Emission, Combustion and Performance Analysis of Neem Oil Methyl Ester Blends with Compressed Natural Gas in the presence of EGR

Ravi Kathirvel*, Vijayabalan Palanimuthu*, Hariram Venkatesan*‡

*Department of Mechanical Engineering, Hindustan Institute of Technology & Science, Padur, Chennai

(ravi.021074@gmail.com, vijayabalan@hindustanuniv.ac.in, connect2hariram@gmail.com)

‡ Hariram V, Department of Mechanical Engineering, Hindustan Institute of Technology & Science, Padur, Chennai, Tamil Nadu, India, Tel: +8939092346

connect2hariram@gmail.com

Received: 31.12.2021 Accepted: 28.01.2022

Abstract- Towards the exertion of cutting down the environmental pollutant emissions and the consumption of fossil fuels considering fuel economy also, scientists have proposed different alternatives among which CNG consolidated with biodiesel fuel is one of the best surrogates to the traditional diesel fuel. The ultimate aim of this examination is to explore the characteristics of performance, emission and combustion pattern of biodiesel conditioned with a steady rate of CNG. Biodiesel is generated from a non-edible oil Neem as it eco-friendly and produces less lethal gasses contrasted with diesel fuels. The Neem oil is converted into a diesel engine compatible product called NME (Neem oil Methyl Ester) by transesterification process that decreases the free fatty acid (FFA) concentration to less than 1%. The resultant NME is mixed in different extents (N10 = 10% and N20= 20%) with pure diesel keeping in mind the end goal to get different biodiesel blends. A stable flow of compressed natural gas (CNG) is filtered, pressure regularized and inducted into the suction line by utilizing CNG injector. The biodiesel in conjunction with a consistent stream (30% energy share) of CNG ensures extensive lessening in emission parameters. Brake specific energy consumption diminished massively by 11.7% with the NME biodiesel blends with CNG contrasted with neat diesel at full load. The release of NOx, CO_2 and smoke density are significantly decreased by 12.8, 21.9 and 40.7% respectively contrasted with neat diesel operation at full load. By the expansion of EGR system into this setup, an augmented advantage in the lessening of emission of oxides of nitrogen by 37.2% is seen with respect to diesel operation . The association of biodiesel blends with a consistent energy share of CNG and accompanied with EGR system enables enhanced characterization in the perspective of conservation of global eco system.

Keywords: Transesterification, Neem oil biodiesel, Compressed Natural Gas, Brake specific Energy Consumption, Oxides of Nitrogen emission and Heat Release Rate

1. Introduction

Environmental air pollution and global warming are a disquieting concern around the world. Escalating population growth, intensification of urbanization and industrialization has exclusively tampered the eco balance of the planet [1, 2]. The pollution level of a most of the metropolitan urban cities has alarmingly surpassed beyond the limit. The hazardous oxides of nitrogen emitted amid the combustion of fuel under high temperature, causes respiratory disorders on prolonged exposure [3]. In addition, this emission contributes to the formation of ground level ozone and particulate matter both of which prompts a dreadful health impacts. Governments are finding a way to empower the utilization of alternative fuels among public with a specific end goal to lessen these pollution risks. Over and above, the exasperating shortage of petrochemical products around the world also urged us to pick alternative energy source. Thus and so, biodiesel in conjunction with CNG turns into a spectacular solution for this universal deprivation. Gangil et al., [4] assessed the characteristics of engine performance, for example, BSFC, BTE and BSEC for different blends of karanja oil biodiesel. BSFC becomes lower for biodiesel blends contrasted with neat diesel. The heat loss in the ignition chamber is equivalently lessened thus BTE winds up noticeably higher. The release of oxides of nitrogen is increased with the blends of biodiesel. Papagiannakis and Hountalas, [5] have surveyed the combustion and exhaust emission characteristics of natural gas with diesel as a pilot fuel. The investigation was done on a single cylinder DI, diesel engine which was altered to be worked under dual fuel mode. Comparative outcomes are attained for various engine rpm and distinctive loads for neat diesel and dual fuel mode independently. The outcome uncovers that the peak cylinder pressure and BSFC is brought down for dual mode. The emission NO_x and soot lessened impressively while emission of CO and HC is increased contrasted with neat diesel mode.

