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Experimental Investigations on Effect of Modified Piston Geometry in CI Engine Fuelled with Blends of Diesel and Tyre Pyrolysis Oil

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The performance and emission characteristics of modification of piston geometry on compressed ignition engine with tyre pyrolysis blends was investigated. The piston geometry was changed to grooved piston (6-holes D8 and 6 mm depth with 2x2 mm slot, each hole on piston crown and 7 V-grooves cut on piston bowl) to create automatic internal swirling of air during suction stroke. Four different blends of diesel and tyre pyrolysis oil like TPO10, TPO20, TPO30 and TPO40 were used to conduct the experiments at a constant speed of 1200 rpm. Experimental results indicate that the brake thermal efficiency, specific fuel consumption and volumetric efficiency are optimal at TPO20 i.e 20% blend with the grooved piston engine. Modified geometry piston with TPO20 blends given complete combustion as well as reduced hydro carbon, and CO emissions. Nitrogen oxides emission was remarkably maximum reduced at ideal condition operated with grooved piston compared to basic line engine. The emission rates were found linearly increasing for more than 20% of blending.

Keywords: Grooved piston, NO_X Emission, Swirling of air, Volumetric efficiency

Introduction

Internal combustion (IC) engines are playing a vital role in day-to-day transportation. The liquid fuels are occupying major share to run IC engines, hence, based on the type of liquid fuels, IC engines are classified either as petrol engine or diesel engine. In general the petrol version is termed as spark ignition engine and the diesel versions are termed as compression ignition (CI) engine. CI engines are also preferred in power generation, marine and agriculture sectors due to its long service life and easy maintenance. In day to day life the usage of CI engines are increasing, which considerably increases the demand of petroleum fuels. Diesel as a fuel is meeting the present day demand, however there is an urgent need to address the problems of depleting of fossil fuels source and increased green house gas emissions. India spends huge resaves of foreign exchange every year for importing crude and petroleum products. Petroleum fuel resources are limited. Need for search of alternate fuels to meet future demand is continuous process since inception of IC engines.[1]

The fossil fuels are giving best in performance; more researchers are working towards increasing the fossil fuel efficiency through various means. One such way is blending the diesel fuel with available fuels from biological products or waste produced from plastic and polymer materials. Plastic and tyre waste are used to produce fuel by pyrolysis process and investigated for their performance against CI engines.[2] The pyrolysis process has been proved as a best in practice for the production of fuels from waste products. The produced fuels were effectively blended with conventional diesel fuel and tested for it performance. The test results proved that blended fuels outperformed conventional diesel fuel at optimal blend ratios.[3] However, the waste plastic oil contains more percentage of Chlorine and Sulfur, which required more knowledge while sorting out the plastic for pyrolysis process. Also there is no certainty about the cost analysis factor on plastic waste fuels.[4,5] The intricacies in the waste plastic oils could be resolved through implementation of changes in standard port timings. The change in retarded injection time affected and produced better emission performance in DI diesel engine.[6] In a similar approach, the DI diesel engine combustion chamber geometry was changes and experimented for its performance against blended diesels. The change in design helped to achieve increased brake thermal efficiency compared with normal one.[7–9]

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The previous research works indicates there is continuous progress is going on towards modification of the engine combustion geometry to have a strong control over emissions. The emission controls either through internal arrangements or external arrangements directly affect the overall engine performance. The internal arrangements mainly talks about the modification of combustion chamber to achieve better emission control. The geometry design helps to greatly influence the combustion processes and controls over emission as well as fuel usage.[10–12] The geometry redesign worked very well with heavy duty engines also, which was proven against the available cylinder head swirl.[13]

The part geometry redesigns attracted more interest as it was proven that the influence of change in part geometry yielded better performance in DI diesel engines. The part geometry and alternative fuels combinations worked out very well against the emission control. A particular combination of diesel blends with redesigned piston bowl geometry achieved very good success rate for high speed DI engines.[14] The parts like bowl chamber geometry was redesigned like step, deep or reentrant shapes and in other cases the nozzles parts like number of holes were changed and experimented against their performance. The experimentation results shown an optimal performance during majority of the cases which are all reiterated in many communications.[15]

