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Experimental investigation of combustion, performance and emission characteristics of a modified piston †

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Abstract

In this investigation, the combustion, performance and emission characteristics of a diesel engine powered with Modified piston (MP) are studied. Engine tests have been carried out using conventional diesel and 20% blend of adelfa biodiesel [A20]. Results obtained from renewable fuel A20 in conventional engine have shown reduction in brake thermal efficiency that may be ascribed to poor air fuel mixing characteristics and higher viscosity of the fuel. This prompted the research towards improvement of turbulence for better air fuel mixing through a novel modification of the piston. The engine with modified piston has shown improved Brake thermal efficiency (BTE), Combustion characteristics and reduced hydrocarbon (HC), carbon mono oxide (CO), and smoke emissions. Nevertheless, the nitrogen oxide emissions have been found to be slightly higher than the conventional unmodified engine.

Keywords: Air movement inducement; Biodiesel; Combustion improvement; Energy efficient

1. Introduction

Diesel fuel is the major source of fuel in various evergreen sectors such as agricultural and transportation due to its superior efficiency. Day by day, decrease of fossil fuel resources is gradually diverting our attention towards replacement of conventional fuel or components as blending agents with it [1]. The two most frequently uttered words are population and pollution. The exponential increase in population and the consequent increase in the transportation modes have caused depletion in the fossil fuel. The worldwide use of conventional fuel for quite a long time now also has forced countries to seriously think of the fast depleting petroleum resources and dependence on limited resources [2]. The forerunner–Rudolf Diesel, who invented diesel cycle, initially tested his engine using peanut oil. The attractive properties and the availability of fossil fuel in abundance impelled the public to use it in spite of alternative fuels during those times. But in recent years, the non-edible oils have been considered as a superior fuel alternative for the depleting fossil fuel resources [3]. The major drawback associated with the vegetable oil is its higher viscosity. The problem associated with viscosity can be surmounted by processes such as direct blending with diesel fuel, emulsification, thermal cracking, and transesterification [4]. Each technique has its own advantages and disadvantages. The conversion of an organic acid ester to another ester in the presence of a catalyst and alcohol is referred to as transesterification [5].

From the careful literature survey, it has been found that of the various known methods, transesterification is a highly reliable technique to reduce the viscosity of the veggie oil and that biodiesel has produced considerable reduction in the emission level. S. Murillo et al. [6] reported that the use of biodiesel [cooking oil] in marine outboard engines reduced carbon monoxide emissions up to 12%. O. Ozener et al. [7] examined the effects of soya biodiesel blends [up to 50%] and reported a 46% decrease of carbon monoxide emissions and 44% reduction of total hydrocarbon emissions. M. S. Shehata [8] reported that biodiesel [Cotton seed oil, Flax seed oil, and Palm oil] caused lower brake thermal efficiency and higher brake specific fuel consumption than diesel. The researchers concluded that the biodiesel could be utilized as a fuel in a diesel locomotive with the various blend ratios, with a reduction of brake thermal efficiency and decreased emissions like carbon monoxide, hydrocarbon and smoke [9-15].

However, only very few works have been identified worldwide, that reported the use of Adelfa as non-edible feed stock for diesel engine. Owing to its higher cetane number and closer calorific value, biodiesel derived from Adelfa came to be considered as a futuristic biodiesel [16-19]. Since Adelfa biodiesel was chosen for this investigation, after a perusal of the available literature it was concluded by the researchers that the 20% blend of biodiesel with conventional diesel fuel en-

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Table 1. Comparison of fuel properties.

Properties	Diesel	Adelfa	A20
Calorific value (kJ/kg)	43200	42652	43090
Specific gravity	0.804	0.828	0.809
Cetane no	49	51	49
Viscosity at 40°(cSt)	3.9	6.5	4.4
Flash point (°C)	56	88	62
Fire point (°C)	64	95	70

abled the engine to run for longer duration without flaws. We are very much aware that the diesel engine has been standardized for the usage of diesel and hence for using an alternative fuel we have to make suitable modification either in the engine or in the fuel. In this research work an attempt has been made to increase the BTE and reduce emission by using a modified piston with A20 as fuel in a four stroke diesel engine.

