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Performance Measurement on Extracted Bio-Diesel from Waste Plastic

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ABSTRACT

This paper presents an important analysis on the fuel extracted from waste plastic using the process of pyrolysis. Here, the plastics collected from local municipality are used for conversion of solid plastic waste to liquid fuel. The fuel prepared is blended with mixtures of oxygenated compounds to test the performance of the fuel. The bio-diesel or waste plastic oil (WPO) from the waste solid plastic is tested with other blended mixtures to find the mechanical efficiency, emission rate, brake test efficiency and total fuel consumption. Here, the efficiency between the pure diesel mixture and WPO with different blends that varied between 10-50% of pure diesel oil is tested. The performance of the produced WPO-diesel blended oil performs with better efficiency than the other fuels.

Keywords: IC engine; Plastic oil; Brake test; Pyrolysis.

1. INTRODUCTION

According to Panda (2010) the reputation of plastics are increasing at a greater extent, since, it is a light weight, low cost, conversable resource and a reusable one. In fact, plastics retain and save energy with reduced CO2 emission. Jacob (2013) stated that increased economic growth, consumption of plastics for varied use and production requirement increased the wastage of plastics. This increased wastage is becoming a major stream of solid wastages in the world. Hence Khan (2015), recycling of plastic solid waste is a better option to convert the waste material to useful resource. In Turner (2015) view at most situations, the recycling of plastic solid wastes is considered economic, in terms of its high demand resource generation. This accounts for the production of bio-diesel from plastic waste that could increase the conservation of resources and reduce the GHG emission. The nature of waste plastic supports higher production of bio-diesel due to its high heat combustion and its availability in local communities (Fig.1) as given by Lohri (2016). By Panda's method (2011) wastage of water during recycling is reduced considerably to a greater extent due to its lesser moisture absorption facility than wood or paper.

The conversion of waste solid plastic into bio-fuel depends upon the type of the plastic material used and suitable methods of conversion the plastics with its economic, social, technical and environmental characteristics. Tillman (2012) showed that the generation of bio-fuel from plastic waste requires the use of nonhazardous and suitable feed stocks. However, Chanashetty (2015) proved that feeds may contain the flam-retardants and other undesirable substances. Hence, prior processing the plastic requires the pre-processing procedure to all the undesirable plastics. The post processing the plastics requires better conditions for the conversation like temperature, fuel quality, composition of flue gas (NOX and HCL), fly and bottom ash, and energy required to convert the plastic to fuel. Fractional distillation is performed to meet the requirements of conversion process, which reduces the hydrocarbons, if available. Then, pyrolysis or thermal decomposition is carried out with nitrogen (inert gas). According to Murata (2004) the thermal decomposition is carried out under 450°C - 550°C for the better conversion process. The major output product from the condenser during the extraction process is oil with liquid hydrocarbons upon reaching the reaction temperature.

1.1 Pyrolysis

The thermal pyrolysis of plastic waste (Cha (2002), Dolezal (2001), Kim (2004), Faravelli (2001)) is an endothermic process that does not employ any catalyst. The thermal pyrolysis is carried out with different types of plastics in the past that includes Polyethylene (PE) plastics, Polypropylene (PP) plastics and Polystyrene (PS) plastics. Moreover, few studies (Kaminsky (2004), Miskolczi (2004)) are carried over PVC, PET, polymethyl methacrylate and polyurethane. The thermal degradation of PS plastics in comparisons with HDPE, LDPE and PP plastics is carried out by uddin (1997). This is because, Miskolczi (2009) PE plastics with HDPE and LDPE and PP plastics requires much higher temperature for the degradation process than PS plastics. Further Lee (2012), the PE plastics can be converted into liquid wax without catalyst rather than the conversion of plastics to liquid oil. Since Lopez (2011), liquid oil obtained from the thermal degradation process possess compounds of heavy oil and the major compounds contains larger carbon chains. The liquid oil obtained from the extraction process contains very low octance content and high solid residues and the presence of sulphur, nitrogen, and phosphorous impurities that leads to low quality output as per Seth (2004).

Fig. 1. Waste plastics collected from local municipality.

