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# Purification of TPO (Tire Pyrolytic Oil) and its use in diesel engine

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***Abstract:*** - Increasing industrialization and motorization has lead to a significant rise in demand of petroleum products. As these are the nonrenewable resources it is difficult to predict availability of these resources in future, resulting uncertainty in its supply and price and is impacting growing economies like Bangladesh. Many alternate fuels like Alcohols, Biodiesel, LPG, CNG etc have been already commercialized in the transport sector. In this context, pyrolysis of solid waste is currently receiving renewed interest. The disposal of waste tyres can be simplified to some extent by pyrolysis. This work includes a process of production of bio-diesel from pyrolysis of TPO. The crude TPO(tire pyrolytic oil) has a higher viscosity and sulphur content compared to diesel fuel. In the present work, the crude TPO was de sulphurised and then distilled through vacuum distillation. In order to reduce the high sulfur content of the fuel, CaO, activated Bentonite catalysts were used. Different properties of oil are compared before and after purification. Purified oil has a light yellowish color as compared to dark redish color of the raw oil. Blends of purified oil and diesel are made as B10,B20,B30 and B50 and are used to run a single cylinder diesel engine. Results are compared between the different groups of blended fuels as well as with diesel fuel. From the experimental result the blend B10 has almost similar performance as compared with diesel fuel.

***Keywords:*** *- Tire pyrolytic oil; Distillation; Diesel engine performance, Pyrolytic oil properties*

## I. INTRODUCTION

The energy crisis and environmental degradation are the main problems in the present days due to growing population and rapid industrialization. Around the world, there are initiatives to replace gasoline and diesel fuel due to the impact of fossil fuel crisis and hike in oil price. Millions of dollars are being invested in the search for alternative fuels. The scrap tire is one by which alternative fuel can be produced and also can be tested the properties of the fuel as well as the performance of the diesel engine by using the tire pyrolytic oil.

A diesel engine (also known as a compression-ignition engine) is an internal combustion engine that uses the heat of compression to initiate ignition and burn the fuel that has been injected into the combustion chamber[1]The engine used in this experiment was a single cylinder water cooled, naturally aspirated (NA),4-stroke,DI diesel engine. The specification of engine are shown in Appendix-I. The experiment was conducted with conventional Diesel fuel and Diesel-TPO blend. The RPM was measured directly from the tachometer.The performance test of the Single cylinder 4-stroke Diesel Engine with water cooling is conducted in this experiment. Initially the engine is tested with pure diesel and later on with different blends such as B10, B20, B30, B50 with diesel. Different engine performance parameters like brake power, brake thermal efficiency, bsfcetc are also determined.As mentioned above that, the performance test of the diesel engine is carried out with the tire pyrolytic oil. This tire pyrolytic oil is obtained from the scrap tire. The scrap tire is one of the very common and important solid wastes all over the world. Scrap tire production shows increasing trend due to increasing number of vehicle in both developed and underdeveloped countries [2]. Nearly 1 billion of waste vehicle tires are accumulated each year [3]. By this accumulated tires pyrolytic oil is produced which carries 85.54% C, 11.28% H, 1.92% O, 0.84% S, and 0.42% N [4]. In our experiment fixed bed pyrolysis process is used to produce tire pyrolytic oil. In addition, chemical products such as benzene, toluene, xylene and limonene can be obtained from waste vehicle tire obtained pyrolysis liquid products [5-8]. I.de Marco Rotriguez et al [9] studied the behavior and chemical analysis of tire pyrolysis oil which gives a positive result. Then by the vacuum distillation process the tire pyrolitic oil is purified and ready for diesel engine performance testing. The previous experimental works by the authors [10-12] studied the effect of lower and higher concentrations of the tire pyrolysis oil/diesel fuel blends on the performance, emission and combustion characteristics of a single cylinder, 4-stroke and water cooled, DI diesel engine running only by varying the load. But in case of our experiment we vary both the speed and load while performance of diesel engine is tested. Also the engine performance using different fuels is compared in our experiment.

