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Experimental investigation and optimization study of combustion chamber geometry on performance and emission parameters using Rice bran biodiesel

*Hariram.V[1] and Hema Kumar. M[2]
[1,2]Department of Automobile Engineering Hindustan Institute of Technology & Science
Hindustan University, Chennai, Tamil Nadu, India.

Abstract:- An experimental investigation and optimization study of various piston geometries was conducted on Greaves single cylinder direct injection compression ignition engine using straight diesel and blends of rice bran biodiesel. The three combustion chamber geometries used in this study were Standard toroidal piston (STP), hemispherical bowl piston (HBP) and Shallow toroidal re-entrant piston (STRP) at compression ratios of 18:1, 19.04:1 and 16.4:1 respectively. Rice bran biodiesel was derived by two step trans-esterification process with an optimum yield of 86% with molar ratio 1:6, 06% of catalyst (KOH), 90 min reaction time and 65^{o}C reaction temperature. The performance parameters like brake specific energy consumption, brake thermal efficiency and the emission parameters like carbon monoxide, unburned hydrocarbons and oxides of nitrogen were analysed in detail. It was noticed that the BSEC of STRP was 12.1% with diesel and 14.02% with B100 biodiesel blend. The brake thermal efficiency was also found to be improved with biodiesel blend with STRP on comparison with STP and HBP. The carbon monoxide and hydrocarbon emission was found to decrease with STRP geometry were as HBP exhibited negative improvement. NO_x emission was also found to increase with STRP.

Keywords:- Toroidal piston, transesterification, biodiesel, hydrocarbon, BSEC

I. INTRODUCTION

Internal combustion engines are broadly classified as compression ignition engine and spark ignition engines. The compression ignition engines also known as diesel engines, which finds major application in transportation and industrial sector. As day by day the application of diesel engines are increased. The consumption of petrol and diesel also increased at tremendous rate and the diesel engine also emits exhaust emission at an elevated level especially oxides of nitrogen. It was found that the consumption of diesel was enormously increased when compared to other petroleum products which made the usage of blends of biodiesel necessary for its usage in Compression Ignition engines because of its environment friendly, biodegrading and non-toxicity factors [2]. Various biodiesels were used by researchers such as Neem, Cottonseed, Rice bran, Rapeseed, Karanja and Jatropha. Since vegetable oil biodiesel contains more amount of oxygen, its emissions which includes oxides of carbon, oxides of nitrogen, polyaromatic and aliphatic compounds were reduced to a greater extent. Generally vegetable oil biodiesel are chains of triglycerides which are transformed into shorter chains of monoglycerides and glycerol by employing transesterification process [1]. One such attempt is experimentally investigated in the present study by varying the combustion geometry of the existing piston fuelled with B100 Rice bran Biodiesel (RBBD) to minimize the exhaust emissions and enhance the performance.

The production of rice bran biodiesel was analysed using two step acid catalysed transesterification in which the free fatty acids were reduced to less than 35% in the primary step and 98% of fatty acid methyl esters were derived in the two step Methanolysis reaction. The reaction found a huge quantity of residues with a mixture of phytosterol and steryl esters [9]. Rice bran biodiesel characterization was carried out with the variations in temperature, catalyst concentration, amount of methanol and reaction time. It was found that the molar ratio 9:1 with 0.75% of catalyst, 55^{o}C of reaction temperature and 1 hour of reaction time yield optimal rice bran biodiesel [1, 17]. Straight rice bran biodiesel was used without diesel in a six cylinder DI diesel engine which showed greater decrease in carbon monoxide, hydrocarbons, smoke and particulates with a minimal increase in oxides of nitrogen [16].

Blends of Pongamia biodiesel was analysed in a single cylinder four stroke direct injection diesel engine with Shallow Depth Re-entrant, Toroidal, Toroidal re- entrant and hemispherical combustion geometries. The performance and emission parameters were studied and found that toroidal re-entrant combustion chamber showed better performance with a notable reduction in emission [5]. Better fuel mixture can be achieved by optimizing the combustion chamber apart from parameters like injection timing, injection pressure, atomization and spray cone angle. Comparison studies were also made on conventional combustion chamber with re-entrant combustion chamber which enhances the dynamics of fluid over the piston during combustion. The combustion chamber geometries along with variation in injection pressure and injection timing were studied to improve the combustion, performance and emission parameters with diesel and biodiesel blends. The shape of combustion chamber helps in atomizing and progress towards complete combustion [7].

