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Effect of toroidal shaped combustion chamber & nozzle geometry on the performance and emission characteristics of Diesel Engine using Rice Bran Oil as biodiesel

#1 Jayshri S. Patil, #2 Vivekanad Navadagi, #3 Abhjit Dandavte

[1] patiljayshri601@gmail.com
[2] v.navadagi@gmail.com
[3] abhidandavate@gmail.com

123 Heat Power Engineering, Savitribai Phule Pune University

ABSTRACT

An experimental investigation was carried out on a single cylinder four stroke direct injection diesel engine operated with rice bran oil methyl ester (ROME) as a biodiesel. The performance and emission characteristics were analyzed with toroidal shaped combustion chamber and different types of fuel injector nozzle geometry. Rice bran biodiesel is derived by two step trans- esterification process by mixing rice bran and methanol in the ratio 5:1 and adding 8gm of sodium hydroxide flakes; heated upto $65^{o}C$ to $70^{o}C$ for 90 min, as a catalyst. The engine performance and the emission parameters like carbon monoxide, unburned hydrocarbons and oxides of nitrogen were analysed. During analyses it was observed that the brake thermal efficiency of the engine was less as compared to that of the neat diesel. Irrespective of this, the biodiesel was used as an alternative fuel. Furth er, it was observed that the toroidal shaped combustion chamber gives higher brake thermal efficiency than that of the hemispherical shaped combustion chamber, with biodiesel as a fuel. This paper reveals indepth analysis of the engine performance and emission para meters with toroidal shaped combustion chamber with four hole fuel injector nozzle geometry.

Keywords— Biodiesel, Rice bran oil methyl ester, Emissions, Combustion chamber shape, nozzle geometry.

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I. INTRODUCTION

Humans are dependent on energy for every aspect of their lives from the essentials to the luxuries. As our economy becomes more global, we must produce more with less to remain competitive. We must also use our resources wisely and protect the environment. To meet the challenge, we must be the catalysts in implementing new technologies and methods that improve the efficiency of diesel engine used for transportation. Renewable energy sources can supply the energy for longer periods of time than that of fossil fuels and have many advantages [1]. Liquid biodiesels are more suitable for diesel engine applications as their properties are closer to diesel [2]. The combustion chamber of an engine plays a major role during the combustion of wide variety of fuels.

In this context, many researchers were performed both experimental and simulation studies on the use of various combustion chambers [6, 7, 8].Optimum combustion chamber geometry of engine must be considered to have a better engine operation, performance and emission levels. Suitable combustion geometry of bowl shape helps to increase squish area and proper mixing of gaseous fuel with air [8, 9]. Designing the combustion chamber with narrow and deep and with a shallow re-entrance and a low protuberance on the

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cylinder axis while the spray should be oriented towards the bowl entrance reduces the NOx emission levels to the maximum extent [7]. The behaviour of fuel once it is injected in the combustion chamber and its interaction with air is important [11].

In these terms, it is well known that nozzle geometry and cavitations strongly affect to evaporation and atomization processes of fuel [12, 13]. Suitable changes in the in-cylinder flow field resulted in differing combustion [10]. In this context, experimental investigations were carried out on single cylinder four stroke direct injection diesel engine operated on Rice bran oil methyl ester (ROME).

The main objective of the present work is to

- Production of biodiesel from rice bran oil by using conventional transesetrification process.
- To conduct performance and emission characteristics of CI engine using ROME with toroidal combustion chamber shapes
- To conduct performance and emission characteristics of CI engine using ROME with different types of nozzle geometry.

