Recycling of Waste Tyres: A Possible Option for Deriving Energy

A Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of

B.Tech. (Mechanical Engineering)

By

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Certificate of Approval

This is to certify that the thesis entitled *"Recycling of Waste Tires: A Possible Option for Deriving Energy"* submitted by *Saumya Kanta Swain (109ME0425)* in partial fulfillment of the requirement for the award of Bachelor of Technology Degree in Mechanical Engineering at the National Institute of Technology, Rourkela (Deemed University) is a genuine work carried out under my supervision.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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Abstract

Depletion of fossil fuel resources and stringent environmental laws have forced researchers to develop methods to sustainably manage resources. Focus has been gradually shifting towards energy recovery from waste materials which can solve both the problems. One of the major wastes in the automobile sector is automobile tyres. These have an adverse impact on the environment if they are not disposed off properly. Further, tyres are a source of high grade energy hence its improper disposal means wastage of energy. Several methods have been developed to extract energy from waste tyres. One of them is pyrolysis of tyres which produces Tyre Pyrolysis Oil (TPO) by thermal decomposition of tyres. The properties of TPO blends with diesel were analysed and compared with diesel and found that it can also be used as a fuel in compression ignition engine. Experiments were carried out on a single cylinder, four stroke, air-cooled, diesel engine running with different blends of TPO from 5% to 20% on volume basis. Experimental results indicated that TPO of 20% blend gave better performance.The Performance and emission characteristics are reported in this thesis.

Chapter 1

Introduction

1.1 General Introduction

Waste disposal is becoming a serious problem in each and every sector of technology. It assumes greater significance in a country like India with a population greater than a billion. The growing demand for automobiles has generated huge amount of waste tyres and disposing it economically and in an environment friendly manner has become a challenge for many local and central governments around the world. Legislative provisions have already been formed in many countries that require treatment of waste tyres before final disposal to landfill. The continuous increase in the management cost of waste tyres has led to illegal dumping and stockpiling, which are inherent costs to local authorities. Further, the waste management techniques used in India are far inferior than the techniques used in other developed countries. Mostly they are either disposed off in landfills or in some inappropriate way such as illegal dumping. Waste minimisation includes recycling, reusing and developing new process of toxicity reduction.

The following can be a typical waste management hierarchy

1. Reduce
2. Reuse
3. Recycle
4. Recover waste by physical, biological and chemical process
5. Landfill

1.2 Current Disposal Methods of Automobile Tyres

The current disposal methods of waste tyres include (i) Landfill (ii) Crumbing (iii) Remould (iv) Incineration (v) Tyre Derived Fuel (vi) Energy Recovery through pyrolysis and gasification.

1.2.1 Landfill

Presently about 50% of the waste automobile tyres are used for landfill in every country. A small percentage is used for engineering purposes at landfill sites. Disposition in large volumes can lead to fires and instability especially by rising to the surface which affect long-term settlement may cause problems in future. Buried tyres in landfill sites cause fire hazards at several places. Such fires are difficult to control as it leads to uncontrolled pyrolysis of tyres which produces a complex mixture of chemicals. Further knowledge of long-term leaching of organic chemicals at the landfill sites is quite limited at the moment.

1.2.2 Crumbing[1]

Crumbing is another method of disposal. In this method, the tyres are cut at several stages until rubber attains crumb form which can be use in several applications like:

- Rubber blocks for children's playgrounds
- Low quality rubber products
- production of asphalt

Although several outlets for tyre crumb are possible, only around 25% is being used at present. It potentially provides the most effective solution for recycling without causing any other direct pollution problem.

1.2.3 Remould

It is a costly process for the manufacturer both in terms of economy and physical work. Further only few designs, about 20%[1], of tyres are suitable for remoulding which may increase by 5%[1] in future.

1.2.4 Incineration

Electrical power can be generated by incineration of waste tyres. However, this method requires high investment costs and further causes a lot of pollution. Thermal recovery in cement kilns and power plants is an important route for disposal of scrap tyres hence legislators may insist on refurbishing of emission systems of certain users.

1.2.5 Tyre Derived Fuel

Since waste tyres are originated from rubber which is an organic matter and has high energy content, tyre can be used to generate heat and electrical power[1]. The usable substance obtained from tyre for this purpose is referred to as Tyre Derived Fuel (TDF). TDF is mainly used for heating purpose in cement kilns. However, the chemicals present in the tyres reduce the manufacturing ability of cement kilns. It also causes atmospheric pollution. Statutory air quality requirements have to be met by any process that utilises TDF.

1.3 Energy Source and Recovery

Disposal of waste tyres by land-filling causes a loss of valuable resource. Recovering energy from waste tyres is a significant way to reuse them as they are a high grade energy source. The approximate composition of tyre is – 85% carbon, 5% cord and 10% steel[1]. Hence it can effectively be used as an alternate fuel in kilns.