The performance and emission parameters were experimentally investigated in the single cylinder diesel engine with variations in ceramic coating of the combustion chamber using diesel and biodiesel. It was found that thermal barrier coating significantly improved the performance parameters like brake thermal efficiency(BTE), mechanical efficiency (ME) and brake specific energy consumption(BSEC) with optimal emissions of unburned hydrocarbons (UBHC), carbon monoxide (CO), oxides of nitrogen (NO_x), smoke and particulates.

Nomenclature and Abbreviations	
CI	**Compression Ignition**
DI	**Direct Injection**
BSEC	**Brake Specific Energy Consumption**
BTE	**Brake Thermal Efficiency**
UBHC	**Unburned Hydrocarbons**
CO	**Carbon Monoxide**
NO_x	**Oxides of Nitrogen**
bTDC	**Before Top Dead Center**
STP	**Standard Toroidal Piston**
STRP	**Shallow Toroidal Re-entrant Piston**
HBP	**Hemispherical Bowl Piston**
RRBO	**Raw Rice bran Oil**
RBBD	**Rice bran Biodiesel**
B100	**100% RBBD**
FFA	**Free Fatty Acid**
FAME	**Fatty Acid Methyl Ester**

II. MATERIALS AND METHODS

A. Biodiesel production and properties

Raw Rice Bran Oil (RRBO) was procured from an oil mill in Vellore district, Tamil Nadu India. It was estimated to contain 12% of Free Fatty Acids (FFA's) with the help of its acid value and titration method. Two step transesterification was used to convert RRBO into biodiesel. It was reported that the base catalysed esterification will be effective with the vegetable oils containing less than 2% of FFA in order to reduce the FFA content acid catalysed transesterification was carried out with 2% of concentrated sulphuric acid and methanol solution [15]. 200 ml of RRBO was heated to 60ᵒC in a round bottom flask and stirred continuously at 250 rpm for 2 hours with the addition of sulphuric acid and methanol. The primary acid catalysed esterification was followed by base catalysed esterification with molar ratio of 1:6, 0.6% of catalyst, 90 minutes reaction time and 65ᵒC reaction temperature. 1.8 grams of potassium hydroxide was selected as catalyst with 1:6 molar ratio of methanol the transesterification reaction was initiated after washing the vegetable oil to reduce storage problems as shown in Fig 1. The base catalyst esterification completely converts the FFA and triglycerides into Fatty acid methyl esters (FAME's). A round bottom flask was used with 60 to 65ᵒC reaction temperature and stirred at 400 rpm with the addition RRBO into potassium hydroxide-methanol solution. The reaction temperature was maintained as above for 2 hours for conversion to take place. The esterification process was completed with a layer formation which separates glycerol and FAME's. The physio-chemical properties of RBBD and fatty acid profiles were estimated and found to be within ASTM standards as shown in Table 1 and 2. [3, 4, 9].

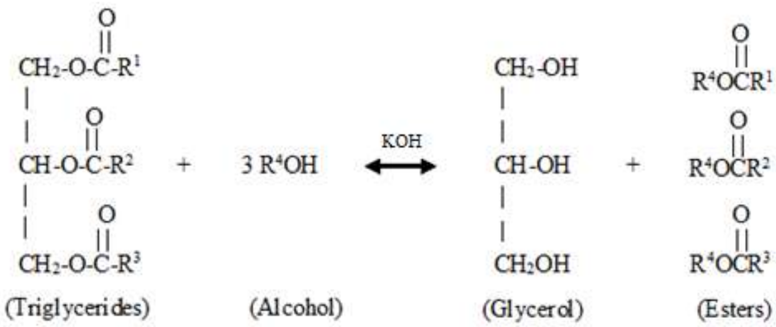

Fig 1. Transesterification Reaction

Table 1. Comparison of Physiochemical properties - Raw Rice bran oil and Diesel

Property / Fuel	Diesel [a]	RRBO
Density(kg/m^3)	840	877
Kinematic Viscosity @ 40°C (cSt)	3.17	5.28
Flash Point (°C)	67	184
Fire Point (°C)	102	198
Cloud Point (°C)	5	11
Pour point (°C)	01	-03
Calorific Value (kJ/kg)	44700	39853
Cetane Number	50	54.6

