# Influence of Combustion Chamber Geometry on the Combustion and Emission Characteristics of a Direct Injection Diesel Engine Operated on Renewable and Sustainable Fuel Derived from Diary Scum Waste

**Sadashiva Lalsangi, V.S. Yaliwal, N. R. Banapurmath**

***Abstract: Present work discusses experimental investigation to study the effect of biodiesel blends and re-entrant combustion chamber on the performance, combustion and exhaust emissions. In the first phase of the work, diary scum oil methyl ester (DiSOME) biodiesel was produced by conventional transesterification process and is blended with conventional diesel fuel in steps of 20 (by volume). Further in the next phase of the work, influence of blended fuel properties and re-entrant combustion chamber (RCC) on the combustion and emission characteristics of a direct injection diesel engine has been investigated. Results of investigation showed that B20 operation with RCC provided increased thermal efficiency by 3-4% with 10% increased smoke, 10-20% decreased hydrocarbon (HC) and carbon monoxide (CO) and 8-10% increased nitric oxide (NOx) emission levels compared to B100 operation. Further increased cylinder pressure and heat release rate were observed with B20. However, Thermal efficiency and NOx emissions are comparatively lower and smoke, HC and CO emissions were found to be slightly higher than base line diesel operation.***

***Key words: Diary scum oil methyl ester, Re-entrant combustion chamber, combustion, emissions.***

## I. INTRODUCTION

In order to lower crude oil import, greenhouse gas emissions, and harmful emission levels from fuel combustion and increased energy production from indigenous energy sources, it is significant to increase renewable energy share in the energy mix. India is having enormous renewable energy resources and which are sustainable in nature [Panwar et al (2011)]. In particular energy resource from biodiesel derived from diary scum is a most promising alternative fuel. Evaluating the potential of diary scum resource in India, it is imperative to develop decentralized power plants in diary. Thereby, grid power can be saved to little greater extent.

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Concentration of energy targets is a significant policy which in turn addresses the reduction in energy shortage, environment and socio-economic issues. Biodiesel production from diary scum resource assessment showed that, the diary scum potential is more than 150 million tons per year in India. Plenty of dairies are engaged in producing not only milk; these are also producing other food products. Several milk diaries with large capacity are engaged in handling milk across the country. One such milk diary named as Karnataka Milk Federation (KMF) Ltd is located in Dharwad, India. It has an infrastructure to handle nearly about 3.10 lakh litres of milk per day. After milk processing, for cleaning the equipments about more than 3 - 4 lack liters of water per day is used. Especially milk processing, milk separation, packaging and washing huge quantity of scum get collected in effluent treatment plant as a scum. It is noticed that about 100-150 kg of effluent scum is wasted every day and which is very difficult to dispose [Benson et al (2013), Shivakumar et al (2011)]. A majority of the literature aims at production and utilization of biodiesels for power generation application using edible and non-edible oils. However, energy from the diary scum is less investigated. Energy from diary scum can be utilized conveniently due to its renewability, greater potential and well distribution across the country. This energy is the main driving force because it is available at a free of cost. but it is very difficult to manage the energy requirement only when the power production is from conventional and biodiesel fuels derived from vegetable oils [Panwar et al (2010, 2011)].

Scum is a waste having low density and formed by mixture of several milk products and large capacity diaries can produce nearly about 400 kg of scum per day [Rahees and Meera (2014)]. This is very difficult to manage and dispose because it contains amino acids and proteins when they degrade and can produce unpleasant smell around the diary plant. Storage temperature, decay of milk and influencing parameters of amino acids is reported [Connell et al (2017)]. At present several diaries following incineration method to dispose the scum or disposing directly on the site. Therefore such methods generate huge amount of pollutants in atmosphere, because it contains carbon and amino acids etc. In addition, scum can create operational problems during waste treatment. This scum is extracted and biodiesel can be produced using conventional trans-esterification process because it is having triglycerides of fatty acids from C4- C18 [Kavitha et al (2019)]. Several investigators have determined its properties and biodiesel derived from scum is very similar to diesel like fuel [Tilak et al (2017)]. Several researchers investigated the combustion characteristics of diesel engine using biodiesels of different origin and reviewed literature describing that use of biodiesel produces same, low or more power output with acceptable emission levels compared to diesel [Roy et al (2014), Guven and Erinc (2016), Henrique et al (2016), Cristina et al (2018), Mofijur et al (2019) , Karthickeyan ( 2019), Kavitha et al (2019), Ramlingam et al (2019)]. DiSOME has high cetane number with good calorific value, but it suffers from poor cold flow properties. However, this property can be improved by adding 20% (v/v) of ethyl acetoacetate (EAA) and ethyl levulinate (EL) to diary scum oil, The low temperature property decreased significantly and improves cloud point and pour point (PP) [Kavitha et al (2019), Shrikanth et al (2017)]. Conventional transesterification was used to produce DiSOME using conventional transesterification. Fatty acid composition was evaluated using Gas chromatography and it was found to be acceptable. Hence, this diary scum oil is best suited for diesel engine applications [Sivakumar et al (2011)]. Response Surface Methodology (RSM) was used to assess the good combination of catalyst concentration for diary scum oil methyl ester production. Statistical model forecasted about 91.636% and 94.091% yield of scum oil methyl ester (SOME) and Hydnocarpus Wightiana oil methyl ester (HWOME) at the optimized reaction conditions [Krishnamurthy et al (2018)]. Biodiesel production using transesterification from diary scum waste using calcined egg shell waste as a catalyst and optimized the process parameters by Kavitha et al (2019). They also studied properties of diary scum oil methyl ester (DiSOME) properties and conducted experiments on a diesel engine. They have reported that DiSOME operation provides acceptable thermal efficiency with reduced nitric oxide (NOx) emissions because it has high cetane number. Contrarily, Srikanth et al (2019) reported that DiSOME blend (B20) provided 3% enhanced thermal efficiency compared to diesel operation. But to produce the same power output, DiSOME consumption is greater. Increase in smoke and NOx emissions with decreased hydrocarbon (HC), carbon monoxide (CO) were observed with all blends tested compared to diesel operation at the condition of maximum load. Further improved combustion characteristics were documented with all blends tested compared to diesel operation. Similar results have been reported by Ramlingam et al (2019) and Manjunath et al (2018) reported that B20 blend resulted in improved thermal efficiency with increased NOx levels and decreased other regulated emission levels. Influence of B20 and compression ratio on the combustion and emission characteristics of diesel engine using DiSOME has been reported. Increased thermal efficiency, peak pressure, heat release rate and decreased HC, CO emissions, but increased NOx emissions have been reported [Manjunath et al (2018)]. Further biodiesel blended fuel (B20) operation with thermal barrier coating resulted in improved performance with reduced emission levels [Sankar et al (2019)]. Premnath et al (2015) investigated the influence of re-entrant combustion chamber on the combustion behavior in a diesel engine using Jatropha methyl ester blend (J20) at three injection pressures. They have achieved 20% increased BTE with reduced smoke and HC CO by 24% and 26% reduced CO emissions.

Extracting of complete energy from DiSOME is possible when fuel and engine modification is done by changing injection timing, injection pressure, compression ratio, combustion chamber configuration and adopting split injection. Some investigators have reported more, low and same power output as that of diesel operation. [Kataria et al (2019), Hawi et al (2019), Ning et al (2019), Shameer et al 2018), Yu et al (2019), Li et al (2018), Singh et al (2017)]. Perfectly matched injector with combustion chamber geometry significantly enhances the combustion. High viscous fuels are injected with high injection pressure, which will reduce the droplet size, increases the vaporization and atomization of fuel. Diesel engines equipped with common rail direct injection (CRDI) technology resulted in nearly 1600 bar injection pressure and it can be controlled by fuel rail pressure. This high injection pressure improves the air-fuel mixing and is accountable for the improved overall performance of a diesel engine [Banapurmath et al (2017)]. Influence of injection pressure (IP) and start of injection (SOI) has been investigated by Shukla et al (2018). Improved performance with reduced emissions and controlled pressure rise and heat release rate has been reported at optimized IP and SOI.