## II. METHODOLOGY

In the overall methodology there are different steps which are described in below

**Production of crude TPO:**

The pyrolysis was done in a Fixed bed pyrolysis reactor in a temperature range 350-400˚C .The setup includes a condenser and fractionating column. Nitrogen gas was used to reach in an inert environment .In this pyrolysis, an automobile tire was cut into a number of pieces and the bead, steel wires and fabrics were removed. Thick rubber at the periphery of the tire was alone made into small chips. The tire chips (feed stock) were washed dried and were fed in a reactor unit.

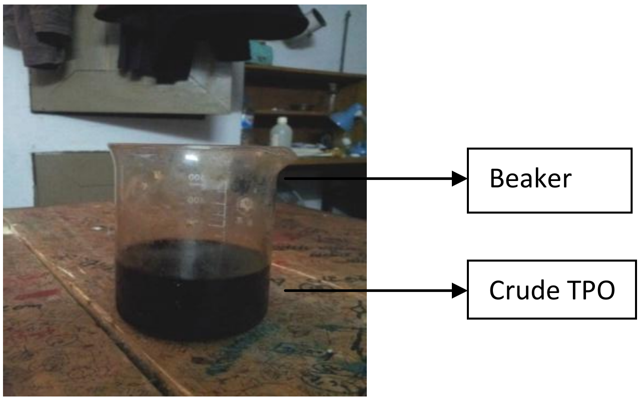


**Fig. 1: Crude TPO**

**Modification of TPO:**The modification of the crude TPO involves three stages, (i) removal of moisture (ii) Desulphurisation (iii) Vacuum distillation.

**Removal of moisture:**Initially crude TPO was heated upto 100 $^{o}$C, in a cylindrical vessel for a particular period of the removal of moisture, before subjecting it to any further chemical treatment.

**Desulphurization:**The moisture free crude TPO contains impurities, carbon particles and sulphur particle. A known volume of concentric hydrosulphuric acid (8%) was mixed with the crude TPO and stirred well. The mixture was kept for about 40 hours. After 40 hours, the mixture was found to be in two layers. The top layer was a thin mixture and lower one thick was sludge. The top layer was taken for vacuum distillation and the sludge was removed and disposed off.

**Vacuum distillation:**Vacuum distillation process was carried out to separate the lighter and heavier fraction of hydrocarbon oil. A known sample of chemically treated crude TPO was taken for vacuum distillation process. The sample was externally heated in a closed chamber. The vapour leaving the chamber was condensed in a water condenser and the TPO was collected separately. Non condensable volatile vapours were left to the atmosphere. The distillation was carried out between 70$^{o}$C and 90$^{o}$C. 80 % of TPO was distilled in the distillation whereas 5 % of TPO was left out as pyrogas and 15 % was found as sludge. The TPO has irritating odour like acid smell.

