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RESEARCH ARTICLE

OPTIMIZATION OF COMPRESSION IGNITION ENGINE FUELLED WITH COTTON SEED BIODIESEL USING DIGLYME AND INJECTION PRESSURE

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ABSTRACT

The main research problem from the usage of diesel engine arises from increased fuel prices and emissions releasing from combustion. The objective of the current work relies on finding out a suitable biodiesel blend and improving the diesel engine characteristics by means of additives. The current study discusses about the optimization of the diesel engine characteristics employing cotton seed biodiesel (CSOME) blends. CSOME 20 was found to give the better engine characteristics. Also the engine characteristics were optimized with the addition of diglyme at proportions of 10 and 15% to CSOME20. Along with further optimization was done with varying injection pressure values. It was observed that CSOME DGM 15 reduced the smoke and carbon monoxide emissions with rise in Nitrogen Oxides. BTE was recorded to be highest at 220 bar. Smoke and hydrocarbon were found to be minimum at 220 bar with maximum NOx emissions.

KEYWORDS

Biodiesel, Diglyme, Injection pressure, Performance, Emission

1. INTRODUCTION

The multifaceted capability of diesel engines made its usage in various sectors and also combines the advantages of high brake thermal efficiency (Jeyakumar et al., 2020; Jeyakumar et al., 2022a). Increase in air pollution is mainly due to fossil fuels burning which produces emissions such as carbon monoxide, hydrocarbon and nitrogen oxides and global warming that creates adverse impacts on the ecosystems and particularly human beings (Sayyed et al., 2022; Narayanasamy et al., 2021; Nagarajan and Balasubrmanian, 2021). The need for the search of bio-based alternative fuels have risen from various factors such as increased demand in power production, limited availability of fossil fuel reserves together with adverse environmental effects. In spite of several positive effects such as non-toxic, biodegradable, and renewable nature made biodiesel to be a reliable substitute to diesel fuel (Imtenan et al., 2014; Jeyakumar et al., 2022b). Biodiesel research has gained a major importance in spite of its various benefits such as better combustion quality, reduced exhaust emissions and an eco-friendly based fuel (Kolakoti et al., 2021). Raw vegetable oil have increased viscosity in the order of > 40 cSt leads to poor atomization which cannot be directly used in diesel engines.

This viscosity can be reduced by employing various techniques like thermal cracking, blending, micro – emulsification and transesterification of which the latter is widely used (Kalakoti et al., 2022a). Among various fuel properties, viscosity and density are predominant factors as they flow through different nozzles, pipe lines and orifices. Fuel atomization greatly depends on fuel viscosity and density which impacts the engine parameters. The usage of oxygenated additives tends to decrease both viscosity and density (Agarwal and Das, 2001). Transesterification is the most suitable way to decrease the viscosity of the raw vegetable oil nearer to that of diesel thus reducing engine related problems. It is the method of treating a triglyceride and alcohol employing a catalyst in order to synthesize glycerol and biodiesel (Nabi et al., 2009).

Biodiesel also offers various benefits such as very low sulphur content, improved Cetane index, inbuilt O_2 content in biodiesel and lubricity (Kolakoti et al., 2022b). The biodiesel synthesised from both non-edible and edible oil category are termed to be first and second generation. Biodiesel synthesised from micro algae and captured carbon are coined to be third and fourth generation biodiesels. Many researchers proposed that blending of about 20 % biodiesel with neat diesel fuel requires no engine modifications. Optimisation of the engine parameters such as performance, combustion and emission parameters depends on mixing single type of biodiesel with diesel fuel (Sayyed et al., 2022).

Gossypium herbaceum and Gossypium hirsutum are the important species of cotton plants employed for the cotton seed oil synthesis. Cotton plants grow up-to a maximum height of about 1.2 m. Different kinds of non-glyceride compounds are present in the oil such as resins, sterols, gossypol, carbohydrates, phospholipids and related pigments. The oil range in the seeds are between 17 to 25 %. The fatty acid content of cotton seed oil comprises of 19.2 to 23.26 % oleic acid, 55.2 to 55.5 % linoleic acid and 11.07 to 20.1 % palmitic acid (Singh et al., 2020). Experimental works have reported that employment of raw cotton seed oil in diesel engine as fuel leads to reduced engine performance, increase in Carbon monoxide & Hydrocarbon emissions and decline in Oxides of Nitrogen (Aydin and Bayindir, 2010). Experimental investigation of utilising cotton seed biodiesel in DI Compression Ignition engine showed increased thermal efficiency, reduced smoke opacity and increased NOx emissions (Geyer et al., 1984).

It was also recorded that slight decrease in performance and rise in specific fuel consumption with rise in CSOME proportion (Carraretto et al.,

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2004). CO emission found to decrease with increased NOx emissions. The oxygenated additive such as DGM (diethylene glycol dimethyl ether) can be blended with diesel fuel to reduce the emissions (Nabi et al., 2019). Experimental investigations indicated that maximum power difference for diesel – cotton seed oil biodiesel blends and diesel increased with the quantity of cotton seed oil biodiesel. For B20, BSFC readings were observed to be less than that of diesel fuel. Minimum CO emissions were noted for B50, B75 and B100 blends. Except B5 blends, NOx emissions were found to be reduced for all other blends. This trend can be related to the increased viscosity and reduced calorific value of the cotton seed oil (Aydin and Bayindir, 2010). Experimental study was carried out employing cotton oil soap stock biodiesel & diesel blends in a single cylinder compression ignition having direct injection.

It was observed that engine power output and engine torque found to decrease by 5.8 % and 6.2 % respectively for biodiesel blends and diesel fuel. Based on the quantity of biodiesel and engine speeds, SFC increased by about 10.5 % (Keskin et al., 2008). In the present research cotton seed biodiesel was synthesised through transesterification and various fuel blends were prepared with various volume % of 20, 40 and 60. The fuel samples were experimented in a diesel engine to determine the engine parameters. The engine characteristics were optimised by varying the fuel samples with oxygenated additive Diglyme and varying the nozzle opening pressure from 180 bar – 220 bar.

2. Materials and Methods

2.1 Biodiesel Production from CSO

NaOH and 99.9 % pure methanol was collected in a strong glass having a narrow neck in order to avoid splashing. The mixture was then shaked well. The product obtained was sodium methoxide which was hot and fume. The raw cotton seed oil was collected in a glass bottle and heated from 40 to 50°C in order to remove the moisture content. Mixing and stirring of sodium methoxide and hot oil was carried out for about 60 minutes and kept in an oven at a temperature of 55 to 60 °C. After about 24h the top layer was found to possess clear reddish liquid with black glycerine settled at the bottom. The biodiesel was collected at the bottom. The biodiesel was isolated from glycerine by employing a separating funnel (Nabi et al., 2009). Diglyme also known as Diethylene glycol dimethyl ether of 99 % purity was purchased from Sigma Aldrich. Biodiesel test fuel samples were made at different blend ratios of 20, 40, 60, and 100 % by volume and labelled as CSOME20, CSOME40, CSOME60 and CSOME respectively. Also, with CSOME 20 diglyme was blended in a volume ratio of 10 and 15% which was labelled as CSOME DGM10 and CSOME DGM 15 respectively.