In the UK, the energy recovered from used tyres is approximately 27% while, it is between 50% and 80%[1] in other European countries like Finland, Austria, Sweden and Germany. The energy value of tyres is higher compared to traditional coal fuels. Hence there exists a large potential towards extracting energy from used tyres. This will not only solve the problems related to disposal but also help in substituting the regular fuels thereby reducing their consumption.

During burning of waste tyres, organic compounds, like pyrolytic oils, can cause environmental damages to flora and fauna by resting in the soil. Entrapment of rainwater in tyre dumps and stockpiles serve as breeding places for insects like mosquitoes. Therefore waste tyres should be reused rather than disposing as it is.

1.3.1 Alternate Fuels

Tyres may be burnt as a whole or may be shredded before burning or may be converted to combustible gas or liquid via pyrolysis[3]. The energy content of tyres varies between 26,000 MJ/tonne and 33,000 MJ/tonne. The main disadvantage linked to reuse of waste tyres is that they are widely scattered and need collection and transportation which consumes resources. Further, due to low bulk density of about 0.16 T/m^3, the transportation cost of whole tyres is very high. Shredding tyres prior to transportation can increase its density to around 500 kg/m^3.

1.3.2 Pyrolysis

Pyrolysis is a process of recovering energy from from different materials by heating them to form volatile gases which is then cooled to form liquid fuel. Attempts have been taken in the US to install a few Pilot plants to decompose tyres and recycle them. Pilot plants for tyre pyrolysis have also been installed in Europe,India and China. But these have not shown any promise.

1.3.3 Gasification

Gasification is the process of converting a solid or liquid into a gaseous fuel without leaving any solid carbonaceous residue. Many countries have installed glassification units for recovering energy from waste tyres. A large glassification plant of 15.5 MW generation capacity is proposed to be set in the UK. The estimated capital cost of this plant is $8 M for a 30,000 tons capacity with operating cost of US $90 per ton.

1.3.4 Polymerisation

A tyre polymerisation plant is being installed by Environmental Waste International Inc. in the UK. The plant, which costs NZ $ 17 M will take 18 months for its construction and will have a maximum processing capacity of 3000 tyres per day. A microwave system is being used to separate scrap tyres into carbon black, steel, oil and hydrocarbons that can be used to generate electricity to run the system with any excess power being sold to national electricity grid.

Chapter 2

Literature Review

The purpose of this literature review is to provide background information on the issues to be considered in the thesis and give importance to the relevance of the present study. This treatise embraces about the importance of waste tyre management and extraction of energy in the form of Tyre Pyrolysis Oil (TPO) which can be used as an alternate fuel.

Waste tyre can be disposed/reused in various ways. This literature discusses only the disposal by pyrolysis after comparing various methods. It also discusses the classification of pyrolysis reactors and the production of TPO.

2.1 Types of Pyrolysis

C. Roy[4] et al have worked on vacuum pyrolysis of automobile shredder residue. The process recovers around 27.7 wt.% of the tyres as organic liquids and 52.5 wt.% as solid residue of which 14 wt.% are useful metals which can be recovered and the rest can be used safely for landfill. S. Wang et al[5] have made extensive research on flash pyrolysis in which experiments were carried out of pyrolysing bio- mass particles in a hot dense fluidised bed of sand to obtain high-quality bio-oil. The results show that flash pyrolysis is an efficient method to produce high yields of liquids that cozld either be directly used as fuel or converted to other valuable chemicals. P. T. Williams et al[3] have used TPO for direct combustion. F. Karaosmanoglu et al[6] have worked on production of biodiesel using slow pyrolysis. A. V. Bridgwater [7] has reviewed the fast pyrolysis of biomass.

2.2 Pyrolysis of Tyres and Production of TPO

I. M. Rodriguez et al[8] have worked on pyrolysis of scrap tyres and found that the pyrolysis oil is of high(42 MJ/kg) gross calorific value. About 30 wt.% of the oil is an easily distillable fraction with boiling points in the range of commercial petrol. H. Aydin et al[9] have worked on optimising fuel production from waste tyres. In order to reduce the high sulphur content of the fuel, CaO, Ca(OH)2, and NaOH catalysts were used. The highest product yield was obtained with temperature of 500°Cand 200 cm3/min N2 flow rate. It was found that, the density and sulphur content of low sulphur tyre fuel fuel were slightly higher than that of diesel fuel, but other features and distillation curves were very close to diesel fuel.

2.3 Commertial Pyrolysis Plant

S Authayanum et al [10] has modelled an industrial fixed bed reactor. M. Ringer et al[11] has published a technical report on large-scale pyrolysis oil production.

2.4 Tyre Pyrolysis Oil as a Fuel

P. T. Williams has used TPO as a fuel for direct combustion. O. Doğan et al[12] have made experiments on running a diesel engine using tire derived fuel/diesel fuel blends. The experimental test results showed that the DI diesel engine can run with the TDF fuel blends up to TDF90. The smoke opacity, unburnt hydrocarbon, and carbon monoxide emissions reduced while nitrogen oxides emissions increased with the increasing TDF content in the fuel blends. S. Murugan et al [13] have made an assessment of pyrolysis oil as an energy source. S. Murugan et al [14] have worked on running a diesel engine with TPO and its blends with diesel. P. M. Bhatt et al [15]have made research on suitability of TPO as an alternate fuel. S Murugan et al[16][17] has made performance analysis of a diesel engine running with alternative fuels such as TPO and its blends. From the experimental work carried out it was observed that engine is able to run up to 90 % DTPO and 10 % DF (DTPO 90). Engine failed to run satisfactorily with 100 % DTPO.