Shailendra Sinha et al. (2008)

B. Modification of Combustion chamber

Standard Toroidal piston (STP), Hemispherical Bowl piston (HBP) and Shallow Toroidal Re-entrant piston (STRP) were analysed in the present investigation. Greaves 5520 Compression Ignition engine was selected with the factory set STP, redesigned HBP and STRP using CATIA software as shown in Fig.2. The dimensions of these pistons were analysed and its corresponding compression ratio were determined by molten wax technique. The compression ratio of standard piston was found to be 18:1 whereas the compression ratio of redesigned HBP and STRP were 19.04:1, 16.4:1 respectively which is shown in Table.3. These variations in piston will affect the atomization of fuel and thereby its performance and emissions shows alteration [13].

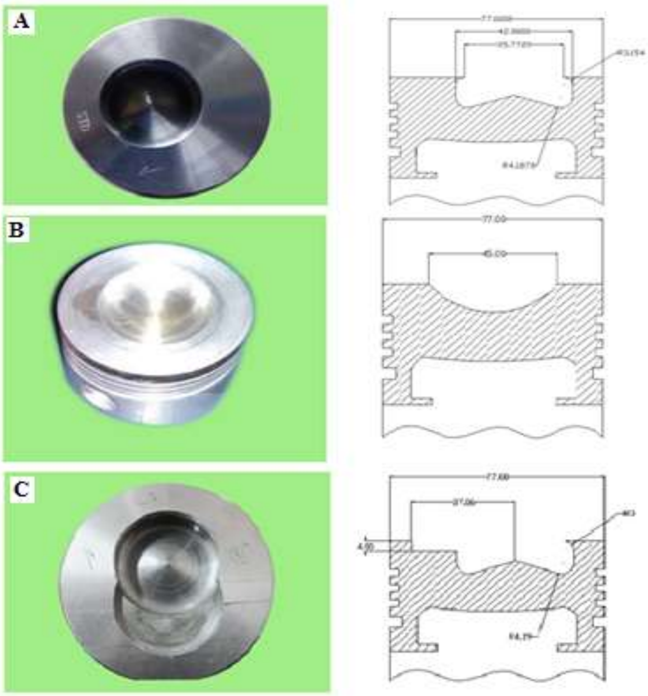

Fig 2. Comparison of Piston Geometries - Standard Toroidal Piston (A), Hemispherical bowl Piston (B), Shallow toroidal Re-entrant piston (C)

Table 2. Fatty acid Profile for Rice Bran Biodiesel

Fatty acids	% by Weight
Palmitic acid	0.28
Lauric acid	0.30
Oleic acid	41.2
Linoleic acid	39
Stearic acid	2.5
Linolenic acid	1.3
Arachidic acid	0.21

Table 3. Compression Ratio for the Piston Geometries

S. No	Combustion	Volume of piston	Compression
1	STP	15.05	18 : 1
2	HBP	12	19.04 : 1
3	STRP	17.5	16.4 : 1

III. EXPERIMENTAL SETUP

The experiments were conducted in Greaves 5520 single cylinder four stroke direct injection naturally aspirated CI engine which is shown in Fig.6. The bore and stroke length were found to be 78 mm and 68 mm respectively with the speed of 3000 to 3600 rpm with a cylinder capacity of 325 cc as given in the Table.4. The factory set engine showed a compression ratio of 18:1 with toroidal piston the test setup is also equipped with an electrical DC generator dynamometer which loads the engine with rheostat load bank. Bosch type of fuel injector was used with an injection timing of 26° BTDC. The performance study was carried out with a three way stopcock burette and the time taken for 10 cc fuel consumption was noted with the help of stopwatch. Crypton 290 five gas analyser was used to analyse the exhaust gas for the presence of UBHC, CO, NO_x as shown in Fig 3 and Fig 4.