Influence of injection timing and high injection pressure on the combustion characteristics of diesel engine using CRDI system has been investigated by Hwang et al (2014). At all injection timings, the biodiesel fuel consumption was higher compared to diesel operation. However, at higher injection pressure and optimized injection timing, biodiesel operation resulted in lower smoke, hydrocarbon and carbon monoxide emissions with increased nitric oxide levels. At all conditions, in-cylinder pressure and heat release rate were found to be lower for biodiesel operation. Efficient air-fuel mixing is also dependent on combustion chamber geometry. It is noticed that design of combustion chamber significantly affect the air motion inside the engine cylinder and decide quality of combustion. Existing diesel engines have hemi-spherical combustion chamber (HCC) and it is provided improved performance for conventional diesel fuel. But, it may not be better for biodiesel and gaseous fuels. Therefore it is essential to develop different combustion chamber for biodiesel operation. In this regard, variations in the combustion chamber by well designed piston bowl can significantly improve the combustion of fuel because it affects the bulk flow of air and turbulence leading to better air-fuel mixing. Appropriately controlled cylinder pressure and heat release rate by adopting appropriate combustion chamber with suitable injection pressure and injection timing can reduce the combustion noise and emission levels. Karthickeyan (2019) investigated the combustion chamber geometry on combustion and emission characteristics of biodiesel powered diesel engine. Greater swirl and squish is achieved by torroidal combustion chamber (TrCC) which in turn improved the air-fuel mixing. With this TrCC, biodiesel operation provided lower emission levels with increased nitric oxide emission levels [Vedharaj et al (2015)]. Researchers used novel combustion chambers by developing lateral and double swirl combustion systems (LSCS and DSCS) to improve the diesel engine performance. They matched both with various fuel injection systems. Use of these combustion chambers changes the flow guide angle. When this angle is 15–27°, the LSCS resulted in appropriate spray and better air-fuel mixture. The smoke and fuel consumption was reduced approximately by 70% and 2.8 – 4.2 g/kWh respectively at different engine speeds compared to DSCS [Xiangrong et al (2018)]. Further, properties of waste plastic oil are improved by addition of composite preservatives (mixture of soy lecithin and di-tert-butyl peroxide) and combustion characteristics are improved by using TrCC. They observed 3.24% increased thermal efficiency with 2.86% decreased specific fuel consumption and lowered CO and NOx emissions were reported compared to the operation with hemi-spherical combustion chamber [Pappula et al (2019)]. Omega combustion chamber was developed by Li et al (2014). They showed improved combustion behavior with newly developed combustion chamber due to increased turbulent kinetic energy, strong squish and air-fuel ratio of in a less time.

Literature review suggests that utilization of biodiesel derived from diary scum waste is less investigated and engine performance was enhanced by creating appropriate air motion inside the combustion chamber. Present work is intended to provide a new line for using waste derived fuel and harness maximum energy by adopting improved air motion inside the engine cylinder for power generation applications. In this context, investigations were carried out in two phases. In the first phase of the work, DiSOME was produced using milk diary scum waste. Biodiesel is produced by conventional transesterification. In the next phase of the work, optimization the blending ratio and influence of re-entrant combustion chamber (RCC) on the combustion and emission characteristics of a diesel engine operating on single fuel mode was investigated. Optimum parameters for trans-esterication and single fuel mode of engine operation are used as per the literature [Shivakumar et al (2011), Banapurmath et al (2008)].

## II. PRODUCTION OF BIODIESEL, FUELS USED AND THEIR PROPERTIES

In this present work, well known conventional transesterification was employed to produce diary scum oil methyl ester (DiSOME). Production of biodiesel from diary scum waste is produced as per the procedure and method given in the literature [Shivakumar et al (2011)]. Therefore, it is not addressed in detail. However, greater care was taken during glycerin separation and water washing. The maximum conversion was found to be 92.4% and optimum parameters for maximum yield were found to be 1.0 wt.% of sodium hydroxide, 5:1 methanol-oil ratio, 70$^0$C reaction temperature, 60 min reaction time at 250 rpm. In this present work, DiSOME and its blends with diesel were used. DiSOME-blended diesel fuels were produced ranging from 0 to 100% on volumetric biodiesel content with an augmentation of 20%. The blend produced with 20% DiSOME and 80% diesel fuel is denoted as B20. Similarly other blends are B40, B60 and B80 are prepared. Diary scum waste is obtained from the Karnataka Milk Federation (KMF), Dharwad. Properties of fuels were measured at college laboratory and Bangalore Test House, Bangalore, India. The properties of fuels used are mentioned in Table 1.

**Table 1 Properties of diesel, DiSOME and its blended fuels**

| Property | Diesel | DiSOME (B100) | B20 | B40 | B60 | B80 |
|---|---|---|---|---|---|---|
| Calorific value, kJ/kg | 43500 | 40165 | 43220 | 42145 | 41280 | 41135 |
| Density, kg/m$^3$ | 840 | 868 | 855 | 860 | 862 | 864 |
| Kinematic viscosity @ 40$^0$C, mm$^2$/s | 3.2 | 3.9 | 4.2 | 3.5 | 3.61 | 3.8 |
| Flash point, $^0$C | 56 | 154 | 130 | 135 | 144 | 148 |
| Fire point, $^0$ C | 68 | 164 | 138 | 142 | 156 | 161 |
| Cetane number | 54 | 60 | --- | --- | --- | --- |
| Carbon residue, % | 0.21 | 0.64 | 0.201 | 0.31 | 0.34 | 0.41 |

## III. EXPERIMENTAL SETUP

In the present work, Kirloskar, TV1, single cylinder, four stroke, water-cooled, direct injection compression ignition (CI) engine test rig is used for experimental investigations. Figure 1 illustrates the schematic experimental test rig. The specification of the compression ignition (CI) engine is given in Table 2. Engine had eddy current dynamometer for loading and hemi-spherical combustion chamber with conventional mechanical fuel injection (CMFI) system. With suitable burette and stopwatch, injected fuel flow rate was measured on the volumetric basis. Engine was operated at a rated constant speed of 1500 rev/min. Engine cooling was accomplished by water circulation via jackets provided in the block and cylinder head. Piezo electric transducer was fitted on the cylinder head as shown in Figure 2. Maximum quantity of DiSOME biodiesel is consumed for attaining fixed brake power because biodiesel has lower calorific value and kinematic viscosity is nearly about double than that of diesel fuel. Governor speed can be adjusted to maintain the constant speed. In addition, the SFC was 260 g/kWh for diesel operation and is 320 kg/kWh for biodiesel. For the measurement of regulated emission levels, HARTRIDGE smoke meter and five gas analyzer were used. Emissions are measured only during the steady state operation. For the present work, the injection timing, injection pressure and compression ratio of the diesel engine was 23$^0$ bTDC, 205 bar and 17.5 respectively. But for the biodiesel operation these values are changed like as shown in Table 3. In the beginning of the work, experiments were carried out using DiOME biodiesel using both hemispherical and re-entrant combustion chamber (HCC and RCC). HCC is an existing combustion chamber and is suitable for diesel operation. However, the DiOSME has poor physic-chemical properties which require amplified swirl and squish. Therefore re-entrant combustion chamber was developed as per the method and procedure used in the literature [Donateo et al (2013, 2014), Jaichandar, K. Annamalai (2012), Yaliwal et al (2016), Mamilla et al (2013), Ganji et al (2018)]. Existing combustion chamber geaometry has been changed to re-entrant combustion chamber (RCC). The dimensions of RCC are presented in Figure 2 (a and b).