II. EXPERIMENTAL SETUP

Experiments were conducted on a Kirloskar TV1 type, four stroke, single cylinder, water-cooled diesel engine test rig. Figure 1 shows the schematic experimental set up. Eddy current dynamometer was used for loading the engine. The fuel flow rate was measured on the volumetric basis using a burette and stopwatch. The engine was operated at a rated constant speed of 1500 rev/min. Cooling of the engine was accomplished by circulating water through the jackets of the engine block and cylinder head. The cylinder pressure was measured using a Piezo electric transducer fitted in the cylinder head as shown in Figure 2. The transesterification process is carried out for rice bran oil and engine was made to run on ROME toroidal combustion chamber shapes, keeping optimum parameters of injection timing, compression ratio, and injection pressure. These optimum parameters were taken from the previous study on it.

The experiments were conducted on the CI engine using ROME as injected fuel with Toroidal Combustion chamber for different nozzle geometries(3holes,4holes and 5holes) keeping optimum parameters of injection timing, compression ratio, injection pressure.

A. Transesterification setup:

Transesterification was carried out in a system which is shown in the figure. Three necked flat bottomed glass flask of 2liter capacity was used for transesterification reaction.

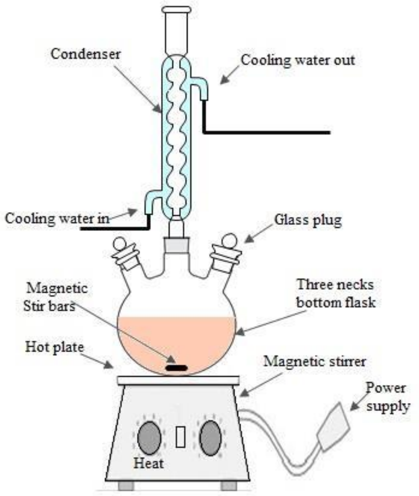

Figure 1: Transesterification setup

A double coiled reflux condenser was fitted to a neck of the glass flask for condensing methanol vapors during the reaction. Water was circulated through coils of the condenser (fig.1). A plate heater with a magnetic stirrer was used for uniform heating of the contents of the flask. Rice bran oil, methanol and NaOH were transferred through the third neck of the flask. In the transesterification process triglycerides of Rice bran oil react with methyl alcohol in the presence of a catalyst (NaOH) to produce fatty acid ester and glycerol. In this process 1000 gm of Rice bran oil, 200 gm methanol and 8 gm sodium hydroxide were taken in a round bottom flask. Items required for transesterification process are Rice bran oil, Methanol, Sodium hydroxide containers. All the contents were heated up to 65^0C to70^0C and stirred by the magnetic stirrer vigorously for one hour when the ester formation begins. The mixture was transferred to a separating funnel and allowed to settle down under gravity for overnight. The upper layer in the separating funnel forms the ester and the lower layer being glycerol was removed from the mixture. The separated ester was mixed with 250 gm of hot water and allowed to settle under gravity for 24 hours. Water washing removes the fatty acids and catalyst dissolved in the lower layer and was separated. Fatty acids and dissolved catalyst were removed by using a separator funnel. Fig. 2 shows experimental set up and fig. 3 shows toroidal shape combustion

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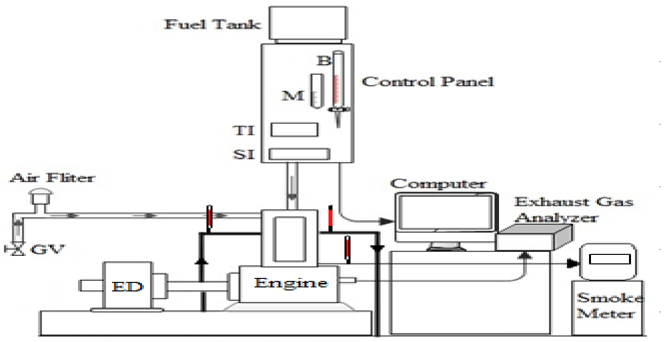

ED- Eddy Current Dynamometer, M-Manometer, TI-Temperature Indicator (^{0}C), SI-Speed Indicator (rpm), B- Burette, GV-Gate valve

Figure 2: Experimental test rig

In the present study ROME was used as injected liquid fuels and their properties are listed in Table 1.

