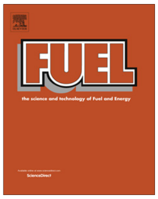
Fuel xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel



Analysis of combustion, performance and emission characteristics of a diesel engine using low sulfur tire fuel

Q1 Hüseyin Aydın [a,*], Cumali İlkılıç [b]

[a] Department of Mechanical Engineering, Faculty of Engineering and Architecture, Batman University, Batman, Turkey
[b] Department of Automotive Engineering, Faculty of Technology, Firat University, Elazığ, Turkey

HIGHLIGHTS

- Fuel produced from waste vehicle tires by the method of pyrolysis for diesel engines.
- A new method was applied for desulfurization of tire fuel with $Ca(OH)_2$, and H_2SO_4.
- Totally the sulfur content of the tire fuel was reduced by 83.75%.
- LSTF–diesel blends were tested in a diesel engine.
- Blends with low percentages of LSTF can be used as alternative fuel in diesel engine.

ARTICLE INFO

Article history:
Received 26 June 2014
Received in revised form 20 November 2014
Accepted 24 November 2014
Available online xxxx

Keywords:
Tire fuel
Diesel engine
Pyrolysis
Desulfurization

ABSTRACT

An alternative fuel for diesel engines was produced from waste vehicle tires by the method of pyrolysis. In order to reduce sulfur content of produced the liquid fuels, during the reaction $Ca(OH)_2$ was used. Then, H_2SO_4 were used after the reaction and the sulfur content of the product was reduced by 83.75%. The properties of diesel fuel, low sulfur tire fuel and fuel mixtures of low sulfur tire fuel and diesel fuel were found. Then the prepared fuel blends and diesel fuel were tested in a diesel engine. Performance, combustion and emission parameters of the engine when using each fuel were obtained and comparisons were made with D2 fuel. Power, torque and mean effective pressure, mass fuel consumption, effective efficiency and bscf values presented. Results justify that the performance of the engine slightly lowers by using blends of LSTF. Cylinder pressure and heat release rate values of the test fuels usage were quite similar with those of D2. CO, HC, and smoke emissions were slightly higher while NOx emissions were lower for LSTF blends. All of these results indicate that desulfurized tire fuels with low percentages can be used as alternative fuel in diesel engine.

1. Introduction

Accelerating rate of fuel demand drive the attentions of researchers to explore new, renewable and clean energy and fuel sources. Utilization of hydrocarbon containing wastes can be a relevant alternative fuel option. In this context, conversion of wastes to energy and especially to a fuel for internal combustion engines is one of the bright ideas. Waste tires contain many of suitable hydrocarbon sources that can be converted to fuel for engines. Pyrolysis can be considered as a method of tire recycling that is recently receiving attention. Several studies have been carried out in the production of tire pyrolysis oil from waste automobile tires by various techniques [1–8].

Rodriguez et al. [9] carried out the pyrolysis of automotive tires in a fixed-bed reactor at 500 °C and reported that product oils consisted of 62.4 wt.% aromatic compounds, 31.6 wt.% aliphatic compounds, 4.2 wt.% nitrogen-containing compounds, and 1.8 wt.% sulfur-containing compounds. Q2

A nitrogen purged static-bed batch reactor was used to pyrolyse 3 kg batches of shredded scrap tires at temperatures between 450 and 600 °C [10]. The fuel properties of the condensed oil including, calorific values, ultimate analyses, flash point, moisture content, fluorine and chlorine contents were determined. The results showed that the derived tire oils had fuel properties similar to those of a light petroleum fuel oil.

Liquid fuels and chemicals are reported to be obtained from pyrolysis of motorcycle tire waste in a fixed-bed fire-tube heating

---

* Corresponding author. Tel.: +90 530 349 2359; fax: +90 488 217 35 02.
E-mail addresses: huseyin.aydin@batman.edu.tr (H. Aydın), cilkilic@firat.edu.tr (C. İlkılıç).

http://dx.doi.org/10.1016/j.fuel.2014.11.075
0016-2361/

Please cite this article in press as: Aydın H, İlkılıç C. Analysis of combustion, performance and emission characteristics of a diesel engine using low sulfur tire fuel. Fuel (2014), http://dx.doi.org/10.1016/j.fuel.2014.11.075

reactor [11]. Chromatographic and spectroscopic studies on the liquids show that it can be used as liquid fuels and chemical feedstock, with a calorific value of 42.00 MJ/kg and empirical formula of $CH_{1.27}O_{0.025}N_{0.006}$.

Dai et al. [12] investigated the effects of feed size and vapor residence time on product yields and compositions with respect to operating temperature for circulating fluidized-bed reactor for a temperature range of 360–810 °C, feed size of 0.32–0.8 mm and residence time of 1–5 s and reported that the optimum conditions were: 500 °C, 0.32 mm and 1 s, respectively, with liquid yields of 50% and char yields of 32%.

Pyrolysis of scrap tires was undertaken in a semi-continuous fluidised bed reactor in relation to the temperature of the fluidised bed. Increasing the fluidised bed reactor temperature for the pyrolysis produced a derived oil with increased concentration of benzene, toluene and xylenes and a reduction in limonene concentration to negligible concentrations [13]. An indirect heated fluidized bed process has been used for the pyrolysis of synthetic and natural rubber [14]. If the pyrolysis results of mainly natural rubber used in this study are compared with selected results from other tire rubber pyrolysis experiments in a fluidized bed process, it can be seen that the carbon black content is less (30 wt.% instead of 40%). The pyrolysis of waste tires in continuous mode has been studied in a pilot plant provided with a conical spouted bed reactor, in the 425–600 °C range, by feeding two types of tire materials with different contents of natural and synthetic rubber [15]. It is reported that the contents of natural rubber and styrene–butadiene rubber in the tire have a significant effect on the liquid composition (contents of aromatics and interesting raw materials, such as styrene and limonene). Therefore, the tires from natural rubber can be seen as a good option for pyrolysis.