Bowl volume was kept same as that of HCC (35759.4 $mm^3$) while development of RCC. Various dimensions of RCC arrived are 47.0, 20.5, 9.2 and 51.5 mm for $D_{th}$ (throat diameter), $H_{max}$ (Maximum bowl depth), $R_{th}$ (Toroidal radius) and Dmax (maximum bowl diameter) respectively. The bowl redirects fuel down and towards the center of the bowl, so that utilization of air is better Finally the results obtained with DiOME operation was compared with base line operation. For each load, at least five readings were recorded and ensured the accuracy of the data. Careful arrangements were done to attain consistent and reliable measurements.

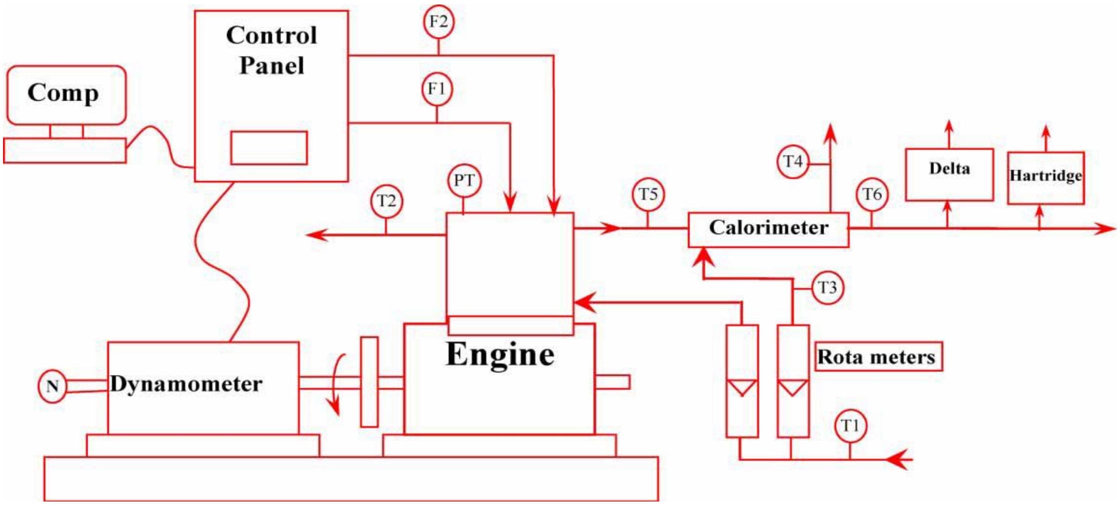


**Fig. 1 Schematic diagram of experimental test rig**

*T*1, *T*3 –water temperature inlet, *T*2 –jacket water temperature outlet, *T*4 –calorimeter water temperature outlet,
*T*5 – exhaust gas temperature before calorimeter; *T*6 – EGT after calorimeter, *F*1 – fuel flow differential pressure unit, *F*2 – air intake DP unit, PT – pressure transducer, N – r/min decoder,
Delta – DELTA 1600S-exhaust 5 gas analyser, Hartridge – Hartridge smoke mete

## IV. RESULTS AND DISCUSSIONS

In this section, experiment al investigations were conducted on a direct injection diesel engine by using diary scum oil methyl ester (DiSOME) and its blends. The injection timing, injection pressure and compression ratio are used as per the values shown in Table 3. The performance and emission levels at 80% load are discussed in the subsequent following section.

### A. OPTIMIZATION OF BLENDING RATIO

Variation in brake thermal efficiency (BTE) for single fuel operation with respect to DiSOME and its blends are illustrated in Figure 2. The BTE values were found to be reduced for DISOME and its blends as compared to diesel. For the same power output, the decreased thermal efficiency by 8.4- 14.5 % for the biodiesel and its blends has been observed and it might be due to inferior properties of biodiesel and its blends. Due to greater viscosity of the biodiesel and its blends, the inappropriate mixture formation and subsequent combustion are deprived than diesel operation. However, B20 blend operation resulted in better thermal efficiency by 2.8% compared to B100. But biodiesel and its blends always resulted in lower performance due to the reasons of inferior properties of biodiesel and its blends. It was due to slightly higher calorific value of B20 and better atomization and spray characteristics.

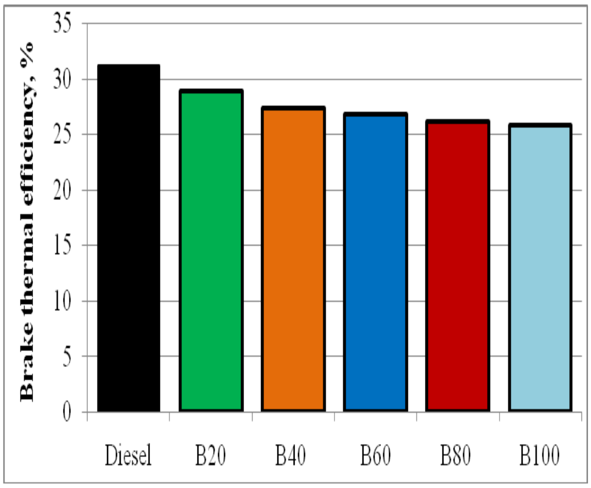


**Fig. 2 Influence of blending ratio on brake thermal efficiency**

However, effective utilization of oxygen available in B20 during combustion is may also be accountable. Further, increasing the biodiesel content in the blends leads to poor performance due to improper combustion caused by the decreased energy content, increased viscosity and density leading to inappropriate mixture formation.

Influence of blending ratio on the smoke opacity for single fuel operation at 80 % load is presented in Figure 3. The smoke values were amplified for DISOME and its blends as compared to diesel operation. For the same operating conditions, the increased smoke levels for the biodiesel and its blends might be due to poor oxidation rate caused by the inappropriate spray characteristics. In addition higher viscosity and density due to heavier molecular weight of biodiesel is also accountable for the observed trend.

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However, B20 blend operation provides decreased smoke levels by 12% compared to B100. It is due to better oxidation rates caused by the utilization of available oxygen in B20. But B20 operation leads to increased smoke levels by 30 % compared to diesel operation due to marginally increased fatty acid content in the blend higher and decreased burning rates. Further increasing biodiesel content in the blends leads to amplified smoke levels due to improper combustion caused by the decreased energy content, increased viscosity and density leading to inappropriate mixture formation. Moreover, fatty acid content of biodiesel has greater carbon, when it burns it provides only black carbon in the engine exhaust.

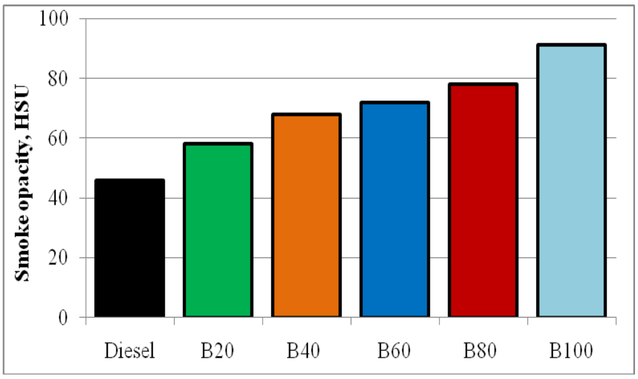


**Fig. 3 Influence of blending ratio on the smoke opacity**

Hydrocarbon (HC) and carbon monoxide (CO) emission levels for single fuel operation at 80 % load for various fuels is illustrated in Figure 4 and 5. Both HC and CO emissions are due to incomplete combustion of fuel. This could also be caused by the over mixing of fuel in the mixture. Results revealed that diesel operation provided 25 - 47.05% lesser HC emissions compared to DiSOME and its blends operation. Similarly CO emissions were increased in the range from 30.0-66.5% compared to diesel operation. This could be due to inappropriate mixture formation of biodiesel and its blends leads to amplified HC and CO levels in the exhaust compared to diesel operation.