Table 1: Properties of diesel, ROME

Sr. No.	Properties	Diesel	ROME
1	Viscosity @ 40^{0}C (cst)	4.59	44.850
2	Flash point 0 C	56	270
3	Calorific Value in kJ / kg	45000	35800
4	Specific gravity	0.830	0.915
5	Density Kg / m^3	830	915
6	Type of oil	----	Non edible

Table 2 Specification of CI Engine

Sr. No.	Diesel engine	
	Parameters	**Specification**
1	Type of engine	Kirlosker Single cylinder four stroke direct injection diesel engine
2	Nozzle opening pressure	200 to 205 bar
3	Rated power	5.2 KW (7 HP) @1500 RPM
4	Cylinder diameter (Bore)	87.5 mm
5	Stroke length	110 mm
6	Compression ratio	17.5 : 1

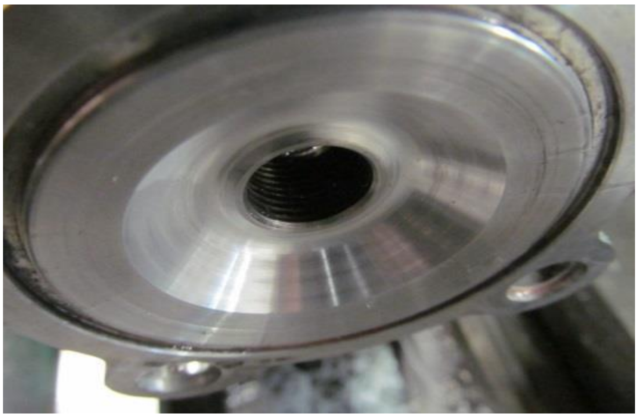

Figure 3: Toroidal shape Combustions Chamber

III. RESULTS AND DISCUSSIONS

A. Effect of Combustion Chamber shapes on the Performance of Diesel Engine:

In the present work, diesel engine was operated on diesel, ROME with hemispherical and toroidal shape combustion chamber. Figure 4 shows the variation of brake thermal efficiency (BTE) with brake power.

III. RESULTS AND DISCUSSIONS

A. Effect of Combustion Chamber shapes on the Performance of Diesel Engine:

In the present work, diesel engine was operated on diesel, ROME with hemispherical and toroidal shape combustion chamber. Figure 4 shows the variation of brake thermal efficiency (BTE) with brake power.

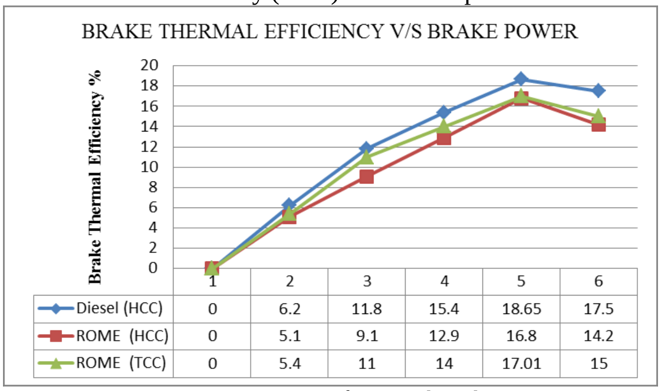

Figure 4: Variation of BTE with Brake Power

It is observed that BTE for diesel fuel mode of operation was higher than ROME fuel operation over the entire load range. This is mainly due to lower calorific value of ROME. Also due to lower flame velocity of the ROME fuel operation and properties of the injected fuel has a major effect on the engine performance. The study with hemispherical and toroidal combustion chamber shapes show that the ROME operation with toroidal combustion chamber results in better performance compared with the other combustion chamber. It may be due to the fact that, the toroidal combustion chamber prevents the flame from spreading over to the squish region resulting in better mixture formation of ROME, as a result of better air motion and lowers exhaust soot by increasing swirl and tumble. The BTE values with hemispherical and toroidal were 14.2 and 15% compared to17.5% for diesel fuel operation respectively with hemispherical combustion chamber.