1.2 Factors Affecting Pyrolysis

The studies by Luo (2010), Yoshioka (2004), Ji (2006), Lee (2007), Troger (2013), Acomb (2015), Lerici (2015), Ates (2013), Chen (2014) and Sharma (2014), pyrolysis process to convert plastic waste to reusable oil is affected majorly by a number of parameters that includes: plastics size and type, temperature, retention time, feedstock composition, catalyst, moisture content, heating rate and particle size. Few of which are discussed below:

Plastics used: The thermal pyrolysis over the varied plastic types of single substrate include: PS plastics, PP plastics, PE plastics with HDPE and LDPE, PVC plastics and PET plastics. By Lee (2009), the pyrolysis process is carried out with mixed, real MSW and municipal plastics. In addition, researches are conducted on polymethyl methacrylate and polyurethane. In experimentations of Sakata (1996), Lopez (2011, 2012) Saker (2011, 2013) pyrolysis is carried out with PVC plastics, which produces chlorine gas. The dechlorination process to remove the effects of chlorine is carried out with low temperature, which reduces the chlorine in the form of HCl compounds.

Use of Catalyst: From the observations of Saker (2011, 2013), Lopez (2012), Syamsiro (2014), the catalyst addition process to the process to improve the fuel output quality and it acts as a reducing agent to maintain the temperature and retention time of the optimization process. Fe_2O_3, $Ca(OH)_2$, FCC, natural zeolite and synthetic zeolite are the catalysts used in the pyrolysis process. The rate of cracking is increased due to the presence of catalyst and the production of gases is increased with reduction in fuel yield. Even if the oil obtained is of lower quantity, the quality of the oil is improved due to larger carbon chain compounds, which is adsorbed either as a catalyst or it is broken down into smaller chains.

Temperature: Temperature is an important factors that has a greater influence over the quality and quantity of the fuel oil obtained from the pyrolysis process as per Remido (2007) and Li (2005). Also, the quantity of the fuel is affected due to cracking reactions of the temperature. However, in low temperatures, the chains of the hydrocarbons will be large due to non-breaking of C-C bonds and vice versa. Hernández *et al.* Also, due to high temperature, the aromatic compounds are evaporated with secondary reactions.

Retention Time: The retention time has nil significant reactions upon the pyrolysis process. The retention time of 30 and 120 min yield similar fuel output similar to Lopez (2011), Lee (2007). The aromatic compounds are same during different retention time over same temperature.

Feedback Composition: The feedstock composition is another parameter that affects the fuel yield during pyrolysis as mentioned by Troger (2013).

Plastic Size: The PE plastics and PP plastics requires much higher temperature to degrade than PS plastics due to its complex particle size and structure.

The major contribution of the paper involves the use of modified pyrolysis from the collected plastic waste from the local municipality. The collected plastic is converted to liquid fuel using the process of pyrolysis. Here, the evaluations are carried out to test the performance of the obtained bio-fuel than the other fuels. The results of the bio-fuel is evaluated under various test bed and experimental evaluation is carried out to test its emission rate, brake power, total fuel consumption, mechanical efficiency and brake thermal efficiency.

Fig. 2. Crushed Waste Solid Plastic.

2. METHODS

The process of pyrolysis involves conversion of high molecular weighted element to a lower one. The catalyst at standard temperature and pressure with/without oxygen plays a substantial role over the conversion process. The quantity of the catalyst depends totally on the quantity of the polymer, where the chains of the polymers are broken down after the reaction of catalyst with polymers exist. This gives the required quality output required for further process.

