Characteristics of Tyre Derived Fuel-Diesel Blends

Rebecca Sebola, Jefrey Pilusa, and Edison Muzenda

***Abstract*—** This paper reviews the behavior of diesel-tyre derived fuel blends as a modified fuel for diesel engines**.** Gas phase de-sulphurisation distillation over membrane sieves was used to prepare tyre derived fuel samples. The samples were blended with 50ppm commercial diesel at various volume ratios. The contamination characteristics of such blends were investigated whereby continuous single pass filtration technique was employed to remove solids contaminants in the fuel blends. It was observed that gas phase de-sulphurisation distillation of crude tyre derived fuel reduces total sulphur content by up to 40%. Blending the distilled tyre derived fuel with low sulphur diesel has shown that up to 25vol. % of distilled tyre fuel can be added to low sulphur diesel without compromising the recommended physical properties of the blend. However the total sulphur content remains higher than the recommended specification as per SANS 342 despite the 85% reduction from the crude tyre derived fuel state.

***Keywords*—** Compression ignition, De-sulphurisation, Pyrolysis fuel, Single pass filtration.

I. INTRODUCTION

PYROLISIS attracts high levels of interest due to the high energy content present in pyrolysis liquids. Considerable effort has been devoted to fast pyrolysis that is high heating rates and low solid residence time over the years and some of the product oils have been tested in diesel engines [1]. Pyrolysis oil is considered to emit hazardous gases during heating; however recent studies have shown that biomass and waste derived pyrolysis oils can give product oil with improved properties and which are to a certain degree more comparable to biodiesel and diesel fuels [2].

A number of studies have been reported in literature relating to the poor distribution and transportation of diesel. Particulate contamination is one of the most common problems associated with diesel fuel. To ensure optimum engine performance and reliability, particulate and water contamination in diesel fuel must be controlled to acceptable limits. Injector The main problem is that particulates entering the fuel system alter the volumetric accuracy of the injector systems hence negatively affecting the performance of the engines. Costs related to the effects of fuel cleanliness are less quantitative, mainly because of a lack of awareness. Investigation has shown that the larger percentage of vehicles on the roads today use standard filters ranging from about 15 to 25 microns [3].

More recently, high efficiency fuel filters about 2 to 5 microns have been introduced which are designed to cope with the higher pressures and smaller orifices of less than 0.005mm of injector nozzles in modern engines [4]. This places more demand on the need for a cleaner fuel to prevent premature blockage of filters which, in turn, will lead to filter replacement at frequencies shorter than the scheduled maintenance. This downtime can be costly and disruptive to operations which require 24 hour service from their vehicles. Torres et al. (2009) [5] investigated the distillation effects of fuels and it was observed that the distillation characteristic of a pyrolysis oil critically influences performance as well as safety during storage and transportation. Distilled pyrolysis oils have high carbon and hydrogen contents and their higher heating values compare well with biodiesel. Carbon residue and ash content are both high, indicating potential deposition problems.

Overall the composition and physiochemical properties of pyrolysis oils as described by Torres et al. (2009) [5] vary and largely depend on the feedstock used and processing technology employed. Pyrolysis oils described in previous research have exhibited properties unfavourable for their use as engine fuels, such as high water content, low heating value and strong acidity [6], [7], [8]. From past studies of alternative fuels in compression engines, the usage of diesel and tyre oil blends in a 2 stroke compression ignition has also been investigated. It was found that the blending of fuel can be used without altering the engine. This particular fuel blend is assumed to result in increased sulphur content and asphaltene which might result in an increase in the fuel consumed by the engine and this might reduce the overall performance of the engine and provoke contamination due to corrosion and filter media [9].

