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EXPERIMENTAL INVESTIGATIONS ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF A COMPRESSION IGNITION ENGINE USING BLENDS OF TIRE PYROLYSIS OIL AND DIESEL

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Abstract

Most of the countries are facing the problem in the disposal of scrap tires and tubes. This problem can be overcome by the production of tire pyrolysis oil (TPO) from these materials. The calorific value and other properties of the TPO are similar to the fossil diesel, and hence in this work, it was used as a partial replacement to the diesel. The fuel blend (DTPO20) was prepared by mixing 20% of TPO with 80% of diesel and properties of this blend was determined and compared with the diesel. The engine tests were carried out on a single cylinder, four strokes, naturally aspirated compression ignition engine with the fuel blend, DTPO20. From the engine tests, it is observed that the engine gives lower thermal efficiency and higher engine exhaust emissions with this blend. Hence, the compression ratio of the engine was increased from 16.5:1 to 17.5:1 and engine tests were carried out again, and results of this engine tests were compared with the compression ratio of 16.5:1.

***Keywords**: Alternative fuel; tire pyrolysis oil; blend, engine tests; compression ratio.*

1. Introduction

A tire is a strong, flexible and ring-shaped component that surrounds a wheel's rim and provides a gripping surface for traction of a moving vehicle. The natural rubber is the main raw material used in the manufacturing of tires. The other materials such as fabric, steel wire, carbon black and chemical compounds such as antioxidants and antiozonants are used to prepare the tires [1]. It is reported that approximately 1.5 billion tires are produced each year [2]. The USA is the largest producer of tires and India accounts for about 6-7% of the global waste tire. Also, the scrap tire arising in Europe increases every year [3]. The developed and developing countries are facing problems in disposal of the waste tire, and this problem can be solved by converting it into fuel. The scrap tires can be converted into liquid fuel by pyrolysis process, and this fuel (tire pyrolysis oil) can be used as a substitute for the diesel in the compression ignition engines.

In recent years, the search for alternative fuels is significant due to stringent norms of emission, depletion of fossil fuels and fluctuating cost of the petroleum products. Finding suitable alternative fuel will be the solution to this problem. The fossil fuel depletion has been identified as a future challenge, and it is important to understand that the fossil energy problem and the anthropogenic climate change problem are tightly connected [4]. The depletion studies for individual fuels are relatively abundant and fewer studies include the demand of the socio-economic system [5].

The TPO has long hydrocarbon chains with a high heating value, and hence TPO can be used as an alternative fuel for diesel engines. India is the second largest producer of reclaimed rubber, and hence it has the potential for the production of the TPO [6]. The scrap tires can be converted into fuel through a pyrolysis process. In this process, the scrap tires and tubes are shredded, and the reaction takes place at a higher temperature in an oxygen-free atmosphere.

The higher reaction temperature breaks down the rubber polymers and these smaller molecules vaporize and condensed to get liquid fuel called TPO. The yield of the pyrolysis process is affected by the type of raw materials, reactor types and type of catalysts. G. Lopez *et al*. results show that 475°C is an appropriate temperature for the pyrolysis of waste tires. Also, they suggested that the quality of the oil is optimum at this temperature and an increase in temperature to 575°C reduced the TPO yield to 53.9 %. However, it substantially changes the chemical composition by increasing the aromatic content [7].

The hydrodesulfurized waste TPO mainly composed of a light naphtha fraction [8]. The pyrolytic oil is a complex liquid mixture, composed mainly of aromatic compounds and olefins. It is reported that the pyrolytic oil has higher detonation resistance in relation to the conventional fuels and the tire pyrolysis oil is miscible with diesel in the entire concentration range [9].

