.134}\text{O}_{0.084}\text{N}_{0.006}\text{S}_{0.013}$.

Comparing both setups, setup 2 has a higher potential of oil production than setup 1. Indeed, Pyrolysis in Setup 1 gave a liquid product yield of 30.81 wt.%. Contrariwise, setup 2 gave a liquid yield of 34.37%. GC studies show that both liquid fuel products consist of aromatics (1-Methyl-naphthalene, 1H-Indene....), followed by alkanes (Limonene) and non-hydrocarbons (Benzothiazole, 2-Methoxy-4-(1-propenyl)-phenol...). D-limonene is the dominant compound with more aliphatic compounds for both setups.

Using setup 1, the HCV and the viscosities were 43.21 MJ/kg and 1.51 mPas respectively. While, when using setup 2, the HCV and the viscosities are 42.649 MJ/kg and 2.3 mPas. In order to characterize the obtained TDO from ELT pyrolysis in terms of fuel properties, pyrolytic oils were compared to diesel properties.

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