Figure 5 shows that the variation of smoke opacity with brake power. It is observed that the smoke opacity for diesel fuel operations was lower than ROME over the entire load range. This may be due to improper fuel – air mixing due to higher viscosity of ROME and higher free fatty acid content of ROME. But the study with different combustion chambers shows that the toroidal shape combustion chamber gives lower smoke levels compared with hemispherical combustion chamber. The smoke opacity values with hemispherical and toroidal were 54and 43 HSU compared to 35HSU for diesel fuel operation respectively with hemispherical combustion chamber.

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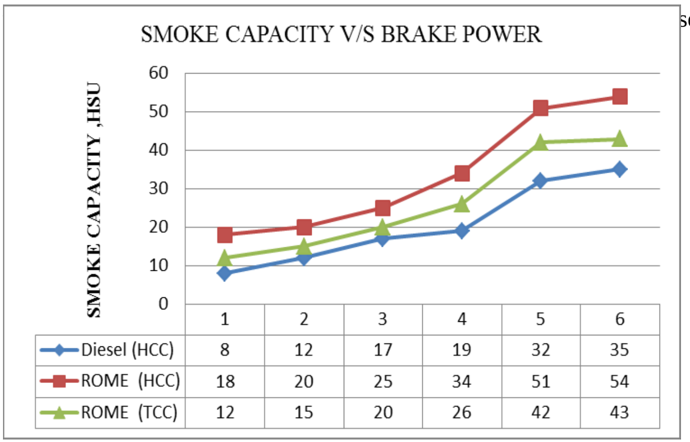
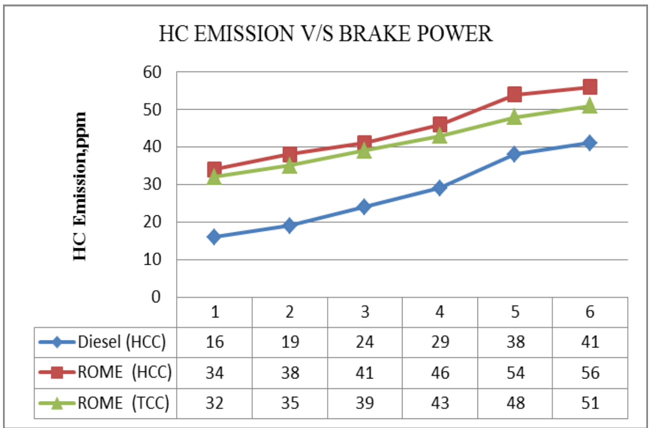


	1	2	3	4	5	6
Diesel (HCC)	8	12	17	19	32	35
ROME (HCC)	18	20	25	34	51	54
ROME (TCC)	12	15	20	26	42	43

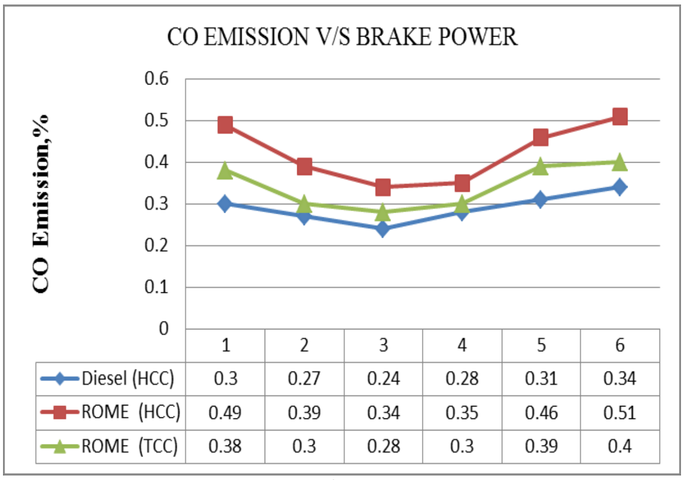
Figure 5. Variation of smoke capacity with Brake Power