Few researchers reported that the properties of the TPO are similar to fossil diesel and hence it can be used as a substitute for the diesel [10]. The integration of solar thermal energy, via concentrated solar power systems, into the pyrolysis process will reduce the operating cost [11]. MN Islam and MR Nahian reported that the distilled TPO is similar to diesel fuel and able to replace diesel fuel in the small engine. They observed that the brake specific fuel consumption of fuel blend of diesel and TPO is close to the specific fuel consumption of diesel and suggested that the fuel blend can be directly utilized in diesel engine [12]. Hürdoğan *et al.* carried out engine tests on a four-stroke, four cylinders, naturally aspirated, direct-injected diesel engine running with various blends of waste tire pyrolysis oil (WTPO) with diesel fuel and the experimental results showed that WTPO–diesel blends indicated similar performance with diesel fuel in terms of torque and power output of the test engine. They suggested that the blends of pyrolysis oil of waste tire WTPO10 can efficiently be used in diesel engines without any engine modifications [13]. Hürdoğan *et al.* carried out engine tests on a six-cylinder, compression ignition, turbocharged, heavy-duty engine with and without an intercooler, at two different engine speeds and at various loads. The engine results indicate that TPO can be efficiently used in turbocharged non-intercooled compression ignition engines at high loads, which opens its use in power generation [14]. The engine tests conducted on a single cylinder compression ignition engine with the mixture of biodiesel and TPO as fuel indicates that the TPO can be used as a partial substitute for the diesel with higher fuel injector nozzle opening pressure [15].

In this work, we prepared the fuel blend of diesel and TPO and used this fuel blend as fuel in the compression ignition engine to reduce the operating cost as TPO is cheaper as compared to the diesel. Also, we studied the effect of compression ratio on the performance and emissions of a compression ignition engine fueled with the blends of diesel and TPO.

2. Materials and methodology

In this work, TPO available in the local market was purchased and used as fuel for the engine tests. The TPO was filtered using filter paper to remove the impurities. The fuel blend was prepared by mixing diesel and TPO, with a ratio of 80:20 (volume basis) and is named as DTPO20. The properties of the diesel, TPO and blend were determined by ASTM and BIS methods. The blend DTPO20 was used as fuel in the diesel engine

The engine tests were carried out on a single cylinder naturally aspirated direct injection compression ignition engine with diesel and DTPO20 blend. The technical details of the engine and experimental setup is given in Table 1. The engine load was varied from no load to full load using an eddy current dynamometer. The compression ratio was varied to study its impact on engine performance and emissions. An AVL make gas analyzer was used to measure the engine exhaust emissions, and necessary instrumentations were provided to measure the engine performance parameters such as airflow, fuel flow, temperature, and load measurement. Figure 1 shows the experimental setup.

Table 1 Technical details of the engine and experimental setup

Engine	Single cylinder,4-Stroke, Naturally Aspirated Diesel Engine
Make	Kirloskar
Rated speed	1500 rpm
Maximum brake power	3.5 kW at 1500 rpm
Displacement	661 CC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Dynamometer	Eddy Current Dynamometer
Thermocouple sensor	Type RTD
Thermocouple range	0 – 1200 Degree C

Figure 1. Engine experimental setup

3. Results and discussion

The homogenous blend was prepared by mixing TPO and diesel vigorously and was used as fuel in the compression ignition engine. The fuel properties of the DTPO20, TPO, and diesel were determined, and the results are shown in Table 2. From the table, it is observed that the properties of DTPO20 are close to diesel.

Table 2. Properties of fuels

Property	Diesel	TPO	DTPO20
Viscosity (mm^2/s)	2.5	3.2	2.7
Calorific value (MJ/kg)	42.04	41.2	41.7
Density (kg/m^3)	845	885	853
Flash Point (°C)	65	42	50
Fire Point (°C)	59	46	57
Carbon residue (%mass)	0.06	0.75	0.19
Pour point (°C)	4.2	6.1	4.6

The engine tests were conducted successfully with the blend of TPO and diesel and studied the effect of compression ratio on engine performance and emissions of the diesel engine. The term brake thermal efficiency indicates the effectiveness of conversion of heat energy possessed by the fuel into mechanical energy. Figure 2 shows the brake thermal efficiency (BTE) of the engine at different loads with various compression ratios. From the figure, we observe that as the load increases the brake thermal efficiency of the engine increases due to the increase in fuel consumption at higher loads. From the figure, it is observed that the BTE of the engine with a higher compression ratio of 17.5:1 results in higher BTE. This may be due to the increase in combustion chamber temperature at a compression ratio which results in better atomization and spray formation of the fuel blend as compared to lower compression ratio.