Fig. 1 — The Engine setup and modified piston

In the present work an attempt was made to change the piston geometry to create swirling motion of air, fuel inside the combustion chamber, that proper mixing of air-fuel, leads to complete combustion of fuel. The paper sought to establish stratified charge engine that gives highest thermal efficiency, minimum brake specific fuel consumption of the engine, minimum smoke density and lower emissions and compare with alternative fuel TPO on conventional CI engine.

Experimental Setup

A 4 stroke 1 cylinder water cooled DI engine with eddy current load engine was modified into geometry changed piston. Tyre pyrolysis oil with diesel blended in the ratio of 10%, 20%, 30%, and 40% was used in the modified engine. The modified piston is shown in Fig. 1 and the engine specification is listed in the Table 1. The experiment was conducted at constant speed of 1200 rpm at all engine conditions.

The oil extracted from waste tyres of automobiles is used to produce tyre pyrolysis oil. The extracted tyre pyrolysis oil was blended with the pure diesel fuel in the ratio of 10%, 20%, 30%, and 40% and named as TPO10, TPO20, TPO30, and TPO40 respectively (named w.r.t. per cent of TPO). The properties of blends were determined by using the ASTM (American society for testing materials) method. The properties of pure diesel and TPO blends are listed in the Table 2 by changing the geometry of the piston with 6–holes with slots on piston crown and 7 v-grooves on piston bowl called as grooved piston (GP). Because of grooved piston in suction stroke the air motion was changed i.e swirling of air is created inside the combustion

Table 1 — Engine Specification

Sl. No	Specification	Ranges
1	Make	Kirlosker
2	Type	4 Stroke single Cylinder
3	Cylinder diameter (mm)	87.5
4	Stroke Length (mm)	110
5	Orifice diameter (mm)	20
6	Dynamo meter arm length (mm)	185
7	Speed (rpm)	1500
8	Power (kW)	3.5

Table 2 — Fuel Properties: Diesel and various blends

	Calorific value (mJ/kg)	Density (kg/m3)
Diesel	42.5	857
TP10	41.8	860
TP20	40.8	868
TP30	39.9	873
TP40	38.1	885

chamber without any additional equipment of engine (like turbocharger and super charger)

Air Motion in Cylinder

According to the stratified charge engine, the air flow doing a vital role in the emission and combustion processes. The air motion inside the cylinder majorly depends on manifold design and piston combustion chamber configuration. The grooves on the piston control the turbulence level and air fuel mixing of engine. The air motions atomizes the injected fuel into droplets of different sizes, distribute the fuel droplets uniformly in the air particles, transfers the fresh air in to the inner portion of fuel drops, confirms complete combustion, reduce emissions after burning of fuel, and reduce knocking affect.

CI engine with normal piston were operated with blends TPO10, TPO20, TPO30, and TPO40. The engine performance and emission characteristics are compared with grooved piston with same blends. The exhaust gas emissions such as HC, CO, CO_2, and NO_X are measured with gas analyzer. AVL smoke meter used to measured the exhaust smoke of the engine

Results and Discussion

In the present work by changing the piston geometry for creating swirling motion of air inside the combustion chamber and along with TPO blends the performance and emission characteristics are compared with basic engine. In the experiment the speed was fixed at 1200 rpm and changing the loads from 0 kg to 12 kg with 3 kg difference.

Brake thermal efficiency (BTE)

The change in BTE with respect to different loads is shown in Fig. 2a. The engine was operated at variable loads along with different blends. Initially the test was conducted between normal piston and grooved piston with diesel fuel. Grooved piston engine showed better BTE value than normal piston engine at maximum load, 12 kg.