Figure 6 and 7 shows the variation of hydrocarbon (HC) and carbon monoxide (CO) emission levels for diesel fuel operation with all loads. Both HC and CO emission levels are higher for ROME fuel operation compared to diesel fuel operation. It could be due to incomplete combustion of the ROME, lower calorific value of ROME, lower adiabatic flame temperature and higher viscosity of ROME and lower mean effective pressures are also responsible for higher HC and CO emission levels. However, combustion with ROME fuel operation with toroidal combustion chamber resulted in lower HC and CO emission levels compared to hemispherical combustion chamber. It could be due to better combustion of ROME with better mixture formation of ROME and improved swirl motion of air. The HC values with hemispherical and toroidal were 56 and 51ppm compared to 41 ppm for diesel fuel operation respectively with hemispherical combustion chamber. Similarly, CO values with hemispherical and toroidal were 0.51 and 0.4 and 0.34 for diesel fuel operation respectively with hemispherical combustion chamber.



	1	2	3	4	5	6
Diesel (HCC)	16	19	24	29	38	41
ROME (HCC)	34	38	41	46	54	56
ROME (TCC)	32	35	39	43	48	51

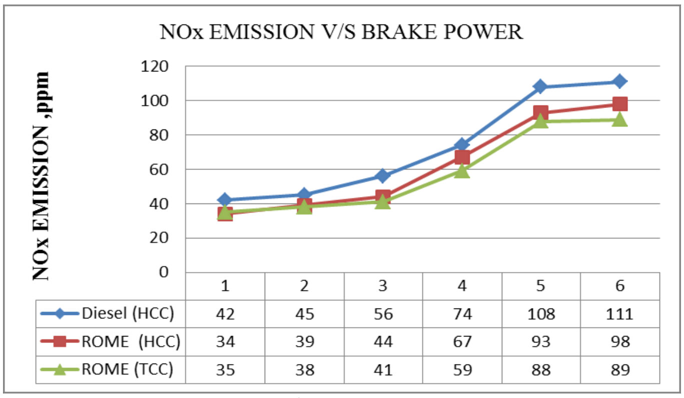
Figure 6: Variation of HC with Brake Power



	1	2	3	4	5	6
Diesel (HCC)	0.3	0.27	0.24	0.28	0.31	0.34
ROME (HCC)	0.49	0.39	0.34	0.35	0.46	0.51
ROME (TCC)	0.38	0.3	0.28	0.3	0.39	0.4

Figure 7: Variation of CO with Brake Power

The NOx emission levels were found to be higher for diesel fuel operation compared to ROME fuel operation over the entire load range (Fig. 8). This is because of higher heat release rate during premixed combustion phase occurs with diesel compared to ROME. Slightly higher NOx is resulted from ROME fuel with toroidal combustion chamber compared to the operation with hemispherical combustion chambers. This could be due to slightly better combustion occurs due to more homogeneous mixing. Also, larger part of combustion before top dead center is responsible for this trend. Therefore it is resulted in higher peak cycle temperature. The NOx values with hemispherical and toroidal were 90ppm, 65ppm,
88ppm, and 95ppm compared to 55ppm for dieselfuel operation respectively with hemispherical combustion chamber.



