STUDIES ON EFFECTS OF COMBUSTION CHAMBER GEOMETRY AND INJECTION PRESSURE ON BIODIESEL COMBUSTION

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Received October 2012, Accepted December 2012
No. 12-CSME-99, E.I.C. Accession 3419

ABSTRACT

Combustion of biodiesels has inherent problems due to their high viscosity and low volatility. This paper relates the modification of engine combustion chamber design, for inducing turbulence to improve the combustibility of combustible mixture. A survey of literature shows that experimental studies have not been done on a tri-chambered piston for evaluating influence on the performance and emission characteristics using diesel blends as well. The objective of this work is to study the effect of combustion chamber geometry and injection pressure on performance and emissions of a biodiesel (Jatropha) fuelled multi-chambered piston diesel engine. The performance and emission characteristics were studied and it has been noticed that for the engine under consideration 200 bar injection pressure gives optimum performance.

Keywords: multi-chambered piston; squish; tumble; Jatropha biodiesel; emissions.

ÉTUDE SUR LES EFFETS DE LA GÉOMÉTRIE DE LA CHAMBRE À COMBUSTION ET LA PRESSION D'INJECTION SUR LA COMBUSTION DU BIODIÉSEL

RÉSUMÉ

La combustion des biodiésels présente des problèmes dus à leur haute viscosité et leur faible volatilité. Cet article concerne la modification de la conception de la chambre de la combustion d'un moteur, pour induire de la turbulence pour améliorer la combustibilité du mélange carburé. Une étude de la littérature démontre qu'il n'y a eu aucune étude expérimentale sur un piston à trois chambres pour évaluer l'influence sur la performance et l'émission en utilisant des mélanges de diésel. L'objectif de ce travail est d'étudier l'effet de la géométrie de la chambre de combustion, et la pression d'injection sur la performance et les émissions d'un biodiésel (Jatropha) dont le moteur est alimenté au diésel par un piston à chambres multiples. La performance et les caractéristiques des émissions ont été étudiées, et on a remarqué que pour le moteur en question, une pression d'injection à 200 bar donne une performance optimale.

Mots-clés : piston à chambres multiples ; Jatropha biodiésel ; émissions.

NOMENCLATURE

TDC	top dead centre
$BTDC$	before top dead centre
$UBHC$	unburnt hydrocarbon
NO_x	oxides of nitrogen
CO	carbon monoxide
CI	compression ignition
PME	poly methyl ester
CFD	computational fluid dynamics
SFC	specific fuel consumption
CV	calorific value
CR	compression ratio
IP	injection pressure
Bth	brake thermal efficiency
BP	brake power

1. INTRODUCTION

Air motion plays a significant role in fuel — air mixing, combustion and emission processes [1]. Along with air motion, spray characteristics, spray angle, injection pressure and injection timing also have a significant role in diesel engine combustion.

Swirl, squish and tumble are the important flow pattern of air motion. These patterns not only affect the fuel-air mixing and combustion process in diesel engines, but also have significant impact on combustion quality [2].

Swirl motion of the air is adequately achieved with good intake port design [3–9]. When there is swirl in the in-cylinder air, the swirl-squish interaction produces a complex turbulent flow field at the end of compression. This interaction is severe in reentrant combustion chamber design [10]. Intensification of turbulence is due to the highly turbulent squish of the air near TDC of compression. The intensification of turbulence leads to efficient combustion which in turn causes higher NO_x emission and less HC emissions [11]. The author however has not reported the effect of tumble. Better air mixing and combustion are possible with higher injection pressure. Higher injection pressure produces smaller fuel droplets which evaporate faster and mix rapidly with air.

Bio-diesels play an important role in the on going balance between two major societal needs, viz., fuel economy and environment friendly Emissions. Bio-diesels can be produced in a way that does not cut into food supplies as Jatropha is non edible oil. Bio-diesel production reduces the dependency on imported oil and supports the agricultural sector [12]. The properties of biodiesel are not the same as diesel fuels especially their high viscosity and low volatility. These properties strongly affect injection pressure injection timing and spray characteristics [13].