2.2 Experimental Setup

The engine setup employed in the present study was one cylinder, 4 stroke, water cooled, DI naturally aspirated compression ignition engine. The engine was load controlled employing a dynamometer with eddy current principle. A standard injection pressure of 200 bar was employed. The engine details were presented in table 1. The photographic view of the engine setup was shown in Figure 1. All the experimental trials were carried out at normal pressure and temperature. The temperature of the cooling water outlet and exhaust gas was evaluated with thermocouples fitted at the respective passage. The engine was made to run at idle conditions with the test fuel samples. The engine was brought to idle conditions using diesel as fuel. Biodiesel in the previous cycle was purged by means of running the engine with diesel before shifting to another blend. AVL Di Gas analyser was employed to evaluate the Carbon monoxide, Hydrocarbon, Nitrogen Oxides emissions with specifications shown in the table. AVL 437C smoke meter was employed to evaluate the smoke emissions. All the experiments were repeated in trials and the average readings were calculated.

Table 1: Engine Specifications

Type	Kirloskar TV-I engine
Bore (mm)	87.5
Stroke (mm)	110
Compression Ratio	17.5:1
Speed (RPM)	1500
Rated Brake Power	5.2 kW
Injection	Direct Injection
Cooling medium	Water
Injection Pressure (bar)	200
Thermocouple	K Type

Figure 1: Photographic View of the Experimental Engine Set Up

Table 2: AVL Di Gas Analyser Specifications

Emission	Range of Measurement	Resolution
Carbon monoxide	0 to 10 % volume	0.1 % volume
Hydrocarbon	0 to 20000 PPM volume	≤ 2000: 1 PPM volume, > 2000:10 PPM volume
Nitrogen Oxides	0 to 5000 PPM volume	1 PPM volume

3. Results and Discussion

3.1 Study on Brake Thermal Efficiency (BTE)

BTE was observed to be lower for higher blends of biodiesel. This can be correlated to the poor combustion properties arising out of higher viscosity and reduced volatility. Earlier experimental studies recorded that increased injection pressure leads to efficient atomisation and good mixing thus reducing BSFC and increasing BTE. Also reduced nozzle opening pressure decreased the maximum gas cylinder temperature, producing poor air fuel mixture thus increasing BSFC and reduced BTE (Imtenan et al., 2014). Reddy et al. 2009 recorded that up to an increase in nozzle opening pressure of 200 bar, BTE increased in spite of fine spray produced during injection and increased atomisation thus producing better combustion. However, increase in injection pressure after a certain limit reduced the BTE because of the reduced momentum of spray fine droplets which decreased the droplet penetration in to the combustion chamber (Imtenan et al., 2015).

Increased brake thermal efficiency is attributed due to improved atomization, spray characteristics and better mixing of fuel and air. However too much increase in injection pressure will lead to problems in spray pattern and penetration (Belagur et al., 2009). Similar results were observed with the Neem oil biodiesel in diesel engine. The increased energy production of diesel fuel in spite of increased calorific value of diesel fuel. The decreasing trend of BTE for biodiesel samples can be related to their decreased density and kinematic viscosity which leads to poor atomisation and combustion characteristics (Viswanathan, 2018). Figure 2 shows the change of BTE with BMEP for fuel samples. Figure 3 shows the change of BTE with BMEP for fuel samples at various injection pressure.

3.2 Study on Brake Specific Fuel Consumption (BSFC)

BSFC is termed as the mass of fuel utilised by the diesel engine to the brake power. Similar results of increased BSFC for the prepared samples of biodiesel are due to lower heating value. Lower blends of biodiesel showed reduced BSFC in spite of its lower kinematic viscosity (Viswanathan, 2018). The increase in BSFC for higher blends of biodiesel are in spite of reduced calorific value which leads to enhanced mass flow rate of the fuel to compensate the fuel energy input. The enhancement of BSFC for the increased % can be correlated to reduced fuel spray angles with enhanced fuel penetration, which negatively affect the air entrainment. Poorly created fuel sprays which affects the air fuel mixing are the reasons for reduced engine performance (Devan and Mahalakshimi, 2009). In case of lower nozzle opening pressure the diameter of the fuel particles increases and thus ignition delay period escalates which increases the BSFC. At higher injection pressure better atomization is observed with better charge mixing of fuel thus increasing the combustion efficiency and reducing the BSFC (Imtenan et al., 2015). Figure 4 depicts the change of Brake Specific Fuel Consumption with BMEP for various fuel samples.

3.3 Study on Nitrogen Oxides Emission

NOx emission is a mixture of various components such as nitrous oxide, nitric oxide and nitrogen dioxide. Amidst the components 90 % is occupied by nitric oxide, 5 % volume was occupied by nitrous oxide and nitrogen dioxide respectively. The combination of nitrogen dioxide and nitric oxide was termed as oxides of nitrogen. In spite of the presence of excess fuel O_2 biodiesel produced increased NOx emissions (Viswanathan, 2018).

It was recorded that Nitrogen Oxides emission enhanced with engine load in spite of temperature of combustion chamber. The most significant factors affecting NOx emissions are local stoichiometric ratio of the mixture and the in-cylinder combustion temperature. NOx reduction was the most harmful emission from diesel engine, and it should be always reduced. The decrease in NOx emissions for pure biodiesel can be correlated to the reduced heating value of test fuel (Devan and Mahalakshmi, 2009). On comparison with diesel, Oxides of Nitrogen emissions were found to be higher with the addition of oxygenates. Increased NOx emissions can be attributed to the following factors such as fuel injection timing, in cylinder temperature, fuel properties, residence time and local availability of oxygen. The reasons for increase in Oxides of Nitrogen emissions with oxygenates addition can be related to increased O_2 concentration leading to complete combustion, increased adiabatic flame temperature, reduced radiative heat transfer (Nabi et al., 2019). Increase in injection pressure produces reduced droplet diameter thus the fuel spray vaporises more quickly. Hence the fuel cannot deeply penetrate into the combustion chamber. Thus it paves to generation of faster combustion rate and increased combustion chamber temperature which increases the NOx (Imtenan et al., 2015). Figure 5 depicts the change of Oxides of Nitrogen with BMEP for different fuel samples. Figure 6 shows the change of Oxides of Nitrogen with BMEP for various fuel samples with Diglyme. Figure 7 depicts the change of NOx with BMEP for various fuel blends at different injection pressure.

