Investigation on the Performance of Diesel Engine with Modified Piston Geometry and Using Waste Plastic Pyrolysis Oil Blend

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Abstract*: The performance evaluation of geometrically modified IC engine against pyrolysis blended diesel fuel was studied. The pyrolysis oil was derivative of waste plastic oil and blended with diesel at different weight ratios. The engine piston considered to be as the most predominant component towards contribution of engine performance and emissions. An attempt has been made to change the piston geometry by offering additional holes in the piston crown and making groves in the piston bowl. The modification in the piston geometry helped to attain the strengthening and boosting the inlet air swirl movement which further assisted improvement in the performance and engine emission characteristics. The experiments were successfully carried out with modified piston geometry based diesel engines with pyrolysis blended diesel oils. The outcome of the present work further proves that the pyrolysis blended diesel oil showing significantly improved performance in brake thermal efficiency and specific fuel consumption. The emission parameter confirms that the Unburnt hydrocarbon, Co and NOx levels also measurably reduced. The results further proves that it could be considered as rapidly emerging blended fuel in replacement of diesel fuels in near future.

***Index Terms*: Grooved Piston, Swirling of Air, Tyre Pyrolosis Oil, Volumetric Efficiency (VE), NO_X Emission.**

I. INTRODUCTION

The characteristic features of our present day society mainly depend on the mechanical energy. Initial days the work got completed through manual forces primarily with human effort later it slowly changed to taking the assistantship from trained animals. Later the technological advancements helped to get assistantship from natural sources like wind and water. However, the big boon in mankind came into exist once the energy conversion techniques were introduced. The engine is one such arrangement was it can convert one type of energy to another useful energy which can take care about the humanoid processes.

Heat engine is one among the various engine types which can easily convert the available thermal energy to useful mechanical work. Based on the combustion types, it can be classified into two types as internal combustion (IC) engines and external combustion (EC) engines. EC engines, the combustion occurs outside the engine in a same fashion IC engines makes the combustion inside the engine. For external combustion engines are steam engines are steam turbines. In case of gasoline or diesel engines the air fuel mixture associates with the combustion process inside the engine cylinder. Here, the working fluid is air fuel mixture and it drives the primary energy source to keep the engine at running condition.

Since the existence of IC engines numerous fuels were studied by many researchers. The primary sources of energy were mainly derived from the chemical combustion process of the combination of used fuel with atmospheric oxygen. The mentioned process liberates the enormous amount of heat energy which could be later converted into the useful mechanical energy inside the engine cylinder. The produced energy is directly proportionate with the type of fuels used inside the process; altogether it plays a vital role in engine efficiency, performance, reliability. However, it is also enviable to generate environmental pollution through engine emission. The fuels are used in IC engines can be operated on different types of fuel i.e. liquid fuels, solid fuels and gaseous fuels depend up on the type of fuel to be used the engine has to be deigned.

Handling of Solid fuels leads with many practical difficulties, as the disposal of burnt out fuel and ashes put a major task in front of every user. After every successful combustion the emission stuffs and un-burnt hydrocarbons has to be handled with most care. Solid fuels are quite difficult to handle and storage and feeding the quite cumbersome. Liquid fuels are used in IC engines which are derivatives of liquid petroleum are used. Gaseous fuels can be incorporated to avoid the un-burnt discrepancies in the IC engines. As the gaseous state is highly encourages the homogeneous mixture of air and fuel, the engine performance may significantly improved compared with liquid fuels. However, the handling of gaseous fuel and storage of fuel leads to complication in the case of IC engines. It further restricts the convenience of gaseous fuels compared with liquid fuels in automobiles.