The oil corrosiveness is another key characteristic to evaluate the quality of the fuel oil, since it determines the fuel system life and engine durability. Pyrolysis oils have been reported to have higher acid levels. [10]. Acidity results from acid number titration indicate that pyrolysis oils have a total acid number of 19.90 and some 33.03 [10]. Both of these are greatly above the biodiesel limit of 0.8, and there is therefore a significant danger of corrosion and consequent damage to fuel system components. The high acid number in pyrolysis oils may be due to the presence of

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phenolics and a certain amount of unidentified substance in the oils, and it is also related to the water content. Further treatment to reduce acid number is strongly recommended before blending pyrolysis fuel with any commercial diesel. The corrosive effect is related to the acidity and reactivity of the oils [10]. Pyrolysis oil cannot, however, be used in their present form as transportation fuels. The high acidity, low thermal stability, high viscosity and poor lubrication are some of the properties limiting their direct use as transportation fuel [9]. In addition to the system wear caused by mechanical friction due to the lack of lubricity and the presence of solid abrasive particulates [11], the electrochemical corrosion induced by the oil acidity plays an important role. Oil acidity may result from the acidity reagent present in the production process or from fuel oil ageing. So far there is no general correlation known between acid number and corrosiveness, however, fuel oils with high acid number have been proven to be associated with fuel system deposits, corrosiveness and increased storage risks [12].

Studies showing the performance results for engines operating with bio fuels were conducted, although very few long-term analysis of wear and maintenance problems are observed [37]. Wander et al. (2011) [13] observed the effect of fuel contamination due to filter housing using compression ignition engines operating with pure diesel oil, pure soy methyl ester (SME100) and pure castor oil methyl ester (CME100). The lubricating oil analysis didn’t reveal any excessive amount of metals compared to the engine with pure diesel. The results indicated that viscosity decreased very soon to values below the minimum recommended due to dilution with the methyl esters, especially with SME100 and the injection system analysis showed higher amount of carbon deposits indicating poor combustion.

This study will investigate the characteristics of tyre derived fuel blended with commercial.

II. METHOD

A. Pyrolysis- diesel blend preparation

5l of rubber derived pyrolysis oil was distilled at temperatures between 150˚C-250˚C prior to the testing of the filter using gaseous distillation. The crude fuel was heated at 100˚C . The temperature was maintained 250˚C to recover the distilled rubber oil from the crude oil.

Fig. 1 Set-up for gaseous distillation of pyrolysis oil

Various percentages of the distilled rubber oil were blended with commercial diesel to prepare different samples as summarised in Table II.

Fig. 2 Distilled pyrolysis fuel at 250^{o}C blended with diesel

B. Tests for corrosion resistance pyrolysis and diesel blends

Samples of distilled rubber derived fuel blended with diesel were added into in a closed plastic sample containers for 24 hours as shown in Fig. 3. A reaction of both plastic containers and pyrolysis diesel blends was observed.

Fig. 3 Pyrolysis-diesel fuel blends stored in plastic sample vials

C. Continuous single pass filtration

The impurities in pyrolysis-diesel blends fuel was investigated using a continuous single pass filtration. The set up consists of a conical filter tube with packed cotton fibres connected to a pressure gauge. Fuel blends of known composition were passed through a layer of cotton fibres at a constant flow rates. Diesel fuel and 5% diesel-rubber fuel blend was passed over a packed cotton fibres with packing density of 983.7 kg/m^3. In this study contamination of fuel blends due to poor filtration processes was investigated using packed cotton fibres. Cotton fibres were packed to allow zero voidage and closely packed in a cylinder as shown in fig. 4 and connected to a vacuum pump to allow fuel suction. Samples were then collected after each run. The same porous layer was re-used for filtration of 10%, 15%, 20%, 25% and 30% diesel-rubber fuel blends over the same time interval to monitor the particles trapped in the cotton fibers.

Fig. 4 Experimental set-up for single stage filtration

III. RESULTS AND DISCUSSIONS

A. Pyrolysis- diesel blend Characterisation

The crude rubber tyre derived oil was distilled at 250^{o}C where the gasses were passed through a layer of membrane sieves prior to condensation to remove moisture and distillable liquid mercaptans. The distillates obtained at 250^{o}C are fractions that resemble diesel as described by Pilusa *et al*. (2012) [14]. All sulphur containing compounds with a lower carbon ring compounds were easily removed due to the lower boiling points [15]. This explains the decrease in sulphur content from 9106 ppm to 4055 ppm during distillation. Table I shows the physical properties of rubber fuel distillates obtained at 250^{o}C under gas phase de-sulphurisation distillation. Molecular sieves were placed in the condenser to allow mass transfer of moisture and distillable liquid mercaptans and asphaltene over the sieves. The results presented in Table I reveals that the light fractions obtained at 250^{o}C under gas phase de-sulphurisation distillation are near the properties of diesel fuel as per South African National Standards (SANS-342) presented in Table I. This method does not only refine pyrolysis fuel but also reduce the sulphur content by 40%. A slight difference in density, flash point and calorific value is observed.