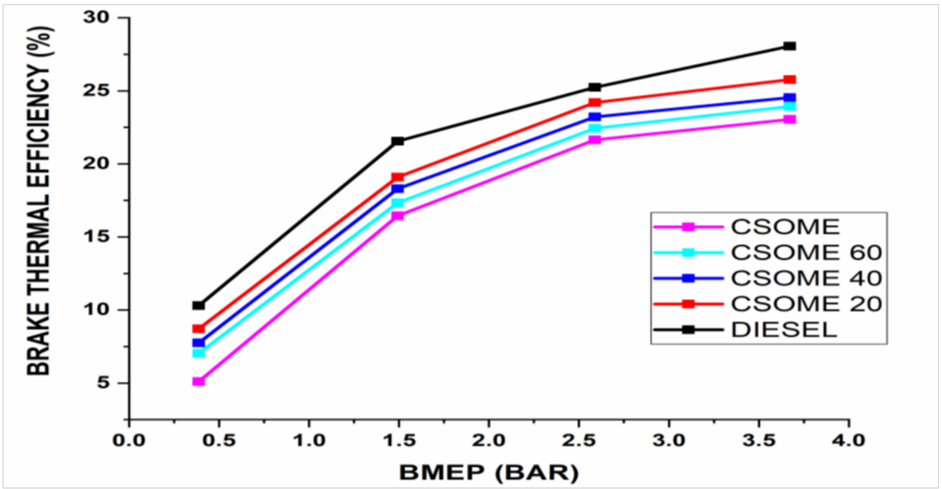

Figure 2: Variation of BTE with BMEP for Fuel Blends

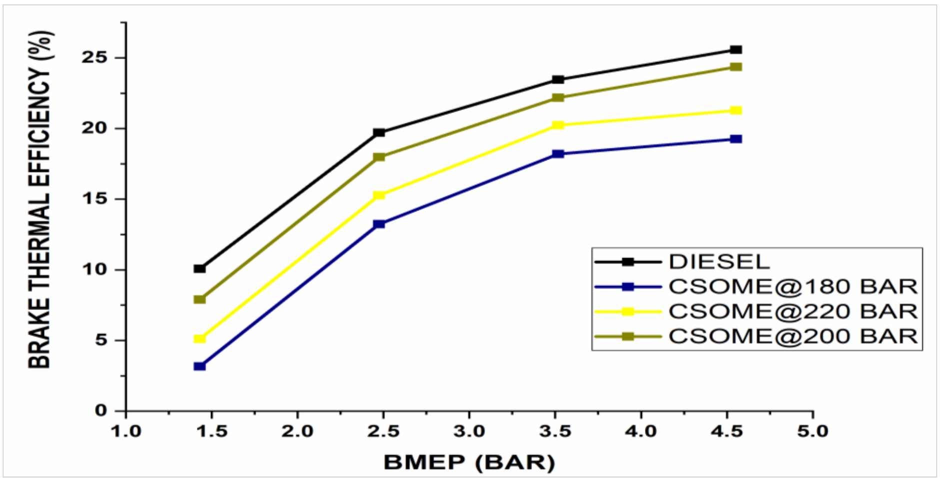

Figure 3: Change of BTE With BMEP for Fuel Samples at Various Injection Pressure

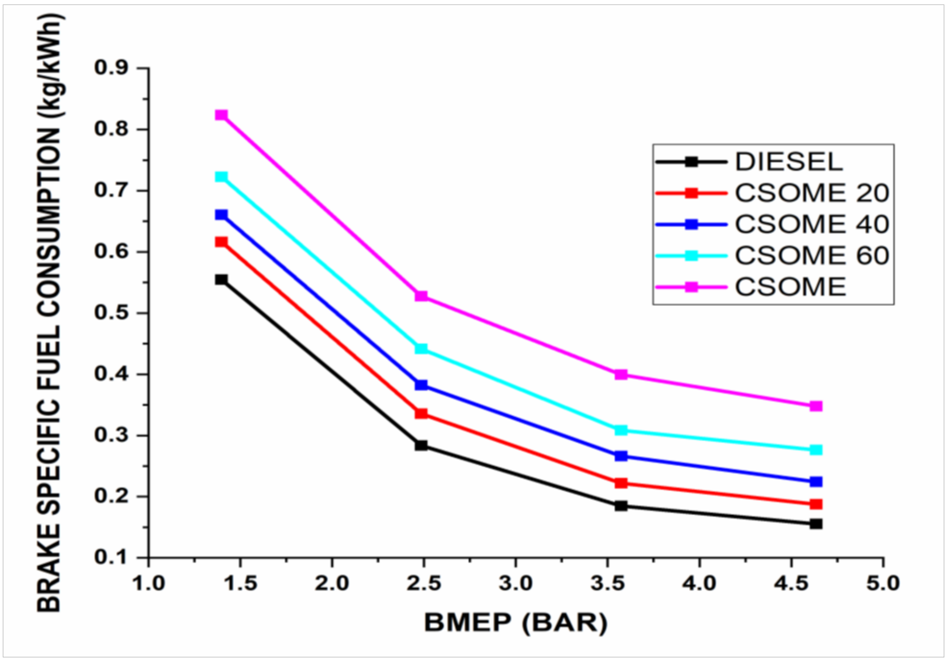

Figure 4: Change of BSFC With BMEP for Fuel Samples

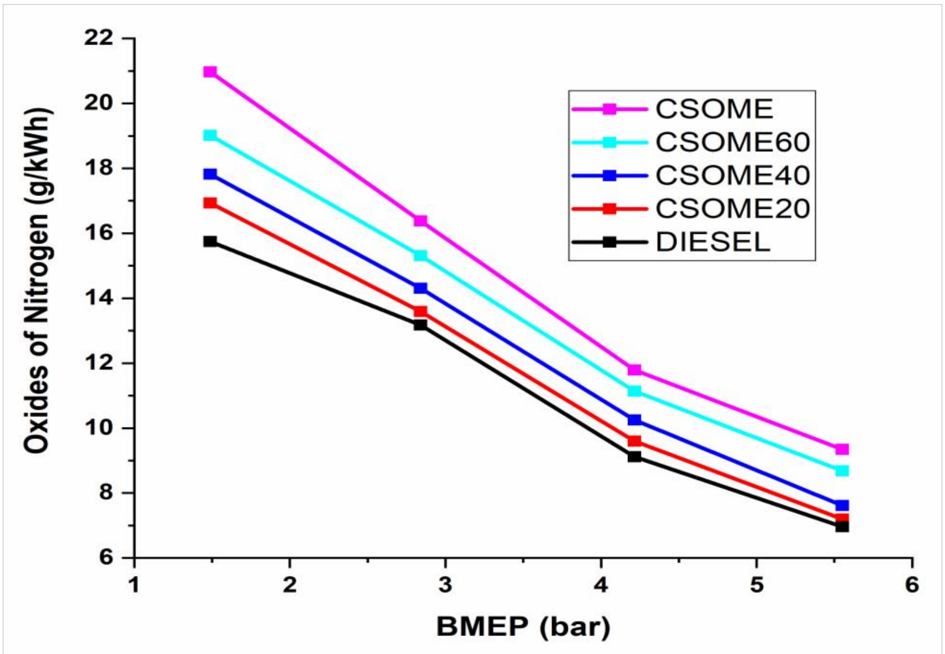

Figure 5: Change of NOx with BMEP for Fuel Samples

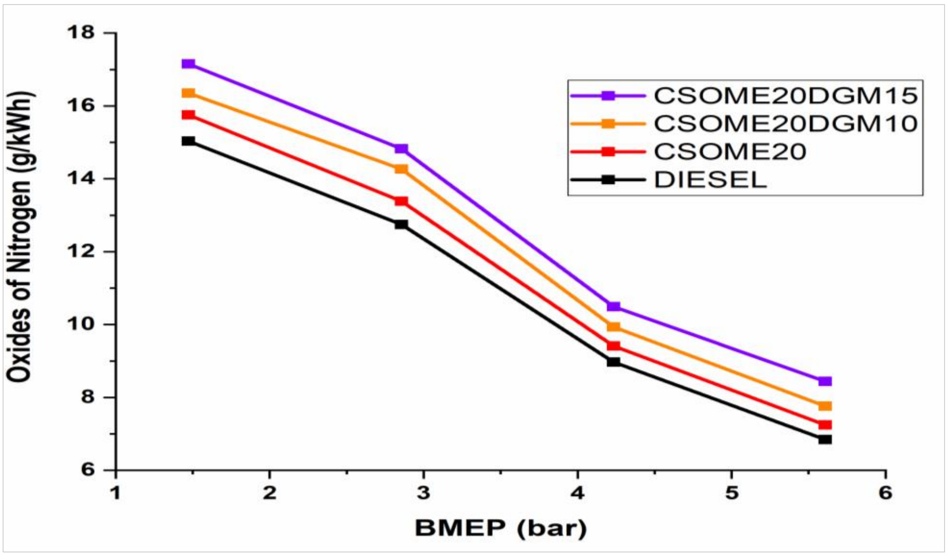

Figure 6: Change of NOx with BMEP for fuel Samples with Diglyme

3.4 Study on Hydrocarbon Emission

Hydrocarbon emission occurs from the diesel engine in spite of incomplete combustion. Hydrocarbon emission depends on factors such as cylinder or cylinder wall temperature, Cetane number and oxygen component existing in the test fuel samples (Sayyed et al., 2022). The hydrocarbon emissions were found to increase except for neat 20 blend on comparison with diesel fuel. The impact of fuel viscosity on fuel spray quality tends to produce increased HC with vegetable oils. Physical characteristics like density & viscosity tends to increase the fuel spray droplet size on comparison with other fuel samples and diesel. The rise in carbon monoxide emissions for fuel blends other than B20 can be attributed to the physical property which impacts the fuel spray quality (Devan and Mahalakshmi, 2009).

Increase in injection pressure produces superior A/F mixture inside the cylinder hence reducing the HC (Imtenan et al., 2019). Air fuel mixing was much appropriate with increased injection pressure thus producing lower HC (Srivastava et al., 2018). It was recorded that increase in injection pressure above a particular limit make the fuel droplet to travel with an increased velocity which may hit the walls of combustion chamber thus producing