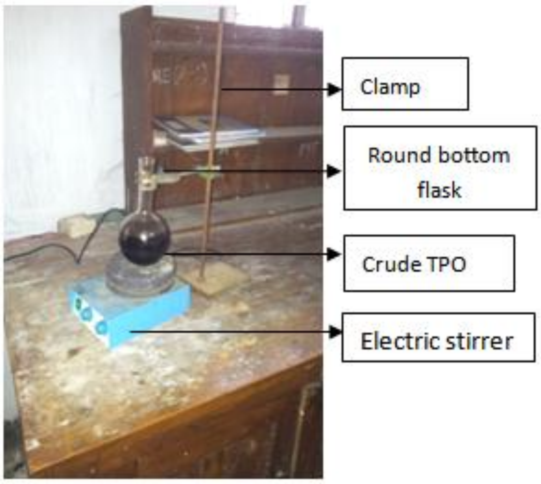


**Fig 2: Desulphurization**

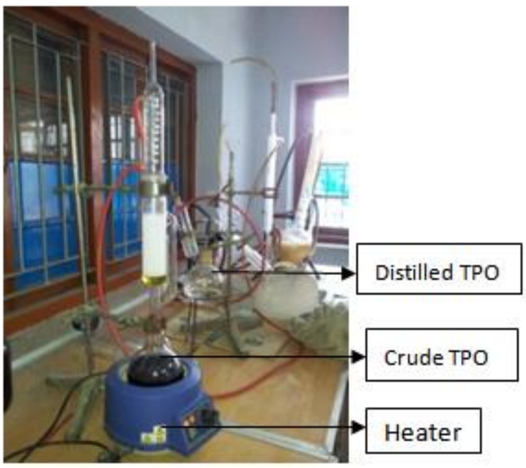


**Fig. 3: Vacuum distillation**

## Our working flow chart:

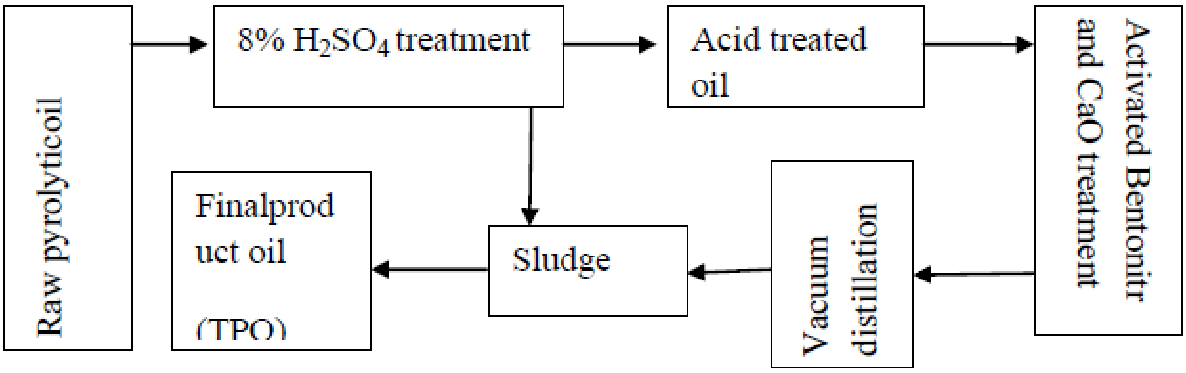


**Fig. 4: Working flow chart**

First we took the raw pyrolytic oil in a beaker. Then the raw tire derived pyrolytic oil was subjected to 8%by weigh of hydro-sulfuric acid ($H_2SO_4$), stirred well by a electrical stirrer during 4 h and left to settle for 40 h. Temperature of the mixture was maintained at 50 ˚C during stirring process. The mixture was found in two layers 40 h later. The top layer was the clear viscous oil, and the bottom layer was the non-viscous acidic sludge. The clear viscous oil was taken for the activated bentonite–Calcium Oxide (CaO) treatment. Secondly, activated bentonite (100 g activated bentonite for every 1000 ml of acid treated pyrolytic oil) and CaO (50 g for every 1000 ml of acid treated pyrolytic oil) were added to the acid treated pyrolytic oil and mixed by an electrical stirrer for about 4 h. Temperature of the mixture was maintained at 70 ˚C during stirring process. The contents were kept for 24 h for the settling of the sludge. Whole contents were then filtered by filter-cloth to obtain healed pyrolytic oil for the vacuum distillation. Thirdly, the healed pyrolytic oil was distilled by vacuum distillation.

**Percentage of oil obtained from TPO:**

Table 1 Percentage of oil obtained from TPO

| Crude TPO | After removing sludge | ( %) oil obtained | After vacuum distillation ( ml ) | Percentage of TPO finally obtained |
|---|---|---|---|---|
| 2150 | 1440 | 66.97 | 490 | 22.79 |

From the above chart we see the percentage of TPO from crude pyrolytic oil after initially removing sludge is 66.97% and after vacuum distillation is 22.79%. In crude TPO sludge carries the maximum portion of it, which is almost 77.21% .

## III. PROPERTIES OF TPO

After vacuum distillation the physical propertiesof TPO are measured and then these properties are compared with the conventional diesel. The engine performance greatly depends upon the chemical reaction between induced air and fuel in the combustion chamber, which permits the utilize of heat energy. For this reason a fuel should possess a number of properties for reliable engine performance .Bio-diesel also should have these properties for using it in diesel engine. These properties are

**Absolute Viscosity:**This refers to a liquid resistance to flow. Viscosity of the TPO we are working is 1.51 centi poise (cp) at 30˚c.