The continuous pyrolysis of waste tires under vacuum conditions (25 and 50 kPa) has been studied [16] in a pilot plant equipped with a conical spouted bed reactor and operating with continuous feed at 425 and 500 °C. The main differences between the continuous and batch processes are in the yield of light aromatics, which is higher in the continuous process, and in that of the heavy liquid fraction or tar, which is higher in the batch process [17].

Certain considerations should be taken into account prior to any comparison between the results obtained in continuous and batch processes, which are: (a) the reaction media in these processes are different, (b) the composition of the volatile stream in the batch process changes over time [18].

The pilot-scale pyrolysis of scrap tires in a continuous rotary kiln reactor was investigated at temperatures between 450 and 650 °C [19]. As the reactor temperature increased, the char yield remained constant with a mean of 39.8 wt.%. The oil yield reached a maximum value of 45.1 wt.% at 500 °C. A pilot scale scrap tire pyrolysis process has been carried out on a reactor consists of a rotary kiln reactor externally heated, and performance and the characteristics of the products under different process parameters, such as temperature, residence time, and pressure were investigated [20]. Results show that process temperature, in the explored range, does not seem to seriously influence the volatilization reaction yield, at least from a quantitative point of view, while it observably influences the distribution of the volatile fraction (liquid and gas) and by-products characteristics.

Pyrolysis of waste vehicle tires with the purpose of fuel production for the usage as a fuel in internal combustion engine can be seen as a hygienic, environmentally acceptable and efficient way of disposing them.

One of the experimental study has been on using tire pyrolysis oil (TPO) obtained from waste automobile tires by vacuum pyrolysis method, as a fuel in diesel engine [21]. Results indicate that reliable operation can be achieved up to 70% of TPO diesel blends. Thermal efficiencies are lower compared to diesel operation. Higher smoke, HC and CO emissions are reported as the result.

Another work has been carried out to evaluate the performance, emission, and combustion characteristics of a single cylinder direct injection diesel engine fueled with 10%, 30%, and 50% of tire pyrolysis oil blended with diesel fuel. It is concluded that it is possible to use tire pyrolysis oil in diesel engines as an alternate fuel in the future [22].

Tire oil as fuel was produced and properties with those of petroleum-derived fuels were made. The oil was combusted in an 18.3 kW spray burner furnace. The results for SO_2 emissions were consistent with higher fuel sulfur contents in the tire oil [23]. Particulate and total unburned hydrocarbon emissions were negligible.

Tire pyrolysis oil derived from waste automobile tires was analyzed and compared with the petroleum products and was found that it can also be used as a fuel for compression ignition engines [21]. However, the crude TPO has a higher viscosity and sulfur content [24].

In a previous study performed by the same authors [25], fuel was produced by pyrolysis of waste vehicle tires under nitrogen environment and with calcium hydroxide ($Ca(OH)_2$) as catalyst. The sulfur content of liquids obtained were reduced by using $Ca(OH)_2$. The liquid fuel of waste vehicle tires was then used in a diesel engine by blending with petroleum diesel fuel by 5% (TF5), 10% (TF10), 15% (TF15), 25% (TF25), 35% (TF35), 50% (TF50), and 75% (TF75) wt. and pure (TF100). It is concluded that the blends of pyrolysis oil of waste tires TF5, TF10, TF25 and TF35 can efficiently be used in diesel engines without any engine modifications. However, the blends of TF50, TF75 and TF100 result in considerably high CO, HC, SO_2 and smoke emissions [25]. The higher sulfur and smoke emissions are attributed to the quite high sulfur content of the pyrolysis oil and it is recommended to remove the sulfur content of tire oil.

In order to reduce sulfur content of produced fuels, during the reaction $Ca(OH)_2$ and then H_2SO_4 were used and the sulfur content of the product was reduced by 83.75%. Low sulfur tire fuel (LSTF)–diesel (D2) blends of LSTF50 (50% of LSTF–50% D2), LSTF75 (75% of LSTF–25% D2) and D2 were tested in a single cylinder diesel engine. Combustion, performance and emission results derived from the tests of each fuels are presented in this paper.

2. Experimental installations and test procedure

Experiments were carried out at Engine Test Laboratory of Automotive Department at Faculty of Engineering and Architecture at University of Batman.

A Rainbow-186 model diesel engine with single-cylinder, air cooling, direct injection was used. The main specifications of the engine are presented in Table 1.

Technical properties of the dynamometer are shown in Table 2. The engine was loaded with a hydraulic dynamometer. The schematic diagram of the experimental installation is presented in

Table 1
Technical specifications of the test engine.

Q5

Type	Rainbow-186 diesel
Injection system	Direct injection
Cylinder number	1
Stroke volume	406 cc
Compression ratio	18/1
Maximum power	10 HP
Maximum engine speed	3600 rpm ± 20
Cooling system	Air cooling
Injection pressure	19.6 ± 0.49 MPa (200 ± 5 kgf/cm^2)
Mean effective pressure (Mep)	561.6 kPa
Medium piston speed	7.0 m/s (at 3000 rpm)

Please cite this article in press as: Aydın H, İlkılıç C. Analysis of combustion, performance and emission characteristics of a diesel engine using low sulfur tire fuel. Fuel (2014), http://dx.doi.org/10.1016/j.fuel.2014.11.075