When performance of grooved piston was compared between diesel and the four blends, TPO10 and TPO 20 showed more BTE than TPO30 and TPO40 at maximum load. The maximum achieved BTE was 32.8% with TPO20 blends on grooved piston. According to piston geometry change the holes with slots and grooves helped to mixed air properly with atomized fuel. Because of proper mixing the complete combustion of air fuel will take place in combustion chamber that leads to formation of less un-burnt hydrocarbons. Best result was obtained with TPO20 on grooved piston compared with TPO30 and TPO40 blends. More percentage of blending leads to increase in the density of blended fuels and decreasing the calorific value. More density fuel take more time to mix with air in combustion chamber, so after combustion it produces some excess un-burnt emissions leading to reduced efficiency of the engine. If un-burnt emissions are formed in combustion chamber that will pre-ignite in next cycle and produces knocking effect. It leads to damage to the piston crown. Finally it's noticed that the grooved piston with TPO20 blend having better BTE than other TPO blends and diesel. So 20% of tyre pyrolysis oil blended with diesel gives optimum blending with grooved piston. The comparison of BTE for all blends is shown in Fig. 2b.

Specific fuel consumption (SFC)

The variation of SFC with respect to brake power (BP) is shown in Fig. 2c. The grooved piston SFC was reduced with increasing BP. By increasing the engine load SFC reduced in all testing conditions. The similar thing was observed when we compared with normal piston and grooved piston.

Changing the piston geometry from bowl shape to grooved shape helped to create more turbulence of air fuel mixture in combustion chamber that leads to rapid combustion. The rapid combustion of air fuel mixture in combustion chamber makes complete burning of air fuel mixture and reduces the ignition lag. Due to more air, less fuel of mixing in combustion chamber leads to less SFC at maximum loads. For grooved piston, the SFC was slightly less in TPO20 compared to other blends at maximum load condition. The combustion of TPO30, TPO40 is delayed and consumes slightly more fuel for same brake power at same load compared to TPO20. Finally TPO20 blend gives less SFC at 12 kg engine load comparative to diesel, TPO30, and TPO40. The minimum fuel economy of TPO20 with grooved piston was 0.0325 kg/kwhr. TPO10 gave SFC results similar to TPO20 blends, shown in Fig. 2d.

Volumetric Efficiency

By increasing the engine load, volumetric efficiency was reduced gradually. In accordance to the effect of IC engines' volumetric efficiency to breathing ratio, the grooved piston gives more density of air at inlet manifold. If volumetric efficiency is more leading to increased air density it helps to reduce the fuel consumption in combustion chamber during combustion stroke. Grooved piston engine