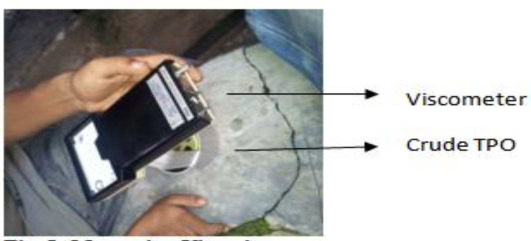


**Fig. 5: Measuring Viscosity**

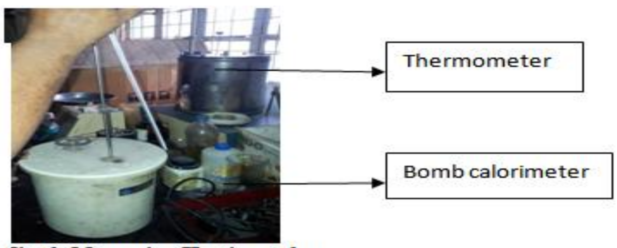


**Fig. 6: Measuring Heating value**

**Density:**Density means mass per unit volume .In SI unit it is expressed in kg per cubic meter or gram per cubic centimeter. The density of TPO we are working on is measured 845.6 $Kg/m^3$.

**Heating value:**Heating value or calorific value of a fuel is the magnitude of the heat of reaction at constant volume at a standard temperature (usually 25˚c) for the complete combustion of unit mass of fuel Complete combustion means that all carbon is converted into $CO_2$ all hydrozen is converted into $H_2O$ any sulfur present is converted into $SO_2$ .

**Pour Point:**The pour point of a liquid is the highest temperature at which it becomes semi solid and loses its flow characteristics (wiki). The pour point of the TPO we were working on is -6˚c.

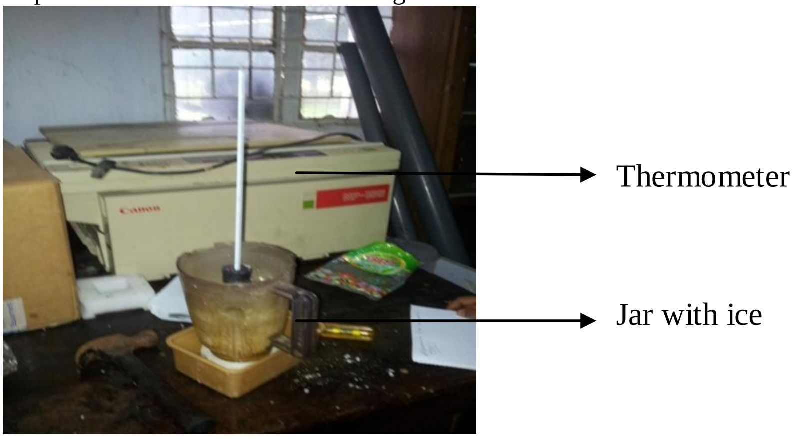


**Fig.7: Measuring pour point**

Table 2: Properties of diesel, crude TPO, TPO

| Property | Conventional Diesel | Crude TPO | TPO |
|---|---|---|---|
| Density( $Kg/m^3$) | 872.3 | 898.7 | 845.6 |
| Viscosity(centi poise) ( at 30˚c) | 4 | 2.8 | 1.51 |
| Calorific value (MJ/ kg ) | 45.85 | 41.5 | 42.37 |
| Flash point (˚c ) | 46 | 40 | 34 |
| Pour point ( ˚c ) | -30 to -40 | -2 | -6 |

Table 3: Comparing the properties of our TPO with a reference thesis paper [13]

| Property | Conventional Diesel | Crude TPO | TPO |
|---|---|---|---|
| Density ($Kg/m^3$ ) | 830 | 935 | 871 |
| Viscosity (centi poise) (at 40˚ c) | 2 | 3.2 | 1.7 |
| Calorific value (MJ/kg) | 46.5 | 42.83 | 45.78 |
| Flash point ( ˚c ) | 50 | 43 | 36 |

## IV. ENGINE PERFORMANCE TEST RESULT AND DISCUSSION

**Making of blends:**For engine performance test different blends are made in a measuring cylinder. In total volume of 100 cc, for making the blend B10, we took 10 cc of TPO and 90 cc of diesel in a 100 cc measuring flask Similarly the B20, B30, B50 were made.