However, DISOME and its blends have greater viscosity than diesel fuel compared to the diesel fuel. The larger droplets of biodiesel may produce after the fuel spray, which in turn lowers atomization, vaporization, penetration and dispersion. Therefore, the biodiesel larger droplet surface only burn and core of the droplet may emit out from the combustion without burning which in turn lead to incomplete combustion. Insufficient time available during ignition delay is also responsible for the observed trend. It is noticed that biodiesel blend B20 resulted in lower HC and CO emissions by 29.14% and 49.1% respectively compared to B100.

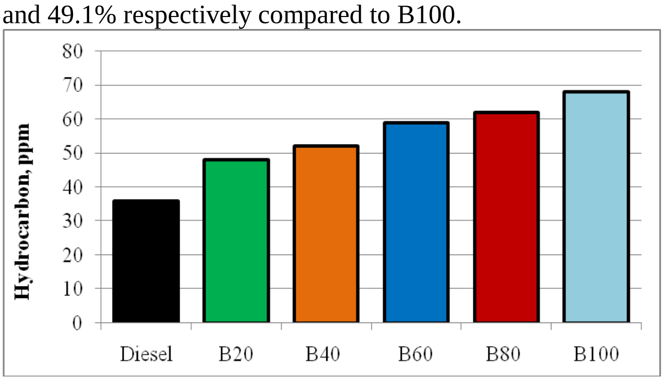


**Fig. 4 Influence of blending ratio on the hydrocarbon emission**

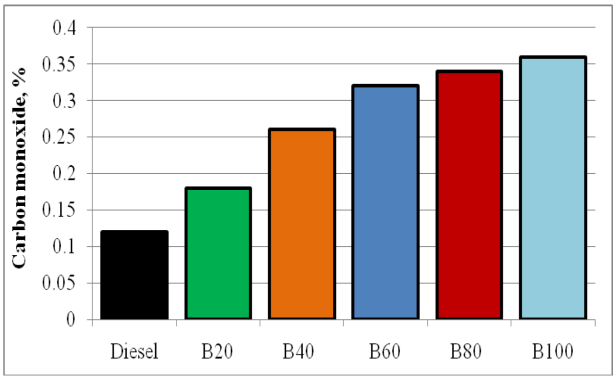


**Fig. 5 Influence of blending ratio on the carbon monoxide**

This is very closely narrated to the viscosity and density of biodiesel. In addition, slightly better oxidation with B20 blend may also be responsible. Further, blends other than B20 are provided amplified emission levels due to decreased thermal efficiency with higher blends. This may be due to the fact that, with same load condition, decreased thermal efficiency for the increased biodiesel content in the blend may lead to higher quantities of fuel injection. Greater HC and CO emissions of the other blends could also be attributed to the inappropriate mixing of the biodiesel content with air leading to incomplete combustion.

Variations in nitric oxide (NOx) emissions with respect to various fuels at 80 % load are displayed in Figure 6. For the same operating conditions, DiSOME biodiesel and its blends showed decreased NOx levels in the range from 15.0-26.8% compared the diesel operation. This could be caused by the decreased premixed combustion during biodiesel based operation. However diesel operation provide increased premixed combustion rather than diffusion combustion rate leading to amplified NOx levels [Banapurmath et al (2009)]. Incomplete combustion of biodiesel and its blends caused by the higher viscosity, inappropriate air-fuel mixing poor spray pattern and lower energy content can lead to decreased combustion rate which in turn lowers the NOx levels in the exhaust. However, B20 blend operation resulted in marginally higher NOx levels by 14.8% compared to B100 due to less biodiesel content in the blend. Further increasing biodiesel content in the blends leads to reduced NOx levels decreasing trend of premixed combustion.

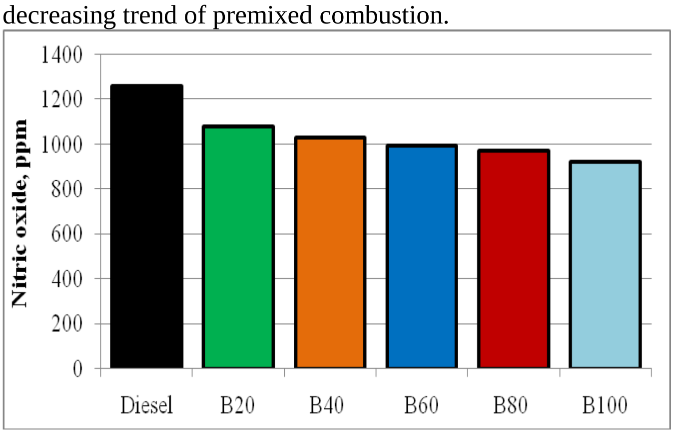


**Fig. 6 Influence of blending ratio on the nitric oxide emission**

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### B. OPTIMIZATION OF COMBUSTION CHAMBER GEOMETRY

From the last section, it is observed that B20 is found to be better due to better performance with acceptable levels of emission levels. In this section, influence of re-entrant combustion chamber geometry on the combustion characteristics of a diesel engine operated on single fuel mode using diesel and B20 is investigated and the same is discussed in the subsequent paragraph.

### PERFORMANCE PARAMETERS

Influence of combustion chamber geometry on the brake thermal efficiency (BTE) is demonstrated in Figure 7. For engine operation with HCC, results showed that diesel operation provided 8.3 % and 14.8% increased BTE compared to B20 and B100 operation respectively at 80% load. It may be due to reduced turbulence and squish during biodiesel blends operation. In addition, inferior qualities of DiSOME in terms of physic-chemical properties are also accountable. However, B20 blend with RCC showed improved thermal efficiency by 2.9% and 4.2% compared to B20 and B100 operation with HCC at 80% load. It may be due to the fact that RCC direct the flow field inside the sub volume at all loads tested. Hence considerable variations in the mixing of fuel and air may be negligible (De Risi et al 2004, Donateo et al 2014). With TCC, the flame propagation may also be improved caused by the proper air-fuel mixture formation. Another possible reason is that, fuel combustion may takes place before TDC when HCC was used which in turn lead to amplified compression work, heat loss and inferior thermal efficiency of an engine. Therefore single fuel engine operation with RCC leads to positive impact on the combustion by improving the atomization, vaporization, flow field and squish. Ignition delay was found to be greater with the HCC during DiSOME and its blends operation which decides the engine performance. Engine operation with high viscous biodiesel and RCC provide amplified burning rate during expansion stroke, leading to prevent the flame diffusion in the squish area leading to better performance.

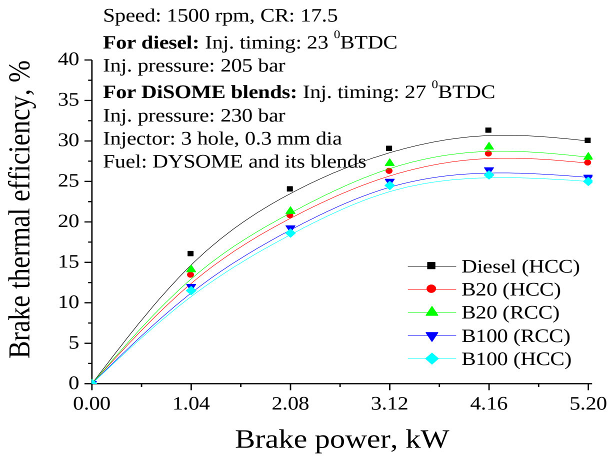


**Fig. 7 Influence of RCC on the brake thermal efficiency**

### EMISSION CHARACTERISTICS

The different emission parameter measurements during the single fuel mode of operation are discussed below.