	1	2	3	4	5	6
Diesel (HCC)	42	45	56	74	108	111
ROME (HCC)	34	39	44	67	93	98
ROME (TCC)	35	38	41	59	88	89

Figure 8: Variation of NOx with Brake power

B. Effect of Injector Nozzle Geometry on the Performance of Diesel Engine:

Figure 9 shows the variation of brake thermal efficiency (BTE) with brake power with different types of injectors. It is observed that over the entire power range, ROME operates at a lower BTE compared diesel. Diesel engine operated with 4 hole injector resulted in higher thermal efficiency compared to 3 and 5 hole injector. It could be due to better mixing of the fuel combinations and better combustion. An important observation is that the better spray dispersion with proper fuel penetration for the 4 hole nozzle compared to the 3 and 5 hole nozzles. This is also due to the enhanced liquid breakup, which leads to smaller droplets and thus higher dispersion for the 4 hole nozzle. This can be a significant advantage for

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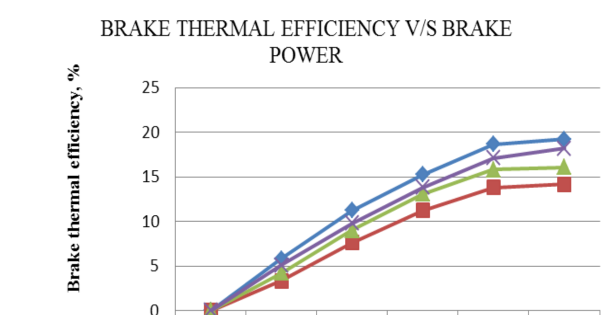
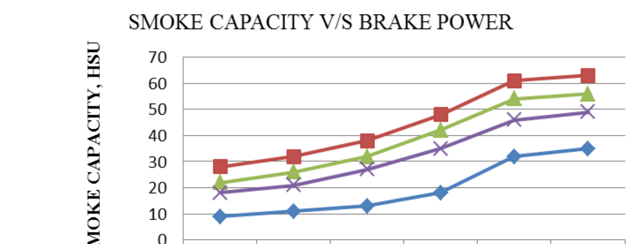
having 4 hole injector nozzles with 0.3 mm diameter hole. The BTE for diesel using 4 hole injector was found to be19.23 and ROME operation with 3, 4 and 5 hole injectors were found to be 14.2, 16.1 and 18.2% respectively for 80% load.



	1	2	3	4	5	6
Diesel (4 Hole)	0	5.85	11.25	15.25	18.65	19.23
ROME (5 Hole)	0	3.35	7.65	11.25	13.8	14.2
ROME (3 Hole)	0	4.23	9.012	13.1	15.85	16.1
ROME (4 Hole)	0	5.12	9.8	13.8	17.1	18.2

Figure 9. Variation of BTE with Brake Power

Figure 10 shows the variation of smoke opacity for diesel and ROME operation with different types of injectors. The smoke opacity with ROME was found to be higher compared to diesel. This could be attributed to lower calorific value, improper spray pattern due to higher viscosity of ROME and free fatty acids with heavier molecular structure compared to diesel results in higher smoke levels. The smoke levels for diesel operation with 4 was found 35 and ROME operation with 3, 4 and 5 hole injectors were found to be 56,49 and 65 HSU respectively for 80% load.

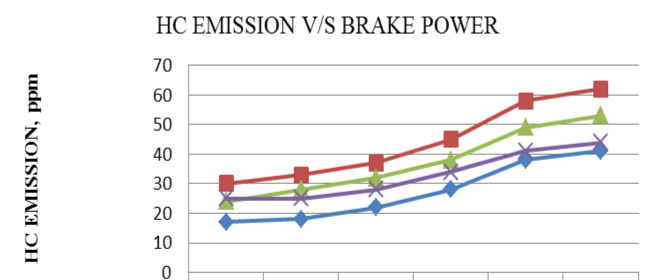


	1	2	3	4	5	6
Diesel (4 Hole)	9	11	13	18	32	35
ROME (5 Hole)	28	32	38	48	61	63
ROME (3 Hole)	22	26	32	42	54	56
ROME (4 Hole)	18	21	27	35	46	49