An increase in viscosity of biodiesel will result in poor atomization characteristics due to decreased cone angle during fuel injection [14]. The pre-heating of vegetable oil gives better performance than raw vegetable oil. It has been observed that viscosity reduces exponentially with temperature. It has also been observed that when pre - heated vegetable oil is injected into the cylinder, spray pattern and atomization character has improved. The injection pressure has an effect on the spray formation of biodiesel blends in CI engines [15]. Also studies have shown that the combustion characteristics alter with the changes in injection pressure. With the increase in pressure, the fuel penetration distance become longer and the mixture formation of the fuel-air was improved [16]. Also when the injection pressure is increased fuel particle diameter will be reduced. The mixing of fuel-air becomes better during ignition delay period [17]. The combined effect of increased compression ratio, injection timing and injection pressure on engine performance, combustion and emission characteristics was discussed [18]. It was observed with increased brake thermal efficiency, decreased SFC and decreased emission for PME 20. The optimum combination was observed at CR=19.1, IP = 240 bar and injection timing of 27° BTDC. Studies on the effect of injection pressure on the performance and emission characteristics of biodiesel fuelled direct injection CI engine [19,20]. It was observed that 200 bar is the optimum injection pressure with B20 and B30 blends.

CFD work on multi chambered piston [21] has been carried out to analyze squish and tumble flow. A maximum of 13.1 m/sec squish velocity was observed at 10° crank angle before TDC. The increase in squish velocity was 31 % compared to a standard engine.

This work relates to engine design modification to induce turbulence by enhancing squish and tumble of charge during combustion. The present work has been undertaken to study the effect of injection pressure on performance and emission characteristics of multi-chambered piston CI engine. The experiments have been carried out at constant speed of 1500 rpm and compression ratio of 17.5 at different injection pressure. The performance parameters such as SFC, brake thermal efficiency, carbon monoxide, NO_x and UBHC have been studied.

2. EXPERIMENTAL SETUP

The experiments were conducted on a computerized CI engine test rig shown in Fig. 1.

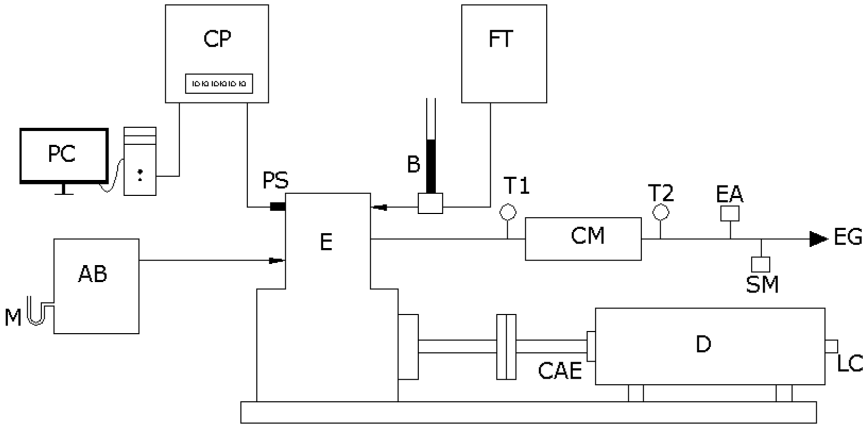

Fig. 1. Schematic diagram of experimental set up.

E	engine	FT	fuel tank
D	dynamometer	B	burette
CAE	crank angle encoder	CM	calorimeter
LC	load cell	T1	exhaust gas temperature before calorimeter
AB	air box	T2	exhaust gas temperature after calorimeter
M	monometer	EA	exhaust analyzer
CP	control panel	SM	smoke meter
PC	computer	EG	exhaust gas
PS	pressure sensor		

A Kirloskar make single cylinder 4-stroke, direct injection, water cooled CI engine test rig of 5.2 kW, CR=17.5, IP=200 bar rated power at 1500 rpm is directly coupled to the eddy current dynamometer the engine and the eddy current dynamometer are interfaced to a control unit, with built in software in a computer. This software is used for recording test parameter such as fuel flow rate, temperatures, air flow rate and speed for calculating performance parameters such as brake power (BP), brake thermal efficiency and specific fuel consumption. The calorific value and the density of particular fuel are fed to the software for calculating above performance parameters. The exhaust emissions such as CO, UBHC, and NO_x were measured with PEA205–5 gas analyzer. The engine specification is shown in Table 1. The properties of Jatropha and Diesel fuels are shown in Table 2.