The waste solid plastic is collected in the form of a syringe and waste plastic chair. The plastic substances are then shredded in a mechanical crusher to break the bigger particle size into smaller ones as shown in Fig. 2.The plastics (shredded) are filled over a hop shaped dish and it is fed into a cylindrical reactor. The temperature (without oxygen) is maintained at 250-300°c, which is the required processing temperature for the plastics. The thermal degradation of the shredded plastic substance takes place in the reactor chamber. The fly ash with suitable proportion is added with the raw material based on the quantity of the plastics. The fly ash is mixed with the plastics through a separate hopper chamber. The chamber then moves the fly ash to the reactor and the plastic materials are cracked down with the suitable fly ash catalyst. The catalyst in turn prevents the dioxins and furans (benzene ring) formation. The vapor is thus developed gradually in the reactor is collected at the condensation unit (Fig.4). Thecollected vapor is converted to liquid in the condensation chamber using the liquid flow through the inlet and outlet chamber. The collected liquid from the condensation unit is filtered and it contains diesel (87%) equivalent substance and petrol (7%) equivalent substance and remaining 6% is the kerosene substance. The fractional distillation unit is used to extract all these three substances and this is how the conversion process takes place. The entire process is shown in Fig.3. The efficiency of the produced bio-diesel is tested with IC engine, which converts the heat to mechanical energy. The specifications of the test engine is shown below:

Brand	-	Kirloskar
Type	-	under load, constant speed
Bore	-	87.5 mm
Stroke	-	110mm
Fuel	-	high speed diesel
RPM	-	1500
BHP	-	3.73kw
Loading	-	electrical loading
Specific gravity	-	0.83gm/cc
Calorific value	-	44800kj/kg

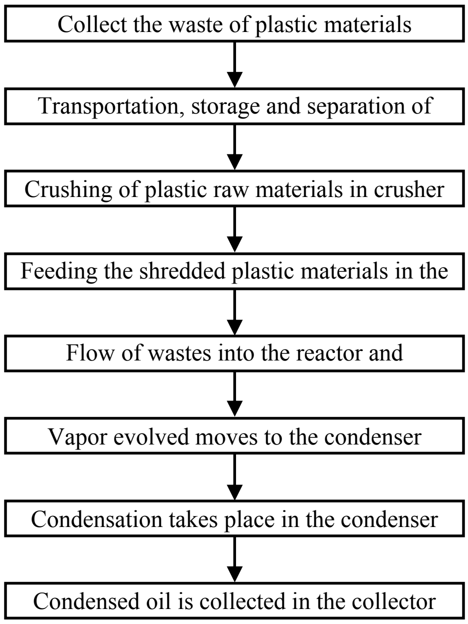

Fig. 3. Processing of Plastic bio-diesel.

3. EXPERIMENTAL EVALUATION

Initially, the experiments are carried out with IC engine having pure diesel as a fuel to generate the ground data. The engine is made to run with the pure diesel for 30 minutes and once the conditions

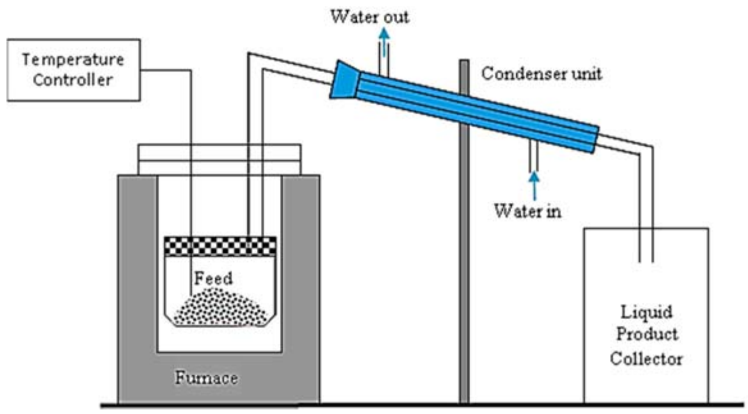

Fig. 4. Plastic Oil Preparation.

are stabilized with steady state, the ground data is collected. Also, the loads are varied with alternator load bank and the values are recorded. Other parameters recorded are: Emission of gas, consumption of fuel from the respective sensor measurement. After the collection of ground data, the engine is made to operate with extracted bio-diesel from the plastic wastes or waste plastic oil (WPO). The proportion of the plastic oil is in the ratio of D: WPO-10:70, 25:75 and 0:100. A fraction of 5%, 10%, and 15% methanol is added as a catalyst to the biodiesel based on volume metrics. Here, the different methanol and WPO blends are mixed and the engine is started, when the engine is highly heated, a different mixture of methanol and WPO blends are sent through the two way valve. The data are collected for various loads and blending composition, upon reaching the steady state is noted.

Fig. 5. Viscosity test.