Figure 8 demonstrate the influence of RCC geometry on the smoke opacity. For engine operation with HCC, showed that diesel operation provided 20.6 % and 46.8% decreased smoke levels compared to B20 and B100 operation respectively at 80% load. It may be due to inadequate mixing of air and fuel caused by the differences in the spray characteristics. However, B20 blend with RCC provide significant reductions in smoke levels by 10.4% and 40.2% compared to B20 and B100 operation with HCC at 80% load.

This may be due to better air –fuel mixing and RCC results in to greater turbulence leading to enhanced combustion and the soot particle oxidation, which in turn lower the smoke emission levels significantly. Improved turbulent kinetic energy during the use RCC compared to the operation with HCC is also accountable for this trend. This is mainly caused by the better air-fuel mixing rate with RCC. However, literatures suggest that slightly wider combustion chamber resulted in reduced smoke levels (Raouf and Zhijun 2013). Therefore single fuel engine operation with RCC leads to positive impact on the combustion by improving the atomization, vaporization, turbuelence and squish. Engine operation with high viscous biodiesel and RCC provide augmented burning rate during expansion stroke, leading to burn the mixture completely.

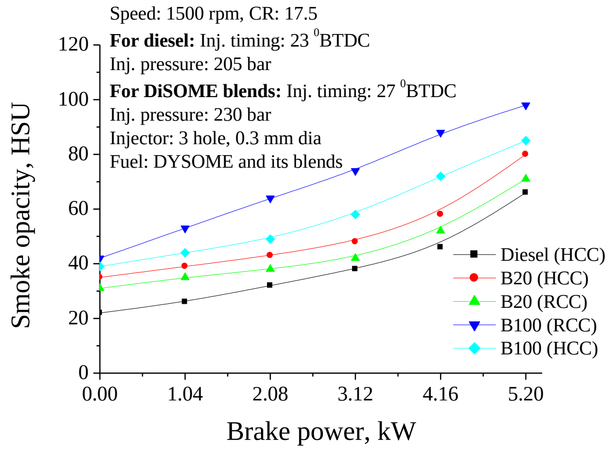


**Fig. 8 Influence of RCC on the smoke opacity**

Influence of RCC on the hydrocarbon (HC) and carbon monoxide (CO) emission levels for DiSOME and its blends operation is illustrated in Figure 9 and 10. At 80% load Single fuel operation with HCC combustion chamber, HC emission levels for B20 and B100 operation were found to be amplified by 26.8% and 37.4% respectively compared to diesel operation. It is due to partial combustion of biodiesel and its blends. However, with RCC, B20 and B100 operation provide lower HC emission by 10.8% and 9.8.4% respectively at 80% load compared to the operation with HCC. Similarly Single fuel operation with HCC, CO emission levels for B20 and B100 operation were found to be greater by 42.8% and 66.2% respectively at 80% load, compared to diesel operation at 80% load. But both B20 and B100 operation with RCC, CO levels in the exhaust were diminished by 14.2% and 13.4% compared to the operation with HCC at 80% load. It is due to partial combustion of biodiesel and its blends. In addition, decreased air-fuel mixing rates caused by the improper spray characteristics and reduced oxidation rates caused by the insufficient oxygen availability of biodiesel and its blends compared to diesel. But with RCC the biodiesel and blends operation leads to reduced HC and CO levels due to improved combustion as a result of enhanced swirl and squish motion of air. However, during engine operation with RCC, presence of moisture content of biodiesel is well utilized during combustion and it may be the cause for amplified thermal efficiency. However, existing combustion chamber (HCC) does not contribute any positive impact on the combustion during biodiesel operation because HCC retard mixing rate of fuel with air.

Figure 11 demonstrates NOx levels verses brake power for diesel, B20 annd B100 operation. For the same combustion chamber (HCC), B20 and B100 operation provides diminished NOx levels by 15.8% and 21.2 % compared to diesel operation at 80% load. It is due to augmented heat release rate during premixed combustion phase which occurs with diesel operation compared to B20 and B100 operation. Under exploitation of oxygen during high temperature zone with biodiesel and its blends operation is accountable for the trend noticed. However, for the same B20 and B100 operation with RCC, marginally amplified NOx levels by 5.6% and 4.8% were recorded compared to the operation with HCC.

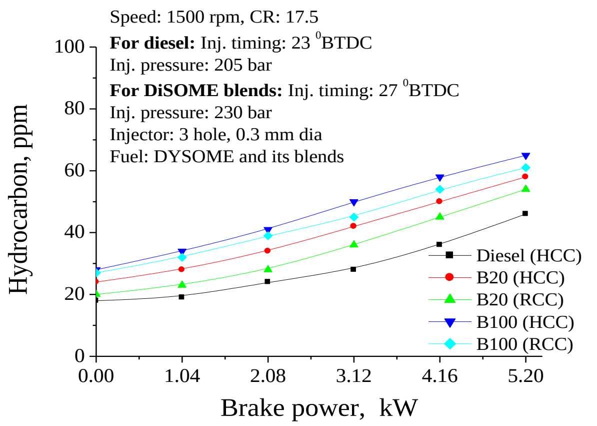


**Fig. 9 Influence of RCC on the hydrocarbon emission**

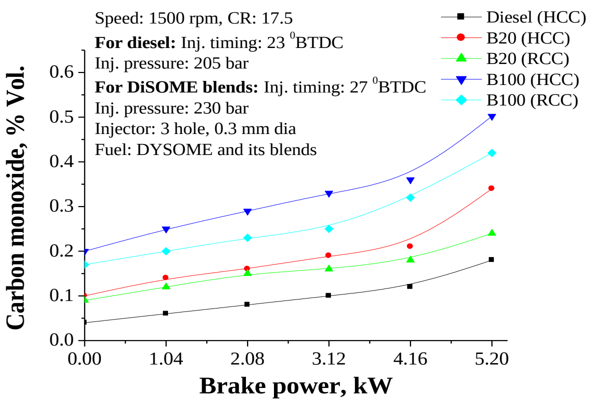


**Fig. 10 Influence of RCC on the carbon monoxide emission**

This is attributed to superior combustion that takes place due to more uniform mixing of air and fuel caused by increased turbulence and squish leading to better combustion that take place before top dead center. Existing moisture content of biodiesel is positively utilized during the engine operation with RCC leading to enhance uncontrolled combustion and combustion temperature hence amplified NOx levels.

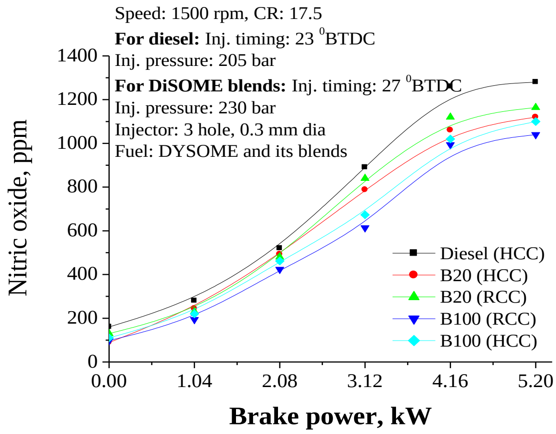


**Fig. 11 Influence of RCC on the nitric oxide emission**

## COMBUSTION CHARACTERISTICS

Air–fuel mixture quality and combustion chamber geometry affect the combustion behavior. Various parameters pertaining to combustion for biodiesel and its blends operation are summarized below.

