Studies on Pyrolysis Oil derived from waste Tires as Fuel for Diesel Engine

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Abstract. In recent years, the number of automotive vehicles are increasing as these vehicles are becoming essential in developed and developing countries; which results in increase in waste tires. In most of the developing and under developed countries, the waste tires are not scientifically disposed and pollutes the environment. The synthetic rubber present in the tire is not biodegradable. Hence a research work is carried out to convert the waste tires and tubes into fuel using the process of pyrolysis. The tire pyrolysis oil (TPO) properties were compared with fossil diesel and it was observed that the properties of tire pyrolysis oil and diesel are closer. In the diesel engine the tire pyrolysis oil was used as partial substitute for the diesel and engine tests were performed by varying the engine loads. The results of the engine tests show that the tire pyrolysis oil can be effectively used as partial substitute in diesel engine with no need of making modifications in the engine’s fuel injection system. This paper discusses the waste tire statistics, conversion of tire into tire pyrolysis oil and engine studies with tire pyrolysis oil.

1. Introduction

A ring like part that surrounds vehicle wheel rim and transfer vehicles load to the ground and provides traction is called as tire. It is fitted on vehicle rims with tubes and filled with compressed air. Natural rubber is widely used in manufacturing tires. However, synthetic rubbers are used in recent years due to its advantages over natural rubber. Tires are used in various applications such as cars, motor cycles, cycle, aero planes etc. The functions of tires are to carry the vehicle load, absorb road irregularities, provide stability and control of the vehicle and transfer traction [1].

The tire consists of about 45% rubber or elastomer, carbon black 22%, metal 18%, additives 7%, textile material 7%, zinc oxide 2%, sulphur 1% etc. The compositions vary depending upon the application, manufacturer, etc. For example, the rolling friction is high in vehicles and hence additives which reduces the rolling friction is added to the components used for preparation of tires. The important parts of tires are synthetic rubber or natural rubber, wire, fabric, tread, carcass, sidewall, shoulder, bead, bead wire, bead filler and liner (Figure 1).
Nearly 1.5 billion number of tires are produced every year which will finally enter into the waste stream thereby representing a major potential waste and pose environmental problem [2]. In India waste tires are increasing and it is reported that India account for about 6 to 7% of world waste tires due to increase in automobile numbers and industrialization. The growth of tire industries in India is about 12% annually and number of major tire industries are about 40. The waste tires (Figure 2) are unsuitable in automobile and is not safely disposed due to increase in waste tire numbers and affordability [3].

Figure 1. Tire Parts

Figure 2. Waste Tires

The changes in India’s environmental regulations made the tire industries versatile to adapt latest technologies to reduce emissions related tire technology [4]. However this is not as effective as developed countries. The industrialization and increase in automobile growth resulted in higher tire demand and it is a challenge to dispose the waste tires [5].

The automobile tires contains more than 60 components and few components are toxic. In landfill, these toxic components of the tires may leach into the soil and may pollute the ground water [6]. In recent years, waste tires are imported to India for recycling or for disposal. If these waste tires are not disposed scientifically, then it may degrade the environment. One of the best methods is converting it into fuel so that the commercial value is increased. Pyrolysis can be used to convert waste tire into fuel [7].

During pyrolysis the shredded tires are heated in a reactor vessel in the absence of oxygen. The rubber is softened in the reactor due to heating. Also the rubber polymers are broken into smaller particles. These smaller particles vaporize and leave the reactor. This vapor is condensed to produce liquid or is
burned directly to produce power. The particles which cannot be condensed can be burnt to produce power. The by-products are in solid state and accounts for 40% of the products of the pyrolysis process. If the process is performed well, then clean fuel can be produced from waste tires. However, it is also reported that this process pollutes the environment due to bad practices followed during pyrolysis [8].

The scrap tires are subjected to pyrolysis in an internally heated batch type fixed bed fire tube heating reactor system. The products of the pyrolysis are liquid, char and gases. It is reported that the maximum char and liquid yield of bicycle and rickshaw tires are 35 and 52% respectively and truck and bus tires, maximum char and liquid yield are 23 and 60 % respectively. The calorific value of pyrolysis oil of truck and rickshaw tires is about 41 MJ/kg [9]. It is reported that the TPO contains complex mixture of organic compounds, aromatics (about 53 to 75%), nitrogenated (about 2.5 to 3.5%) and oxygenated compounds (about 2.3 to 4.9%). The sulfur content is about 1 to 1.5% along with xylene, toluene, benzene, limonene etc. The calorific value of TPO is higher than the commercially available heating oil’s [10].