3.1 Viscosity Test

Initial test is conducted to measure the viscosity of the bio-fuel oil. Here, viscosity of the fluid measures the flow resistance of the bio-fuel and determines the flow ability of the lubricating oil. Lower the viscosity value, greater is the flow ability of the oil, which is due to molecules' cohesion force. The experimental test best for viscosity measurement is shown in Fig.5.

Table 1 Tabulation of viscosity test

Temperature of oil (°C)	Time taken for collecting 50cc oil in flask	Kinematic viscosity (cent stoke)
37	31	2.511
43	28	1.137
46	27	0.649
47	26	0.144
49	25	0.038

Kinematic viscosity

$=at-(B/t)$ cent stoke

$= (0.26\times31)- (172/31)$

$=2.511$ cent stoke

Dynamic viscosity

$=$ *kinematic viscosity×density*

$=2.511\times0.761$

$=1.911$ cent stoke

3.2 Flash Point

The flash point (shown in Fig.6) is the lowest temperature required to generate the flammable vapors using the liquid, which is ignited in air by the flame above its surface. The flash point is determined experimentally by heating a vessel chamber filled with the bio-fuel liquid. Here, the flame is brought at regular instances over the surface of the liquid. When the vessels gets the flash (Fig.7), then it is noted that the temperature of the bio-fuel has reached its threshold level. Here, the test vessel is kept open and the measurement is taken in open-cup. The classification of flammable liquid is determined as per the prescribed standards as seen in Janes (2013). The test value shown in Table.2 provides values, which match with the prescribed standards and the threshold levels of the bio-fuel is marked. Out of 9 observations, two flash points (50°C and 56°C) are noted using the bio-diesel fuel.

Fig. 6. Flash and Fire Point Test.

Fig. 7. Fire Point.

Table 2 Flash Point and Fire Point Test

S.no	Name of the oil sample	Temperature	Observation
1	Plastic oil	40	No flash point
2	Plastic oil	42	No flash point
3	Plastic oil	45	No flash point
4	Plastic oil	48	No flash point
5	Plastic oil	50	Flash point
6	Plastic oil	52	No fire point
7	Plastic oil	54	No fire point
8	Plastic oil	55	No fire point
9	Plastic oil	56	Fire point

4. PERFORMANCE TEST ON WASTE PLASTIC OIL

Diesel engine is considered here to test the thermal efficiency of the collected bio-fuel. The testing condition with DC engine is shown in Fig.8. The main disadvantage is that it emits high level of nitrous oxides; hence, the emission of the produced bio-fuel is tested for its emission level. The performance of the pure diesel with the produced bio-diesel is tested on this light duty engine to compare the emission and combustion factors. Also, wood pyrolysis oil (WPO) is used as a base indicator to check the performance of the other fuels. Here, several tests are carried out with WPO blends with different oxygenated compounds and micro-emulsions of WPO on a single cylinder of diesel engine. The reliability of the liquid is achieved, when the blend of WPO is 44% in die ethylene glycol dimethyl ether and two different emulsions with WPO of 30% in diesel fuel. The corrosion trace is unavailable in these blends. Also, the blend of WPO with diglyme produced low hydrocarbon and nitrous oxides than the diesel fuel.

The comparison with plain wood oil and WPO in IC engine proved that the WPO oil performed with better characteristics. Since, the wood oil provides poor ignition and excessive deposits of carbon, clamping of ignition system, incompatible with lubricant and highly acidic.

Fig. 8. Testing Machine with Load Condition.

The performance of emission characteristics using a single cylinder with direct injection diesel engine, which is fuelled by 10%, 30% and 50% blends of tyre pyrolysis oil (TPO) with diesel fuel (DF) is evaluated. The combustion parameters like cylinder peak pressure, heat release rate and change in pressure is analyzed. From the results, it is found that the η_{bt} of the engine with WPO-DF blend increases the efficiency than the DF. The peak pressure of the cylinder is increased from 71.4 to 73.8 bars and the emissions of NOx, HC and CO are found high with higher loads for WPO-DF. Finally, the delay in ignition is quite longer than DF.