The liquid petroleum based products are also used as fuels in IC engines which are categorized as liquid fuels. These liquid fuels are basically benzl alcohol based products and emerged as primary fuels for all automotive engines. This liquid fuels are very limited in nature and will be elapsed after some years. It motivated many researchers to look out for alternative fuels where waste plastic is also considered as one among the alternative fuels. The waste plastic oil is not bio degradable in nature also to exhibits toxic in nature which is not suitable for living things in the earth. It can be

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overcome by decomposing the condensed organic matters through pyrolysis process. As the process is carefully using input materials of straw, sawdust and other agricultural waste, the environment will not get affected by this. The process mainly carried out using high temperature and pressure.

The homogeneity of the blends will be maintained at required level by using the emulsifier. The plain diesel will be blended with pyrolysis oil at various weight percentages and used in the CI engine. It is already reported that the waste plastic oil can be successfully used as replacement of diesel in IC engine and 100% oil can help to run engine without any hurdles.

The experimentation on Diesel engine using waste plastic oil was performed and the performance characteristics of the plastic oil with diesel fuel were compared for the suitability of plastic oil as fuel to diesel engine [1]. The setup was designed to work for 100% plastic oil and the results were recorded for evaluation purpose. The results indicated that the plastic oil produced more NOx and CO compared to normal diesel fuel. At max load condition the plastic oil produced more smoke and hydrocarbons compared with Diesel fuels. However, the reported thermal efficiency with plastic oil was very high (80%) compared with diesel fuel at all load conditions. In a similar effort the derivative of kaoline catalyzed pyrolysis was used as waste plastic oil and sufficiently blended with normal diesel was tested for effective performance [2]. The observed test results proved that the plastic oil blended with diesel can be considered as an alternative fuel for present normal diesel fuels. The plastic oils blended up-to 30% ratio produced better performance, however, the performance trend were declined while increasing the plastic oil blend ratio. It was reported that the engines was suitable to operate up-to 50% blend ratio later the increase in blend ratio shown negative trend in engine performance with severe vibrations. The higher level of emissions was started at maximum load conditions. The engine performance was stable with better BTE.

The engine setup was slightly modified with direct injection, water cooled and single cylinder setup to check the suitability of increased volume ratio (70%) of plastic oil. But the results were once again proved that maximum of 50% blend only recorded the improved performance than diesel fuels later the increase in blend volume ratio caused severe degradation in engine performance [3].

The waste plastic oil (WPO) blended with diesel fuel was studied for the suitability to use as alternate fuel in transportation services [4]. The thermal method was used by the authors to prepare the WPO blended diesel and for study purpose it was blended up to 5% of volume. The FTIR spectrum method was used to make sure the maintenance of required quality level in the blends. The fuel properties like viscosity and density were studied for both the blend as well as normal diesel fuel. The Kirloskar Diesel engine was used to understand the possibility of using WPO as fuel for transportation vehicles which explored further feasibility of using waste oils produced from PVC materials as fuel. The performance characteristics were measured using upto the maximum load condition of 3.7kW (electrical loading condition). The performance indicated increased BTE with decrease in both total fuel consumption (TFC) as well as specific fuel consumption (SFC).

R. Baskarna et.al. [5] Performed the experiments using 10%, 20% and 30% plastic WPO oil and diesel blends at constant speed condition on the standard diesel engine setup. The performance characteristics including engine BP, brake thermal efficiency, SFC, mechanical efficiency, and TFC were studied. The results indicated no significant power reduction in the engine operation and had an increase in BTE and mechanical efficiency on 20% with plastic WPO oil and diesel blends as compared to diesel alone. The similar report was also recorded for the effective improvement in engine performance by using WPO blended diesel engine [6].

Apart from WPO some other alternate oils are tested with diesel engines. In that order, rice brand oil methyl ester was used and blended with normal diesel to test the performance characteristics of the diesel engine. The ratio was taken at the least quantity of 1%, 3% and 5% volume ratios. It was evident that the blended fuels reportedly reduced the NOX, CO and HC emissions considerably [7]. Similarly annona methyl ester was also tested to study for its suitability to use as alternative fuels. As the blend was needed with anti-oxidents, the p-phenylenediamine, a-tocopherol acetate, 1,4-dioxane, and l-ascorbic acid were added and tested its performance in diesel engines [8]. The results further proved that the prepared alternative fuel helped to attain reduction in NOx emission nearly 50%.