Influence of different combustion chamber configurations on ignition delay is illustrated in Figure 12. It is found out by the time period between injection start and timing of rapid pressure rise on the pressure curve. Single fuel operation with HCC, increased ignition delay by 9.8% and 15.4% has been recorded for B20 and B100 operation compared to diesel operation. Increased physical mixing rates and chemical kinetics during diesel operation compared to biodiesel is responsible for the observed trend. This is also due to reduced droplet size of diesel fuel and increased cylinder gas temperature inside the cylinder. But, engine operation using same B20 and B100 with RCC provide marginally decreased ignition delay by 3.2 % and 2.8% compared to the operation with the same fuels (HCC). It may be due to more amount of biodiesel being able to take a part in the delay period positively. Better air–fuel mixture and mixing rates are also responsible due to increased turbulence with RCC. Finally it is concluded that, ignition delay for biodiesel and its blends with RCC operation is adequate compared to the operation with HCC. Greater flame speed development due to better mixing of biodiesel with air, increased temperature and appropriate turbulence and squish due to use of RCC is accountable for this trend.

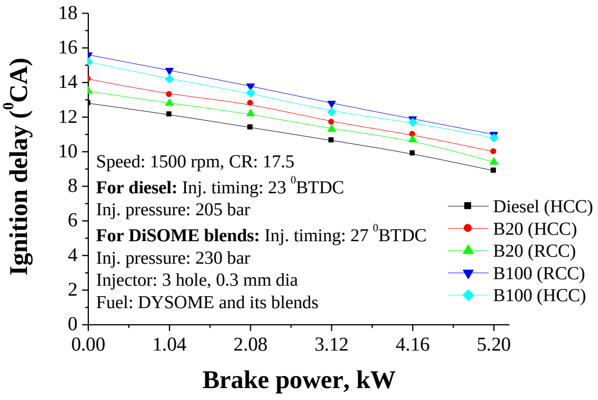


**Fig. 12 Variation of ignition delay with brake power**

The combustion duration for diesel, B20 and B100 are shown in Figure 13. It is computed from the duration between the combustion start and 90% cumulative heat release. When load was increased, the quantity of fuel injected is increased leading to amplified combustion duration. For B20 and B100 fuels with RCC, decreased combustion duration by 6.8% and 4.5% was observed compared to the operation with HCC. Increased turbulence caused by the use of RCC which in turn makes the air-fuel mixture more homogeneous and leads to superior premixed combustion. However, single fuel operation with HCC using biodiesel and its blends, creates second highest peak in the later stages of combustion i.e., diffusion-burning phase. This is due to inferior properties of biodiesel and lowered air – fuel mixing rates. Further which prepares lower quantity of fuel for uncontrolled combustion after the delay period. Hence considerable amount of fuel burns in the diffusion phase instead of premixed phase with biodiesel operation is also a reason for this trend. Drastically amplified combustion rates may takes place during later stages which may lead to amplified exhaust temperatures and reduced BTE. Further, engine operation with RCC, presents enhancement of heat release rate compared to the operation with HCC. However, diesel operation always resulted in decreased combustion duration compared to B20 and B100 operation due to appropriate diesel spray characteristics and mixing rates. It can be concluded that, use of RCC, increases the swirl and squish leading to homogeneous air-fuel mixture due to better evaporation of biodiesel and hence reasonably lesser combustion duration.

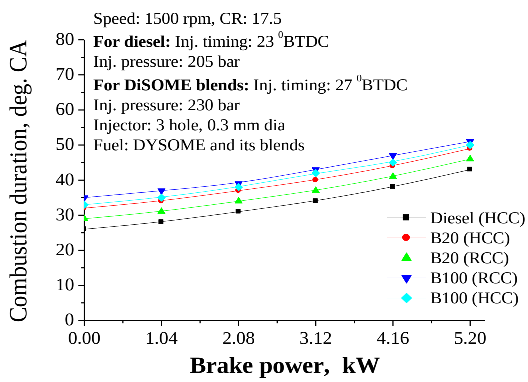


**Fig. 13Variation of combustion duration with brake power**

The history of cylinder pressure–crank angle history at 80 % load for diesel, biodiesel and its blends is shown in Figure 14. It depends on quantity of fuel consumption and combustion during uncontrolled combustion period. This is administrated by the ignition delay and the mixture quality during the ignition delay. It shows that, mixture quality and quantity during the ignition delay period are accountable for greater rate of pressure rise. Figure 14 revealed that B20 and B100 operation with both HCC and RCC configurations shows lower cylinder pressure compared to diesel operation due to appropriate mixture formation during diesel operation. Further, B20 and B100 with RCC provide amplified cylinder pressure than the operation with HCC. It may be due to the fact that, engine operation with RCC, the flame velocities may increase due to better mixture formation, which in turn direct the flame propagation entire combustion chamber and hence mixture was ignited better. This may lead to amplified in-cylinder pressure with RCC configuration than the engine operation with HCC. Engine operation with RCC, increased turbulence speed up pre-flame combustion reaction leading to affect combustion significantly and results in better air-fuel mixing and reduced combustion duration. Further physical delay and reactions during pre-flame combustion were completed quickly leading to speedy combustion in the piston bowl. Further, it is obvious that, generation of second peak during the diffusion phase was decreased slightly with a use of RCC compared to the operation with HCC. Hence energy produced by the combustion is competently converted into work with RCC.

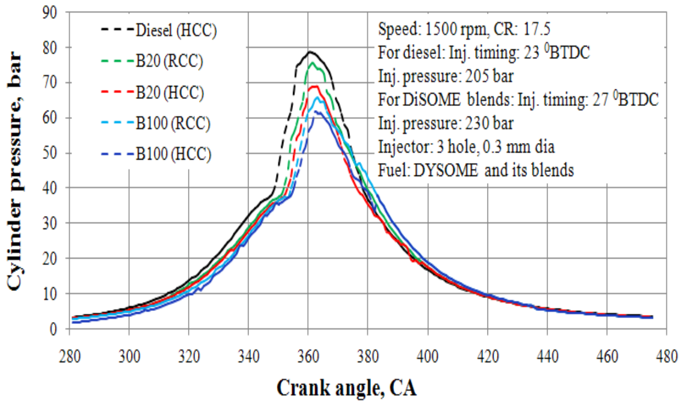


**Fig. 14In-cylinder pressure versus crank angle with different combustion chamber configurations for biodiesel and its blends at 80 % load**

Figure 15 demonstrate heat release rate versus crank angle for diesel, B20 and its blends with different combustion chamber configurations at 80% load. Turbulent mixing of air and fuel caused by the different combustion chambers significantly influence the heat release rate. It is obvious from the Figure 16 that, for both B20 and B100 operation with RCC, the heat release rate was found to be greater than the engine operation with HCC. This may be due to extended delay period, combustion duration and increased second peak in the diffusion combustion phase with HCC during biodiesel and its blends operation. Further, it is seen that center of gravity of heat release rate diagram moved towards after TDC which clearly shows the reduction of work.

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This decreased heat release rate indicate reduced pressure rise rate which in turn shows reduced combustion noise. It is also seen that during B20 and its blends operation with HCC that, unburnt hydrocarbon was increased in the exhaust. However, for the same biodiesel operation with RCC and at optimum operating conditions, heat release rate was comparatively greater with marginally increased NOx emission levels compared to the operation with HCC. This is due to optimum turbulence caused by the use of RCC. In general, engine operation with HCC, the poor spray characteristics of biodiesel due to inferior properties may hinder the mixture quality. However, B20 and B100 operation with HCC and RCC combustion chamber configurations, diesel operation provide amplified heat release rate due to its superior characteristics.