Chapter 3

Production of Tyre Pyrolysis Oil

3.1 General

Pyrolysis is a relatively new and potential process to recover value added products from a solid or liquid waste substance. In the process, thermal decomposition of a substance takes place in the absence of oxygen or in the presence of insufficient oxygen. It is not possible, practically, to achieve a completely oxygen free environment and hence a small amount of erudition occurs. The products of pyrolysis are liquid, gasses and a solid containing carbon and ash.

3.2 Availability and Composition of Tyres

Since the number of automobiles used in India is less than the developed countries, the problems related to disposal of waste tyres is not seriously realised as on today. But it is supposed to become a serious problem in the near future. Hence, proper treatment methods for waste tyres have to be put in place in advance.

A tyre is artificially engineered by the human mind. it contains chemicals, rubber, steel and fabric. Approximately 80% of the original constituents remain at the end of its service. The theory to reduce, reuse and recycle is difficult to implement with tyres owing to their complex nature, durability, varying size, numbers involved and different dimensions.

3.3 Various parts of Tyres

A car tyre has a mass of about 8.5 kg, whereas the mass of a tyre of a passenger or light duty vehicle is around 11 kg. The constituents of truck tyre are given in Table 3.1. The various parts of an automobile tyre include bead, bundle, body, belt, cap sidewall and tread.

The raw materials used in tyres include synthetic and natural rubber, nylon, polyester cord, carbon black, sulphur, oil resin and other chemicals. These constituents provide the tyre with a good strength and flexibility to ensure adequate road holding properties under all conditions. About 80% of mass of car tyres and 75% of mass of truck tyres are rubber compounds. The components of tyre manufactured by different manufacturers are very similar as shown in Table 3.1. The tread portion of a tyre is primarily used for energy recovery to obtain TPO, pyrogas and carbon black.

Table 3.1: Components of truck Tyre [2]

Component	**Proportion(%)**
Natural Rubber	45
Synthetic Polymer	4
Carbon Black	22
Oil	6
Chemicals	4
Steel Wire	16.5
Others	2.5

3.4 Composition of Tread Rubber

The elemental composition of tread rubber is given in Table 3.2. It can be seen from the table that tyres contain hydrogen, carbon, sulphur, nitrogen and other elements. Therefore, it can produce hydrocarbon mixtures as products if tyres are properly converted into value added products by pyrolysis process.

Table 3.2: Experimental Composition of Tread Rubber

Element	**Percentage (%)**
Carbon	88.87
Hydrogen	7.09
Oxygen	2.17
Nitrogen	0.24
Sulphur	1.63

3.5 Pyrolysis Process and its Types

The different methods of pyrolysis processes are discussed in the following subsections.

3.5.1 Based on Nature of Pyrolysis

(i) **Vacuum Pyrolysis**

In this process, organic material is heated in vacuum to reduce its boiling point and also to avoid adverse chemical reactions. Flash Vacuum Pyrolysis (FVT) is a process of vacuum pyrolysis in which the residence time of the substrate at working temperature is limited as much as possible, again to minimise secondary reactions. Vacuum Pyrolysis has been investigated on different materials by C. Roy et al [4]. W. J. Peláez et al [18] have published their results on flash vacuum pyrolysis.

(ii) **Flash Pyrolysis**

In flash pyrolysis, the biomass is ground into fine particles and the insulating char layer that forms at the surface of the reacting particles is continuously removed. Flash pyrolysis of biomass particles has been carried out and a report is published by Shurong Wang et al [5].

(iii) **Fluidised Bed Pyrolysis**

In this process pyrolysis is done on a fluidised bed which is created by placing a certain quantity of a solid particulate substance in under appropriate conditions to cause the solid/fluid mixture to behave as a fluid. Experiments using on fluidised bed have been done by Shurong Wang et al[5] and P. T. Williams et al[19].

3.5.2 Based on Residence Type

(i) **Slow Pyrolysis**

Slow or conventional Pyrolysis is characterised by slow heating rate of biomass (in the range of 0.1°C to 2°C), low temperatures (<400°C) and high residence times (typically greater than 5s for volatile materials and can be several minutes, hours or even days for solids). During conventional Pyrolysis, the biomass is slowly devolatilized; hence tar and char are the main products. F Karaosmanoğlu et al[6] has worked on producing biofuel using the process.

(ii) **Fast Pyrolysis**

In this process, heating rates are in the range of 200°C and 100°C per second and the temperatures are normally higher than 550°C. Due to short vapour residence times, products are of high quality, ethylene rich gases which can be used subsequently to produce alcohols or gasoline. The production of char and tar is considerably less in this process. A review of fast pyrolysis of biomass has been published by A. V. Bridgwater[7].