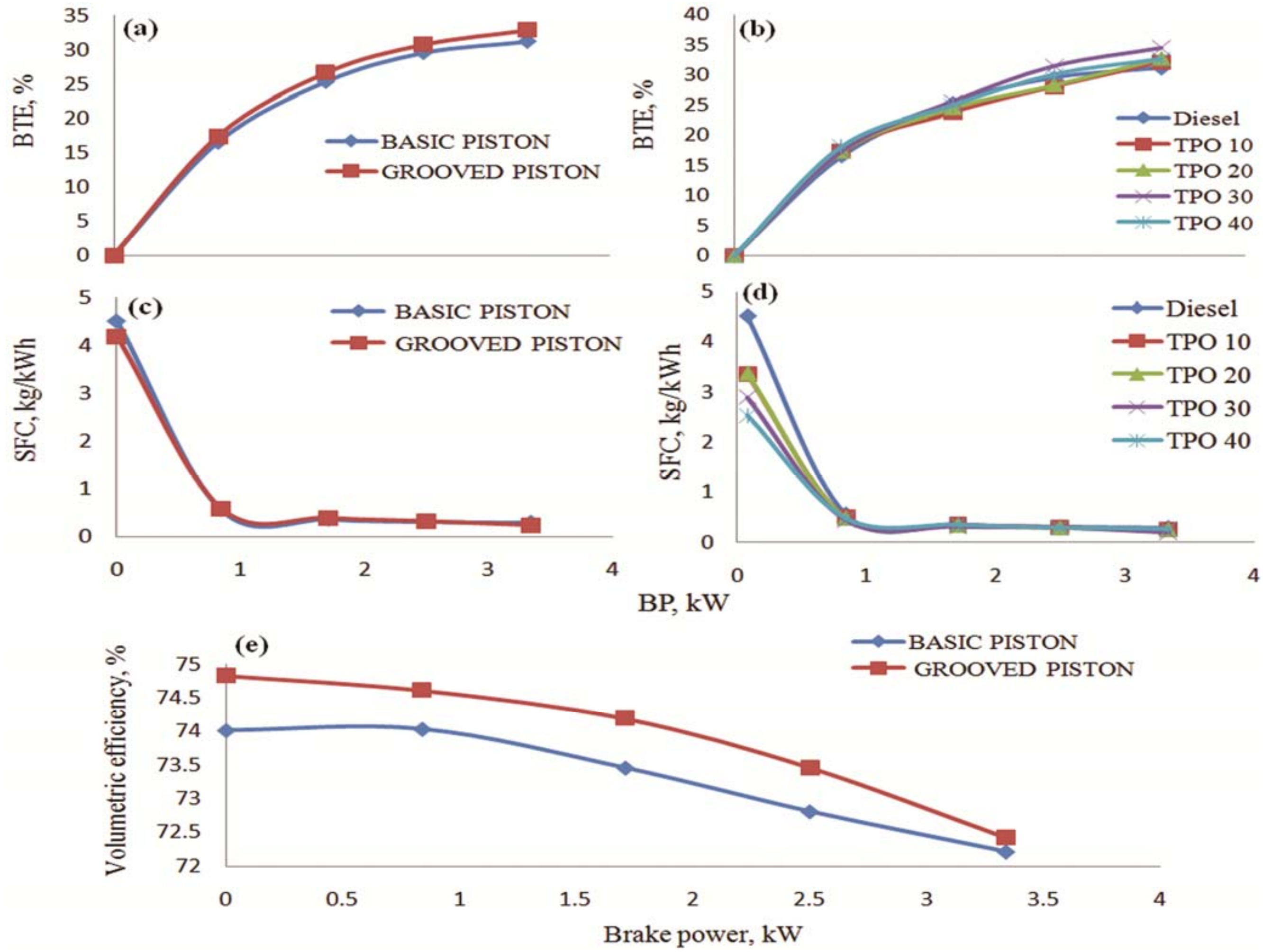

Fig. 2 — (a & b) Brake power against BTE for various blends of fuel; (c & d) Brake power against Specific fuel consumption for various blends of fuel; (e) Brake power against volumetric efficiency for various blends of fuel

having more breathing effect than basic piston at initial engine load condition is shown in Fig. 2e.

NO_X Emission

The chain reaction of NO_X caused due to N_2 and O_2 in air facilitating the NO_X emission noticed in reciprocating engines is due to more temperature in exhaust manifold. Many researchers have worked on CI engine with TPO blends without changing the geometry of the piston and found NO_X emission around 55% in test results. The variation of NO_X emission with different loads between normal piston and grooved piston is shown in Fig. 3a. Because of less amount heat produced at exhaust, NO_X emission at low loads was less. At maximum load NO_X produced by engine was more, because rich fuel burns in combustion chamber and exhibits high temperatures. Comparison of TPO blends at ideal condition of engine, diesel fuel produced more amount of NO_X whereas with TPO blends up to 40% on grooved piston gives approximately zero NO_X emission after that gradually increased by increasing the load as shown in Fig. 3b.

Hydro Carbon (HC)

Basic piston operated with TPO blends produces NO_X somewhat more compared to grooved piston. It is because, in normal piston engine hydrocarbon (HC) is formed at the crown of piston whereas in grooved piston HC is not much affected. The HC formed normal piston and grooved piston are shown in Fig. 3c.