The de-sulphuration and distillation is carried out in crude tire pyrolysis oil (cTPO) to improve its properties and the emission and combustion performance using four stroke single cylinder and air cooled engine is tested. Two different fuel blends, 30% cTPO and 70% DF (cTPO30) and 30% distilled cTPO and 70% DF fuel (cDTPO 30) is used to measure the test performance. The results indicated that there is 8% reduction in nitrous oxide than TPO and 10% than DF. The emission of HC is again reduced by 2% than TPO30. Finally, the smoke emission is reduced in cTPO30 and diesel fuel than the cDTPO30.

Again the emission and combustion performance of a four stroke single cylinder and air cooled diesel engine is studied with distilled tire pyrolysis oil (dWPO). The engine ran successfully with WPO (90%) and DF (10%) (DTPO90) and the engine failed to run with 100% WPO. The η_{bt} is increased in % of WPO blend than DF blends with 3% drop is noted. The emission of nitrous oxide in DTPO80 is reduced by 21% and in DTPO90, it is 18%, which are lesser than DF. This is due to the availability of unsaturated HC in WPO, which again results in increased smoke in the blends of DTPO-DF than the DF. WPO-DT has increased delay in its ignition than the DF, which is 2°C and 2.5°C, quite longer for WPO80 fuel and DTPO90 fuel, respectively than DF.

The plastic oil is prepared from waste polypropylene with kaolin at 500°C and the catalyst (fly ash) is added at 3:1 ratio in a batch reactor. The WPO is tested without blends against the DF oil. From the observation, it is found that the engine operates well in WPO (10%) and diesel (90%) than pure DF. It is noted that the nitrous oxide of WPO is 25% higher than DF, CO emission is 5% high than DF, HC with 15% increase in WPO and 40% increased smoke with full load. However, the thermal efficiency of the WPO (10%) and diesel (90%) is 80% with full load (Table.8), which is higher than the pure diesel oil (Table.6.). The exhaust gas temperature of the blend fuel is higher than DF at all loads. The ignition delay of WPO is found longer than pure diesel, however, the thermal efficiency is increased upto 75%.

The tests are carried out with four injection timings: 23, 20, 17 and 14 BTDC. It is found that the standard injection timings (23 BTDC), the 14 BTDC (retarded injection timing) leads to reduced NOx, CO, unburned HC. Also, the brake thermal efficiency is increased under all the above test conditions. It is also found that the peak pressure of the cylinder is marginally low than the pure diesel oil. The Brake thermal efficiency using WPO fuel with 14 BTDC is higher than the 23 BTDC. The smoke intensity is increased by 35% under full load conditions with 14 BTDC in WPO operation than the 23 BTDC.

The effect of cooled exhaust gas recirculation (EGR) on 4 stroke, single cylinder, and direct injection (DI) diesel engine using 100% waste plastic oil is studied. The results have higher level of NOx fueled with WPO and the aggrenox emissions are reduced. Then engine is operated with cooled EGR and the only 20% significant reduction in NOx emission, smoke, CO and HC emission. The smoke emission of WPO is found higher in all loads and the combustion parameters are found comparable with/without EGR. The compression engine running on WPO emits higher NOx levels and the ηbt varied between 14-30% without EGR than 13-29% with 20% full load. The ηbt decreased further with increased EGR that result in larger replacement of air.

5. EXPERIMENTAL SETUP

The experimental test bed is shown in Fig.9. The engine is coupled to an electrical dynamometer to provide the engine load. The air box with U-tube manometer is connected to the engine intake. The consumption air by the engine is measured using U-tube manometer. The consumption of bio-fuel is measured with a burette, which is fitted with 3-way cock, where a line from fuel tank is connected at one end, burette at other end and the fuel supply system at the third end. The flow rate of the fuel is measured on volumetric basis with a stopwatch.

A Chromelaurel thermocouple with digital thermometer measures the exhaust temperature. The exhaust gas emissions are measured with AVL degas analyzer. The density of the smoke is measured with AVL 437 C diesel smoke meter. The exhaust gas from the engine is collected through a probe. The experiments are conducted at 1500 rpm with WPO with diesel blends of 10-50% compositions. The compositions are not made higher since, the engine may get detonated. The blends are denoted as 10% B WPO, 20% B WPO, 30% B WPO, 40% B WPO and 50% B WPO.