3.6 Commercial Pyrolysis Plant

Setting up of a commercial pyrolysis plant requires several clearances from authorities environmental, state and central regulatory authorities. M. Ringer et al [11] have published a technical report in this respect. In typical commercial pyrolysis plant, scrap tyres are fed into a cylindrical chamber which is placed over a burner. The burner is normally fuelled by firewood. Chemical reaction for pyrolysis occurs at a temperature of approximately 550°C. The vapours of the volatile materials are passed through cooling chambers (generally water cooled). The liquid components are then collected in tanks. The gaseous components are collected in a separate chamber which stores the gasses upto a fixed pressure limit and relieves it when the pressure exceeds the limit. The gaseous components from the chamber are fed to the burner as a supplement to wood. Suthida Authayanum et al [10] have modelled an industrial fixed bed reactor based on lumped kinetic models for hydrogenation of pyrolysis gasoline.

Chapter 4

Experimental Materials and Methods

4.1 Tyre Pyrolysis Oil

For the present study, TPO was collected from a pilot pyrolysis plant. The plant uses truck tyres as feed-stock. The composition of the feed-stock used in the pyrolysis plant is given in Table 3.1. The chemical composition of the truck tyres used in the plant is given in Table 4.1. The plant is of 5T per batch capacity which uses a horizontal and rotating type reactor. The reactor is externally heated with the help of waste wood. The temperature rise of the reactor was found to be 30°C/h - 40 °C/h. Pyrolysis is performed at 550 °C- the temperature at which maximum yield of oil is obtained. The vapour evolving from the reactor during pyrolysis, enters a water cooled condenser, where it is condensed and converted into pyrolysis oil. Some of the vapour which is not condensable is used as secondary fuel for heating the reactor. Photographs of some blend samples is shown in Fig. 4.1.

Table 4.1: Chemical Composition of Truck Tyre [2]

Proximate Analysis (wt.%)		**Ultimate Analysis (wt.%)**	
Volatile Matter	66.64	Carbon	83.87
Fixed Carbon	27.96	Hydrogen	7.09
Moisture Content	0.62	Oxygen	2.17
Ash Content	13	Nitrogen	0.24
		Sulphur	1.23
		Moisture	0.62
		Ash	4.7
Total	100		100

4.1.1 Properties of Tyre Pyrolysis Oil

Properties of tyre pyrolysis oil and diesel are given in Table 4.2

Figure 4.1: Photograph of blend samples

Table 4.2: Properties of Diesel and TPO Blends

Property	Diesel	TPO	TPO05	TPO10	TPO15	TPO20
Density (kg/m^3 at 20 °C)	820	920	825	830	835	840
Kinematic Viscocity(cSt at 40°C)	2-4	5.4	3.12	3.24	3.36	3.48
Caloriefic Value (MJ/kg)	43.8	39.2	43.57	43.34	43.11	42.88
Flash Point by Abel Method (°C)	50	43	49.65	49.3	48.95	48.6
Fire Point (°C)	56	50	55.7	55.4	55.1	54.8
Cetane Number	45-50	25-30	44-49	43-48	42-47	41-46

4.2 Test Engine

A single cylinder air cooled diesel engine was used for the experiment whose specifications are given in Table 4.3.

4.3 Experimental Procedure

Experiments have been conducted in a single cylinder, four-stroke, air cooled, direct injection, diesel engine with a developing power of 4.4 kW at 1500 rpm. The technical specifications of the engine are given in Table 4.3, and the schematic diagram of the experimental arrangement is shown in Fig. 4.2. Photographs of actual setup are shown in Fig. 4.3 Experiments were initially started with diesel and then switched to different blends after the engine reached the warm up condition. A fuel level indicator was used

Table 4.3: Engine Specifications

Specification	
Make/Model	Kirloskar TAF 1
Brake Power (kW)	4.4
Rated Speed (rpm)	1500
Bore (mm)	(87.5)
Stroke (mm)	110
Piston Type	Bowl in Piston
Compression Ratio	17.5:1
Nozzle Opening Pressure (bar)	200
Injection Timing (CA)	23 BTDC
Injection Type	Pump-line-nozzle injection system
Nozzle Type	Multi Hole
Number of Holes	3

for measuring the total fuel consumption. A U-tube manometer connected with an orifice mounted on air box in the suction was used for measuring the intake air flow rate. A K-type thermocouple was installed to measure the exhaust gas temperature. The exhaust emission of the engine was measured by an AVL DiGas444 exhaust gas analyser. After conducting all the tests with the blends, the engine was run on diesel again to ensure that there was no trace of the TPO blends, to prevent any deposits, and cold starting problems.

