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Performance & Durability Analysis of Diesel Engine Using Crude TPO and Refined TPO Blends

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ABSTRACT: The objective of this study is to study the performance of diesel engine using crude TPO (Tyre Pyrolysis Oil) -diesel blend and refined TPO-diesel blends. The crude TPO was refined in various stages and during each stage, the TPO-diesel blend was tested in the diesel engine. The diesel engine set up used was single cylinder, four stroke, naturally aspirated & water-cooled generally used for agricultural purpose. The tests were conducted at two engine speeds 600rpm & 700rpm. During study the parameters, brake power (BP), brake specific fuel consumption (BSFC), thermal efficiency (ɳth) didn't show significant deviation as compared to that with the mineral diesel. To estimate the long term effects of the blended fuel on the engine life & engine wear was also inspected.

Keywords: TPO- Tyre Pyrolysis Oil, BP- Brake Power, BSFC- Brake Specific Fuel Consumption, BSEC- Brake Specific Energy Consumption, DTPO- Distilled Tyre Pyrolysis Oil, LSDTPO- Low Sulphur Tyre Pyrolysis Oil.

1. INTRODUCTION

The day by day increasing demand of fossil fuels has spurred global unrest. In order to develop a sustainable fuel, its continuous supply is necessary. In this paper, waste tyre is cited as the potential fuel. The quantum of waste tyre generated is about 16 million tons [1] per year globally, out of which India alone generates 1 million tons per year. Waste tyres being non-biodegradable are of concern to the environment. This paper attempts to address both the problems of fuel shortage as well as recycling of waste tyres. Waste tyres can be converted to fuel with the waste to energy technique known as pyrolysis.

Diesel engines have a high tolerance of fuel & high thermal efficiency which makes them an obvious choice for experimenting with alternate fuels. In the following text the performance parameters of the diesel engine are studied by modifying the crude waste tyre pyrolysis oil. Literature study has shown significant scope in TPO as a fuel. Kennedy ZR et al [2] have conducted experiments with 20%, 40%, 60% & 75% distilled TPO on DI diesel engine & concluded with similar performance & lower emissions of HC and CO. Ilkılıç C et al [3] have showed decrease in output power and engine torque while brake specific fuel consumption increased with the increasing tyre derived fuel content in the diesel fuel blends. S. Murugan et al [4] was able to run a diesel engine at a maximum percentage of 70% crude TPO- diesel blend. Further higher viscosity & higher Sulphur interfered with the normal combustion process of the engine. Later they [5] were able to run with 90% distilled TPO-diesel blend. It reported a drop of 3% in thermal efficiency. On the other hand, ironically the peak pressure raised about 1.6 bar to 2 bar but NOx decreased by 21%. Although they only did concentrated acid (sulphuric acid) treatment of TPO. However A.S.M.R. Nabi et al [6] performed activated bentonite & calcium oxide treatment. But still high content of Sulphur was a still the problem which would accelerate the wearing process in the cylinder. O. Dog˘an et al [7] in addition to above treatment also performed healing with formic acid & hydrogen peroxide. This resulted in reduced Sulphur content in the fuel. The oil obtained from this process is called healed TPO. During performance tests with 70% healed TPO & diesel blends, a mild 1.6% decrease in the output torque & power of engine was observed.

When engine is made to run on alternate fuel, its brake thermal efficiency decreases, while specific fuel consumption increases [13]. The same can't be generalized about the wear rate, carbon deposition rate, and lubrication oil contamination in an engine. Agarwal et al [14-15] studied the wear pattern of in-cylinder engine components and lubricating oil tribology of a diesel engine fueled with B20 linseed oil methyl ester by conducting a 512 hour endurance test. He inferred a 30% lower wear debris and prolonged life of the engine oil. The reason is the high viscosity of biodiesel help in lubrication, decreasing wear. Wear characteristics of the spray nozzle have also been studied by X-ray spectroscopy [16].

This study aims to consider short term durability analysis of the engine, when fed with TPO, DTPO, LSDTPO – diesel blend. For the engine used, 50 hours of operation was chosen as the test duration. After 50 hours the cylinder head was dismantled. Carbon deposition in the cylinder and other visual inspection were studied & conclusions were drawn to give a long term picture.