TABLE I
PHYSICAL PROPERTIES OF CRUDE RUBBER OIL, DIESEL FUEL AND DISTILLATES AT 250^{o}C

Property	Crude Rubber Fuel	Diesel Fuel	Distillates @250^{o}C	SANS 342 Specification
Density @ 20^{o}C (kg/m^{3})	926	831	807	800-950
Viscosity @ 40^{o}C (cSt)	9	2.6	1.5	2.2-5.3
Flash Point (^{o}C)	94	54	44	>55
Total Contamination (mg/kg)	143	2.6	5.5	<24
Total Sulphur (ppm)	9106	50	4055	<500
Water Content (vol. %)	3.54	0.05	0.065	<0.04
Gross Calorific Value (MJ/kg)	43	46	43.7	-

Due to its high viscosity and high sulphur content of pyrolysis oil as shown in Table I, its direct application as a fuel in diesel engines is not recommended, however when blended with diesel fuel it can be used as alternative additive. In this study pyrolysis oil was blended with commercial diesel at varying percentages from 0% to 30% respectively as presented in Table II.

TABLE II
PYROLYSIS –DIESEL BLENDS

Sample	Pyrolysis- diesel blends						
	0%	5%	10%	15%	20%	25%	30%
Diesel (ml)	500	475	450	425	400	375	350
Pyrolysis oil(ml)	0	25	50	75	100	125	150
Totalvolume(ml)	500	500	500	500	500	500	500

The physical properties of pyrolysis- diesel fuel blends of different dosages are observed in Table III. The viscosity of a fuel is defined as it's resistance to flow thus the higher the viscosity, the greater the resistance to flow [5]. Between 0% and 25% pyrolysis diesel blends, viscosity ranges between 2.2 and 5.6 cSt which comply with SANS 342. For 30% blend the viscosity was 2 cSt which was very low according to SANS 342. High fuel oil viscosity is considered beneficial in lubricating the fuel supply system and thus decreasing mechanical wear, however on the other hand it worsens the flow characteristics of the oil and its atomisation quality which can cause incomplete combustion and engine power loss [16] therefore to burn most cleanly, fuel must be injected such that the momentum of the atomised fuel disperses it evenly throughout a combustion chamber. Similarly high fuel surface tension leads to poor atomisation [16]. A fuel with too low viscosity produces a spray which is too soft and does not penetrate far enough into the combustion chamber, affecting combustion, reducing both power output and fuel economy. In addition, a fuel rich zone is produced around the injector, which leads to excessive soot formation.

High sulphur content in fuel is associated at a molecular level with complex structures that are not easy to burn [15].

High sulphur content in all diesel blends is observed. Distilling the oil reduced the sulphur content present in the crude rubber oil by 40% and further treatment of the blends is recommended before used in diesel engines .Sulphur acts as lubricity agent and an anti-oxidant for the fuel. Fuels containing moderate amounts of sulphur protect a fuel pump and injectors from wear and deposit forming products of thermal degradation and oxidation. A high amount of light volatiles during distillation indicates a tendency to generate potentially explosive vapours, while a high heavy fraction is the major determinant of solid combustion deposit [2]. These properties explain the reaction of plastics with diesel blends during storage because the nature of the oil composition gives rise to an unfavourably high acidity level, which leads to a certain corrosiveness to plastic.