SL No.	Engine parameters	Specifications
01	Engine type	TV1 (Kirloskar)
02	Number of cylinders	Single cylinder
03	Number of strokes	Four-stroke
04	Rated power	5.2 KW (7HP) @ 1500 RPM
05	Bore	87.5 mm
06	Stroke	110 mm
07	Cubic capacity	661 cc
08	Compression ratio	17.5:1

Table 1. Engine specification.

Property	Diesel	Jatropha biodiesel
Kinematic viscosity at 30°C	4	5.34
Flash point	65	128
Fire point	78	136
CV kJ/kg	45,000	41,000

Table 2. Properties of diesel and Jatropha biodiesel.

3. MODIFICATION MADE TO PISTON CROWN

Turbulence is very important in mixing and combustion of fuel with air in CI Engine. In the present work the turbulence was induced by modifying the base piston face to a multi chambered piston. During the modification, i.e. formation of multi chambers, care was taken to maintain compression ratio of 17.5. This was done by removing a thin layer of material on the piston crown by surface grinding operation and introducing three chambers in the piston crown in such a way that the volume of the material added balances the volume of material removed so that the compression ratio of the engine is not altered in any way. The surfaces over the piston crown were finished to close tolerances on an engraving machine. The multi-chamber piston consists of three small cavities called swirl chambers 120° apart on the piston land. Pictorial views of original and multi-chambered pistons are shown in Figs. 2(a) and 2(b) respectively.

At the end of compression stroke, the fuel vapor squeezes into multi-chamber tangentially due to direct compression, which leads to the enhancement of turbulence for better mixing and combustion. However

(a) (b)

Fig. 2. (a) Standard piston (b) multi-chambered piston.

the author foresees there may be a possibility of increase in induced thermal stress over the piston head in view of the fact that the effective thickness is reduced as well as the stress-concentration effects. However, it is always possible by employing failsafe design and damage tolerant design approaches during the design stage itself to circumvent the above problem. Shot-Peening the piston face is another possible approach during manufacturing to enhance the fatigue resistance (i.e. endurance limit) of the piston material, so that even in the presence of stress concentration effects, its actual life and durability is not affected.

4. EXPERIMENTAL PROCEDURE

A set of experiments were conducted for standard and modified piston engine at the rated engine speed of 1500 rpm at compression ratio of 17.5 and at three different injection pressures of 175, 200 and 225 bar. Tests were conducted at 20 % load, 40 % load, 60 % load and 80 % load. The test was conducted at the injection timing of 21° before TDC. The performance characteristics such as specific fuel consumption and brake thermal efficiency were found and emission characteristics like CO, UBHC and NO_x were recorded for diesel and subsequently for different blends of Jatropha viz. J10, J20 and J30.

5. RESULTS AND DISCUSSION

The results of the engine experimentation are presented in Figs. 3–10. All comparisons have been made at constant engine speed 1500 rpm and injection timing 21° crank angle.

5.1. Specific Fuel Consumption

Figure 3 shows the variation of the specific fuel consumption (SFC) with load for standard and modified pistons at CR=17.5, IP=200 bar for diesel and biodiesel J20. It is observed that, at higher loads, the SFC has decreased slightly, compared with standard piston engine. This may be due to better combustion owing to induced turbulence due to squish motion generated with the modified piston.

In Fig. 4 the effect of injection pressures on SFC at all loads with the modified piston at CR=17.5 for J20 blend are shown. It is observed that the specific fuel consumption at 80 % load for CR=17.5, IP=175, 200 and 225 bar is 0.406, 0.351 and 0.382 Kg/kW-hr respectively. The specific fuel consumption was reduced with 200 bar injection pressure compared to 175 bar and 225 bar injection pressures, due to more area coverage of spray formed in the combustion chamber and utilization of air effectively. At 225 bar injection pressure, the SFC was increased due to too rich mixture.