un burnt hydrocarbon emissions (Puhan et al., 2009). The droplet size production and rate of penetration of fuel inside the cylinder are impacted by fuel characteristics like viscosity and surface tension which promotes the air fuel mixing inside the cylinder (Viswanathan, 2018). Figure 8 shows the variation of HC with BMEP for fuel blends. Figure 9 shows the change of Hydrocarbon with BMEP for fuel samples at various injection pressure.

3.5 Study on Carbon Monoxide Emission

Carbon monoxide formation originates from the sluggish combustion of fuel. Biodiesel are considered to be oxygenated fuels and the existence of O_2 in their fuel structure lead to improved combustion thus reducing CO emissions on comparison with diesel fuel as they do not possess O_2 molecules with it (Sayyed et al., 2022). Increase in injection pressure promotes good air fuel mixing, complete combustion of smaller fuel droplets thus decreasing the CO emissions (Imtenan et al., 2015). In spite of high-pressure complete combustion of fuel occurs in spite of better air fuel mixing thus producing reduced CO emissions (Srivastava et al., 2018). Increased CO can be related to sluggish combustion of fuel inside the cylinder. Increased O_2 content in the biodiesel and minimised possibility of fuel rich formation zones are the reasons to achieve complete combustion. Results from the previous studies indicated that increased CO emission was recorded for diesel fuel than the biodiesel fuel samples (Viswanathan, 2018). Figure 10 shows the change of Carbon monoxide with BMEP for fuel samples. Figure 11 shows the change of CO with BMEP for fuel samples with Diglyme.

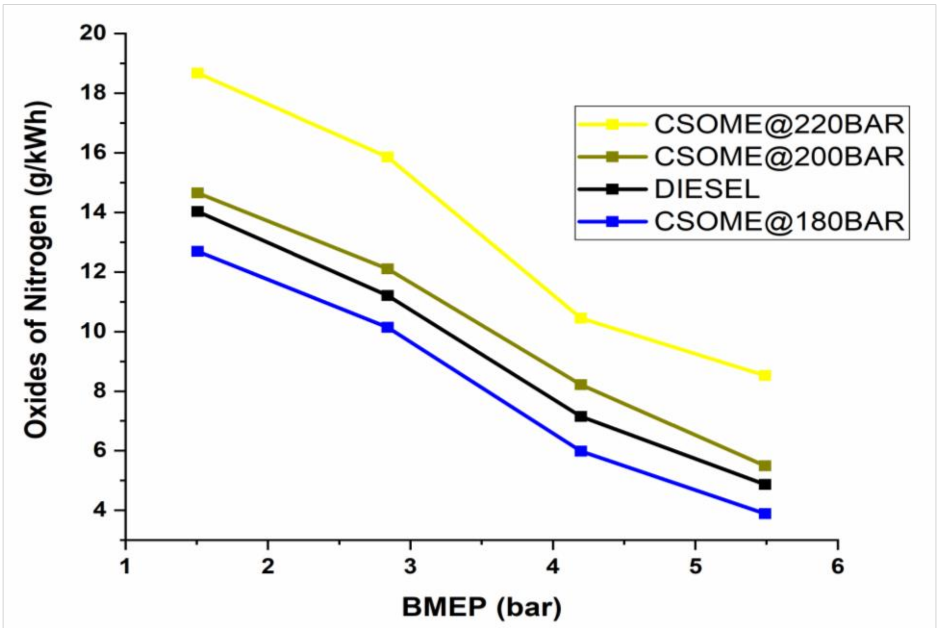

Figure 7: Change of Nitrogen Oxides with BMEP for Fuel Blends at Various Injection Pressure