In reciprocating CI engine HC is formed due to the incomplete combustion of air fuel mixture in combustion chamber. The formation of HC on Piston crown leads to pre-ignition before combustion i.e., before reaching of piston to TDC. This phenomenon leads to abnormal combustion i.e., knocking effect.

Hydrocarbon load is fluctuated according to load as shown in Fig. 3d. More HC is produced at low loads,

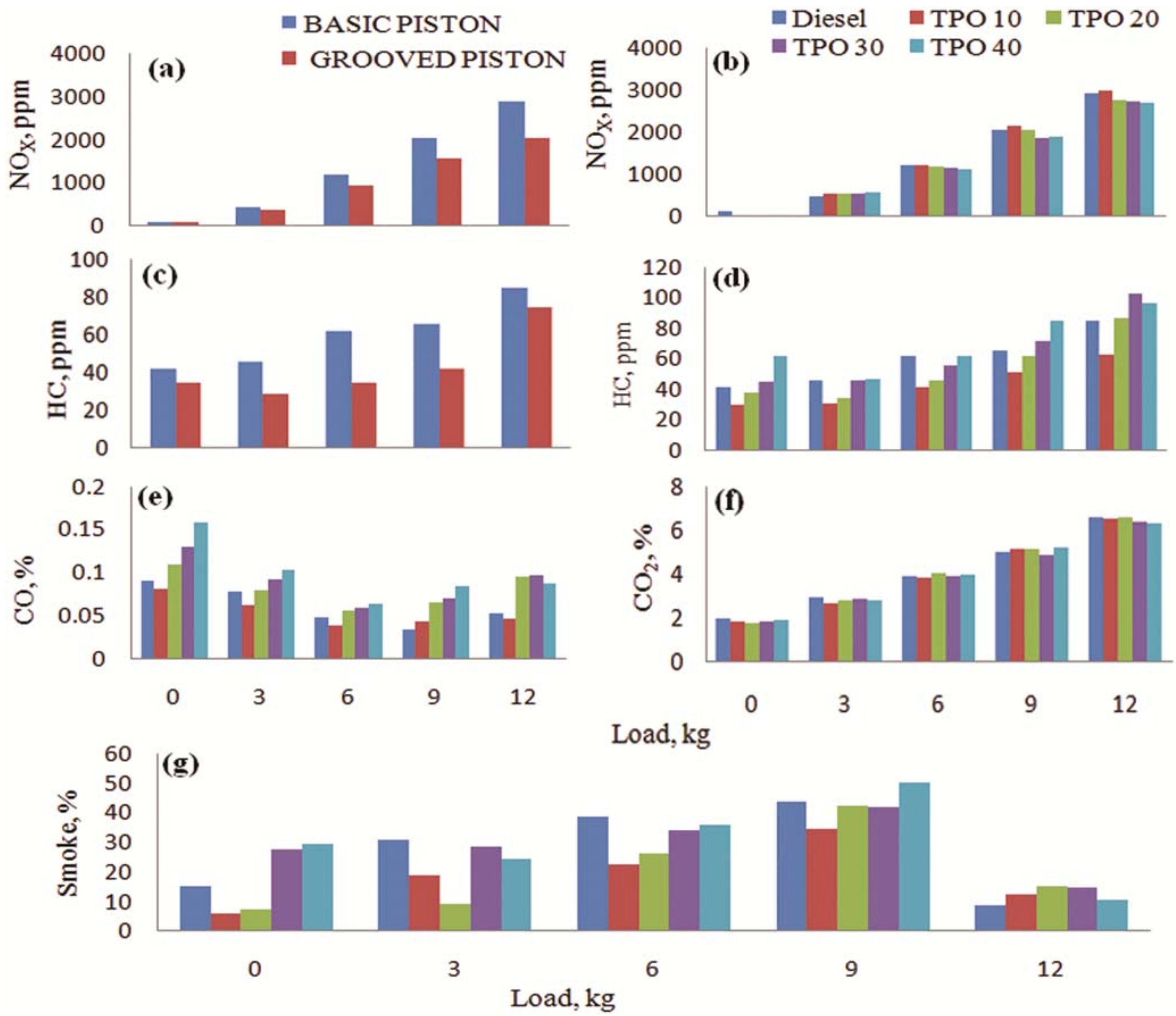

Fig. 3 — (a & b) Load against NO_X for various blends of fuel; (c & d) Load against HC for various blends of fuel; (e & f) Load against CO for various blends of fuel & CO_2 for various blends of fuel; (g) Load against Smoke for various blends of fuel

because of more fuel and less air; similarly maximum load also produced rich mixture of air and fuel. In present work changing the geometry of piston with grooves and slots, HC cannot able to stick on the crown of piston. Because of grooves swirling or turbulence of air fuel mixture taking place in combustion chamber that encourages the complete combustion without producing un-burnt hydro carbon on piston crown. The sequence of events that happens in the modified piston is: Swirling of air → proper mixing of atomized fuel + air → more turbulence of air fuel mixture in combustion chamber → complete combustion → No HC on piston crown → good scavenging process → reduction of knocking effect → life of engine increases → less emissions in exhaust. Out of all TPO blends TPO20 produced less amount of hydro carbon on grooved piston crown.

Carbon monoxide (CO)

The comparison of CO emission at different blends, and different loads on grooved piston was done. Results showed that CO emission decreased with increasing loads. Its emission depends mainly on the carbon present in the fuel, the faster it reacts with atmospheric oxygen and produces CO_2 in exhaust. The CO and CO_2 variations are inversely proportional with loads as shown in Fig. 3 (e & f). After combustion of air fuel mixture in combustion chamber HC and CO are produced due to partial oxidation of carbon particles in a fuel.