The TPO derived by vacuum pyrolysis method is comparable to diesel. Also the crude tire pyrolysis oil has to be subjected to several processes to make TPO properties similar to diesel [11]. TPO being a liquid product and having high sulfur content is not suitable for direct use as fuel hence the desulfurization of TPO is an important aspect during the process of oil production prior to its use [12]. The quality of the crude TPO can be improved by subjecting it to (i) moisture removal, (ii) desulfurization and (iii) distillation. During moisture removal process, the crude TPO is heated above 100°C to remove the moisture content. Desulphurization involves five stages [13], viz sulfuric acid treatment, calcium-oxide treatment, vacuum distillation, sulfurization, washing and drying. During desulphurization sulfur is made to settle in the bottom layer as sludge, and is removed. The top layer is subjected to distillation to obtain quality fuel from the TPO. For distillation, conventional process is used for purifying any liquids is used.

The pyrolysis reactors can be classified into three types. They are

1.1. Mechanical Pyrolysis Reactors
This type of pyrolysis reactors uses mechanical devices to produce crude TPO. Based on the mechanical device used, it may be called as auger type pyrolysis reactor, rotary type pyrolysis rector and ablative type pyrolysis rectors and stirrer type pyrolysis reactors. Figure 3 shows the different types of mechanical pyrolysis reactors.

![Mechanical Pyrolysis Reactors](image)

**Figure 3. Mechanical Pyrolysis Reactors**

1.2. Pneumatic Bed Pyrolysis Reactors
This type of reactors may be classified into fixed bed and fluidised bed reactors. In the fluidised bed reactor, the shredded tires are suspended in the air. The gaseous products are
obtained on the top side and char is obtained at the side as shown in the figure 4 (a). In the fixed bed reactor, shredded tires and air are supplied from the top and products of the reaction were obtained in the bottom and as shown in the figure 4 (b).

![Fluidised bed reactor vs Fixed bed reactor](image)

**Figure 4.** Pneumatic Bed Pyrolysis Reactor

### 1.3. Gravity type Pyrolysis Reactors

In this type of reactor uses column type reactor for the pyrolysis of tires. The shredded tires are supplied through the top of the reactor and the gasous products and char are obtained after passing through the column.

![Gravity type Pyrolysis Reactor](image)

**Figure 5.** Gravity Type Pyrolysis Reactor

The crude TPO contains high sulfur and cannot be used for fuel in internal combustion engine. Hence crude oil should be desulfurized before its use as fuel. Figure 6 shows the schematic of pyrolysis plant which is used for the pyrolysis of waste tires.
The vegetable oil obtained from the seed of Artocarpus heterophyllus can be converted into biodiesel and can be used as substitute for the diesel. The property values of this biodiesel are close to the fossil diesel. The engine performance with this biodiesel is comparable to fossil diesel and slight variations in engine emissions were reported. This biodiesel resulted in CO reduction by about 57%, however NOx emissions were increased by about 13% [14]. The waste cooking oil problem can be solved by converting it into biodiesel using silica bifunctional catalyst [15]. In Indonesia, durian consumption produces a large amount of peel waste which is a biomass waste. It can be converted into useful material using the slow pyrolysis method which carried out at 300°C [16]. However, the cost of the biodiesel is higher than the TPO. The various forms of pyrolytic reactors are available and the selection for the pyrolysis of waste tire is based on constructions and operating principles [17]. The rubber materials present in the scrap tire can be converted into fuel at high temperatures and in the absence of oxygen. It is reported that the gas fraction of the pyrolysis has higher calorific value and hence it can be used as fuel. The calorific value of the pyrolysis oil is about 40 MJ/ kg [18]. It is reported that tire pyrolysis oil can be blended with fossil fuel and can be used as a partial substitute for the petrol in electric generator. The engine tests shows that the partial substitution of TPO results in significant reduction in CO emission. It was concluded that, as a substitute for the diesel the TPO can be used partially as it is available in limited quantity. Hence, in this work, an attempt is made to use TPO as the partial substitute for the fossil diesel in agricultural diesel engine [19].

2. Material and Methods

For the present work, tire pyrolysis oil (TPO) was obtained from peenya industrial area, Bangalore, India. It was filtered using filter paper and the filtered TPO was mixed with normal diesel with different proportions. The mixture ratios of diesel to TPO used are 95: 5, 90:10, 85:15 and 80:20. This fuel mixtures are named as D95T05, D90T10, D85T15 and D80T20.

The tests were carried out on a single cylinder naturally aspirated diesel engine. Table 1 shows the specifications of the engine. An eddy current dynamometer was used for the engine tests. Figure 7
shows the engine experimental setup. An AVL make engine exhaust gas analyser and smoke meter was used for measuring the engine emissions and smoke opacity. The experimental setup consists of single cylinder diesel engine of four stroke type having eddy current dynamometer for the purpose of loading. Provision is also made for interfacing fuel flow, airflow, temperatures and the measurement of load. The set up has stand alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement.