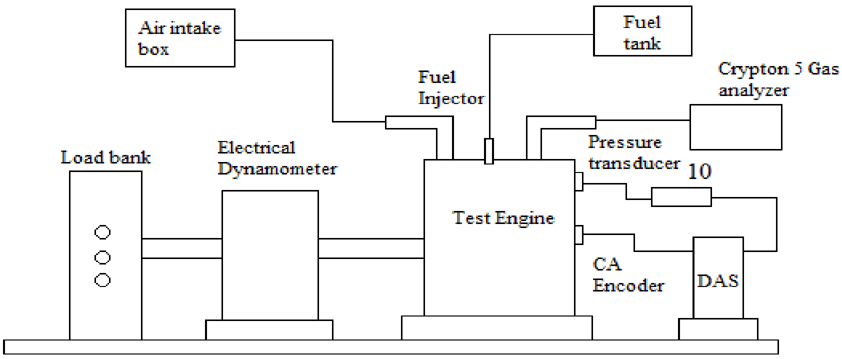

Fig 3. Schematic sketch of Experimental setup

Table 4. Specification of test engine

Make and Model	Greaves 5520
Engine type	Single cylinder, Four Stroke
Bore (mm)	78
Stroke(mm)	68
Speed(rpm)	3000-3600
Rated Power	3.73 kW @ 3000 rpm
Cylinder capacity(cc)	325
Compression ratio	18:1
Injection Timing	26° BTDC

Fig 4. Pictorial view of Test engine

IV. RESULTS AND DISCUSSION

The performance and emission parameters were analysed with the Greaves 5520 engine with the variations in piston geometries i.e. STP, STRP and HBP with straight diesel and Rice bran biodiesel (RBBD). The parameters like Brake Specific Energy Consumption, Brake Thermal Efficiency, Oxides of Carbon, Oxides of Nitrogen and Unburned Hydrocarbons were studied for the above mentioned combustion chamber.

C. Variation in performance parameters

The Brake Specific Energy Consumption (BSEC) varying with Brake Mean Effective Pressure (BMEP) is shown in Fig.5. At low loads the BSEC for HBP was found to be 40 MJ/kW-hr with diesel as fuel whereas B100 showed 38.12 MJ/kW- hr. At part load condition the BSEC for all type of piston and fuel showed a decreasing trend with STRP consuming 12.47 MJ/kW- hr which may be due to better air fuel mixing and spray atomization. At full load condition HBP showed an abnormal increase with diesel and B100 which is a result of incomplete combustion. At the same load the STP and STRP with diesel and B100 blend showed a decreasing trend in comparison with HBP geometry. It was evident from the Fig 5. that the BSEC of STRP with B100 blend showed 15.08 MJ/kW- hr of energy consumption [6].

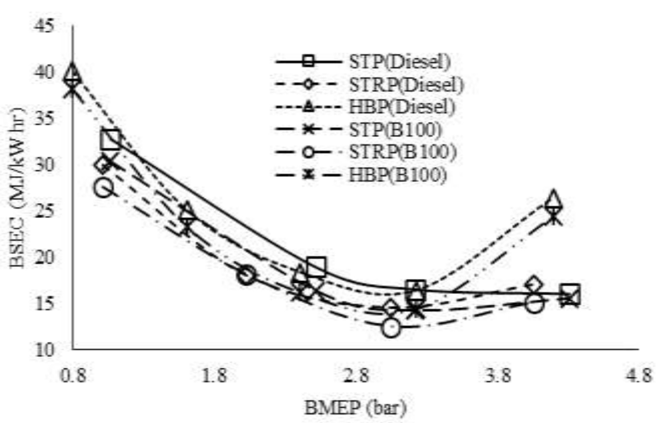

Fig 5. Variation of BSEC with BMEP

The variation of Brake Thermal Efficiency (BTE) and Brake Mean Effective Pressure for STP, STRP, and HBP with straight diesel and B100 RBBD is shown in Fig 6. Initially at low loading conditions the BTE of STP with diesel and B100 was found to be 11.23% and 13.16% respectively whereas STRP exhibited 12.1% and 14.02% with straight diesel and B100 blends respectively. The HBP showed a very minimal BTE of 9.53% and 11.15% with straight diesel and B100 as shown in Fig.8. at part loads the BTE of all the piston geometries showed an increasing trend with the STRP has the highest BTE further it has been noticed that at full load conditions the BTE of STRP with straight diesel and B100 RBBD as 27.33% and 29.31% respectively whereas STP showed only 27.24% with B100 blend which may be due to better combustion, swirl and squish created in the re-entrant piston geometry. The HBP showed a negative increase in BTE at full load as shown in Fig.8 which may be due to poor premixed combustion phase [10-12].