2. Materials and methods

2.1 Adelfa

Adelfa or Nerium oleander is an evergreen shrub with deep green straight sword like leaves, growing tall up to 6 m, comes under the family Apocynaceae. The blossoms of the shrub are yellow, white and pinkish yellow in colour. Its seed kernel has high oil content up to 67%. However, its closer calorific value and higher cetane number and its non-edible nature have made it very suitable for the production of biodiesel for countries like India. The key properties of the adelfa biodiesel and diesel are compared in Table 1.

2.2 Modified piston [MP]

Piston bowl geometry has a strong influence on combustion, performance and emission characteristics in diesel engines [20-25]. Owing to the high velocities inside the combustion chamber, the flow has been termed turbulence. Heat transfer, fuel air mixing, and rate of combustion are increased due to this turbulence. This turbulence inside the combustion chamber has been categorized as squish, swirl, and tumble. The rotational motion of the fluid mass within the cylinder is termed swirl. It can be generated by means of suitable design of inlet manifolds, valves, and piston faces. It improves the combustion process by rapid fuel air mixing. Radially inward flow occurring at the end of the compression stroke [piston nearing TDC] is called squish which facilitates better fuel air mixing. After reaching the TDC the squish motion generates a secondary flow called tumble.

The proper designing of the inlet manifold and the geometry of the piston play a vital role in the combustion in IC engines. In the modified piston, the squish and the tumble motions are inhibited by the provision of a squish head. Novel swirling grooves have been provided in the piston top face to inhibit the swirling motion. The fabricated Modified piston (MP) and the schematic representation of air flow path in it are shown in Fig. 1.

Table 2. Test engine specification.

Description	Data
Manufacturer	Kirloskar oil engines ltd
Model	TV1
Type of engine	Vertical, four stroke, water cooled, single cylinder, DI diesel engine
Rated output at 1500 rpm	5.2 kW
Bore	87.5 mm
Stroke	110 mm
Cubic capacity	0.661 Liters
Compression ratio	17.5:1
Fuel injection pump	Micro jerk inline type
Governor type	Mechanical, centrifugal type
Fuel injection timing	23° bTDC
Nozzle opening pressure	200 bar

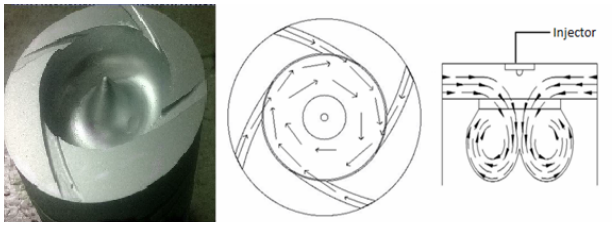

Fig. 1. Fabricated Modified Piston and Schematic representation of air flow in modified piston.

2.3 Experimental setup

A single cylinder, four stroke Kirloskar diesel engine capable of developing a power of 5.2 kW, shown in Fig. 2, was used as a test engine operated at a constant speed of 1500 rpm. Fig. 3 shows the schematic representation of the experimental set-up. The detailed engine specification is shown in Table 2. An eddy current dynamometer was used to load the engine. The operating conditions such as injection pressure and injection timing were kept unaltered and they were as initially fixed by the manufacturers. By using stop watch and burette based on volume basis analysis the flow rate of the fuel was measured. The five gas analyzer was used to measure the emissions like hydrocarbon, carbon monoxide, carbon dioxide, and oxides of nitrogen. A hatridge smoke meter was used to measure the smoke emissions. The combustion part in the experiment was analysed using AVL combustion analyzer. To measure the in cylinder pressure a pressure transducer was used besides A to D converter and charger amplifier. For accuracy and for minimising the error occurrence the experiments were repeated three times and their average values were plotted in the graph. The experiment was conducted in steady state condition for better results. For the experimental investigation vari-

Table 3. Uncertainties in the measured parameters.