The study of alternative fuels dragged very good interest to many researchers in the same manner; few researchers focused their research towards modification in engine geometry. This modification was believed to be having the greater impact on the performance improvement in Diesel engines. In this aspect, combustion chamber was re-modified with suitable modification in the piston geometry. It helped significantly in the mixing of air fuel volumes and increased the engine peak pressure as well as heat release rate [9 - 13].

II. EXPERIMENTAL PROCEDURE

Experiments were conducted on a single cylinder 4 – stroke diesel engine coupled with eddy current dynamometer. The test will conduct 240 PE IC engine software. The waste plastic oil is produced by the pyrolysis process using batch reactor.

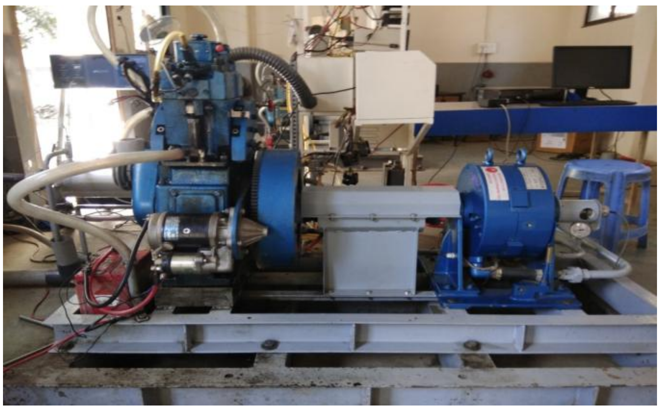

Fig. 1: Experimental setup

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This plastic pyrolysis oil are blended with diesel on volume basis 15% blend (WPPO 15) 25% blend (WPPO 25) and 35% blend (WPPO 35) of WPO with diesel fuel is prepared. The experimental setup is shown in Fig.1. The Engine Specifications and basic properties of fuel are listed in the Table I and II respectively. The density and viscosity of the blended fuel with increase in WPO %. The calorific value of pyrolysis oil blends are lesser compared to diesel fuel. The cetane number of plastic pyrolysis oil blends are lower than diesel fuel with basic piston by applying load on eddy current dynamometer 0 kg and considered the readings of emission smokes and fuel consumption per mint. Repeat the same loads 3kg, 6 kg, 9 kg and 12kgs when we complete all reading change the basic piston to grooved piston further necessary modification on the piston bowl and piston crown can be carried out in this engine.

Table I. Engine Specifications

No.of cylinders	1
No.of Strokes	4
Cylinder diameter (mm)	87.5
Stroke length (mm)	110
Orifice diameter (mm)	20
Dynamo meter arm length (RPM)	1500
Power (kW)	3.5

Table II. Basic Properties of Fuels

S.No	Characteristics	Diesel	WPPO 15	WPPO 25	WPPO 35
1	Calorific volume KJ/Kg	46500	43238	42698	41355
2	Density at 15^0C Kg/m^3	835	846	851	867
3	Kinamatic Viscosity 40^0C in Cst	2.15	2.48	2.59	2.67
4	Cetane Number	53	51	49	47
5	Specific Gravity	0.84	0.71	0.65	0.51

(a)  (b) 

Fig 2: (a) Normal Piston (b) Grooved Piston

(a)  (b) 

Fig 3: (a) Front view of Piston (b) Grooved Piston Arrangement in Cylinder

The changes made in the Piston geometry are illustrated in Fig. 2 & 3. The engine was allowed to run in a ideal condition to create necessary warm-up, later the experiments were performed in diesel engine with grooved piston was done by adding 6 holes D 8 and 6 mm depth with 2x2 mm slot each hole on crown and 7 V Grooves on bowl to get the performance and emissions.