## V. CONCLUSIONS

Significant variations in the thermal efficiency and environmental characteristics for dual-fuel fuel operation have been analyzed. In the present work, experiments were conducted on a diesel engine using DISOME and influence of combustion chamber has been investigated. Results of investigation showed that RCC create a strong swirl and squish resulting in to outstanding performance with diminished emission characteristics. This present work provides a new line to for the utilization of high viscous fuels in a diesel engine. The most important outcomes drawn from the present investigation are summarized as below:

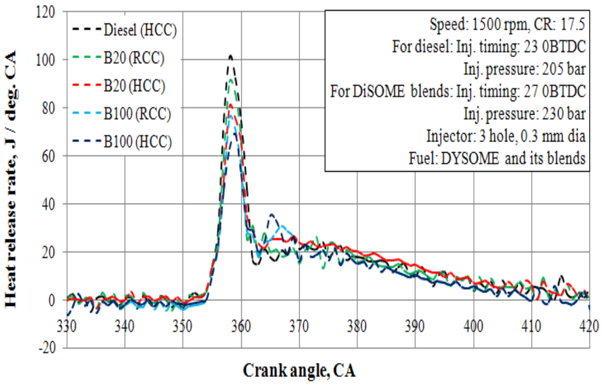


**Fig. 15 Rate of heat release versus crank angle with different combustion chamber configurations for biodiesel and its blends at 80 % load**

- Use of RCC for biodiesel and its blends operation speed up formation of air-fuel mixture and increase the combustion rate compared to other blends tested. The experimental results show that the B20 blend with RCC showed improved thermal efficiency by 2.9% and 4.2% compared to B20 and B100 operation with HCC at 80% load.
- As for as emissions are concerned, B20 blend with RCC provide significant reductions in smoke levels by 10.4% and 40.2% compared to B20 and B100 operation with HCC at 80% load.
- With RCC, B20 and B100 operation provide lower HC emission by 10.8% and 9.8.4% respectively at 80% load compared to the operation with HCC.
- Similarly, B20 and B100 operation with RCC, CO levels in the exhaust were diminished by 14.2% and 13.4% compared to the operation with HCC at 80% load
- B20 and B100 operation with RCC provide marginally augmented NOx levels by 5.6% and 4.8% were recorded compared to the operation with HCC. Ignition delay and combustion durations with RCC were decreased. Also it provides amplified in-cylinder and heat release rate. Hence greater power output has been documented with RCC operation.
- The results with RCC show that an amplified swirl with lowered local fuel-rich zones in the combustion chamber.

On the whole it is concluded that DiSOME could be used as an alternative and renewable fuels in diesel engines. Running the engine in single fuel mode requires no major modifications in the existing diesel engine. DiSOME operation with optimum parameters resulted in overall better engine performance with reduced emission levels.

## REFERENCES

1. N.L. Panwar, S.C. Kaushik, Surendra Kothari. Role of renewable energy sources in environmental protection: A review. Renewable and Sustainable Energy Reviews, 15, 2011, pp 1513–1524
2. Benson Varghese Babu, R Suresh, K V Yathish. Effects of Diary Scum Oil Methyl Ester on a DI Diesel Engine Performance and Emission. IOSR Journal of Applied Chemistry (IOSR-JAC). 3(6) 2013, PP 09-15. e-ISSN: 2278-5736
3. Sivakumar P., Anbarasu K., Renganathan S., Bio-diesel production by alkali catalyzed transesterification of dairy waste scum. Fuel. 90, 2011, PP 147–151.
4. N.L. Panwar, Hemant Y.Shrirame, N.S. Rathore, Sudhakar Jindal, A.K. Kurchania. Performance evaluation of a diesel engine fueled with methyl ester of castor seed oil. Applied Thermal Engineering, 30, 2(3), 2010, PP 245-249
5. Rahees K., Meera V., Production of biodiesel from diary waste scum. International journal of scientific and engineering research, 5(7), 2014, PP 194-199.
6. O'Connell A, Kelly A. L., Tobin J., Ruegg P. L., Gleeson D.,The effect of storage conditions on the composition and functional properties of blended bulk tank milk. Journal of Dairy Science. American Dairy Science Association, 100(2), 2017. PP 991-1003 https://doi.org/10.3168/jds.2016-11314 ,
7. Kavitha V.,Geetha V., Jennita Jacqueline P., Production of biodiesel from dairy waste scum using eggshell waste. Process Safety and Environmental Protection. Volume 125, 2019, PP 279-287
8. Tilak S.R., Chandrashekar K., Yogish H., Evaluation of performance and emission characteristics of biodiesel derived from diary scum oil on a computerized C.I engine. International Journal of Emerging Trends in Engineering and Development. 1(7), 2017. PP 119-127. http://www.rspublication.com/ijeted/ijeted _index.htm ISSN 2249-6149.
9. Roy Murari Mohon, Effect Of Fuel Injection Timing And Injection Pressure On Combustion And Odorous Emissions In DI Diesel Engines‖ J. Energy Resour. Technol. 131(3), 2009, PP1-8, Doi:10.1115/1.3185346
10. Ekrem Buyukkaya, Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics, Fuel, 89, 2010, 3099-3105.
11. Gunfeel Moon, Yonggyu Lee, Kyonam Choi, Dongsoo Jeong, Emission characteristics of diesel, gas to liquid, and biodiesel-blended fuels in a diesel engine for passenger cars, Fuel, 89, 2010, PP 3840 – 3846.
12. Huseyin Aydin, Hasan Bayindir, Performance and emission analysis of cotton seed oil methyl ester in a diesel engine, Renewable Energy, 35, 2010, PP 588 – 592.
13. Rasim Behçet, Performance and emission study of waste anchovy fish biodiesel in a diesel engine, Fuel Processing Technology, 92, 2011, PP 1187–1194.
14. Senthil Ramalingam, Sudagar S, Balamurugan R, Naveen R., Performance and emission behavior of biofuel from milk scum: a