TABLE III
PHYSICAL PROPERTIES OF 0% TO 30% PYROLYSIS –DIESEL BLENDS

Property	**Pyrolysis- diesel blends**						
	0%	5%	10%	15%	20%	25%	30%
Density @ 20^oC (kg/m^3)	831	837	837	837	837	836	836
Viscosity @ 40^oC (cSt)	2.6	2.9	2.8	2.5	2.4	2..2	2
Flash Point (^oC)	54	50	48	42	44	38	34
Total Contamination (mg/kg)	2.6	5.2	5.6	6.1	6.4	9.2	11.7
Total Sulphur (ppm)	50	667	849	1057	2055	2257	2330
Water Content (vol. %)	0.05	0.021	0.021	0.014	0.017	0.011	0.007
Gross Calorific Value (MJ/kg)	46	44.8	44.8	44.7	43.7	43.7	43.7

B. *Continuous single pass filtration*

Motor vehicle industries are challenged with the purification of fuel. For fuel to be considered clean, it must meet the following requirements: the size of contaminant determined to be the most detrimental to the engine must be removed, it must have the capacity to hold that contaminant for the recommended service interval and also to have the ability to allow the fuel to continue to flow through the filter and be cleaned even as the restriction in the filter increases [18]. Packed cotton fibres were used in this study with zero voidage and packing density of 983.7 kg/m^3 as described by equation 1.

$$\partial_\rho = \left(\frac{12.m_i}{\pi.d^2.(h + 3l_t)} \right) \quad (1)$$

∂_p Packing density in (kg/m^3)

m_i Average mass of cotton fibres (kg)

d_i Average diameter of filter media housing tube (m)

l_t Active length of filter media housing tube (m)

TABLE IV
TEST RESULTS FOR MICRO FILTRATION OF PYROLYSIS-DIESEL BLENDS

Mass of cotton (kg)	**Mass of cotton (kg)**	**Mass of cotton (kg)**
0.02403	0.02604	0.02408
	Average	
Average mass	**0.02472 kg**	
Length of tube(mm)		100
Height of cone (mm)		30
Diameter of tube Volume (mm)		40
Tube Volume (m^3)		0.02513
Filter Media Packing Density(kg/m^3)		983.7

Tyre derived fuel-diesel blends were passed through the layer of cotton fibres for to measure the particles trapped in the cotton. The longer the fuel is passed through the filter the more black the cotton became which illustrates the impurities injected to the fuel system. These results are shown by fig. 5. These problems results in higher fuel costs and lessened availability due to higher concentration of particulate matter in fuels. As the larger particles are removed from the fuel by the primary filter, it remains a challenge to deal with larger quantities of particles that are small enough to pass through the primary filtration system and eventually reports in the fuel injection system [17]. Therefore the use of pyrolysis blended with commercial diesel is not recommended without a secondary filter that will remove smaller particles that can pass through as primary filter.

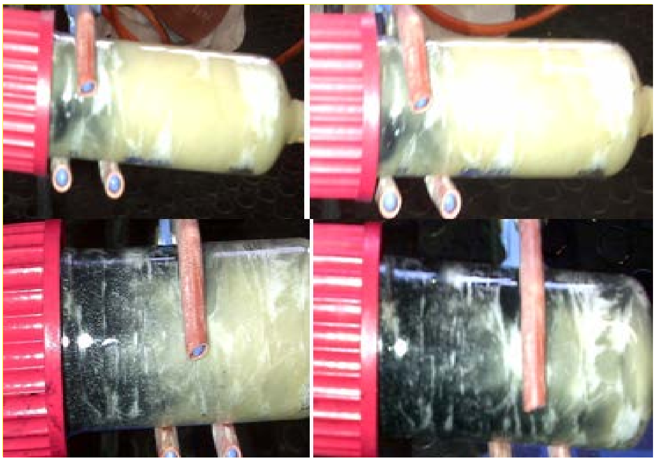

Fig. 5 pyrolysis-diesel blends passed through packed cotton fibres

IV. CONCLUSION

This study showed that the distilled rubber oil properties of obtained from gas phase de-suphurisation distillation at 250^oC are nearly comparable to commercial diesel. Calorific value of pyrolysis-diesel blends is also within acceptable limits although it decreased by approximately 5%. Sulphur content was also reduced by 40% during gaseous distillation. 25vol. % of distilled rubber oil with diesel showed satisfactory viscosity of 2.2 cSt however the sulphur content increased and flash point decreased therefore further sulphur treatment and flash point alteration in the blends are recommended. High sulphur levels in the blends are associated at a molecular level with complex structures that are not easy to burn. High particulate matter content in fuels affects engine performance therefore the use of pyrolysis-diesel blends without a secondary filter that will remove smaller particles which can easily pass through as primary filter is not recommended

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