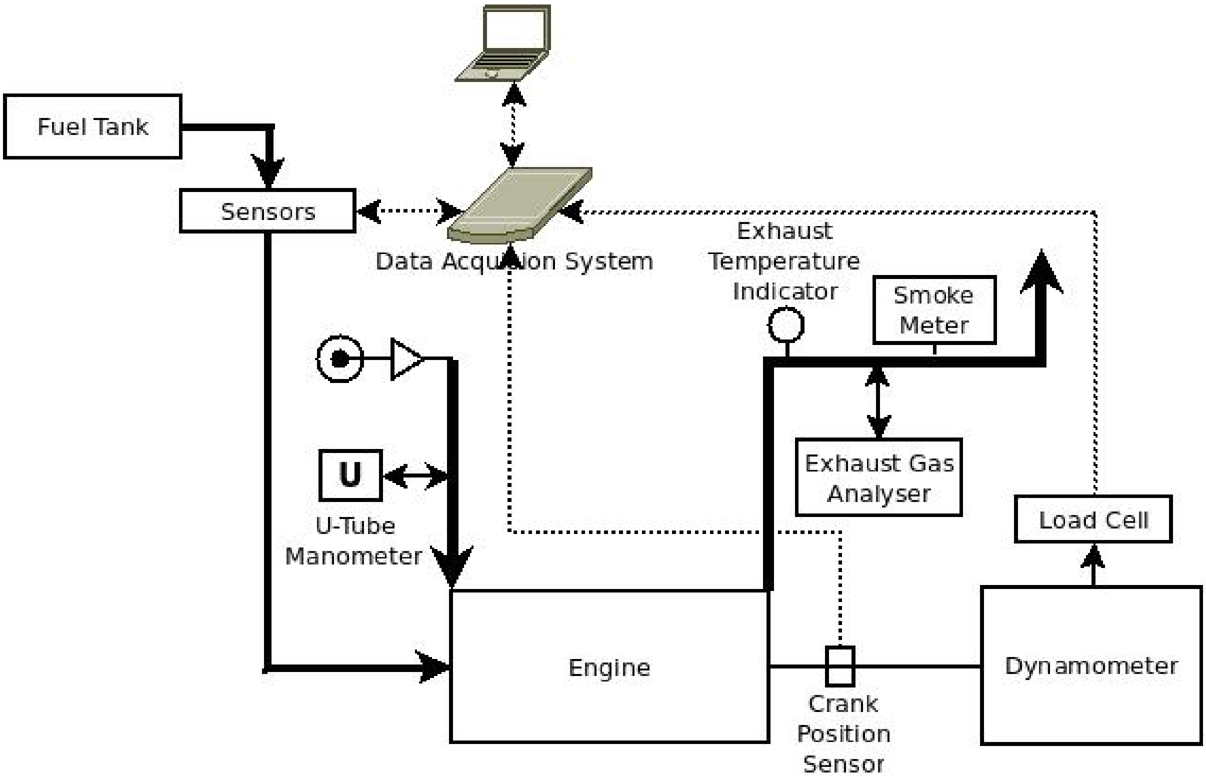

Figure 4.2: Schematic Diagram of Experimental Setup

Figure 4.3: Photograps of Experimental Setup

Chapter 5

Results and Discussion

5.1 Performance Study

5.1.1 BSFC

A column chart showing variation of BSFC with brake power is shown in Fig. 5.1. The BSFC for diesel at full load is 0.281 kg/kWh load. For TPO05, TPO10, TPO15 and TPO20, it is 0.293, 0.332, 0.309 and 0.275 kg/kWh respectively. With the increase in brake power the BSFC decreases for up-to a load of 3.3 kW and increases for a load of 4 kW. The BSFC of TPO10 is high where as BSFC of diesel and TPO20 are almost equal.