Parameter	Percent uncertainty
Pressure	1.00%
Speed	1.00%
Load	0.50%
Brake power	0.40%
Brake specific energy consumption	0.80%
Brake thermal efficiency	0.50%
Carbon monoxide	0.30%
Hydro carbon	0.30%
Oxides of nitrogen	0.20%
Smoke opacity	0.80%

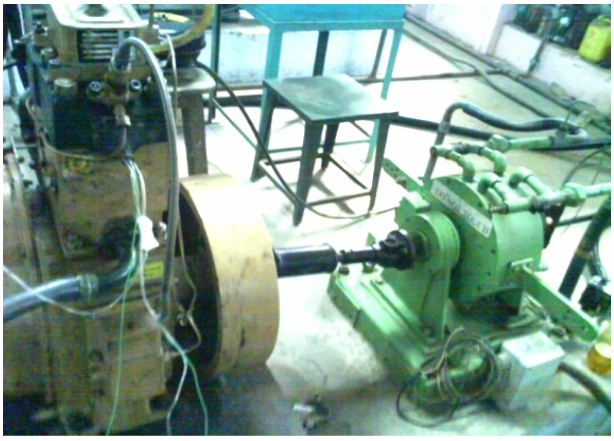

Fig. 2. Experimental engine set-up.

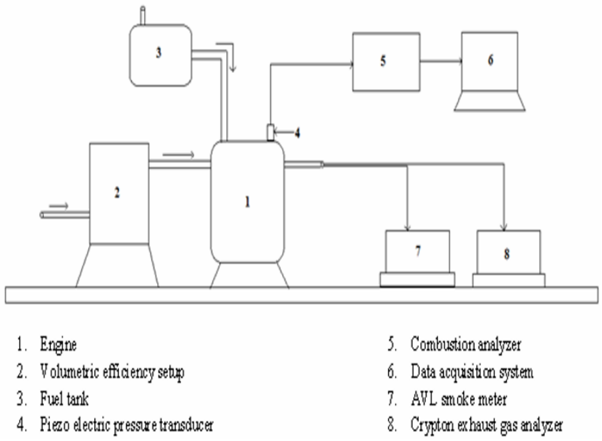

Fig. 3. Schematic sketch of experimental set-up.

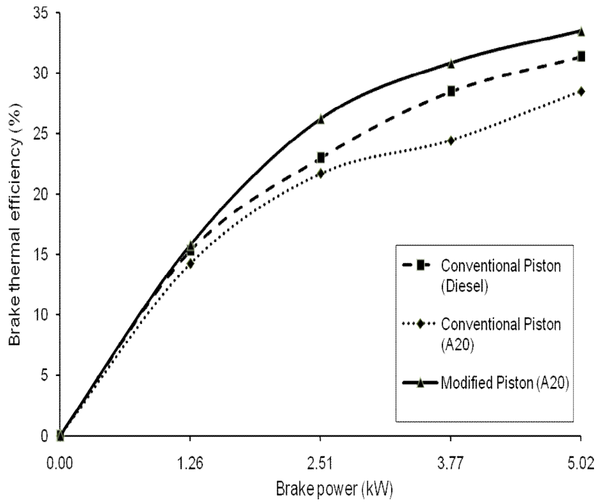

Fig. 4. Variation of brake thermal efficiency with brake power.

ous instruments were used for the measurement of different parameters. Errors and uncertainties in the experiments may occur due to the selection of instruments, working conditions, calibration, environment, observation and method of conduct of the tests. Uncertainty analysis is necessary to prove the accuracy of the experiment. These instruments and equipment are made by different manufacturers using different technologies. Hence the uncertainty occurs due to fixed or random errors. The uncertainties in the measured parameters were estimated based on analytical methods. Table 3 displays the uncertainties in the measured parameters.

3. Results and discussion

The tests were carried out with diesel and A20 in a conventional diesel engine. Later on the conventional hemispherical combustion chambered piston was replaced with novel modified piston. All tests were conducted for five times and test conditions were maintained constant to ensure the accuracy and repeatability of the results.

3.1 Effect of modified piston on performance parameters

Fig. 4 shows the comparison of BTE of A20 diesel blend fuel with the conventional piston and modified piston. The BTE of conventional engines with diesel fuel is also plotted for comparison purpose. The BTE of the A20 diesel blend is lower [1.23%] compared with that of diesel at rated load. This is ascribable to the slightly lower calorific value and higher viscosity, which have major bearing on initial combustion and spray behaviour. After introducing modified piston the BTE of the A20 diesel blend is improved by 2.58% at rated load. This is ascribable to the increase of percentage of complete combustion due to better air motion.