Fig. 9. Engine Performance Test.

5.1. Engine Performance:

The diesel engine is made to run up to 50% blend ratio. Upon increasing the blend rate, the noise and vibrations increased that affects the performance. The parameters like brake thermal efficiency, exhaust gas temperature, brake specific fuel consumption are considered as testing factors with 10-50% blended oil.

5.2. Brake Thermal Efficiency:

BTE is calculated to identify the calorific value of WPO-diesel blend. It is found that the calorific value of WPO-diesel oil is high than WPO, even though the exhaust gas temperature is marginally higher in WPO-diesel. At full load, the exhaust temperature of the WPO is marginally higher than the diesel oil. This leads to higher head loss, then the BTE value is low in case of WPO-diesel blend (Fig.13).

5.3. Emission Analysis:

The IC engine emissions analysis is carried out with two fuels: Pure Diesel and WPO (10%) and DF (90%). Here, the emission test is carried out to find the presence of CO, NOx and HC in both the test fuels. It is found from the results that the blended fuel provides marginally low emission than the pure petrol, shown in Table 3 and 4.

The other results related to Brake power comparison (Fig. 10), TFC comparison (Fig. 11) and Comparison of Mechanical Efficiency (Fig. 11) is evaluated between the test fuels. It is found that the blended mixture performs better than the pure diesel.

5.4. Performance Test Calculation for Plastic Oil

Table 5 Observation Reading on Pure Diesel

Load %	Calculation Load (amp)	Applied Load(amp)	Time of 10cc fuel		
			T1	T2	T
0	0	0	60	65	62.5
20	2.5	2.5	55	54	54.5
40	5.2	5	50	49	49.5
60	7.70	7	39	38	38.5

Table 6 Pure Diesel Performance

Load (amp)	BP (kw)	TFC (Kg/hr)	SFC (Kg/kwhr)	I.P (kw)	η_{mech} %	η_{BT} %
0	0	0.478	0	0.8	0	0
2.5	0.718	0.548	0.762	1.518	47.32	10.53
5	1.437	0.625	0.435	2.237	64.25	18.47
7	2.012	0.776	0.385	2.812	71.55	20.83

Brake Power (*BP*)
= $VI\cos\phi/(AE\times1000)$
= (230×2.5×1)/ (0.8×1000) = 0.7187kw
Total Fuel Consumption (*TFC*)
= 3.6*x*/*t*× specific_gravity
=(3.6×10/54.5) ×0.83 =0.548kg/hr
Specific fuel consumption=TFC/*BP*
=0.548/ 0.787
=0.7623kg/kWhr.
Mechanical efficiency (η_{mech}) = (*BP*/*IP*)×100
= (0.7187/1.518)×100 =47.32%
Brake thermal efficiency (η_{bt})
=((*bp*×3600)/(*tfc*×44800))×100
=(0.718×3600)/(0.548×44800)×100
=10.53%.

5.5. Performance Test on Mixture of WPO (10%) Anddiesel (90%):

Table 7 Observation reading on Mixed WPO10% andDiesel 90%

Load %	Calculation Load (amp)	Applied Load (amp)	Time of 10cc fuel		
			T1	T2	T
0	0	0	76	71	73.5
20	2.5	2.5	59	54	56.5
40	5.2	5	52	50	51
60	7.70	7	41	41	41

Table 8 Performance on WPO (10%) andDiesel (90%)

Load (amp)	BP (kw)	TFC (kg/ hr)	SFC (kg/kw hr)	I.P (kw)	η_{mech} %	η_{BT} %
0	0	0.372	0	0.7	0	0
2.5	0.727	0.484	0.665	1.427	50.94	12.19
5	1.455	0.537	0.369	2.155	67.51	21.99
7	2.037	0.668	0.327	2.737	74.45	24.76

Brake Power (*BP*)
=$VI\cos\phi/(AE\times1000)$
= (230×2.5×1)/ (0.7×1000)
= 0.727kw
Total Fuel Consumption (*TFC*)
= 3.6*x*/*t*× specific gravity
= (3.6×10 /54.5) × 0.76
= 0.484 kg/hr
Specific fuel consumption (*SFC*)
= *TFC* / *BP*
= 0.548 / 0.787
= 0.7623 kg/kW-hr.
Mechanical efficiency (η_{mech})
= (*BP*/*IP*)×100
= (0.727/1.427)×100
= 50.94%
Brake thermal efficiency (η_{bt})
= ((*bp*×3600)/(*tfc*×44800))×100
=(0.727×3600)/(0.484×44800) ×100
= 12.19%.