The fuel injection time was set at 24˚ BTDC (before Top dead center).An inclined water tube manometer, connected to the air box (drum)was used to measure the air pressure. Fuel consumption was measured by a burette attached to the fuel tank. A stop watch was used to measure fuel consumption time for every 10cc. The engine was electrically loaded**.** Then the different engine performance is tested with these blends. The performance results with these blends are showed by the different graphs.

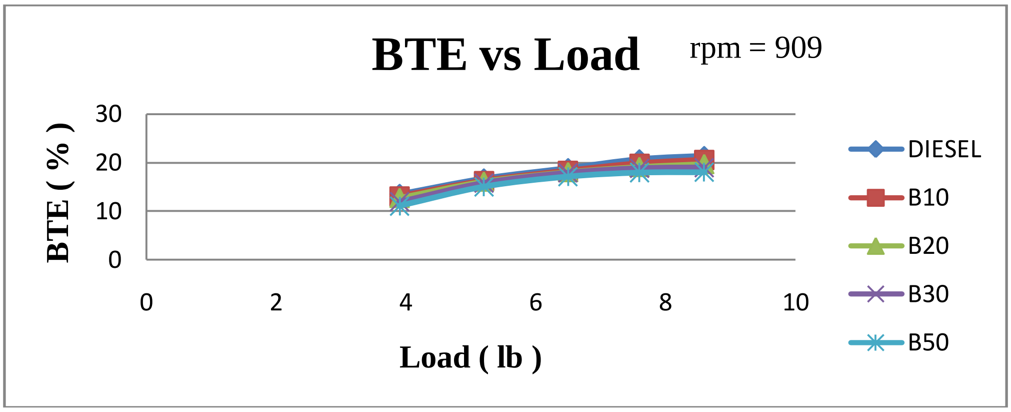


**Fig. 8 BTE vs Load**

The Fig 8 represents that increase in load would increase BTE with respect to variable loadand constant rpm**.** A slight drop in brake thermal efficiency is found with the TPO blends when compared with diesel. This drop in thermal efficiency may be due to poor combustion characteristics of biodiesel blends due to high viscosity.

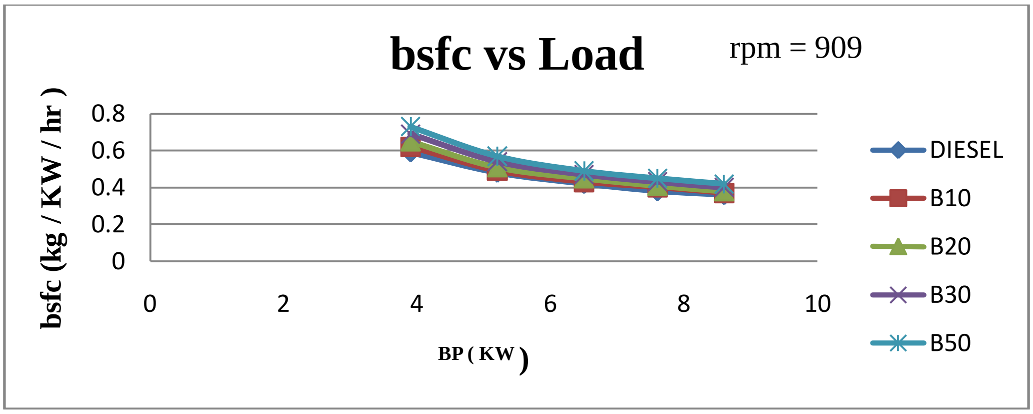


**Fig. 9bsfcvs Load**

The Fig. 9 represents the variation of specific fuel consumption with load for various blends of biodiesel and diesel with respect to variable load and constant rpm. It can be observed that the specific fuel consumption of differentblends is found to be slightly higher than the diesel at full load.It is also observed that specific fuel consumption of B10 blend is very close to specific fuel consumption of diesel at all loads. For blends B20, B30 and B50 the specific fuel consumption is found to be higher than the diesel because of poor combustion as load increases due to impurities and sulphur content.