Fig. 5 shows the variations of Brake specific energy consumption (BSEC) of a conventional unmodified engine with diesel and modified engine with A20 diesel blend. The ratio between the energy produced through fuel injection and the power output is called Brake specific energy consumption (BSEC). It has been noticed that the brake specific energy expenditure of the unmodified engine with A20 biodiesel blend is higher [0.5%] than the diesel, which corroborates the earlier reports on biodiesel blends.

Owing to better air fuel mixture formation the specific en-

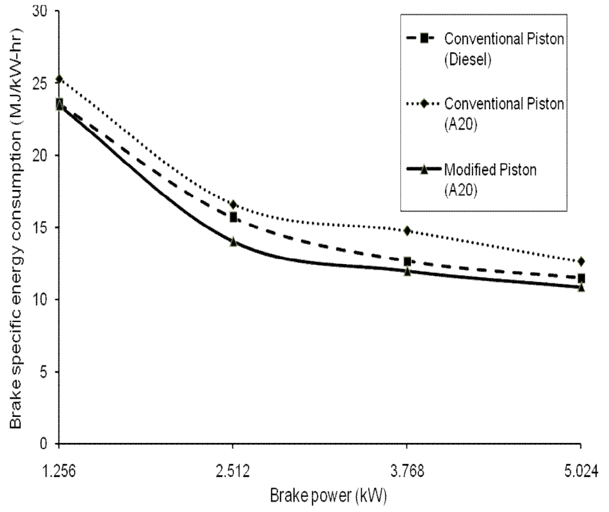

Fig. 5. Variation of brake specific energy consumption with brake power.

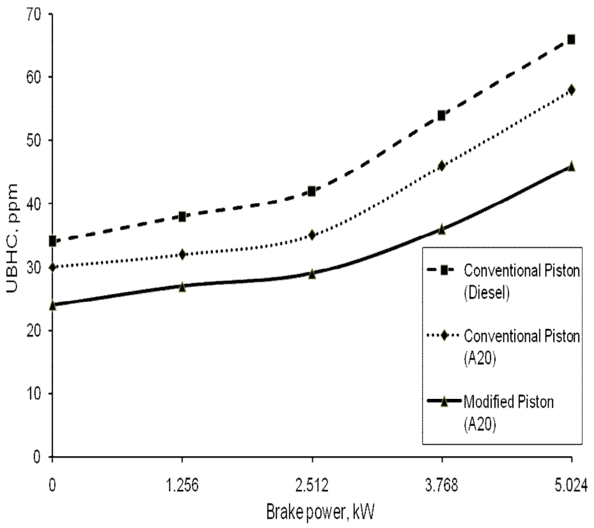

Fig. 6. Variation of unburnt hydro carbon emission with brake power.

ergy consumption of the modified engine is reduced by 1.049%. This affirms that the engine with modified piston can get one kilowatt power with lower energy input compared to conventional diesel engine.

3.2 Effect of Modified piston (MP) on emission parameters

Incomplete combustion is the major cause of hydrocarbon emission. Fig. 6 indicates that there is a decrease in hydrocarbon emission while using A20 diesel blend when compared with the diesel fuel. This is mainly attributed to fuel bound oxygen content which boosts diffusion combustion thus reducing the unburnt hydrocarbon emissions. In our experiment fuel air mixing improved, modified engine fuelled with A20 diesel blend reduced the hydrocarbon emissions up to 20 ppm. This is primarily ascribable to the enhanced swirl, squish, and

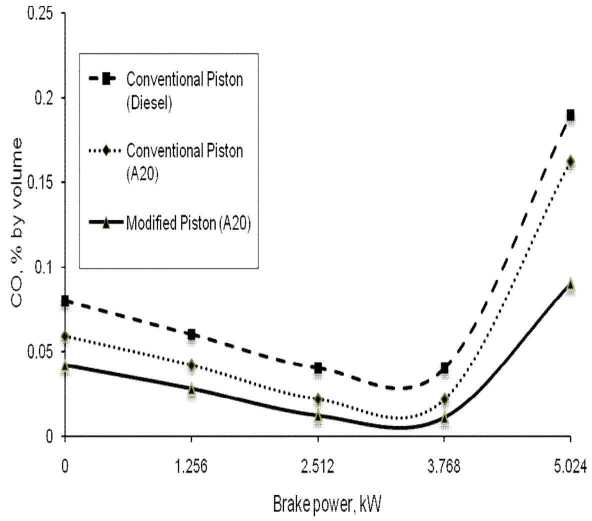

Fig. 7. Variation of Carbon monoxide with brake power.