5.2. Brake Thermal Efficiency

Figure 5 shows the variation of brake thermal efficiency (Bth) with load for standard and modified pistons at CR=17.5, IP=200 bar for diesel and biodiesel J20. An improvement of 2 to 3 % brake thermal efficiency has been noticed with the modified piston due to better combustion.

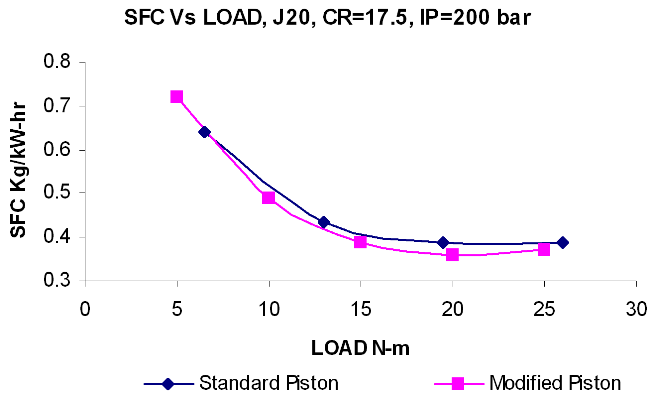

Fig. 3. SFC vs. load for standard and modified piston.

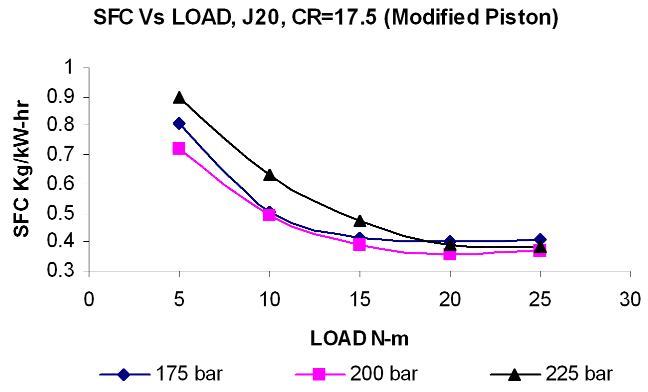

Fig. 4. SFC vs. load for J20 blend.

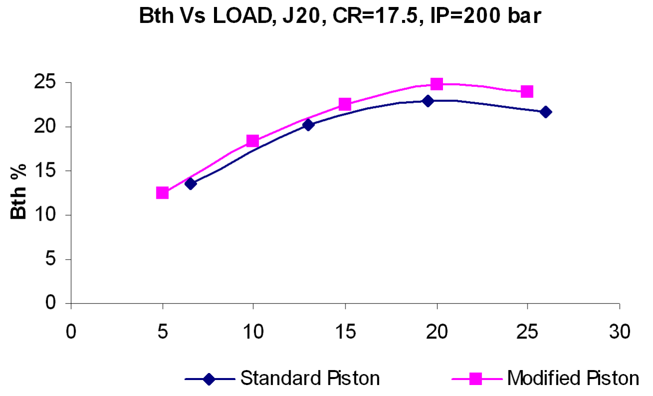

Fig. 5. Bth vs. load for standard and modified piston.

The effect of injection pressure on brake thermal efficiency is observed from Fig. 6. The brake thermal efficiency at 80 % load for CR=17.5, IP=175, 200 and 225 bar is 22.15 %, 24.52 % and 22 %. The brake thermal efficiency was improved at 200 bar injection pressure compared to 175 and 225 bar injection pressure since more surface area to volume ratio and finer spray which in turn reduce the physical delay period. At 225 bar injection pressure the brake thermal efficiency decreases due to ineffective combustion because of decreased depth of penetration [18].