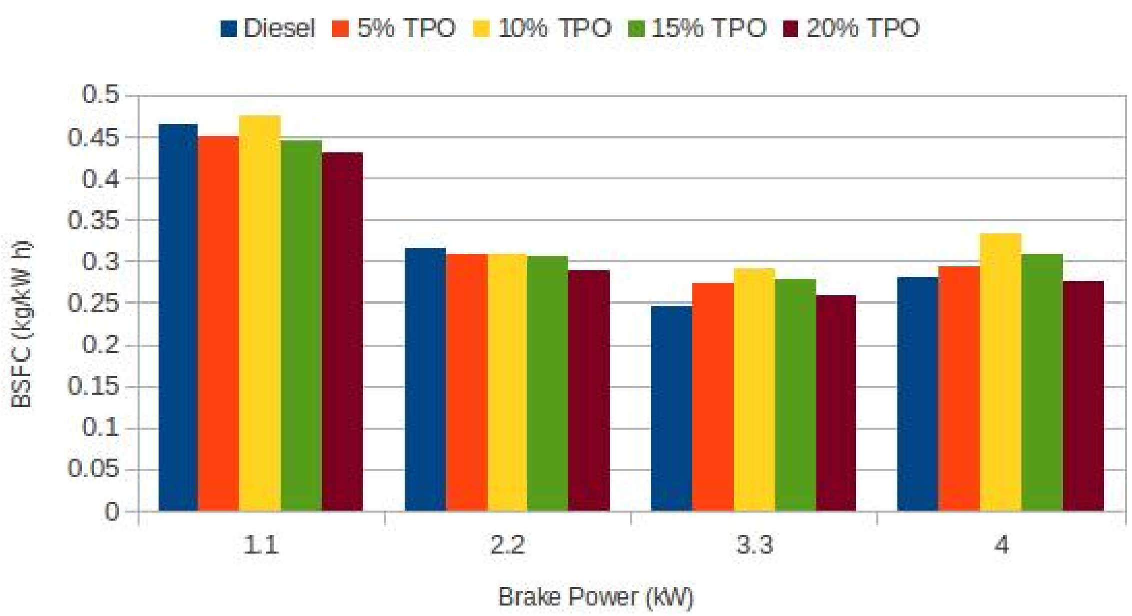

Figure 5.1: Variation of BSFC with Brake Power

5.1.2 BTE

A column chart showing variation of brake thermal efficiency with brake power is shown in Fig. 5.2. The brake thermal efficiency for diesel at full load is 29.282. For TPO05, TPO10, TPO15 and TPO20, it is 28.233, 24.998, 27.002 and 30.486 respectively. With the increase in brake power the BTE increases for up-to a load of 3.3 kW and decreases for a load of 4 kW. The BTE of TPO10 is lowest where as BTE of TPO20 is either equal or somewhat higher than diesel.

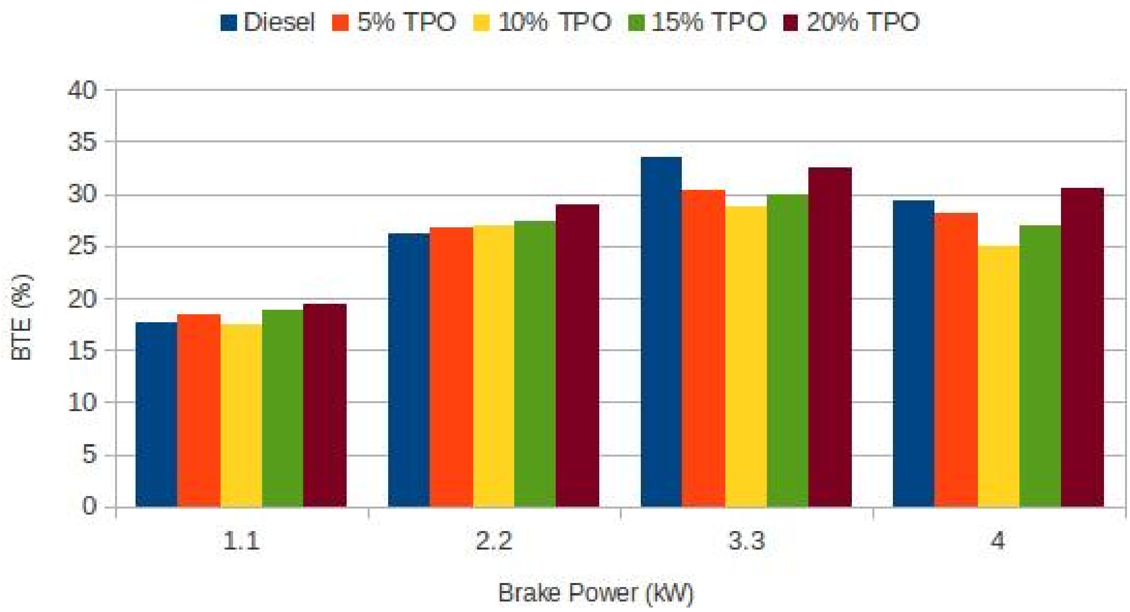

Figure 5.2: Variation of BTE with Brake Power

5.1.3 Exhaust Gas Temperature

A column chart showing variation of exhaust gas temperature with brake power is shown in Fig. 5.3. The EGT for diesel at full load is 338.4521°C. For TPO05, TPO10, TPO15 and TPO20, it is 340.503, 370.906, 344.624 and 344.4248 °Crespectively. The EGT increases with brake power for all fuel samples used. The BTE of TPO10 is the highest where as BTE of TPO20 is almost equal to that of diesel.

5.2 Emission Parameters

The emission is lowest with TPO20 for almost all loads.

5.2.1 HC Emission

A column chart showing variation of HC Emission with brake power is shown in Fig. 5.4. The HC emission for diesel at full load is 16 ppm. For TPO05, TPO10, TPO15 and