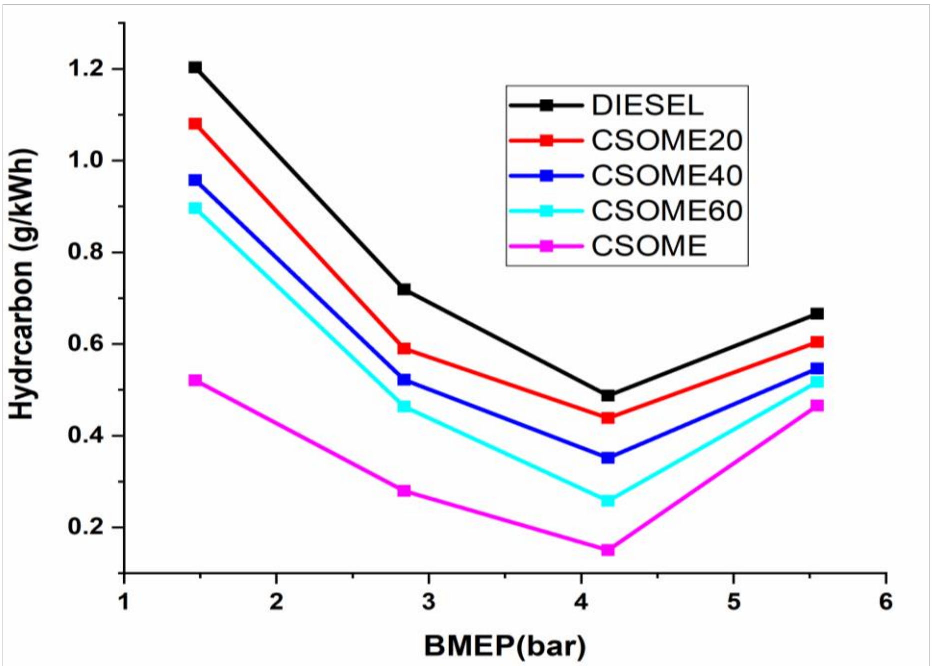

Figure 8: Change of HC with BMEP for Fuel Samples

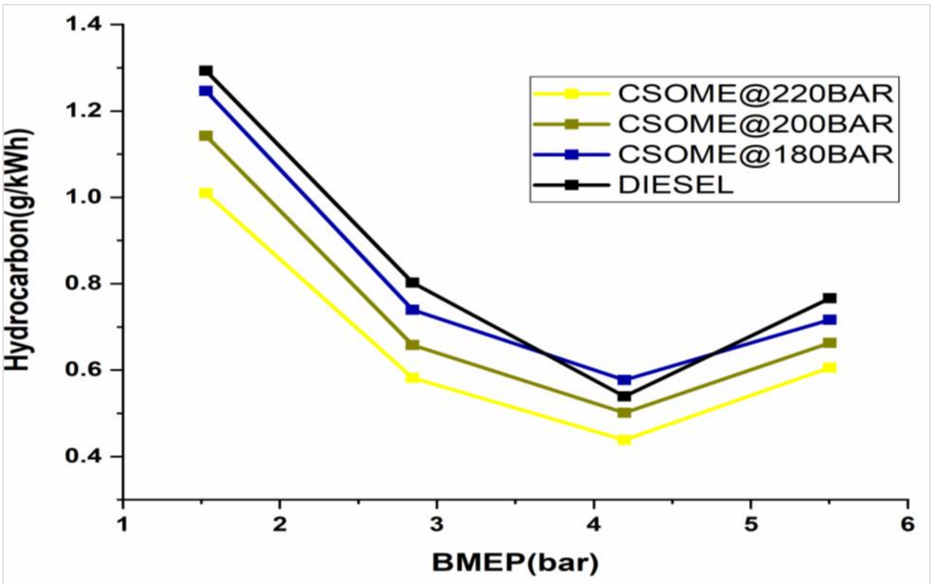

Figure 9: Change of HC with BMEP for Fuel Samples at Various Injection Pressure

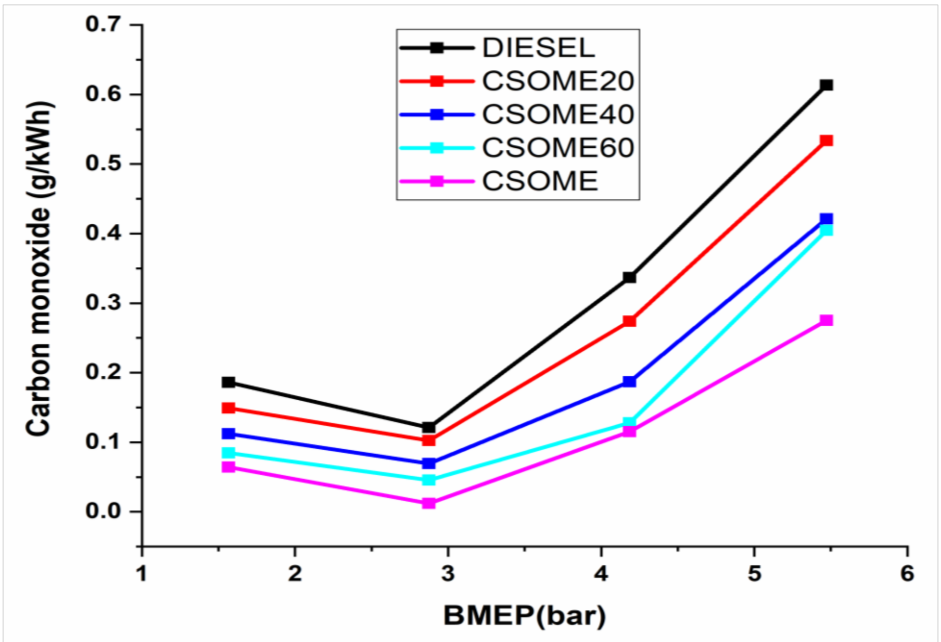

Figure 10: Change of CO with BMEP for Fuel Samples

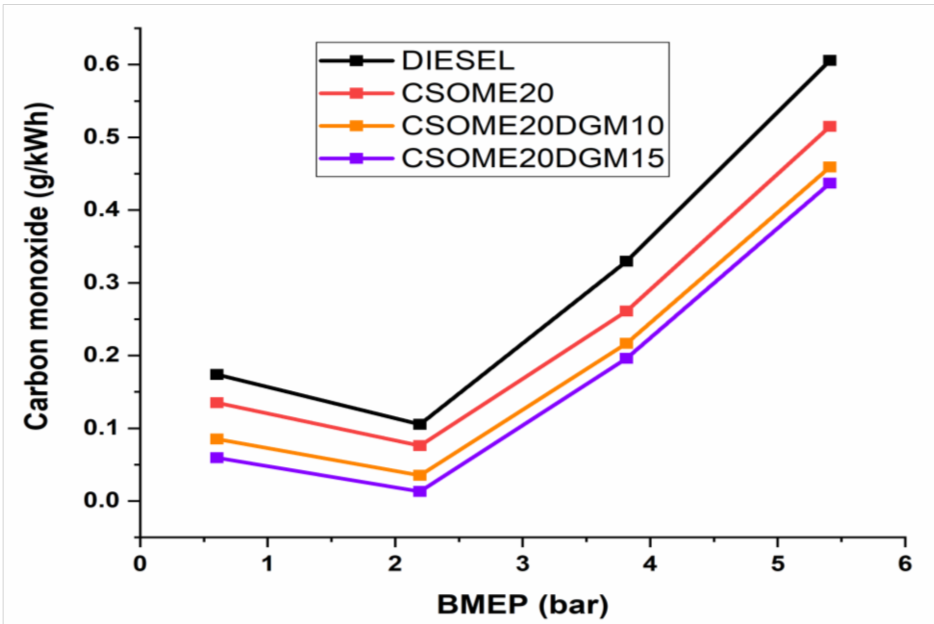

Figure 11: Change of CO with BMEP for Fuel Samples with Diglyme

3.6 Study on Smoke Emission

Smoke is formed due to the reaction in partial manner between unburned Hydrocarbon & Carbon in liquid level. Increase in injection pressure reduced the residence time for smoke opacity formation and promote better mixing of A/F mixture. Previous experimental studies indicated that smoke level reduced by about 52 % when the fuel injection pressure is increased from 200 bar to 240 bar. The increase in nozzle opening pressure resists the formation of particle and smoke level by promoting enhanced OH radicals which acts as oxidants (Fayad, 2019).

The lower smoke emissions observed for biodiesel are due to the factors such as better spray atomisation, increased mixing of fuel and air and presence of O_2 molecules in the biodiesel samples (Viswanathan, 2018). Higher smoke emissions obtained for higher blends of biodiesel are in spite of higher viscosity which reduces the air fuel mixing rate and produces larger mean droplet diameter (Devan and Mahalakshmi, 2009). Figure 12 shows the change of Smoke with BMEP for fuel blend samples. Figure 13 depicts the change of Smoke with BMEP for fuel blends with Diglyme. Figure 14 shows the variation of smoke with BMEP for fuel samples at various injection pressure.

3.7 Study on Cylinder Pressure

The area below the second peak which indicated the phase of diffusion burning is higher than that of the phase of premixed combustion. This is because at the stage of ignition reduced F/A mixture is formed for combustion at the ignition time. So enhanced burning persists in the diffusion burning stage on comparison with premixed phase. B20 blend shows better combustion characteristics in spite of better spray formation and reduced viscosity. The cylinder pressure values were analysed to evaluate the heat release rate (Viswanathan, 2018). Injection pressure has a major impact on the combustion parameters of compression ignition engine. The combustion characteristics taken into account for study includes in maximum rate of pressure rise, combustion chamber pressure and heat release rate. In general ignition delay reduces with rise in injection pressure.

Previous experimental studies indicated that with increase in nozzle opening pressure, the maximum cylinder pressure rate and peak in cylinder pressure has been increased. Increase in in-cylinder pressure indicates that more quantity of fuel is burnt in the earlier combustion stage or in the premixed combustion stage (Imtenan et al., 2015). The variation of cylinder pressure can be attributed to the increased viscosity and density of the test fuel samples. Lower heating value and Cetane number of the biodiesel test samples promotes variation in Heat Release Rate (Sayyed et al., 2022). Figure 15 shows the change of cylinder pressure with Crank Angle for the test fuel samples. Figure 16 shows the change of Cylinder pressure with Crank Angle for fuel samples with Diglyme.