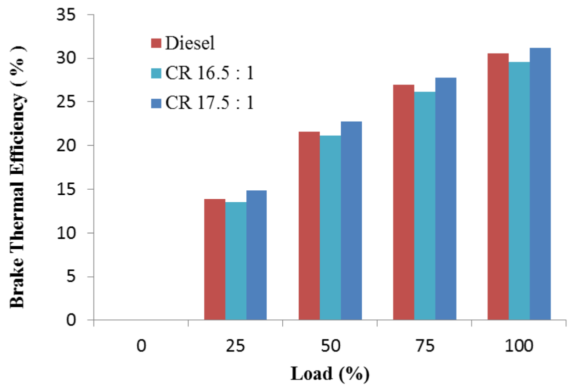

Figure 2. Effect of compression ratio on brake thermal efficiency at different loads

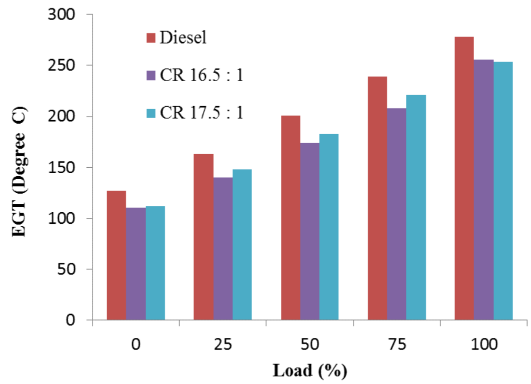

Figure 3. Effect of compression ratio on EGT at different loads

Figure 3 compares the engine exhaust gas temperature (EGT) of the diesel and TPO blend at different loads with different compression ratio. The consumption of the fuel increases with increase in the load, and hence the EGT of the engine increases with the load. The EGT of the diesel is higher than the TPO blend. However the higher compression ratio of 17.5:1 results in higher EGT as compared to the compression ratio of 16.5:1 and this is due to better combustion of the blend. A slight variation in EGT of the engine was observed at different compression ratios.

The carbon monoxide (CO) and unburnt hydrocarbon (HC) emissions of the engine indicates the combustion quality of the fuel inside the combustion chamber. The main reason for the formation of CO emission is due to a lack of sufficient oxygen and oxidization temperatures. The poor combustion of the fuel results in higher CO emission. The CO emission of the engine with diesel and TPO blend and at different compression ratio is shown in Figure 4.

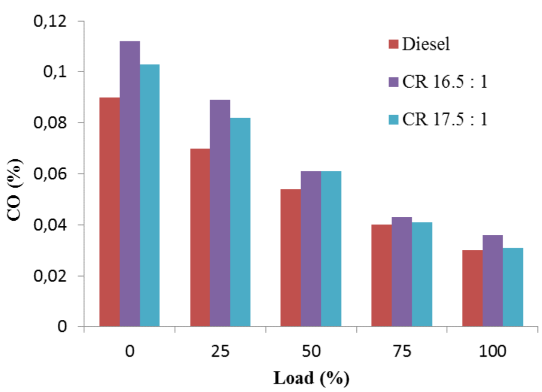

Figure 4. Effect of compression ratio on CO emission at different loads

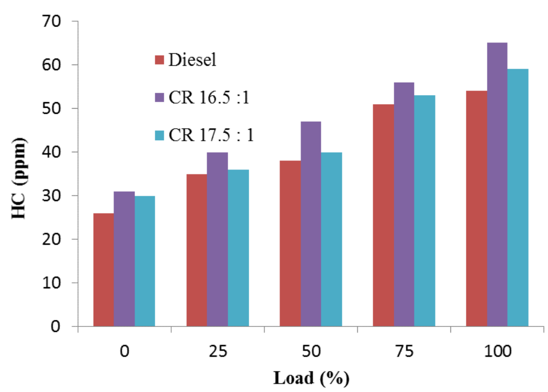

Figure 5. Effect of compression ratio on HC at different loads

From the figure, it is observed that the engine emits lower CO emission with the diesel as compared to the TPO blend. The compression ratio of 16.5:1 results in higher CO emission as compared to the compression ratio of 17.5:1. This is due to higher aromatic content of the

TPO which results in higher CO emission. However, the higher compression ratio with TPO blend results in higher combustion chamber temperature and better oxidation of the fuel which causes lower CO emission. The variation in CO emission is low at higher loads, and this may be due to higher combustion chamber temperature and lower ignition delay at higher loads.