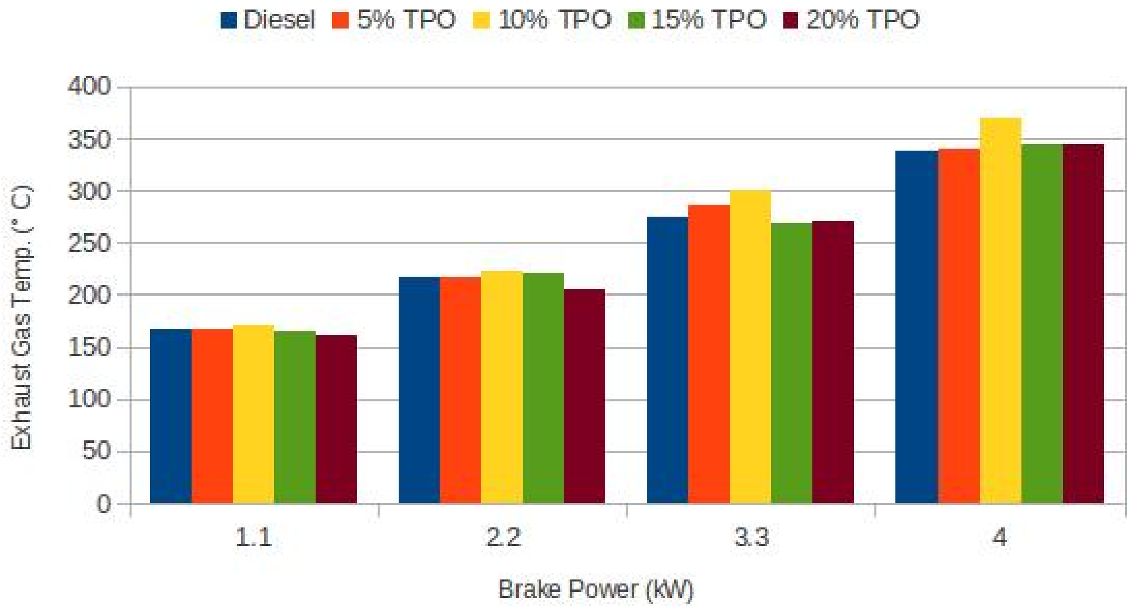

Figure 5.3: Variation of Exhaust Gas Temp. with Brake Power

TPO20, it is 19.333, 11.333, 13 and 10 ppm respectively. HC emission does not show any defined pattern.

5.2.2 CO Emission

A column chart showing variation of CO Emission with brake power is shown in Fig. 5.5. With increase in load, the emission decreases up-to a load of 3.3 kW and then increases for 4 kW. The CO emission for diesel at full load is 0.027 vol.%. For TPO05, TPO10, TPO15 and TPO20, it is 0.0333, 0.11, 0.0567 and 0.0567 wt.% respectively.

5.2.3 NO Emission

A column chart showing variation of NO Emission with brake power is shown in Fig. 5.6. With increase in brake power, the emission of NO increases up-to a load of 3.3 kW and then decreases for 4 kW. The NO emission for diesel at full load is 230 ppm. For TPO05, TPO10, TPO15 and TPO20, it is 230.667, 370.906, 103.333 and 167 ppm respectively.