III. RESULTS AND DISCUSSIONS

The diesel engine setup was arranged and the experiments were performed using normal piston and grooved piston. The engine performances were benchmarked based on brake specific fuel consumption as well as the brake thermal efficiency. The results were recorded based on the emission characteristics; the engine was slandered in terms of un-burnt HCs, CO, NOx and smoke opacity. The results are obtained by the grooved piston were compared with test performed with normal piston. Present experimental work was restricted up to 2000W load capacity and it was not conducted up to peak loads of 3750W due to technical reasons which is not in the present scope of the work.

A. Brake Thermal efficiency Vs Brake power

The BTE is the useful work attained by the engine through chemical energy derived from the fuel. It is the representation of engine combustion behavior. Fig. 4 shows the variation of BTE of grooved piston with pure diesel fuel at WPPO 35 compared to normal piston it is noticed that the BTE increased with increasing the break power at WPPO 35 of grooved piston. The brake thermal efficiency of WPPO 35 with grooved piston (28%) compared to normal piston with WPPO 35 at full load. The effect may be accredited to proper mixture formation of WPPO 35 and air, as the improved air circulation attained through the grooved piston and leads to complete combustion of WPPO 35 blend.

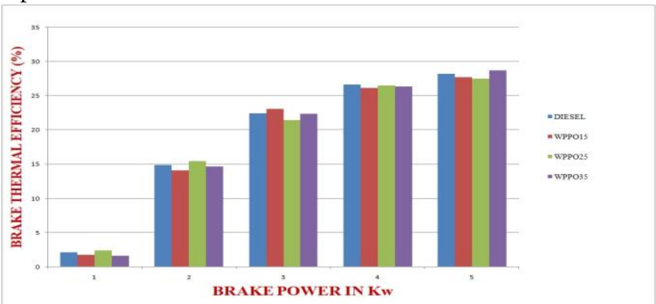

Fig. 4 BTE vs BP

The brake thermal efficiency is the most important factor for finding the performance of the engine. The variation of BTE with respect to load for grooved piston and normal piston were tested. It is observed that the BTE was minimal in the case of normal piston and considerable increased level was attained in the case of grooved piston. The geometrical modification in the engine geometry induced the enriched air swirl inside the combustion chamber which maintained proper air fuel mixture as well as absolute combustion inside the engine combustion chamber.

The BTE indicates how efficiently the energy in the fuel is converted into mechanical power. It shown that increased BTE with increasing the BP for all types of combustion chamber.

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B. Brake specific fuel combustion Vs Brake power

The specific fuel combustion of WPPO 35 with grooved piston (0.325 kg / kW-h) was lesser than the normal piston this may be attributed to better atomization and vaporization of WPPO 35 and better air fuel mixture by the grooved piston at full load.

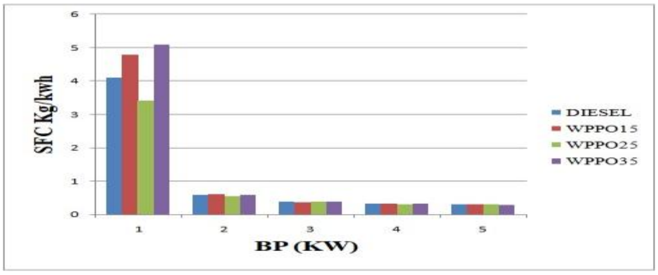

Fig. 5 SFC vs BP

Brake SFC against BP is illustrated in a detailed manner in the Fig. 5. Here, SFC is inversely proportionate to the brake thermal efficiency of the engine. It shows that the brake specific fuel combustion decreased with increasing the brake power for all types of combustion chamber. The obtained phenomenal further greatly influenced the complete combustion inside the chamber through perfect air motion and complete vaporization of the fuel. A lower value of brake specific fuel combustion indicates a higher overall efficiency of the engine.