5.6. Comparison Between Pure Diesel and WPO Based on Load

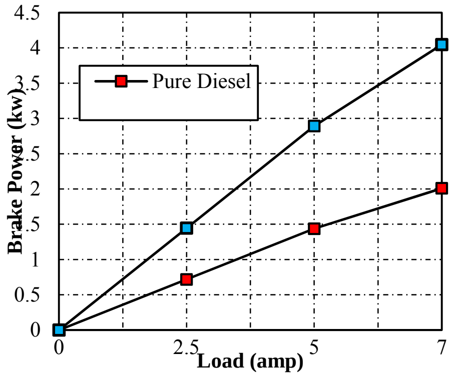

Fig. 10. Brake power comparison.

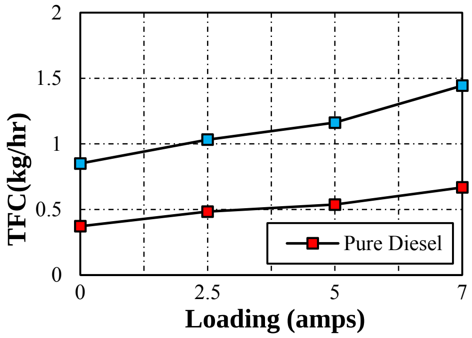

Fig. 11. TFC comparison.

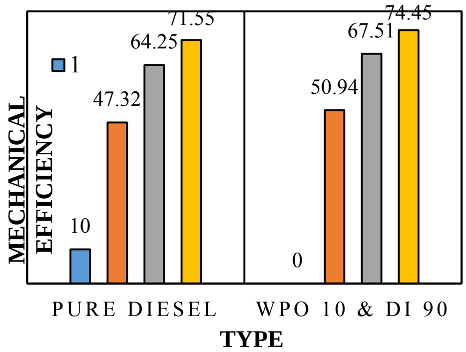

Fig. 12. Comparison of Mechanical Efficiency.

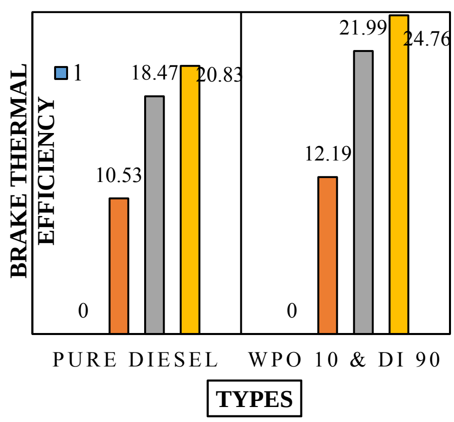

Fig. 13. Comparison of Brake Thermal Efficiency.

6. CONCLUSIONS

This paper reduces the usage of raw oil fuel scarcity and increased the production of bio-fuel from pyrolysis and condensation process, which is a simple production model. The performance of the bio-diesel possesses similar performance when blending the diesel with lesser ratio. However, the performance has a slight improvement when the diesel is blend at moderate ratio with fewer loads. The performance of the bio-diesel is high, when the engine load is increased. Other performance parameters like brake thermal efficiency and volumetric efficiency. The bio-diesel fuel has low viscosity with high heating value; the bio-diesel fuel has reduced exhaust temperature and brake specific fuel comparison. The bio-diesel production from the model contains reduced sulfur content, which reduces the SO2 emission and 78% less CO2 than the regular diesel fuel. Further, the work can be extended to increase the production of fuel by increasing the stages of condensation and distillation process. Also, the performance evaluation on the bio-diesel can be checked with increased blending ratios.

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