**Table 1. Details of the Engine**

| Particulars                   | Details                                      |
|------------------------------|----------------------------------------------|
| Engine                       | Single cylinder, 4-Stroke, Naturally Aspirated Diesel Engine |
| Engine Make                  | Kirloskar                                    |
| Displacement                 | 661 CC                                       |
| Rated Brake Power            | 5.2 Kw                                       |
| Engine Rated Speed           | 1500 rpm                                     |
| Engine Compression Ratio     | 17.5 : 1                                     |
| Engine Bore                  | 87.5 mm                                      |
| Engine Stroke                | 110 mm                                       |
| Injection                    | Single hole                                  |
| Dynamometer used for loading | Eddy Current Dynamometer                     |
| Thermocouple Range           | 0 – 1200 Degree C                            |

**Figure 7. Experimental Setup**
3. Results and Discussions
The TPO was mixed with the diesel and a homogenous mixture was prepared. Table 2 shows the properties of the diesel, TPO and diesel-TPO blends. It is seen that the engine was running smoothly with the mixtures of TPO and biodiesel.

Table 2. Properties of Fuels

| Property          | Diesel | D95T05 | D90T10 | D85T15 | D80T20 | TPO  |
|-------------------|--------|--------|--------|--------|--------|------|
| Calorific Value (MJ/kg) | 42.5  | 42.4   | 42.3   | 42.1   | 42     | 40.2 |
| Density (kg/m³)    | 841.0  | 842.2  | 843.4  | 844.7  | 845.8  | 865.0|
| Viscosity (mm²/s)  | 2.59   | 2.63   | 2.66   | 2.70   | 2.75   | 3.35 |
| Flash Point (°C)   | 60.1   | 60.2   | 60.4   | 60.8   | 61.1   | 61.5 |
| Fire Point (°C)    | 68.0   | 68.5   | 69.1   | 69.8   | 70.2   | 73.0 |
| Pour point (°C)    | -18    | -17.2  | -16.7  | -16    | -15.5  | -6   |

The engine tests were conducted successfully without any problems. The engine performance parameters and emissions were recorded and discussed in the following paragraphs. Figure 8 depicts the impact of TPO on the engine’s brake thermal efficiency (BTE) at different loading conditions. It is observed that the engine results in higher BTE with the diesel and BTE value increases with increase in load. The increase in mixture value of the TPO results in lower BTE of the engine. The D80T20 mixture results in lower BTE when compared with other mixtures. This is due to higher viscosity and density of the D80T20 which affects the fuel atomization and spray formation which in-turn reduces the combustion performance of the fuel. This leads to lower BTE. From the figure it is observed that D95T05 can be used as fuel with BTE comparable to diesel.

![Figure 8. Impact of TPO on the BTE of the Engine at different Loads](image)

The impact of TPO on the engine exhaust gas temperature (EGT) is depicted in the figure 9. There is an increase of EGT value as the percentage of load goes up. There is an increase of engine’s fuel consumption with an increase of engine load. The combustion temperature increases with increase in fuel consumed. The diesel results in higher EGT as compared to fuel mixture. The EGT value decreases with increase in concentration of TPO in the fuel mixture. This indicates the deterioration in the combustion of the fuel. The D80T20 mixture results in lower EGT when compared with other fuel samples.
Figure 9. Impact of TPO on the EGT of the Engine at different Loads

The influence of TPO on the CO emission of the diesel engine for different loading conditions is depicted in the figure 10. The emission of CO from the engine increases with the increase of load on the engine due to the increase of fuel consumption. The diesel results in lower CO emissions in comparison to other fuel mixtures. The variation in the CO emission of diesel and D95T05 is small, however the variation increases with increase in TPO concentration which shows poor combustion. This leads to increase in CO which is the major product of incomplete combustion of the fuel. At higher loads, D85T15 and D80T20 results in higher CO value.

Figure 10. Impact of TPO on the CO of the Engine at different Loads

Figure 11 depicts the impact of TPO on the emission of NOx from the diesel engine. The NOx emission is one of the major and harmful emissions of the diesel engine. Different types of techniques are used to reduce this emission. The addition of TPO to the diesel reduces the NOx emission. The
reduction in combustion temperature reduces the NOx emission. The fuel mixtures such as D85T15 and D80T20 results in lower NOx emission due to deterioration in the combustion.

![Figure 11. Impact of TPO on the NOx of the Engine at different Loads](image)

The impact of TPO in the engine’s smoke emission is shown in the Figure 12. The value of smoke emission increases gradually when engine load increases due to the increase of consumption of fuel.

![Figure 12. Impact of TPO on the Smoke of the Engine at different Loads](image)

4. Conclusions
The increasing trend in automobile population and industrialization has lead to increased production of tires. This is also not only resulting in increase of waste tires but also in unscientific disposal of the tires causing pollution related issues. Tire pyrolysis will help in safe reuse of the waste tires and also produce wealth by converting the tire waste into fuel. From the experimental evidences through the current work it was observed that 5% TPO can be comfortably substituted with diesel without making any modifications in the fuel injection system. It also has comparable performances as that of use of only diesel. However, higher percentage of TPO is not found to be giving appreciable results. Hence, also keeping in mind the limited supply of TPO, it is suggested to use TPO as partial substitute for the diesel.
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