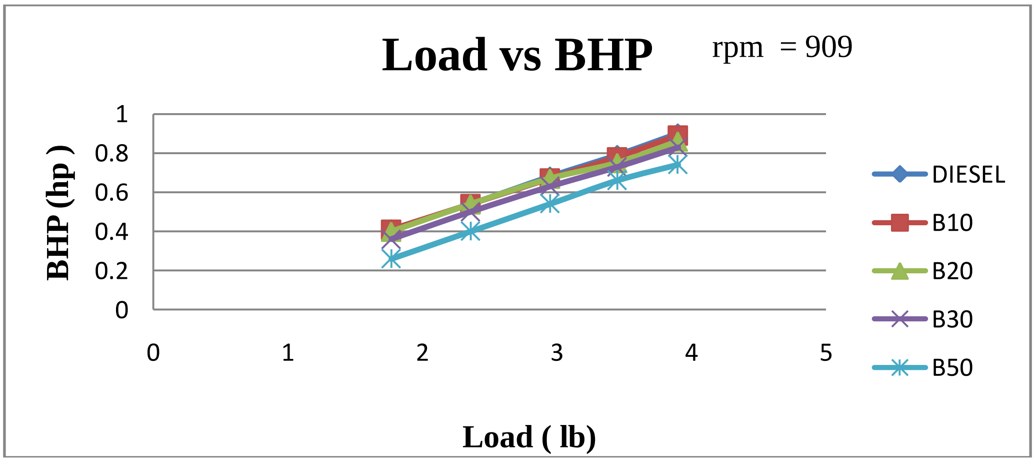


**Fig. 10 BHP vs Load**

The Fig. 10 represents the variation of BHP with Load for various blends of TPO and diesel with respect to variable load and constant rpm. It can be observed that the BHP of different blends such as B10 is similar to diesel but B30 and B50 is much lower than diesel

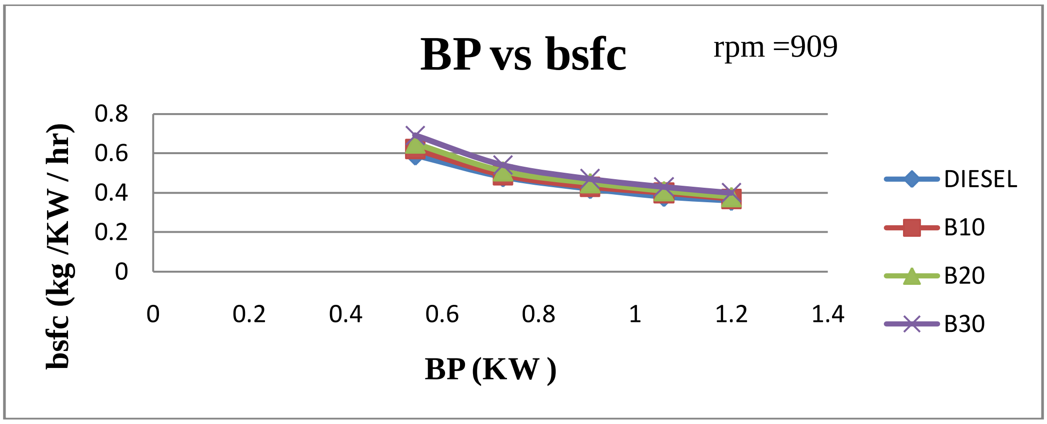


**Fig. 11bsfcvs BP**

The Fig. 11 represents the variation of specific fuel consumption with BP for various blends of TPO and diesel with respect to variable load and constant rpm. It can be observed that the specific fuel consumption of different blends is found to be slightly higher than the diesel .It is also observed that specific fuel consumption of B10 blend of biodiesel is very close to specific fuel consumption of diesel at all loads. For blends B20 to B30 the specific fuel consumption is found to be higher than the diesel because poor combustion. Poor combustion occurs for blends due to high sulphur and impurities content.