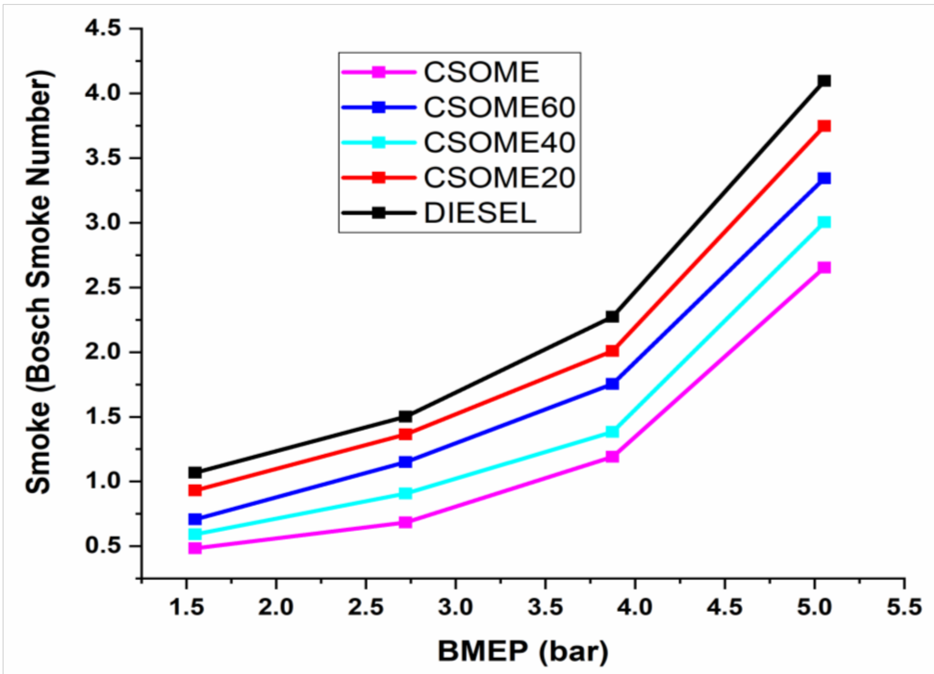

Figure 12: Change of Smoke with BMEP for Fuel Samples

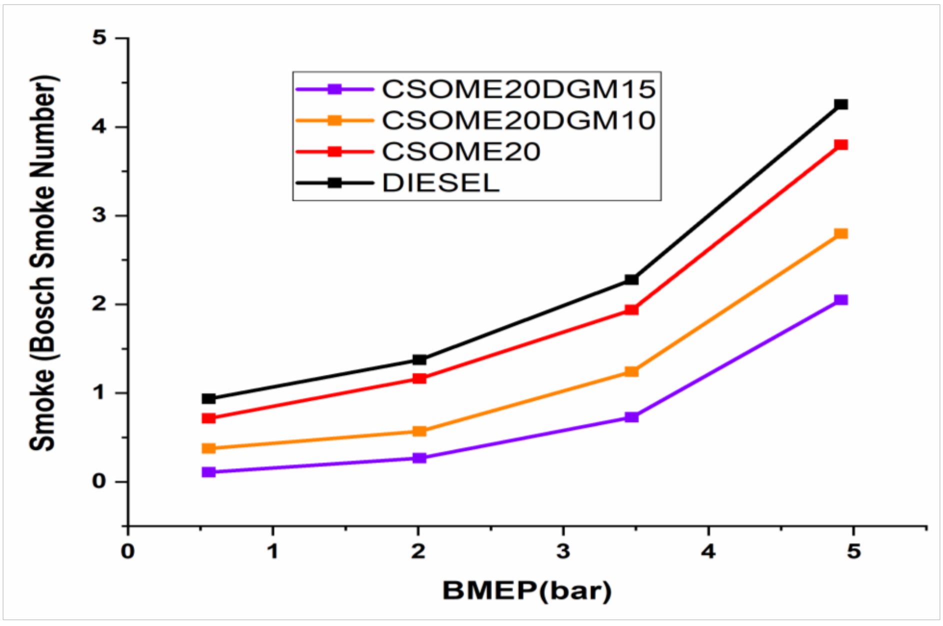

Figure 13: Change of Smoke with BMEP for Fuel Samples with Diglyme

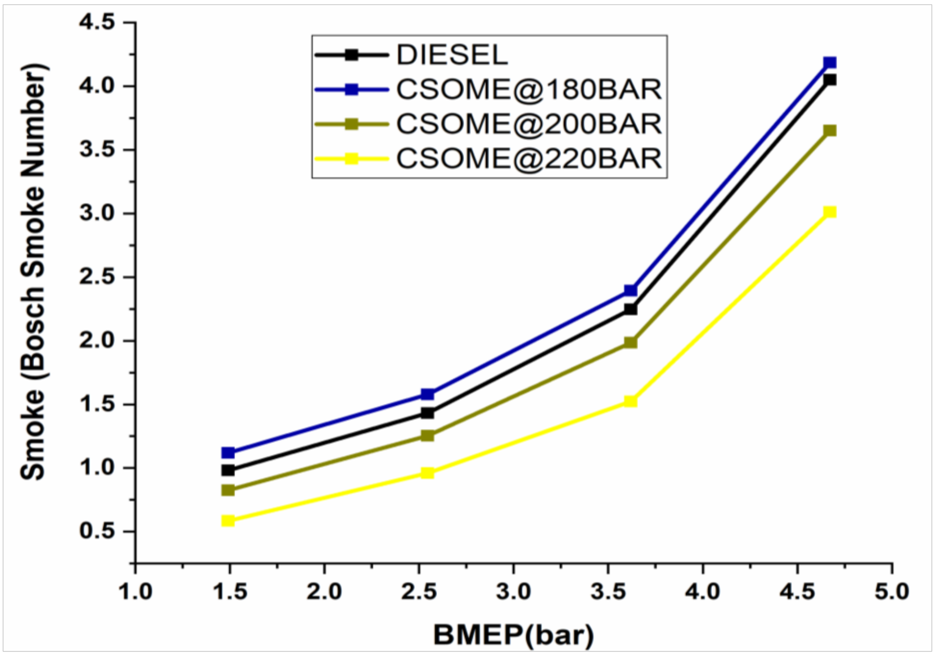

Figure 14: Change of Smoke with BMEP for Fuel Samples at Various Injection Pressure

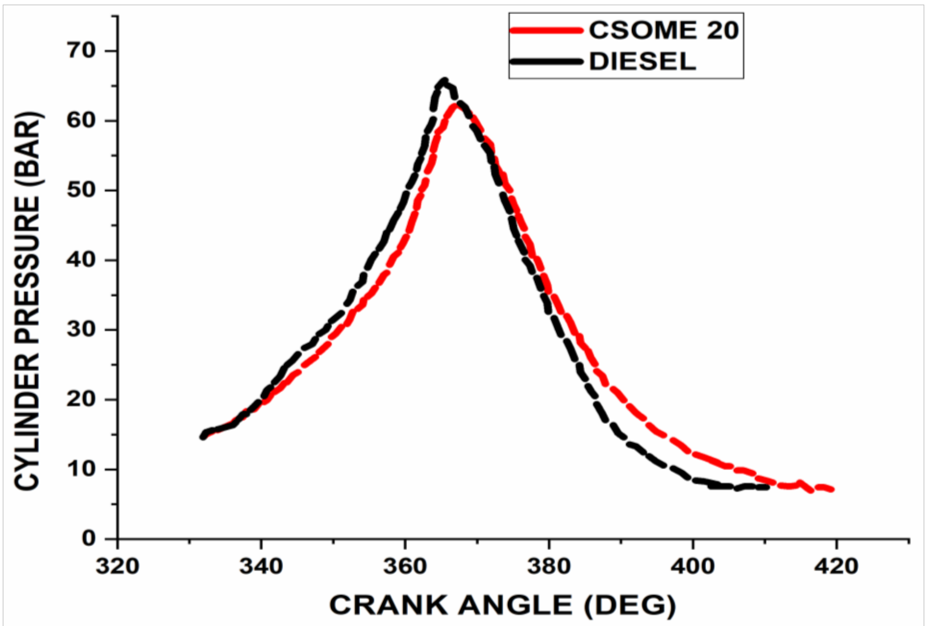

Figure 15: Change of Cylinder Pressure with Crank Angle for Fuel Samples

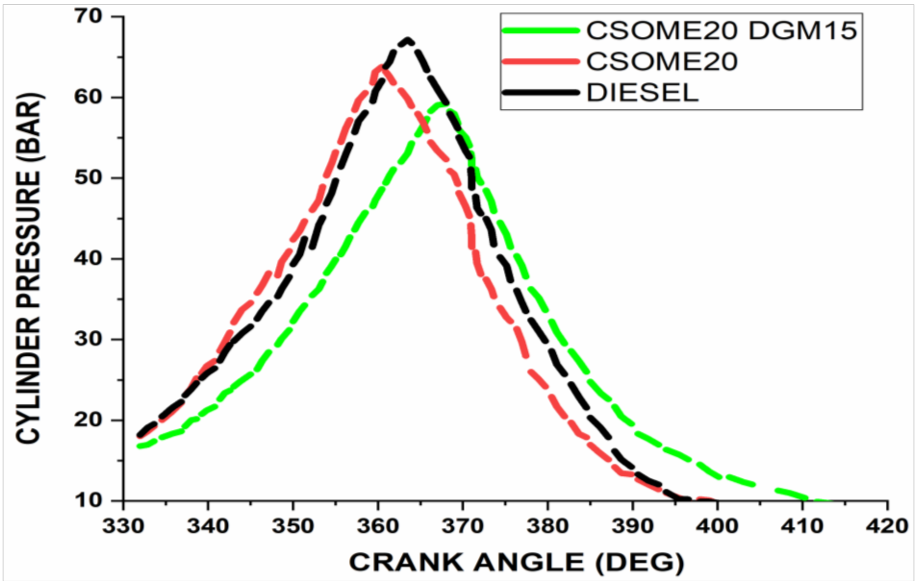

Figure 16: Change of Cylinder pressure with Crank Angle for Fuel Samples with Diglyme

3.8 Study on Heat Release Rate

Mixing rate of air- fuel, ignition lag, and the calorific value of fuel are the factors affecting the heat release from combustion of fuel. The fuel samples show a negative HRR during the ignition lag. Ignition occurs when the HRR gradient is positive. During the onset of combustion, the heat release from the fuel is less than chemical reactions / cooling heat loss. In spite of higher energy content for diesel fuel, high peak pressure is observed (Nabi et al., 2019).