15. waste product from dairy industry. Energy sources. Part A, Recovery, utilization, and environmental effects. 2019. DOI: https://doi.org/10.1080/15567036.2019.1633441
16. Benson Varghese Babu, R Suresh & K V Yathish. Effects of Diary Scum Oil Methyl Ester on a DI Diesel Engine Performance and Emission. IOSR Journal of Applied Chemistry (IOSR-JAC) e-ISSN: 2278-5736. 3(6), 2013, PP 09-15
17. V. Kavitha, V.Geethab, P. Jennita Jacqueline. Production of biodiesel from dairy waste scum using eggshell wasteProcess Safety and Environmental Protection. 125, 2019, PP 279-287
18. Srikantha H.V., Venkatesh J., Sharanappa, Godiganur, Venkateswaran S., Bhaskar Manne. Bio-based diluents improve cold flow properties of dairy washed milk-scum biodiesel. Renewable Energy. 111, 2017, PP 168-174
19. Krishnamurthy K.N., Sridhara S.N., Ananda Kumar C.S., Synthesis and optimization of Hydnocarpus wightiana and dairy waste scum as feed stock for biodiesel production by using response surface methodology. Energy. 15, 2018, PP 1073-1086
20. Srikantha H.V., Venkatesh J., Sharanappa, Godiganur, Bhaskar Manne, S. Bharath Kumar.Combustion, performance, and emission characteristics of dairy-washed milk scum biodiesel in a dual cylinder compression ignition engine. 2019. https://doi.org/10.1080/15567036.2019.1618996
21. Manjunath N. Channappagoudraa,, Ramesh K., Manavendra G.,Influence of compression ratio on diesel engine fueled with dairy scum oil methyl ester. AIP Conference Proceedings, 2018, 2039(1), PP 1-8., https://doi.org/10.1063/1.5078966.
22. Sankar Vishnu, Manoj Ramachandran, Gireeshkumaran T hampi B.S., M.K.Jayaraj. Combined effects of thermal barrier coating and blending of diesel fuel with biodiesel in diesel engines. 11(3), 2019, PP 903-911
23. S. Premnath, G.Devaradjane. Improving the performance and emission characteristics of a single cylinder diesel engine having re-entrant combustion chamber using diesel and Jatropha methyl esters. Eco-toxicology and Environmental Safety.121, 2015, PP 10–15
24. Jatinder Kataria, S. K. Mohapatraa, K.Kundu. Biodiesel production from waste cooking oil using heterogeneous catalysts and its operational characteristics on variable compression ratio CI engine. Journal of the Energy Institute. 92(2), 2019, PP 275-287
25. Meshack Hawi, Ahmed Elwardanya, Shinichi Ookawara, Mahmoud Ahmed. Effect of compression ratio on performance, combustion andemissions characteristics of compression ignition engine fueled with jojoba methyl ester. Renewable Energy 141 2019, PP 632-645
26. Le Ning, Qimeng Duan, Yuhao Wei, Xin Zhang, Kang Yu, Bo Yang, Ke Zeng. Effects of injection timing and compression ratio on the combustion performance and emissions of a two-stroke DISI engine fuelled with aviation kerosene. Applied Thermal Engineering 161. 2019. PP 114-124.
27. P. Mohamed Shameer, K.Ramesh. Assessment on the consequences of injection timing and injection pressure on combustion characteristics of sustainable biodiesel fuelled engine. Renewable and Sustainable Energy Reviews. 81(1), 2018, PP 45-61
28. Yu Guanting Li Xiumin , Weibo Shi, Chuanzhao Yao, Sen Wang, Qingxu Shen. Effects of split injection proportion and the second injection timings on the combustion and emissions of a dual fuel SI engine with split hydrogen direct injection. International Journal of Hydrogen Energy. 44(21), 2019, PP 11194-11204
29. Liu Jie, Junle Wang, Hongbo Zhao. Optimization of the injection parameters and combustion chamber geometries of a diesel/natural gas RCCI engine. Energy, 164, 2018, PP 837-852
30. Singh Varun Paramvir , Samaresh Kumar Tiwari, Rituparn Singh, Naresh Kumar. Modification in combustion chamber geometry of CI engines for suitability of biodiesel: A review. Renewable and Sustainable Energy Reviews. 79, 2017, PP 1016-1033
31. S.V.Khandal, N.R.Banapurmath, V.N.Gaitonde. Effect of exhaust gas recirculation, fuel injection pressure and injection timing on the performance of common rail direct injection engine powered with honge biodiesel (BHO), Energy, 139, 2017, PP 828-841
32. Agarwal Avinash Kumar , Akhilendra Pratap Singh, Rakesh Kumar Maurya, Pravesh Chandra Shukla, Atul Dhar, Dhananjay Kumar Srivastava. Combustion characteristics of a common rail direct injection engine using different fuel injection strategies. International Journal of Thermal Sciences, 134, 2018, PP 475-484
33. Hwang Joonsik , Donghui Qi Yongjin Jung, Choongsik Bae. Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel. Renewable Energy. 63, 2014, PP 9-17
34. Karthickeyan V., Effect of combustion chamber bowl geometry modification on engine performance, combustion and emission characteristics of biodiesel fuelled diesel engine with its energy and exergy analysis. Energy, 176, 2019, PP 830-852
35. Vedharaj S., R.VallinayagamaW.M., Yanga C.G., Saravanan, P.S.Lee.Optimization of combustion bowl geometry for the operation of kapok biodiesel – Diesel blends in a stationary diesel engine. Fuel. 139, 2015, PP 561-567
36. Xiangrong Li, Yanlin Chen, Liwang Su, Fushui Li. Effects of lateral swirl combustion chamber geometries on the combustion and emission characteristics of DI diesel engines and a matching method for the combustion chamber geometry, Fuel, 224, 2018, PP 644-660
37. Pappula Bridjesh, Pitchaipillai Periyasamy, Narayanan Kannaiyan Geetha. Combined effect of composite additive and combustion chamber modification to adapt waste plastic oil as fuel on a diesel engine Journal of the Taiwan Institute of Chemical Engineers. 97, 2019, PP 297-30.
38. Li J., W.M. Yang, H. An, A. Maghbouli, S.K. Chou, Effects of piston bowl geometry on combustion and emission characteristics of biodiesel fueled diesel engines, Fuel, 120, 2014, PP 66-73.
39. N.R. Banapurmath, P.G. Tewari, R.S. Hosmath. Performance and emission characteristics of a DI compression ignition engine operated on Honge, Jatropha and sesame oil methyl esters. Renewable Energy, 33, 2008, PP 1982–1988
40. Mobasheri, R. and Peng, Z., "Analysis of the Effect of Re-Entrant Combustion Chamber Geometry on Combustion Process and Emission Formation in a HSDI Diesel Engine," *SAE Technical Paper* 2012-01-0144, 2012,
41. Mamilla V., Mallikarjun M.V., Lakshmi Narayana Rao G., Effect of Combustion Chamber Design on a DI Diesel Engine Fuelled with Jatropha Methyl Esters Blends with Diesel. International Conference on design and manufacturing, (IConDM), Procedia Engineering 64, 2013, PP 479 – 490.
42. Matsumoto, K., Inoue, T., Nakanishi, K., and Okumura, T., "The effects of combustion chamber design and compression ratio on emissions, fuel economy and octain number requirement," *Society of Automotive Engineers*. Paper No. 770193, 1977. doi:10.4271/770193.
43. Saito, T., Yasuhiro, D., Uchida, N., Ikeya, N., "Effects of Combustion Chamber Geometry on Diesel Combustion", SAE Paper 861186, 1986.
44. De Risi Arturo, Teresa Donateo, Domenico Laforgia. Optimization of the Combustion Chamber of Direct Injection Diesel Engines. Society of Automotive Engineers, Paper No.: 2003-01-1064, 2003.
45. Donateo Teresa, Antonio Paolo Carlucci, Luciano Strafella, and Domenico Laforgia. Experimental Validation of a CFD Model and an Optimization Procedure for Dual Fuel Engines. Society of Automotive Engineers, Paper No.: 2014-01-1314, 2014.
46. S.Jaichandar and K.Annamalai. Effects of open combustion chamber geometries on the performance of pongamia biodiesel in a DI diesel engine. Fuel. 98, 2012, PP 272-279
47. Yaliwal, V. S., Banapurmath, N. R., Gireesh, N. M., Hosmath, R. S., Donateo, T., Tewari, P. G., Effect of nozzle and combustion chamber geometry on the performance of a diesel engine operated on dual fuel mode using renewable fuels. Renewable energy, 93, 2016, PP 483-501
48. Ganji Prabhakara Rao, Rudranath Singh, V. R. K Raju, S. Srinivasa Rao. Design of piston bowl geometry for better combustion in direct-injection compression ignition engine. Sådhanå, 2018, PP 43:92 https://doi.org/10.1007/s12046-018-0907-x.
49. Raouf Mobasheri, Zhijun Peng. The Development and Application of Homogeneity Factor on DI Diesel Engine Combustion and Emissions. 2013. SAE Technical Paper.DOI: 10.4271/2013-01-0880


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