2. PYROLYSIS PROCESS

Pyrolysis is not a new technique. In 1800 charcoal was the main fuel during industrialization. It was derived by pyrolysis of wood[a]. Pyrolysis is the process in which the matter is shredded in to small particles and thermal cracking is done in the absence of Oxygen to break long chain hydrocarbons into short chain hydrocarbons. Here absence of Oxygen is crucial as, it would otherwise burn the volatile substances present in the oil. During pyrolysis, gas, char and oil are produced. The temperature here is most crucial for the production of different products. It has been found that between temperatures 300-350^{0}C maximum oil is produced. At higher temperature gaseous products dominate. Process efficiency for Pyrolysis is about 70% & can be made to 90% if the derived gases are used a fuel.

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2.1 Tyre Pyrolysis Oil

The crude TPO has a high calorific value (about 38 MJ/kg), compared to that of waste tyres (33 MJ/kg). The calorific value of TPO is even higher than that of bituminous coal (28 MJ/kg) and wood charcoal (30 MJ/kg). TPO is classified into six classes, fuel oil 1 to 6, according to boiling point, composition and purpose. TPO can be used either directly as a fuel or as a raw material in the petroleum industry. The oil has proven to be a good replacement for refined fuel in areas like furnace heating, Bhatti, brick making industry etc. In order to ideally replace the conventional diesel fuel, its crucial properties need to be compared.

Table 1. Properties of Diesel, TPO & DTPO (refined & distilled TPO)

Property	Diesel	TPO	DTPO
Density at 15°C (kg/m^3)	0.830	0.96	0.90
Kinematic Viscosity at 40°C (cst)	2.58	3.77	2.7
Net Calorific Value (MJ/kg)	42	38	43.8
Cetane Number	48	38	42
Flash Point (°C)	50	43	36
Fire Point (°C)	56	50	38
10% Boiling Point (°C)	240.5	124.3	-
50% Boiling Point (°C)	278.5	287.2	-
90% Boiling Point (°C)	330.5	385.4	-

Table 2. Proximate analysis of TPO reported by various researchers

Element	S. Murugana et al [8]	C. Wongkhorsub et al [9]	Bhatt Prathmesh et al [10]	Abhishek Sharma et al [11]	Williams et al [12]
C	84.6%	84.67%	84%	86.92%	85.9%
H	11.2%	10.44%	22%	10.46%	8%
N	0.5%	-	(trace)	0.65%	0.4%
S	1.4%	0.9%	0.88%	1.02%	1.0%
O	2.2%	4.17%	-	-	2.3%

3. EXPERIMENTAL PROCEDURE

The engine was made to run on commercially available diesel; till it reached a steady condition. The speed of the engine was adjusted to 600 rpm. Fuel consumption for different loads was measured keeping the speed constant. After diesel, the engine was made to run till all the fuel in the fuel line is consumed [17-19]. Then the engine was fed with various fuel blends and the engine performance parameters were studied.

Fuel Preparation- The oil used was opaque black and smelled of burning rubber. The TPO was acidic in nature & literature survey [8-12] hinted on high Sulphur content of the oil. A 2% mixture of crude TPO (rest diesel) was prepared and test was conducted.

In order to exploit the fuel to commercial viability, further refining of fuel was done. The refining process was divided into following stages-

i. Concentrated sulphuric acid treatment

At this stage crude TPO was mixed with 8% (by weight) concentrated sulphuric acid. The contents were then well stirred for 4 hours and left to stay for 48 hours. Since reaction is an exothermic one, average temperature of mixture recorded was 600C for the first hour. The gas evolved was allowed to escape. After 48 hours the mixture was found to be in 2 layers. The top one consisted of oil whereas the bottom was thick sludge. The average yield of the process was 78%. The oil obtained was collected & subjected to further treatment.

ii. Activated bentonite- calcium oxide treatment

In this stage the oil was subjected to a mixture of calcium oxide & activated bentonite, mixed in the ratio of 1:2(10% of calcium oxide by weight of the oil taken). The temperature of the contents was maintained 700C during the 4 hour stirring process. Then the mixture was left untouched for 24 hours. After 24 hours the oil was filtered out using filter paper and taken for distillation. Approximate yield of the process was 95%.