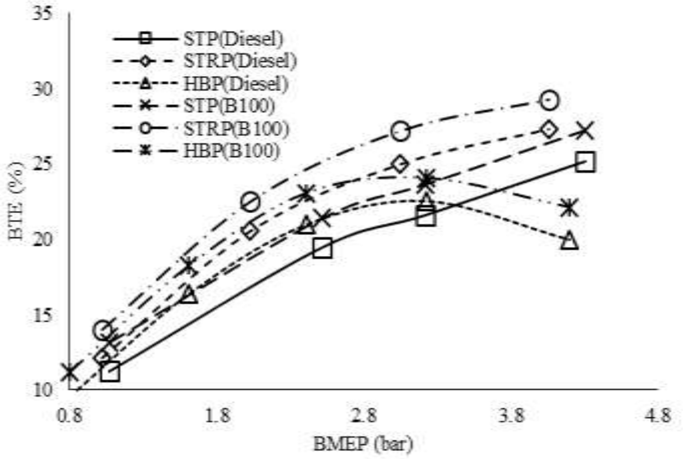

Fig 6. Variation of BTE with BMEP

D. Variation in Emission parameters

CO emissions are mainly formed due to incomplete combustion and improper oxidation of carbon atoms to carbon dioxide. The Fig.7 shows an increasing trend of CO emissions across all loads in STP, STRP and HBP geometries with diesel and B100 fuels. The STP exhibits 0.09 to 0.04 % of CO emissions at part load conditions with diesel and RBBD B100. At similar load the HBP and STRP showed 0.11 to 0.08% and 0.08 to 0.03% of CO for straight diesel and RBBD respectively. From the Fig.8 it is evident that the STRP emits lesser quantity of CO for both diesel and Biodiesel blends which may be due to better oxidative stability and enhanced swirl squish motion in the combustion chamber. Generally HBP showed a negative increase of 5 to 7% on comparison with STP as shown in Fig.9 [6,8].

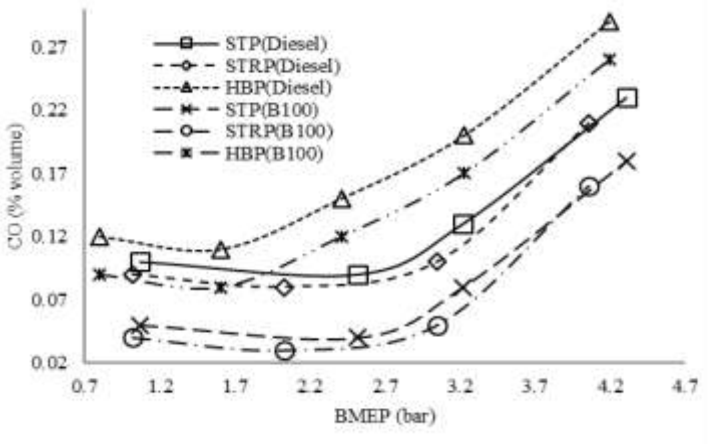

Fig 7. Variation of CO with BMEP

Fig.8 shows the variations in UBHC emission for STD, HBP and STRP with diesel and B100 RBBD. On general comparison the emissions of UBHC showed an increasing trend irrespective of piston geometries with STRP B100 as 3 ppm and HBP B100 as 11 ppm at low loads the UBHC emission was found to be varying between 3 ppm to 17ppm across all piston geometries. At part load and high load HBP exhibit higher emissions of HC as given in the Fig.10 which may be due to incomplete combustion and effect of cylinder wall quenching. STRP with diesel and B100 RBBD were found to emit 17 ppm and 11 ppm of UBHC during part load condition 25 ppm and 19 ppm during full load condition which is 13 to 15% lower than HBP [14].