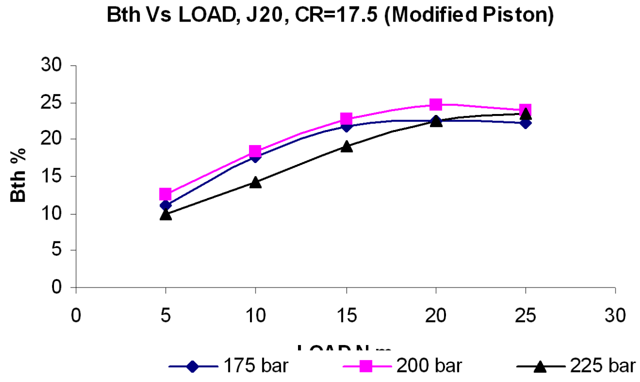

Fig. 6. Bth vs. load for J20 blend

5.3. UBHC Emission

Figure 7 compares the HC emissions with standard and modified pistons at CR=17.5 and IP= 200 bar for J20 blend. It is observed a substantial reduction in HC emissions due better mixing and complete combustion of fuel.

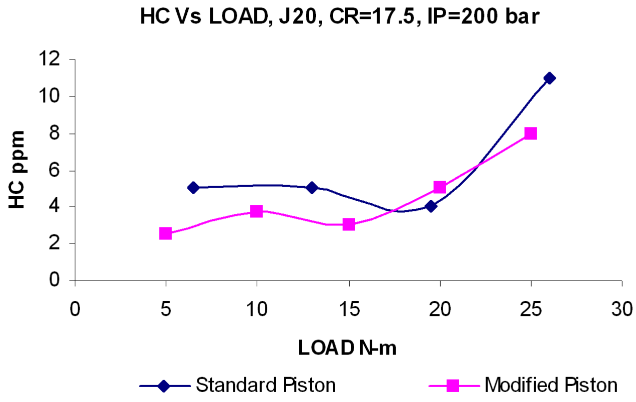

Fig. 7. HC emissions vs. load for standard and modified piston.

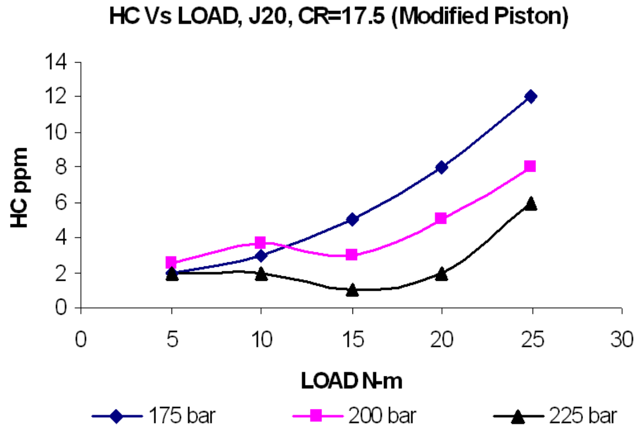

Fig. 8. HC emissions vs. load for J20 blend

It is observed from Fig. 8, that the UBHC at 80 % load for CR=17.5, IP=175, 200 and 225 bar is 12, 8 and 11 ppm. The UBHC emission was reduced at 200 bar injection pressure compared to 175 bar and 225 bar injection pressures. As the IP increased from 175 bar to 200 bar unburnt hydrocarbon emission reduced due to the fine spray formed during injection and improved atomization [14,19]. With further increase in injection pressure, an increase in the unburnt hydrocarbon emission is seen, due to finer fuel spray which reduces momentum of droplets which might probably result in incomplete combustion.

5.4. CO Emission

The exhaust emissions of carbon monoxide is lower for J20 blend with modified piston at CR=17.5, IP=200 bar, compared to standard piston engine as shown in Fig. 9. Lower concentration of CO in exhaust is a clear indication of complete combustion of fuel. The CO levels with standard piston are high due to combustion inefficiencies.

It is observed from Fig. 10, that the % CO emission at 80 % load for CR=17.5, IP=175, 200 and 225 bar is 0.33 %, 0.286 % and 0.32 % The CO emission was decreased at 200 bar injection pressure compared to 175 and 225 bar injection pressure. With increase in injection pressure from 175 to 200 bar the CO emission reduces due to effective combustion of air fuel mixture and reduced viscosity.