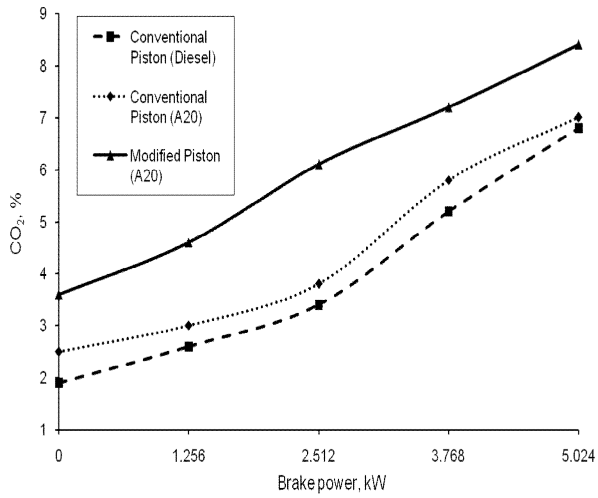

Fig. 8. Variation of Carbon dioxide with brake power.

tumble motion.

Carbon monoxide is colourless, odourless, and tasteless toxic gas which establishes itself as an undesired emission. Enhanced air movement by the modified piston and the presence of fuel bound oxygen in the case of A20 diesel blend; MP has recorded the reduced carbon monoxide emission as shown in Fig. 7.

Carbon dioxide emission is the product of complete combustion. In the case of A20 diesel blend carbon dioxide emission is high due to higher levels of carbon oxidation of fuel borne oxygen [26]. From Fig. 8, it is clear that the modified piston has shown higher carbon dioxide emission due to promotion of combustion by improving air movement.

Fig. 9 shows oxides of nitrogen emission with A20 diesel blend for the standard engine and the engine with modified piston compared with the diesel fuelled conventional engine emission. It is clear that the emission of NO_x is higher for biodiesel blend. The higher temperatures of combustion and oxy-

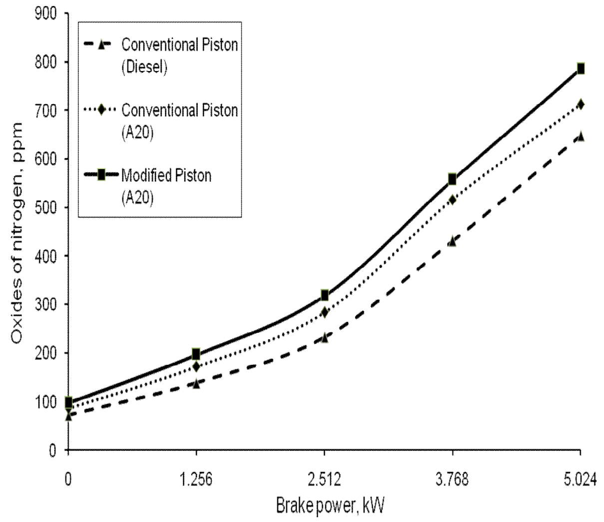

Fig. 9. Variation of Carbon dioxide with brake power.

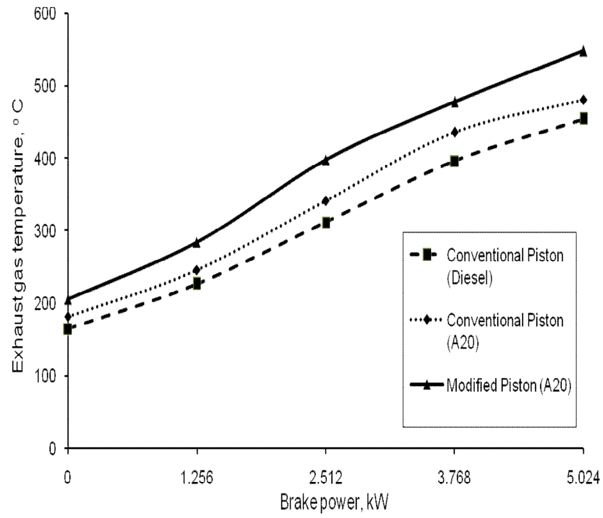

Fig. 11. Variation of exhaust gas temperature with brake power.