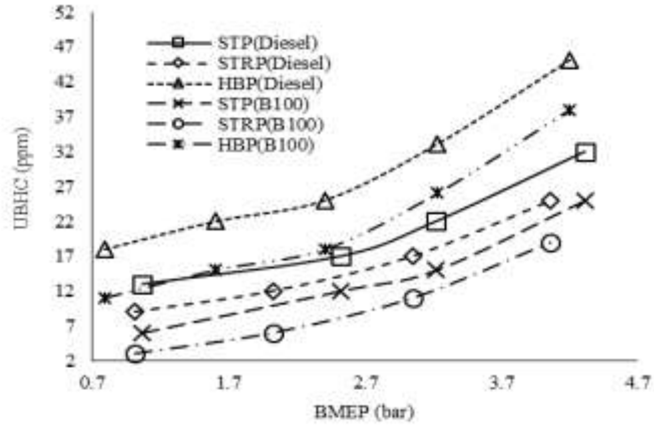

Fig 8. Variation of UBHC with BMEP

The variation in Oxides of nitrogen for all the piston geometries with straight diesel and RBBD B100 blend is shown in Fig 9. The STP exhibited 154 ppm, 242 ppm, 428 ppm at low load, part load and full load respectively which is a decrease in 3 to 4% with RBBD B100 as the fuel. HBP exhibited 86 ppm at part load and 274 ppm at full load for RBBD blend and 118 ppm at part load and 304 ppm for straight diesel. This piston was subjected to 20% more than the full load condition which showed a sharp increase in the NO_x emission upto 450 ppm which is 2% to 4% lesser than STP. The STRP was found optimum at low load, part load and full load conditions where the NO_x emissions were found to be 178 ppm and 210 ppm, 272 ppm and 304 ppm, 453 ppm and 485 ppm respectively for RBBD blend and straight diesel which may be due to lack of oxygen for oxidation, atomization of fuel and fuel viscosity at higher loads. Generally HBP was not suitable at part load and full load operation on comparison with STP and STRP. [18]

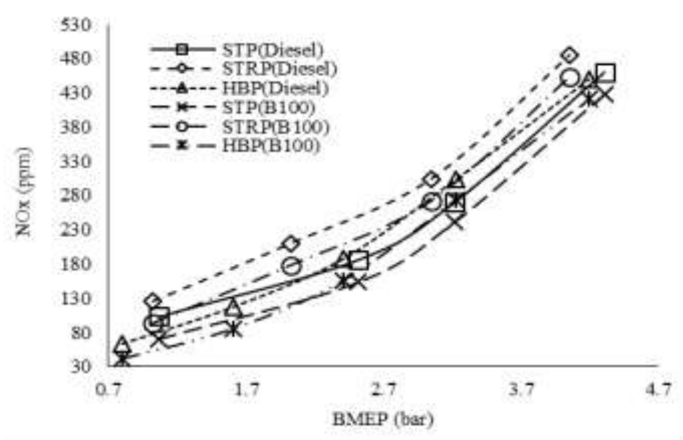

Fig 9. Variation of NO_x with BMEP

V. CONCLUSION

From the present experimental investigation and optimization study, it can be concluded that rice bran biodiesel yield was optimum in two stage transesterification process. The yield of biodiesel was found to be higher at 1:6 molar ratio with KOH as catalyst. With the increase in reaction time and reaction temperature more than 2 hrs, the biodiesel conversion rate showed no significant improvement. The physio-chemical properties of the rice bran biodiesel were found with ASTM standards. The three piston geometries studied were STP, HBP and STRP which were designed and machined. The modified piston geometries were tested in Greaves single cylinder direct injection compression ignition engine and found that STRP geometry exhibited better performance and emission characteristics. The BSEC of STRP with RBBD B100 was found to be 15.08 MJ/kW-hr were as STP and HBP showed 15.5 MJ/kW-hr and 14.34 MJ/kW-hr respectively at full load condition. The BTE was also found to be increased between 10% to 15% for STRP on comparison with STP and HBP which was due to higher calorific value of RBBD B100 and higher swirl and swish for STRP. The emission of CO showed a variation between 0.17% to 0.26% for STP, HBP and STRP. Since RBBD contained more oxygen, the CO emission was reduced in STRP geometry by 6% to 8%. HBP showed higher CO emission which was due to improper mixing of air and fuel. The variation of UBHC was also found to be better in STRP than STP and HBP at part load and full load operations. The UBHC emission for STRP was 25 ppm and 19 ppm for diesel and biodiesel blend at full load which was due to the effect of wall quenching and incomplete combustion. The NO_x emission was found to be higher at all loads for STRP than STP and HBP geometries which was due to lack of oxygen at higher temperature, higher swirl and swish.