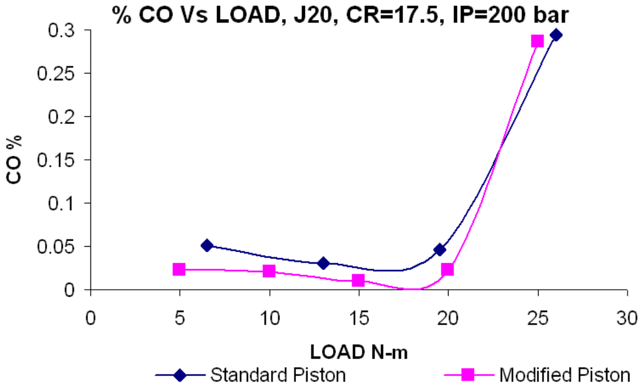

Fig. 9. CO % vs. load for standard and modified piston.

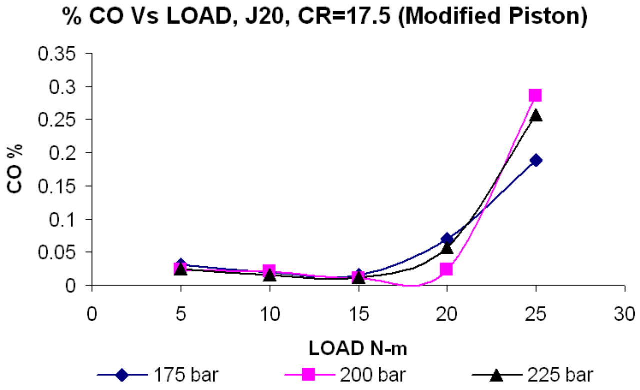

Fig. 10. CO % vs. load for J20 blend.

6. CONCLUSIONS

The experimental investigation on performance of multi chambered piston CI engine was conducted on single cylinder, 4-stroke, direct injection, constant speed diesel engine. The test was conducted at CR=17.5 at different injection pressures of 175, 200 and 225 bar. The major conclusions observed from the experiments are as follows:

- A comparison of the results obtained on the standard and a modified piston engine have been made with reference to the performance and emission characteristics and is generally observed that the modified piston gives enhanced performance and lower emissions compared to the standard piston.
- Specific fuel consumption has shown reduction with increase in injection pressure. The optimum injection pressure was observed at 200 bar for J20 blend fuel for the experimental engine.
- Brake thermal efficiency has improved with increase in injection pressure up to 200 bar and with further increase in injection pressure the brake thermal efficiency has reduced.
- The UBHC emission has improved with increased injection pressure. The optimum injection pressure was 200 bar for the modified piston engine.
- The % CO emission is clearly showing a reduced trend with increased injection pressure for the tested engine with modified piston.

ACKNOWLEDGEMENTS

The work reported here has been financially supported by Department of Science and Technology (DST), New Delhi. DST's support is gratefully acknowledged. The authors would like to thank the Principal and the Management of Sri Siddhartha Institute of Technology, Tumkur for their kind support to carry out this work.

REFERENCES

1. Heywood J.B., *Internal Combustion Engine Fundamentals*, McGraw-Hill, New York, 1988.
2. Dehong Z. and Hill, P.G., " Effect of swirl on combustion in a short cylindrical chamber", *Combustion and Flame,* Vol. 106, No. 3, pp. 318–332, 1996.
3. Brandl F., Reverencic, I., Cartellieri W. and Dent, J., "Turbulent air flow in the combustion bowl of a D.I. diesel engine and its effect on engine performance", *Society of Automotive Engineers*, Technical Paper No. 790040, 1979.
4. Bicen, A.F., Vafidis, C. and Whitelaw, J.H., "Steady and unsteady air flow through an intake valve of reciprocating engine", *Journal of Fluids Engineering*, Vol. 107, No. 3, pp. 413–419, 1985.
5. Arcoumanis, C. and Tanabe, S., "Swirl generation by helical ports", *Society of Automotive Engineers*, Technical Paper No. 890790, 1989.
6. Dent, J.C. and Chen, A., "An investigation of steady flow through a curved inlet port", *Society of Automotive Engineers*, Technical Paper No. 940522, 1994.
7. Floch, A., Dupont, A. and Baby, X., "In cylinder flow investigation in a gasoline direct injection four valve engine: bowl shape piston effects on swirl and tumble motions", *Fédération Internationale des Sociétés d'Ingénieurs des Techniques de l'Automobile, World Automotive Congress*, Paper No. F98T049, Paris, France, 1998.
8. Lee, J.W., Kang, K.Y., Choi, S.H., Jeon, C.H. and Chang, Y.J., "Flow characteristics and influence of swirl flow interactions on spray for direct injection diesel engine", *Fédération Internationale des Sociétés d'Ingénieurs des Techniques de l'Automobile, World Automotive Congress*, Paper No. F2000A097, Seoul, Korea, 2000.
9. Pipitone, E. and Mancuso, U., "An experimental investigation of two different methods for swirl induction in a multivalve engine", *International Journal of Engine Research*, Vol. 6, No. 2, pp. 159–170, 2005.