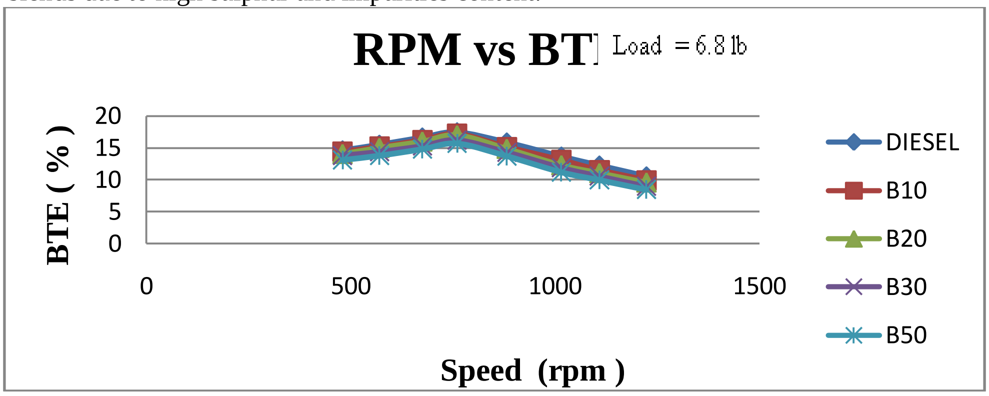


**Fig. 12 BTE vs RPM**

From above Fig.12 we see the BTE is increased with the increasing in speed (rpm) at constant load. But at certain rpm the efficiency decrease with increasing speed .Here it's also seen that the BTE is slightly decreased for blends with respect to Diesel.BTE of B10,B20 is almost similar to diesel. But B30,B50 has lower BTE compared to diesel because lower calorific value and lower viscosity

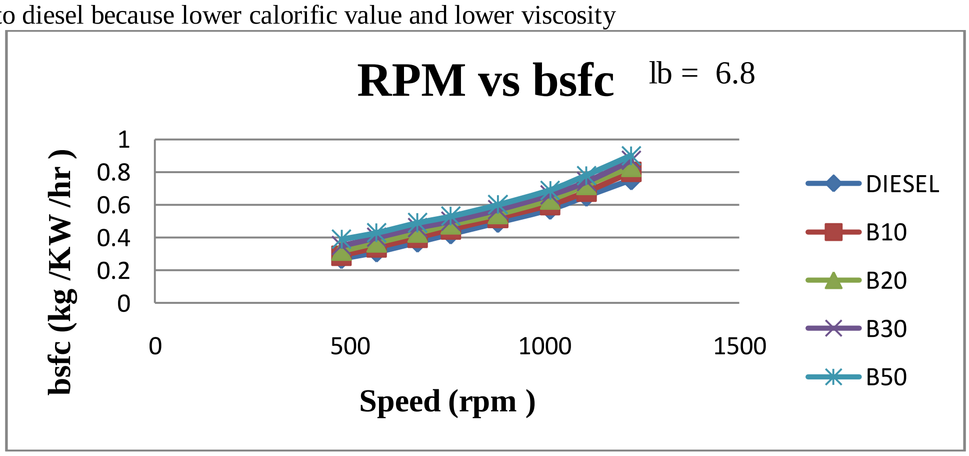


**Fig.13bsfcvs RPM**

From Fig. 13bsfc increase with the increase in rpm at constant load. Here we see the bsfc is little higher for the blends with respect to dieselbecause of lower calorific value.B10 has almost similar bsfc as compared to diesel. But B20,B30,B50 has higher bsfc as compared to diesel.
From Fig.14 bsfc increases with the increase of BP. It also shows that the specific fuel consumption for variable rpm at constant load for TPO blends are higher with respect to diesel.B10 has almost similar bsfc as diesel. But other blends has higher bsfc than diesel because of poor combustion due to lower calorific value.
From above Fig. 15 we see the BHP is increased with the increasing speed (rpm) at constant load. At certain speed BHP starts to decrease .Here it's also seen that the BHP is slightly decreased for blends with respect to Diesel.