The present study finally reveals that STRP geometry was found more suitable with blends of rice bran biodiesel at part and full load conditions due to better mixing of air-fuel and higher swirl and swish air motion in re-entrant combustion chambers.

REFERENCES

[1]. Altin R, Cetinkaya S and Yucesu HS. The potential of using vegetable oil fuels as fuel for diesel engine. Energy Conversion Management 2001;42(5):529 – 38.

[2]. Cerit M, Buyukkaya E and Engin T. Thermal analysis of a partially ceramic coated piston: Effect on cold start HC emission in a spark ignition engine. Applied Thermal Engineering 2011;336 – 41.

[3]. Cigizolu K.B, Ozaktas T and Karaosmanoglu F. Used sunflower oil as an alternative fuel for diesel engines. Energy Sources 1997;19:559 – 66.

[4]. El Boulifi N, Bouaid A, Martinez M and Aracil J. Optimization and oxidative stability of biodiesel production from rice bran oil. Renewable Energy 2013;53:141 – 47.

[5]. Hanbey Hazar. Cotton methyl ester usage in a diesel engine equipped with insulated combustion chamber. Applied Energy 2010;87:134 – 40.

[6]. Hariram V and G.Mohan Kumar, Combustion analysis of algal oil methyl ester in a direct injection compression ignition engine. Journal of Engineering Science and Technology 2013 : 8(1) : 77-92.

[7]. Jaichandar S, Annamalai K, and Arikaran P. Comparitive evaluation of pongamia biodiesel with open and re-entrant combustion chambers in a DI diesel engine. International Journal of Automotive Engineering and Technologies 2014;3(2):66 – 73.

[8]. Jaichandar S, Senthil Kumar P and Annamalai K. Combined effect of injection timing and combustion chamber geometry on the performance of a biodiesel fuelled diesel engine. Energy 2012;47:388 – 94.

[9]. Pramanik K, Properties and use of Jatropha curcas oil and diesel fuel blends in compression ignition engine. Renewable Energy 2003;28:239-48.

[10]. Puhan S, Vedaraman N, Sankaranayanan G and Ram B.V.B, Performance and emission study of mahua oil (madhuca indica oil) ethyl ester in a 4 stroke natural aspirated direct injection diesel engine. Renewable Energy 2005;30:1269 – 78.

[11]. Rajendra Prasath B, Tamil Porai P and Mohammed Shabir F. An Experimental Comparison of Combustion, performance and emission in a single cylinder thermal barrier coated diesel engine using diesel and biodiesel. Global Journal of Science Frontier Research 2010;10(4):2 – 8.

[12]. Rajendra Prasath B, Tamil Porai P and Mohammed Shabir F. Analysis of Combustion, performance and emission characteristics of low heat rejection engine using biodiesel. International Journal of Thermal Sciences 2010;49:2483 – 90.

[13]. Saito T, DaishoY Uchida N, and Ikeya N. Effects of combustion chamber geometry on diesel combustion. Society of Automobile Engineers Paper; 1986. 861186.

[14]. Saravanan S, Nagarajan G, Lakshmi Narayana Rao G and Sampath S. Feasibility study of crude rice bran oil as a diesel substitute in a DI-CI engine without modifications. Energy for Sustainable Development 2007;11(3).

[15]. Saravanan S, Nagarajan G and Lakshmi Narayana Rao G. Feasibility analysis of crude rice bran oil methyl ester blend as a stationary and automotive diesel engine fuel. Energy for Sustainable Development 2009;13:52 – 55.

[16]. Shailendra Sinha, Avinash Kumar Agarwal and Sanjeev Garg. Biodiesel development from rice bran oil: Transesterification process optimization and fuel characterization. Energy Conversion and Management 2008;49:1248 – 57.

[17]. Siti Zullaikah, Chao-Chin Lai, Shaik Ramjan and Vali, Yi-Hsu Ju. A two-step acid-catalyzed process for the production of biodiesel from rice bran oil. Bioresource Technology 2005;96:1889 – 96.

[18]. Usta N. An experimental study on performance and exhaust emissions of diesel engine fuelled with tobacco seed oil methyl ester. Energy Conversion Management 2005;46:2373 – 86.