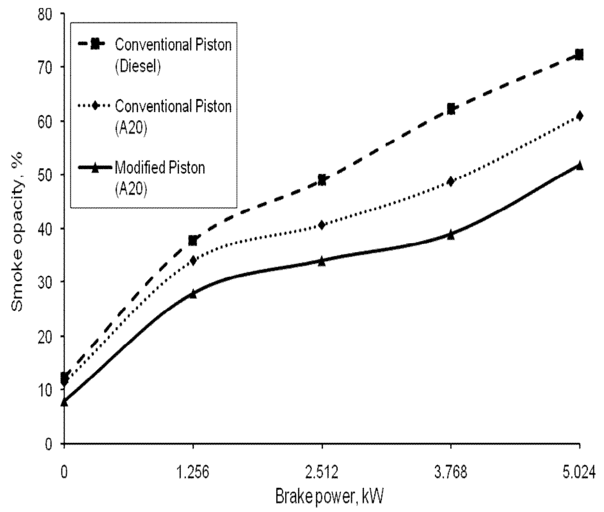

Fig. 10. Variation of smoke opacity with brake power.

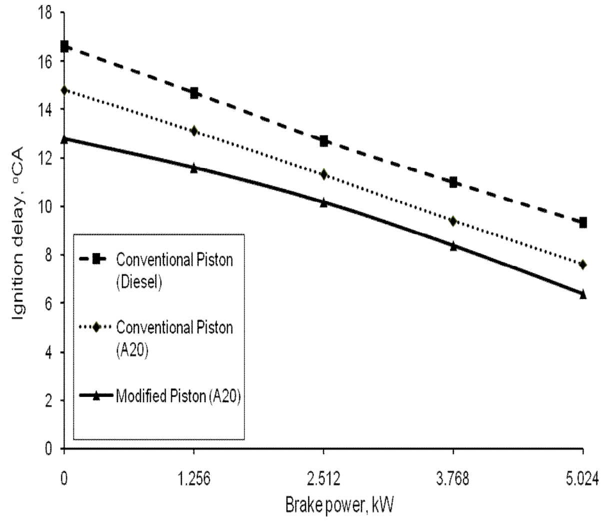

Fig. 12. Variation of ignition delay with brake power.

gen abundance have caused higher NO_x emission from the engine. Since the air movement is enhanced in the case of the modified engine, the NO_x emissions are higher due to higher combustion temperature resulting in better combustion; due to the higher oxygen content the NO_x emissions are higher than diesel.

Fig. 10 shows smoke emissions. It is seen that the complete stable combustion property of the A20 diesel blend due to its oxygen content has led to lower smoke emissions. Smoke emissions from A20 diesel blend are reduced further due to the better fuel air mixing that would have minimized the droplet combustion of the biodiesel.

Fig. 11 shows the exhaust gas temperature variation. The amount of the energy released during combustion is attributable to combustion temperature that can be determined by exhaust gas temperature. Exhaust gas temperature from the A20 diesel blend is higher than that of diesel due to its fuel borne oxygen content that improves the combustion, and this has already been reported by researchers. The exhaust gas temperature of the modified engine is attributable to the better combustion and higher oxygen content of the A20 diesel blend.

3.3 Effect of modified piston in combustion parameters

Fig. 12 shows the variation of ignition delay with crank angle. The ignition delay for any fuel can be calculated based on the duration between the start of fuel injection and the start of combustion. The period between the start of fuel injection and the start of combustion is called Ignition delay. Because of the minimal compressibility and slightly higher viscosity the combustion with biodiesel blend is more advanced than that of diesel. The shorter delay period may be attributed to the higher oxygen content of the biodiesel. It can be noticed that

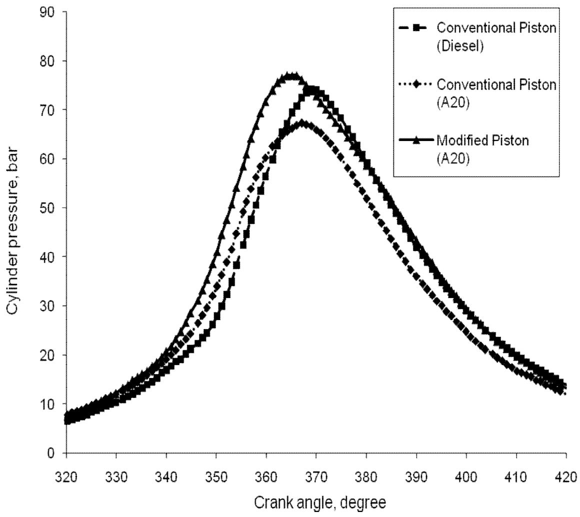

Fig. 13. Variation of cylinder pressure with brake power.