10. Arcoumanis, C., Bicen, A.F. and Whitelaw, J.H., “Squish and swirl-squish interaction in motored model engines”, *Journal of Fluids Engineering*, Vol. 105, No. 1, pp. 105–112, 1983.
11. Saito, T., Daisho, Y., Uchida, N. and Ikeya, N., “Effects of combustion chamber geometry on diesel combustion”, *Society of Automotive Engineers*, Technical Paper No. 861186, 1986.
12. Huang, J., Yang, J., Msangi, S., Rozelle, S. Weersink, A., “Biofuels and the poor: Global impact pathways of biofuels on agricultural markets”, *Food Policy*, Vol. 37, No. 4, pp. 439–451, 2012.
13. Yamane, K., Ueta, A. and Shimamoto, Y., “Influence of physical and chemical properties of biodiesel fuels on injection, combustion and exhaust emission characteristics in a direct injection compression ignition engine”, *International Journal of Engine Research*, Vol. 2, No. 4, pp. 249–261, 2001.
14. Ryan III, T.W., Dodge, L.G. and Callahan, T.J., “The effects of vegetable oil properties on injection and combustion in two different diesel engines”, *Journal of the American Oil Chemists Society*, Vol. 61, No. 10, pp. 1610–1619, 1984.
15. Nagaraj, A.M. and PrabhuKumar, G.P., “Effect of injection pressure on engine performance with rice bran oil as biodiesel”, *XVIII National Conference on IC Engine and Combustion*, pp. 581–587, Tiruvanthapur, India, Dec. 17–19, 2003.
16. Lee, S.W., Tanaka, D., Kusaka, J. and Daisho, Y., “Effects of diesel fuel characteristics on spray and combustion in a diesel engine”, *Japan Society of Automotive Engineers Review*, Vol. 23, No. 4, pp. 407–414, 2002.
17. Çelikten, I., “An experimental investigation of the effect of the injection pressure on engine performance and exhaust emission in indirect injection diesel engines”, *Applied Thermal Engineering*, Vol. 23, No. 16, pp. 2051–2060, 2003.
18. Venkatraman, M. and Devaradjane, G., “Effect of compression ratio, injection timing and injection pressure on a DI diesel engine for better performance and emission fueled with diesel-diesel biodiesel blends”, *International Journal of Applied Engineering Research*, Vol. 1, No. 3, pp. 288–298, 2010.
19. Shankar, K.S., Desai, V. and Mohanan, P., “The effect of injection pressure on the performance and emission characteristics of a biodiesel fueled direct injection single cylinder 4-Stroke diesel engine”, *Proceedings of the 2007 International and XX National Conference on I.C. Engine and Combustion-ICONICE*, pp. 27–33, Hyderabad, India, Dec. 6–9, 2007.
20. Yamane, K., Ueta, A. and Shimamoto, Y., “Effects of high-pressure injection and biodiesel fuel sources on combustion and emission characteristics of a DI diesel engine”, *Transaction of Society of Automotive Engineers of Japan*, Vol. 32, No. 2, pp. 25–30, 2001.
21. Arahanth, J., “Numerical Simulation of Multi Chamber Piston CI Engine”, Master of Technology Thesis, Sri Siddhartha Institute of Technology, Tumkur, India, 2011.