The brake SFC was increased in blends, which was higher than the normal diesel fuel in the entire load range. As it has lower calorific value, higher density and hence higher bulk modulus incase of grooved piston the fuel consumption decreases with increasing load due to the brake power increases the higher percentage compare to fuel consumption. Fuel consumption decreases with grooved piston compare to normal piston condition.

C. Load Vs Hydrocarbon

The variations of hydrocarbon emissions with BP for WPPO 35 at grooved piston compared to normal piston are illustrated in the Fig. 6. The HC emission was increased in the case of WPPO 35 while there was an increase in load condition; however, this emission was considerably lesser in the normal diesel fuel as standard engine position. The changes in HC emission may be raised because of improper mixing occurred with diesel blend and intake air.

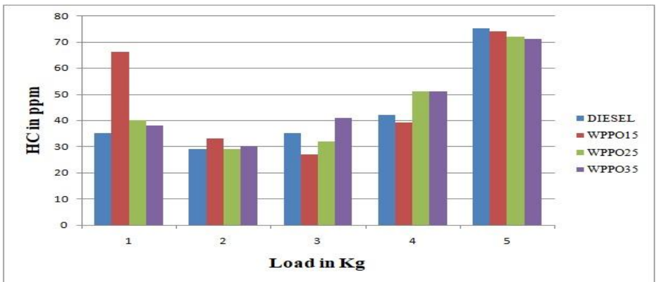

Fig. 6 HC vs LOAD

It is also noted that the rate of HC emission was meager due to the air swirl motion effect inside the combustion chamber which helped complete combustion inside of the engine. The formation of un-burnt hydrocarbon emission is obtained due to incomplete combustion of fuel. UBHC emission is focused in extremely rich or lean. Combustion process may witness either more diluted exhaust gases or uncompleted flame propagations. The specific problems may be endorsed for the optimized combustion with efficient atomization and vaporization of air-fuel mixture. It reduced 12% of UBHC emission of grooved piston compared to normal piston when test was performed under full load condition.

D. Load Vs Carbon monoxide (CO)

The incomplete combustion mostly leads to production of CO, a toxic gas. In some cases the poor mixture of air or deficiency in oxygen level also leads to CO emission during the vehicle operational conditions.

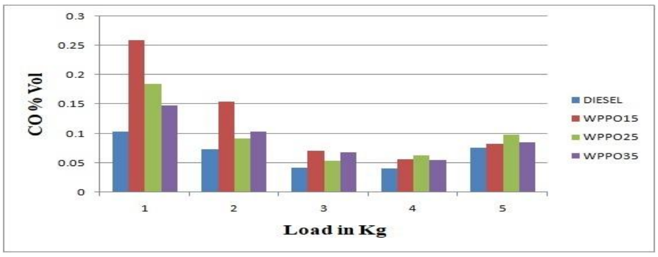

Fig. 7 CO vs LOAD

The improved spray atomization process reduced the CO level in accordance to the increase in blend proposition during full loads condition. The figure 7 illustrate the CO emission according to change in load condition with respect to various fuel intakes.

The variations of CO with respect to load are observed for normal piston grooved piston the results shows that CO emission of grooved piston is lower than normal piston it is observed that the emission concentration are lower than BHARATH STAGE III. Up to load of 2000W.

It may be due to higher air movement in grooved piston. The reduction in CO emission with increasing load and it may be observed the effective atomization, evaporation of WPPO 35 blend and leads to complete combustion this was a reduction of 35% CO emission for the grooved piston compare to normal piston when test were carried out with WPPO 35.

E. Load Vs Oxides of Nitrogen

The chemical reactions between the Nitrogen and oxygen gases at high temperature results formation of oxides of the nitrogen. In common the level of NO percentage will decide the NOx emission during combustion process. It is also observed that the percentage of NOx formation is more with respect to increase in load conditions for normal fuels, however, the effect was reverse in the case of WPPO fuels. It is observed that the NOx emission was reducing for different load conditions of WPPO fuels.