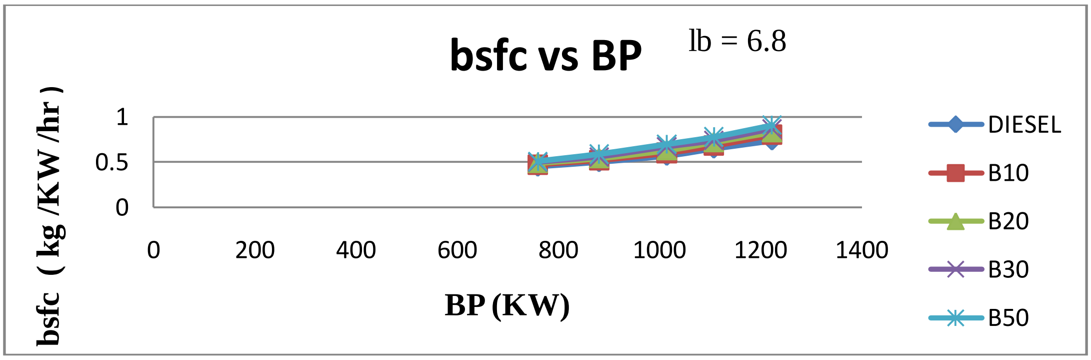


**Fig. 14bsfcvs BP**

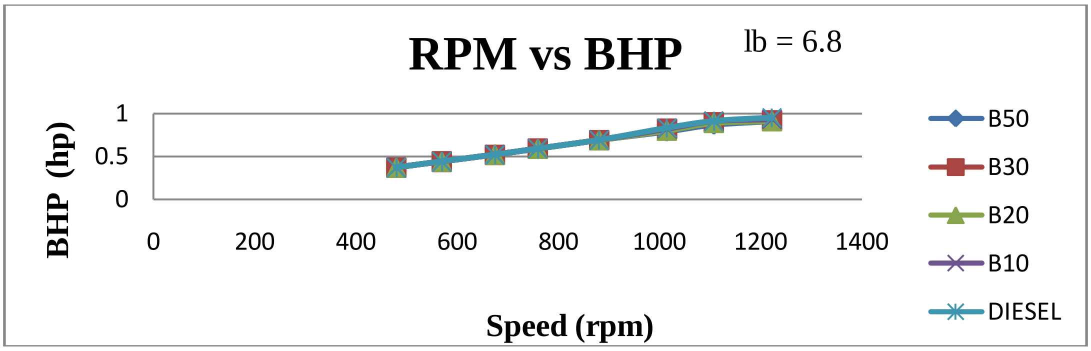


**Fig. 15 RPM vs BHP**

## V. CONCLUSION

The fuel properties of different blends of TPO are nearer to the diesel and blends B10 and B20 is giving good results. The fuel properties of blend B30,B50 are not in good agreement with the diesel so it is advisable not to use B30,B50 blend in CI engines.
Following are the conclusions based on the experimental results obtained while operating single cylinder diesel engine with TPO blends.

- B10 and B20 blends can be directly used in diesel engines without any engine modifications..
- The brake thermal efficiency of TPO blend of B10, B20 is slightly lesser than the diesel. But B30,B50 has lower brake thermal efficiency than diesel.
- Specific fuel consumption of B10 blend is very close to specific fuel consumption of diesel at all loads. For blends B20 to B50 the specific fuel consumption is found to be higher than the diesel.

## VI. ACKNOWLEDGEMENT

It is a great pleasure and privilege for the authors to present this report on **"Purification of TPO and it's use in DI diesel engine"** The authors wish to express their deepest sense of gratitude to their supervisor Professor Dr. Nirendra Nath Mustafi, Department of Mechanical Engineering, Rajshahi University of Engineering and Technology (RUET) for his incentive guidance and valuable suggestions regarding this work. His help in inspiration was undoubtedly a matter of pride.
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**Appendix-I**

Engine specification

| | |
|---|---|
| Engine type | 4-stroke DI diesel engine |
| Number of cylinders | one |
| Bore × stroke | 80×110 |
| Swept volume | 553cc |
| Compression ratio | 16.5:1 |
| Rated power | 4.476Kw @ 1800 rpm |
| Fuel injection pressure | 14 MPa (at low rpm 900to 1099rpm) 20 MPa (at high rpm 1100 to 2000 rpm) |
| Fuel injection timing | 24˚ BTDC |

**NOMENCLATURE**

TPO Tire pyrolytic oil
DI Direct ignition
bsfcbrake specific fuel consumption
sfc specific fuel consumption
BP Brake power
BHP Brake horse power
DF Diesel Fuel
cpcenti poise
lb pound
rpmrevolution per minute
MPa Mega Pascal
BTE Brake thermal efficiency
B10 Blend of 10% biodiesel 1nd 90% diesel
B20 Blend of 20% biodiesel 1nd 80% diesel
B30 Blend of 30% biodiesel 1nd 70% diesel
B50 Blend of 50% biodiesel 1nd 50% diesel