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iii. Vacuum distillation

The oil obtained in above process was distilled by vacuum distillation technique. All the vapors below 1800C were condensed. Hydrocarbons with higher boiling point were discarded. The oil obtained was clear in appearance and had density & viscosity comparable to that of mineral diesel. The healed TPO obtained had high percentage of Sulphur but still tests were performed with this fuel to study its effect on engine.

iv. Oxidative- desulphurization

In this process, 100gm of a mixture containing 98% formic acid and 30% hydrogen peroxide in the ratio of 1:2 by weight was added to 1000ml of the distilled oil obtained during (iii). The mixture was maintained at 600C and stirred by mechanical stirrer for 2 hours and left for overnight. In morning it was found to be in 2 layers with a white layer separating them. The above layer is collected and heated to about 1100C to remove residual moisture. This oil was used to create LSDTPO- diesel blends.

Table 3. Nomenclature of the fuel used

Nomenclature	Modification to crude TPO	Blend composition
TPO2	None	2% crude TPO & rest diesel
DTPO10, DTPO15, DTPO22	a) Conc. Sulphuric Acid treatment b) Activated bentonite-calcium oxide treatment c) Vacuum distillation (below 180^{0}C)	10%,15%, 22% chemically treated-distilled TPO & rest diesel respectively
LSDTPO10, LSDTPO15, LSDTPO22	In addition to above process oxidative-desulphurization treatment	10%,15%, 22% chemically treated-distilled-de-sulphurised TPO & rest diesel respectively

Table 4. Specifications of the engine test rig

Specifications	Magnitude
Rated Power	6 HP (4.5kW) at 600 rpm
Diameter of the piston	114 mm
Length of the stroke	140 mm
Type of fuel (specified by maker)	Commercially available Diesel
Calorific Value of Diesel used	41800kJ/kg

4. RESULTS & DISCUSSIONS

4.1 Brake thermal efficiency

The variation of brake thermal efficiency as a function of brake power is plotted in Fig. 1. Using mineral diesel maximum brake thermal efficiency (BTE) observed was 29.2%. For crude TPO2 the BTE was marginally lower at 28.5%. The reason for lower BTE is high viscosity & high ash content in the crude TPO which interferes with the spray characteristics of the injector nozzle. Maximum BTE observed with DTPO10, DTPO15 & DTPO22 were 30%, 29% & 26% respectively.

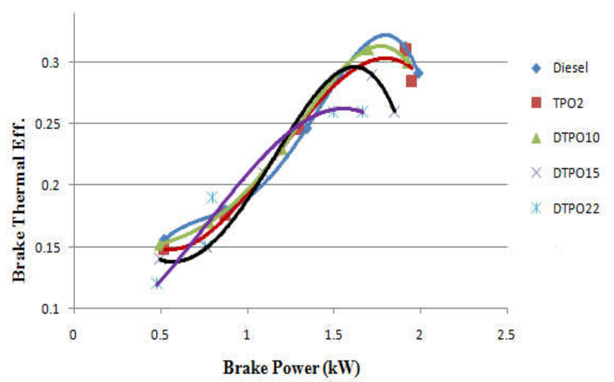

Figure 1: Variation of brake thermal efficiency with brake power

Highest BTE observed was with DTPO10 which is 2.74% higher than pure diesel. DTPO has a marginally high viscosity, which enhances its lubrication property. This might be the possible reason for a slight increase in BTE. On further increasing DTPO content the high density interferes with the normal spray characteristic in the nozzle decreasing BTE.

4.2 Brake specific fuel consumption & brake specific energy consumption

Brake specific fuel consumption (bsfc) initially decreases for all fuels & then tends to decreases. The reason for this behavior is, initially the engine performs at part load consuming more fuel. This is followed by optimum point and after that engine becomes overloaded. With DTPO – diesel blend, the bsfc observed is always higher than that of pure diesel.