Rise in nozzle opening pressure produces improved fuel atomization at the outlet of nozzle thus producing vapour phase in uniformly distributed and efficient combustion. Smaller particles of atomised fuel also produces reduced ignition delay. Thus more quantity of fuel accumulated in the ignition delay period and producing high premixed heat release rate because of large quantity of fuel burning. In summary, it can be concluded that increased injection pressure reduces the ignition delay, increases phase of premixed combustion thus increasing peak combustion chamber pressure & heat release rate (Imtenen et al., 2014). Figure 17 depicts the change of Heat Release Rate with Crank Angle for Diesel fuel. Figure 18 depicts the change of HRR with Crank Angle for fuel blends with CSOME20. Figure 19 depicts the change of HRR with Crank Angle for fuel blends with CSOME20-Diglyme.

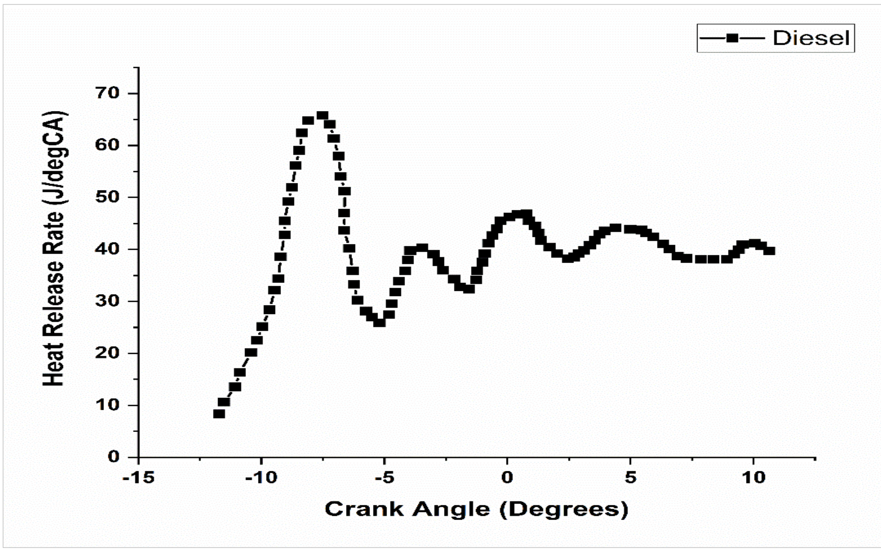

Figure 17: Change of HRR with Crank Angle for Diesel

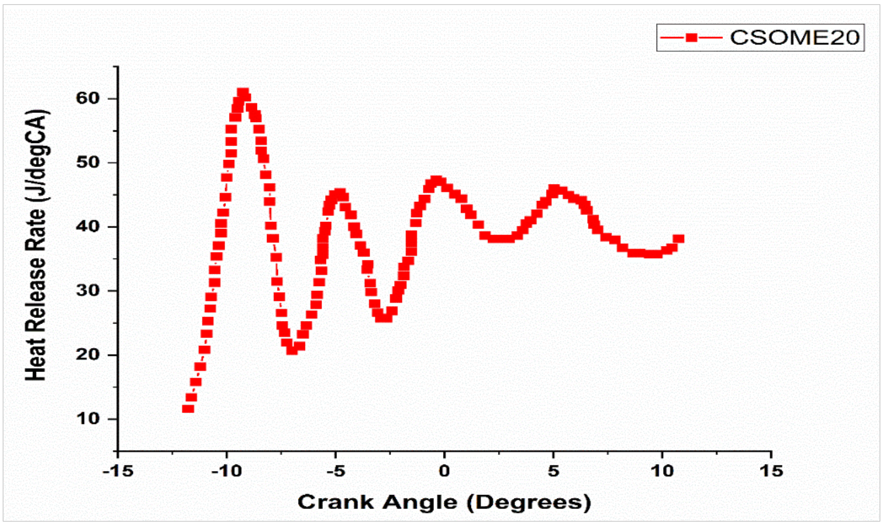

Figure 18: Change of HRR with Crank Angle for CSOME20

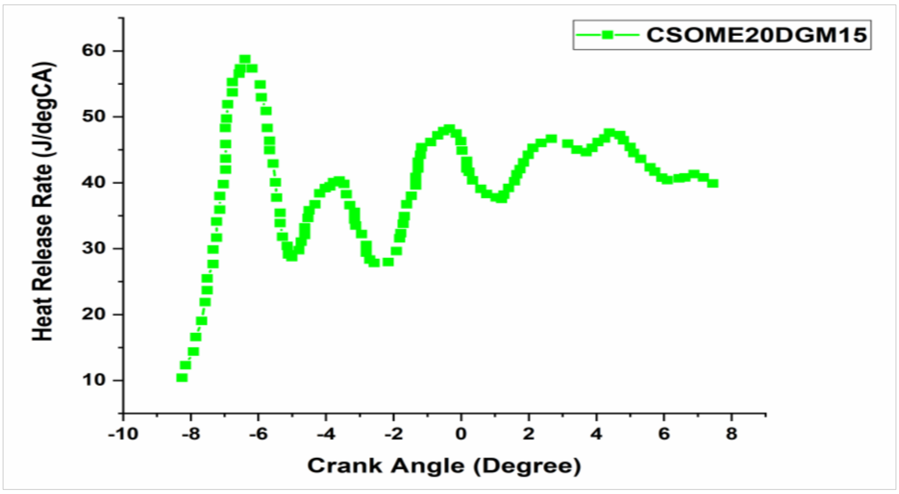

Figure 19: Change of HRR with Crank Angle for Fuel Samples with Diglyme

4. Conclusions

In the current research work cotton seed biodiesel was synthesised through transesterification and various fuel blends were synthesised with various volume % of 20, 40 and 60. The fuel samples were experimented in a compression ignition engine to determine the engine characteristics. The CI engine characteristics were optimised by varying the fuel samples with oxygenated additive Diglyme and varying the nozzle opening pressure ranging from 180 bar to about 220 bar.

The following observations were made as follows:

- Among the tested fuel samples CSOME 20 was found to give the better engine characteristics.
- Also the engine characteristics were optimized with the addition of oxygenated additive Diglyme at proportions of 10 and 15% to CSOME20.
- Along with further optimization was done with varying nozzle opening pressures ranging from 180 to 220 bar.
- It was observed that CSOME DGM 15 reduced the smoke and carbon monoxide emissions with rise in Nitrogen Oxides emissions.
- BTE was observed to be highest at 220 bar.
- Hydrocarbon and smoke opacity were found to be minimum at 220 bar with maximum NOx emissions.

The future scope of the work can be improved by inclusion of RSM optimization and ANN modelling in production of biodiesel [8].

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