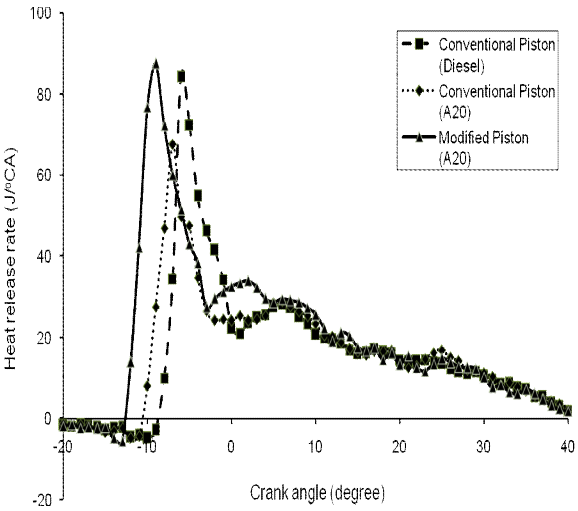

Fig. 14. Variation of heat release rate with brake power.

the ignition delay of the A20 diesel blend is further reduced due to the reduction of physical delay by enhancing air fuel mixing.

Fig. 13 shows the variation of cylinder pressure with crank angle at full load condition. The peak pressure of the A20 diesel blend is lower than that of diesel in unmodified engine; this is due to the decline in the air-fuel mixing process as a result of higher viscosity. The occurrence of peak pressure also has slightly shifted from the diesel's peak pressure crank angle due to the inferior atomization of the A20 diesel blend. The peak pressure of the modified engine with the MP shows maximum higher peak pressure due to its promotion of air fuel mixing process.

Fig. 14 shows the variation of heat release rate with respect to crank angle. The heat release rates for A20 diesel blend and diesel are recorded in the figure for test conditions. Negative heat release is observed due to the gathering of fuel during the ignition delay period. Combustion with the A20 diesel blend is earlier due to the lower ignition delay and due to the higher Cetane value compared with diesel. Modified engine with A20 diesel blend as a fuel has shown the maximum heat release rate due to its combustion enhancement ability by influencing in the air fuel mixing.

4. Conclusions

In the present work, the effect of modified piston on performance, combustion, and emission characteristics of renewable biodiesel A20 was studied. The results obtained from modified piston are summarized below:

- Modified piston (MP) in the test engine improved the formation of mixtures of A20, which in turn improved the brake thermal efficiency and specific energy consumption.
- The reduction of incomplete combustion by better air motion reduced the carbon monoxide, hydrocarbon, and smoke emissions.
- Reduction of physical delay by better air movement reduced the ignition delay of A20. Improvement in combustion and fuel borne oxygen content increasing the emission of oxides of nitrogen in the case of MP incorporated engine with A20 as fuel were noticed.

Thus the present investigation improved the overall performance, combustion, and emission characteristics of renewable A20 biodiesel. However, these results are valid for the test engine with A20 as fuel. Even though these results cannot be generalized for fuels with various viscosities and engine, it is possible to improve the performance, combustion, and emission characteristics for better turbulence by modifying the piston design.

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Nomenclature

A20 : Fuel blend of 80% of diesel and 20% of adelfa biodiesel
BP : Brake power
BSEC : Brake specific energy consumption
BTE : Brake thermal efficiency
CA : Crank angle
CI : Compression ignition
CO : Carbon monoxide
CO_2 : Carbon dioxide
DI : Direct injection
HC : Hydrocarbon
HCC : Hemispherical combustion chamber
ID : Ignition delay

MP : Modified piston
NOx : Oxides of nitrogen
ppm : Parts per million
TDC : Top dead centre

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