Figure 10: Variation of Smoke capacity with Brake Power

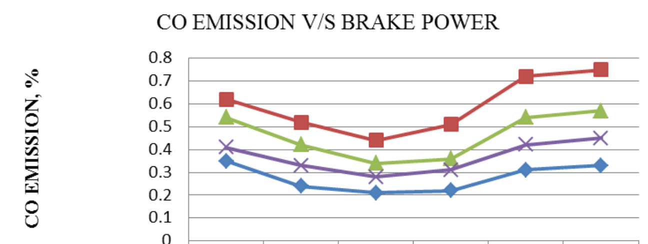
Figure 11 and 12 shows the variation of hydrocarbon (HC) and carbon monoxide (CO) emission levels for diesel and ROME operation with different types of injectors. Both HC and CO emission levels are higher for ROME compared to diesel. It could be due to incomplete combustion of the ROME. The incomplete combustion resulted is due to presence of free fatty acids in a ROME and insufficient oxygen available for combustion. Also, lower calorific value of ROME, lower adiabatic flame temperature and higher viscosity of ROME and lower mean effective pressure are responsible for higher HC and CO emission levels.

The ROME with 4 hole injector resulted in lower HC and CO emission levels compared to 3 and 5 hole injector. It could attributed to better combustion with 4 hole injector due to better mixing of the fuel combinations caused by better spray pattern and penetration. However, 5 hole injector resulted in higher HC and CO emission levels and it may be due to under-mixing of fuel injected and resulting in fuel-air ratios that are too rich for complete combustion.



	1	2	3	4	5	6
Diesel (4 Hole)	17	18	22	28	38	41
ROME (5 Hole)	30	33	37	45	58	62
ROME (3 Hole)	24	28	32	38	49	53
ROME (4 Hole)	25	25	28	34	41	44

Figure 11: Variation of HC Emission with Brake Power



	1	2	3	4	5	6
Diesel (4 Hole)	0.35	0.24	0.21	0.22	0.31	0.33
ROME (5 Hole)	0.62	0.52	0.44	0.51	0.72	0.75
ROME (3 Hole)	0.54	0.42	0.34	0.36	0.54	0.57
ROME (4 Hole)	0.41	0.33	0.28	0.31	0.42	0.45

Figure 12: Variation of CO Emission with Brake Power

The HC for diesel with 4 hole injector was found to be 41 and ROME with 3, 4 and 5 hole injectors were found to be 53, 44 and 62 ppm respectively for 80% load. The CO for diesel with 4 hole injector was found to be 0.33 and ROME with 3, 4 and 5 hole injectors were found to be 0.57, 0.45 and 0.75% respectively for 80% load.

The NOx emission levels were found to be higher for diesel compared to ROME with different types injectors over the entire load range (Fig.13). However, ROME resulted in lower NOx emission levels compared to diesel. This is mainly due to the combined effect of incomplete combustion due to higher viscosity and lower energy density of ROME. Higher cetane number and absence of aromatic hydrocarbon in the ROME improves fuel combustion and reduces HC, NOx and smoke levels in the exhaust. This is also responsible for lower NOx and PM emissions. However, it is observed that the NOx levels were found to be lower for 3 and 5 hole injector operation compared to 4 hole. It could be attributed to lower heat release rate due to incomplete combustion caused by improper spray pattern. The NOx levels for

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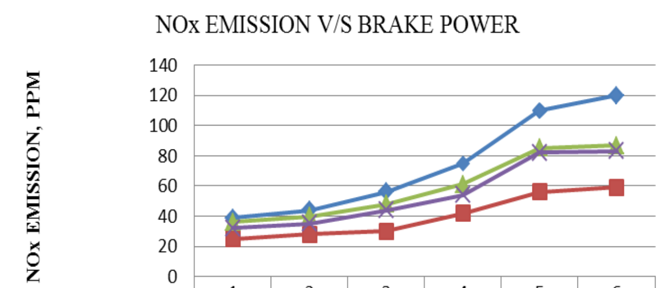
Diesel with 4 hole injector operation was 120 ppm and ROME with 3, 4 and 5 hole injector operation were found to be87,83 and59 ppm respectively for 80% load. The increase in hole number with reduced or smaller hole size may lead to efficient mixture preparation due to improved air utilization, which results in low HC and CO emissions. However, NOx emission increases due to the rise of the combustion temperature.