When comparing two fuels of different densities & different calorific values, bsfc doesn't always give the clear picture because it accounts for the density alone. It is brake specific energy consumption (bsec) which considers heating value as well as density [20]. Bsec follows a similar trend as that of bsfc as shown on the Fig. 3.

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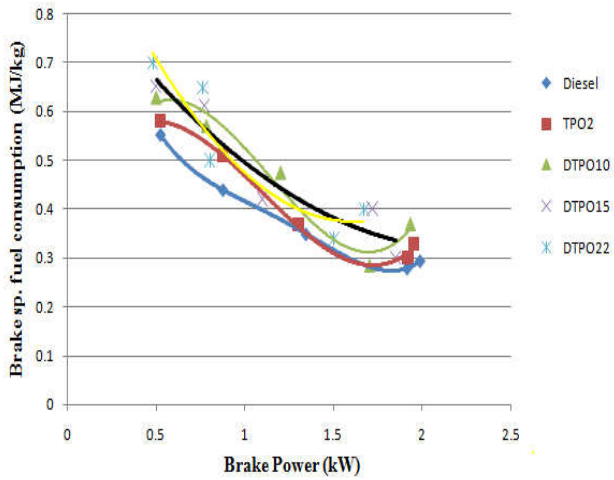

Figure 2. Variation of brake sp. fuel consumption with brake power

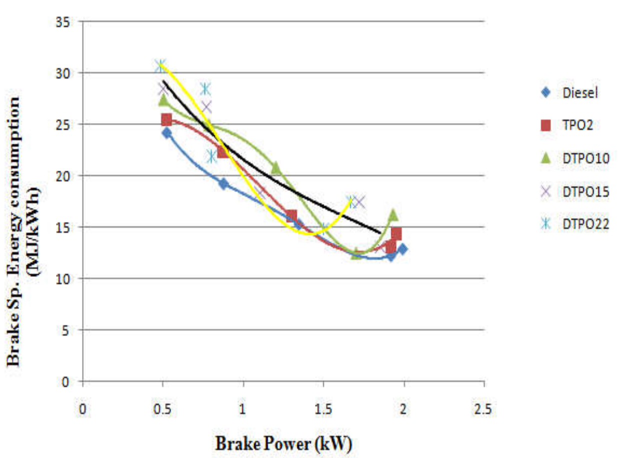

Figure 3. Variation of brake sp. energy consumption with brake power

4.3 Exhaust gas temperature

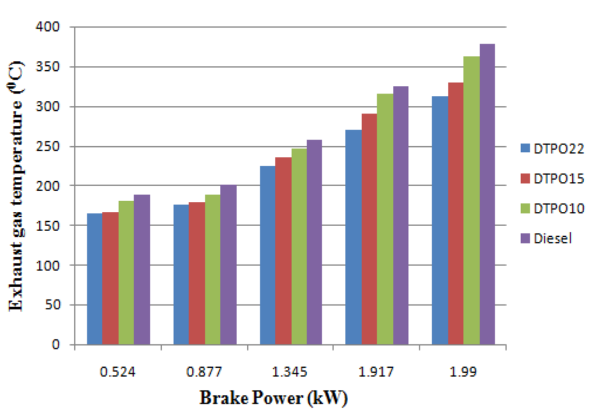

Figure 4: Variation of exhaust gas temperature with brake power

Fig. 4 shows variation of exhaust temperature with brake power. Lowest temperature is recorded at least load and it increases with increase in load.

DTPO- diesel blend leads to a marginally lower exhaust gas temperature. This is because of lower viscosity resulting in lesser penetration of the fuel and the lesser amount of heat is release inside the combustion chamber [5] [21].

5. CONCLUSION

The agricultural based diesel engine was successfully run on TPO2- diesel blend and with DTPO10, DTPO15 & DTPO22 after modifications to the TPO. Though minor drop in brake power was observed but it is still in the tolerance zone. The brake specific energy consumption of DTPO-diesel blend is higher as compared to pure diesel. This is due to inferiority of DTPO as compared to diesel.
A 50 hr durability test was conducted on the engine and significant wear was observed affecting long term performance of the engine. The wear in the injection system had an impact on the injection pressures, timing, spray patterns & hence on combustion phenomenon.

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