Figure 5 shows the hydrocarbon (HC) emission of the diesel engine at different loads with different fuels and at different compression ratios. From the figure, it is observed that the TPO blend results in higher HC emission as compared to diesel. The HC emission is lower with the higher compression ratio of 17.5:1 as compared with the compression ratio of 16.5:1. The higher compression ratio results in lower ignition delay and hence the HC emission of the 17.5:1 is lower than the 16.5:1.

The oxides of nitrogen (NOx) emissions of the diesel engine depend upon the combustion temperature. The NOx emission of the engine with different fuels and at different loads is shown in Figure 6. From the figure, it is observed that the NOx emission of the engine with diesel results in lower NOx emission as compared to the TPO blend with the compression ratio of 17.5:1. The NOx emission of the engine with the compression ratio of 16.5: 1 is lower than the other compression ratio and diesel. The higher compression ratio of 17.5:1 results in higher combustion chamber temperatures and pressure which results in better combustion and causes higher NOx emission.

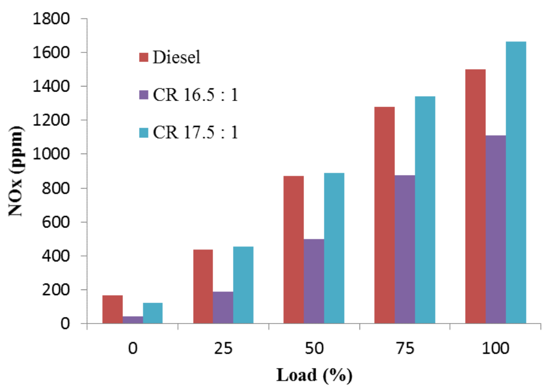

Figure 6. Effect of compression Ratio on NOx at different loads

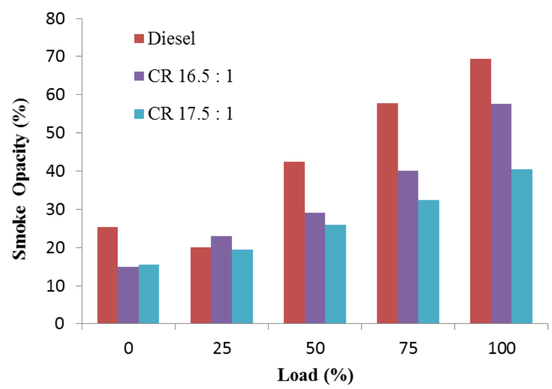

Figure 7 Effect of compression ratio on smoke opacity at different loads

One of the major emissions of the diesel engine is smoke emission and is an incomplete combustion product. Generally, it is formed in the rich mixture in the combustion chamber. The engine smoke emission with different fuels at different compression ratios and loads is shown in Figure 7. From the figure, it is observed that as the load increases the smoke emission also increases and this is due to a reduction in air-fuel ratio. The diesel results in higher smoke emission as compared to TPO blend at higher loads. The compression ratio of 16.5:1 results in higher smoke emission as compared to the compression ratio of 17.5:1. The compression ratio of 17.5:1 results in lower smoke emission is due to higher combustion chamber temperature which results in better oxidation and combustion of the fuel.

4. Conclusion

The pyrolysis of scrap tire and tubes is one of the effective methods of disposal of scrap tires and tubes. Also, the pyrolysis oil can be used as a partial substitute for the diesel in the compression ignition engines as the properties of the TPO are similar to the diesel. The engine tests were carried out with the blends of TPO and diesel and studied the effect of compression ratio on the performance and emissions of the engine. From this work, we observe that the higher compression ratio results in better brake thermal efficiency and lower CO, HC and smoke emissions. However, it results in higher NOx emissions. This is due to higher combustion chamber temperature which results in better combustion and lower engine exhaust emissions. From this work, we suggest that the fuel blend of diesel and TPO can be used as fuel in the compression ignition engine with a higher compression ratio.

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