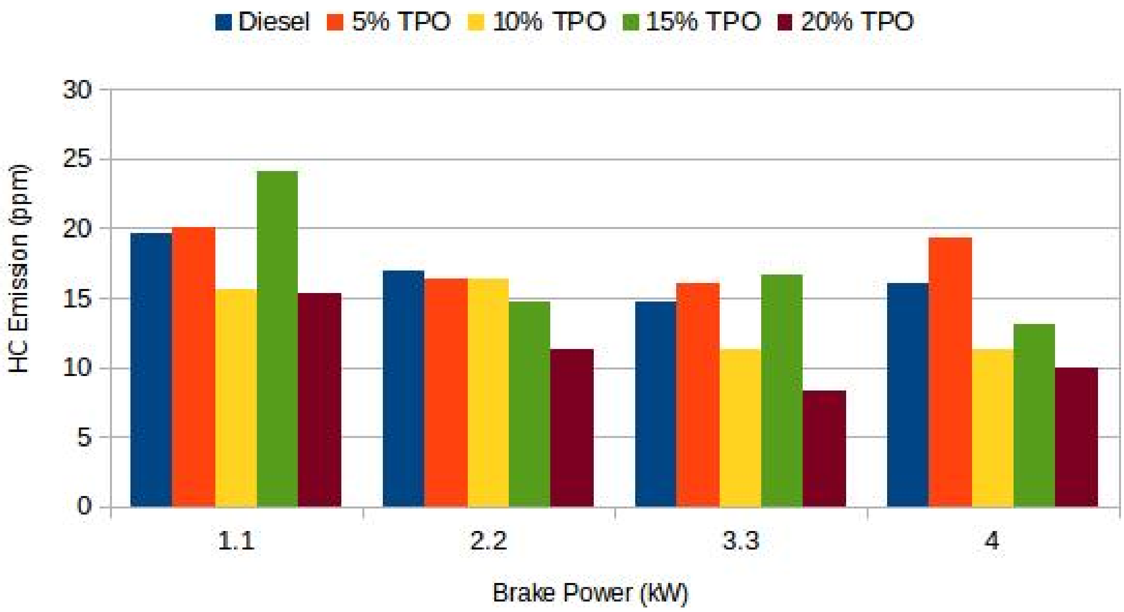

Figure 5.4: Variation of HC Emission with Brake Power

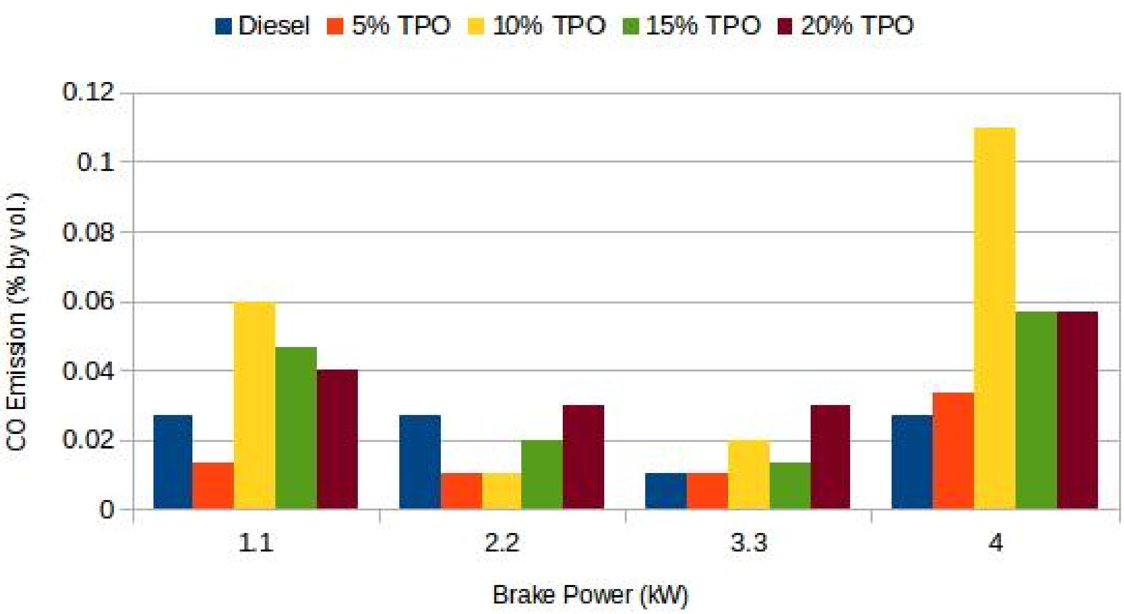

Figure 5.5: Variation of CO Emission with Brake Power

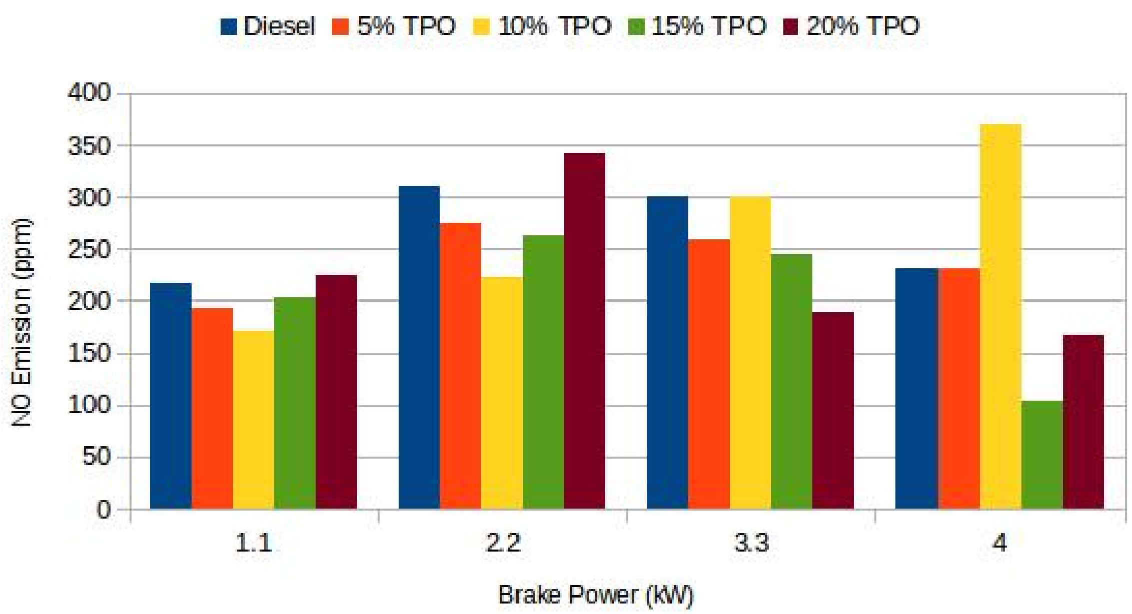

Figure 5.6: Variation of NO Emission with Brake Power

Chapter 6

Conclusion

The results of the above experiment indicate that tyre pyrolysis oil can be successfully used as an alternative fuel by blending it with diesel for small percentages of TPO as others' studies have shown that pure TPO cannot be used as a fuel. The experimental results show that the 20% TPO blend with diesel has best performance. Further the production of TPO from waste tyres would serve as a good medium of waste tyre disposal.

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