It is observed that the NOx of grooved piston was increased compared with normal piston at full load condition. The grooved piston helped to achieve optimal mixing of air fuel mixture before the combustion process which maintained the required oxygen level at combustion chamber before to the combustion process.

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Also the change in piston geometry helped to achieve effective mixing of inlet air and fuel, which taken care of reduction in NOx emission after combustion. The complete behavior of NOx emission with respect to different fuels and various load conditions are illustrated in Fig. 8.

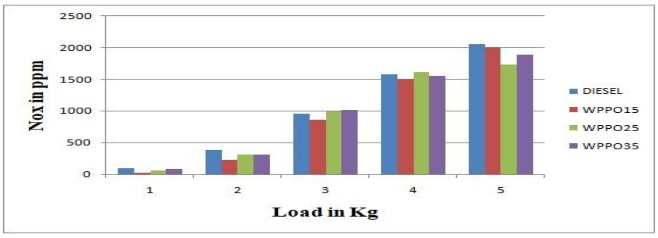

Fig. 8 NOx vs LOAD

F. Load Vs Smoke Opacity

The experiment results indicated that the level of soot emission by using different WPPO blended diesel fuels are always lesser than compared with normal diesel fuel. However, it is also observed that the various load conditions always increasing the smoke opacity for all different type of fuels. The complete behavior of smoke with respect to different fuels and various load conditions are illustrated in Fig. 9.

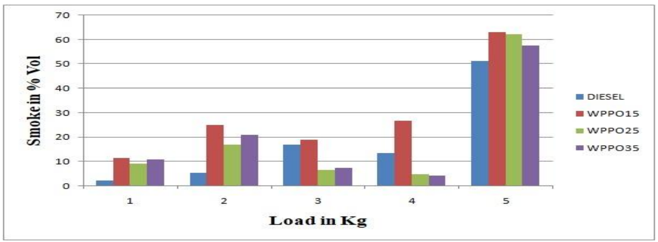

Fig. 9 SMOKE vs LOAD

The smoke opacity was decreased for WPPO blend up-to the part load of 75% and then increases due to improper mixing of air at full load. Soot forms in the rich un-burnt fuel when the fuel vapor is heated by mixing with hot burned gases. The maximum reduction of smoke opacity for WPPO 35 is 25 % compared to normal piston.

IV. CONCLUSION

Test was conducted in diesel engine with diesel and WPPO. The WPPO is suitable fuel for a diesel engine with modification in the engine. The blending of WPPO and diesel to decrease the viscosity and there by increased the atomization of air fuel mixture this was the reason for the enhancement of brake thermal efficiency. The higher brake thermal efficiency was obtained for WPPO 35.

The performance of direct injection diesel engine was conducted experiments with grooved piston and compared with normal piston and the conclusion of the test results are given below.

The maximum increasing brake thermal efficiency for a grooved piston compared to normal piston was found to be 28%. The brake thermal efficiency was increased by 1.9% in grooved piston compare to normal piston.

The brake specific fuel combustion was decreased for WPPO 35 with grooved piston 0.3 Kg/kwh compare to normal piston at full load operation.

The un-burnt hydrocarbon are lesser at WPPO 35 for grooved piston compare to normal piston and to increase the load, the UBHC is increased. The HC emission is 38 PPM at 35 WPPO 35 of grooved piston compare to normal piston.

The CO emission at WPPO 35 is 35 % at initial load and the CO emission is decreased full load condition.

The NOx emission is very less at initial load and to increase the load the NOx also increase at full load.

The smoke emission at WPPO 35 is 15% volume at initial load and the smoke is decreased when we increase the load.

From the above it can be concluded that the blends of WPPO – DF and with the use of grooved piston it has been improvement in brake thermal efficiency and reduce the brake specific fuel combustion and decrease the emissions. CO, HC, smokes and increases the NOx emissions

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