In present work Grooves on piston helped in mixing and spreading of air fuel mixture over entire combustion chamber volume i.e., there is no chance of creating hotspot on any particular place of piston crown. According to test results basic fuel, TPO10 and TPO20 gives less amount of CO emission compared to other blends TPO30 and TPO40 as TPO bears somewhat more carbon compared to diesel. Optimum blending of tyre pyrolsis oil with diesel is TPO20 on grooved piston. The variation of CO emission with different blends is shown in Fig. 3e.

Smoke

Generally smoke is formed in three colors i.e., blue, black and white. Among all the black smoke emission as a result of incomplete combustion of fuel is more common in diesel engines. The black smoke is caused due to over fueling, dirty EGR system, incorrect fuel to air ratio, overloading the engine and poor fuel quality. Similarly blue smoke is caused by entire lubricating oil burning and white smoke is caused due to passing of raw and un-burnt fuel into the exhaust stream.

In some test results black smoke per volume was produced due to in proper combustion of TPO blends with normal piston. Present work, by changing the geometry of piston helped to create the internals swirling of air at suction stroke. That helped to make it properly mixed with atomized fuel leading to complete combustion. More smoke was shown by TPO10 than other blends and TPO20 emitted the least. The variation of smoke accordingly load different blends were shown in Fig. 3g.

Conclusions

The test results shows grooved piston engine is more suitable for best performance and less emissions with TPO blends. The Optimal condition for increased brake thermal efficiency in grooved piston engine with TPO blends attained at TPO20 blend (20 % TPO & 80 % of diesel). The SFC was reduced & good economy was given in TPO20 blend. The optimal condition for reduction of NO_X emission in grooved piston engine at ideal condition given approximately zero NO_X of all TPO blends. More CO emission was seen in TPO10 blends. Maximum reduction of HC in emission was by TPO20 blend & smoke was slightly vitiated in all TPO blends. Out of all test emission results blend TPO20 with grooved piston gave less emissions at exhaust manifold i.e., the optimal percentage of blending of TPO with diesel is 20 % on geometry changed piston engine.

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