	1	2	3	4	5	6
Diesel (4 Hole)	39	44	56	75	110	120
ROME (5 Hole)	25	28	30	42	56	59
ROME (3 Hole)	36	40	48	61	85	87
ROME (4 Hole)	32	35	44	54	82	83

Figure 13: Variation of NOx with Brake Power

IV. CONCLUSIONS

The following conclusions were made for the present study.

1) The bio-diesels can be used in diesel engine without any major engine modifications.
2) Homogeneous fuel and air mixing is possible with toroidal combustion chamber when compared to hemisherical combustion chamber tested.
3) Higher brake thermal efficiency with lower emission levels obtained with toroidal combustion chamber.
4) The HC, CO and smoke emission was less with the use of 4 hole injector compared to three and five hole injectors used for fuel injection.

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REFERENCES

[1] Goldemberg J., Coelhobn S.T., Renewable energy-traditional biomass vs. modern biomass. Energy Policy; 32, 2004,711-714

[2] Sridhar G., Sridhar H. V., Basavaraj, M.S, Sudarshan H. I., Somsekhar, Dasappa S., Paul P. J., "Case study on distributed decentralized generation based biomass gasifier system", The Energy & Resources Institute (TERI), New Delhi, 2008, 1- 15.

[3] N.Banapurmath N.R., andTewariP.G., Combustion characteristics of a 4-stroke CI engine operated on Honge oil, Neem and Rice Bran oils when directly injected and dual fuelled with producer gas induction.Renewable Energy, 34(7), 2009, 1877–1884.

[4] Singh R.N., Singh S.P., Pathak B.S. Investigations on operation of CI engine using producer gas and rice bran oil in mixed fuel mode, International Journal of Renewable Energy, Volume 32, Issue 9, July 2007, Pages 1565-1580.

[5] Kapur T, Kandpal T. C, Garg H. P, Electricity Generation form Rice Husk in Indian Rice Mills; Potential and Financial Viability. Biomass and Bioenergy, 10, No: 5/6, 1996, 393 - 403.

[6] Arbon I. M, "Worldwide Use of Biomass in Power Generation and Combined Heat and Power Schemes. Journal of Power and Energy, Proc. Instn. Mech. Engrs. Vol 216, Part- D, 2002,41- 57.

[7] N.R. Banapurmath, P.G. Tewari, V.S. Yaliwal, SatishKambalimath, Y.H Basavarajappa "Combustion characteristics of a 4-stroke CI engine operated on Honge oil, Neem and Rice Bran oils when directly injected and dual fuelled with producer gas induction', Renewable Energy, 34, 2009, 1877–1884.

[8] Arturo de Risi, Teresa Donateo, DomenicoLaforga, Optimisation of combustion chamber of direct injection diesel engines, SAE International, Paper No. 2003-01-1064.

[9] TanajiBalawant Shinde, Experimental investigation on effect of combustion chamber geometry and port fuel injection system for CNG engine,IOSR Journal of Engineering (IOSRJEN,) ISSN: 2250-3021 2(7). 2012, 4954.

[10]Raghu R, Ramadoss G., "Optimization of injection timing and injection pressure of a DI diesel engine fueled with preheated rice bran oil". International Journal Of Energy And Environment, Vol 2, Issue 4, pp.661-670.

[11] Jaichandar S, Senthil Kumar P, Annamalai K, "Combined effect of injection timing and combustion chamber geometry on the performance of a biodiesel fueled diesel engine". ELSEVIER Energy 47, 388-394.

[12] Mahesh Joshi P. Akshay Pawar A.,"Experimental study of performance – Emission characteristics of CI Engine fuelled with cotton seed oil methyl ester biodiesel and optimization of engine operating parameters". Sciencedirect procedia Engineering, Vol. 4, issue 1,pp.185202.

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