Paul et al., [6] influenced a comparative study on emission and performance pattern of compressed natural gas with pongamia pinnata methyl ester (PPME) and diesel as pilot fuel. The outcome recommended that biodiesel – CNG dual fuel mode is viable than diesel – CNG dual fuel mode in the parts of both performance and emission characteristics. The hike in brake thermal efficiency and decline in CO emission and smoke opacity is seen in PPME and CNG mix. Senthilraja et al., [7] concentrated the combustion, emission and performance characteristics of diesel, ethanol, and cotton seed oil methyl ester (CSOME) in combination with compressed natural gas (CNG). The outcome demonstrated that NO_x and CO_2 emissions are extensively decreased at all load conditions while carbon monoxide (CO) and hydrocarbon (HC) emissions are equivalently higher for fuel blends with CNG.

Basavarajappa et al., [8] experimented in a single cylinder, 4-stroke, water cooled, direct injection CI engine with 1500 rpm rated engine speed. The CNG was inducted into the inlet manifold and the optimized CNG flow rate was found to be 0.5 kg/h.Biodiesels were produced from honge and jatropha oils and their blends with ethanol (15 %) were used as pilot fuels and injected. The effect of CNG induction on the combustion and emissions characteristics with dual fuel was studied and showed that use of CNG in dual fuel mode with biodiesel in a diesel engine improves the performance and reduces the emissions from the engine except for HC and NOx emissions. No major modifications done on engine.

Tarabet et al., [9] used natural gas and eucalyptus biodiesel on single cylinder diesel engine to study the effects on the performance and emissions at different loads and the results were compared with pure diesel fuel. Natural gas was inducted and biodiesle was injected for 10% energy share. The combustion characteristics of biodiesel as pilot fuel revealed the similar pressure-crank angle trend with highest peak, as neat diesel resulted in conventional and dual fuel mode. The result revealed that the exhaust emission of unburned hydrocarbon, carbon monoxide and carbon dioxide at high loads in dual fuel mode were reduced compared to diesel fuel modes. However the BSFC and NOx emission were increased marginally due to lower calorific value and the presence of oxygen in eucalyptus biodiesel.

Barik et al., [10] utilized karanja methyl ester as a pilot fuel bio gas run direct injection (DI) diesel engine. The bio gas was given with intake air and biodiesel was straightforwardly infused into the combustion chamber. The infusion timing of the pilot fuel is changed from 21.5 °CA bTDC to 27.5 °CA bTDC with an increment of 1.5 °CA. The outcome demonstrated that biodiesel dual fuel mode of 24.5 °CA delivered the better performance and emission characteristics with a minor trade off on emission of oxides of nitrogen. Blended Neem oil with diesel was experimented in CI engine by few researchers [10, 11, 32] and observed at 20% Neem oil blend improves BSFC by 10% and reduces emission 30% and 8% respectively for UHC and CO. addition of EGR decreases volumetric efficiency due to specific heat of gases. Biodiesel can be extracted from various sources like edible oils, non-edible oils etc. Utilizing non-edible oils like Karanja and Neem would be the optimum selection as it is readily obtainable abundantly everywhere particularly in southern India at the most reduced cost. Generally these seeds contain 27% - 39% of oil content [11, 32].

1.1 Objective of the research work

Based on literature survey, various biodiesel can be produced by the process of transesterification from raw oil and used as a supplementary fuel by blending 10 to 30% with diesel, in that way the Neem oil can be made appropriate for using as a biodiesel fuel as NME (Neem oil methyl ester) and blending the NME from 10 to 20% with diesel fuel. Even though many research work were carried out with biodiesel along with gaseous fuel, less or no work was carried out with combination of Neem oil and CNG with Exhaust gas recirculation. The Novelty in this experiment is to evaluate the various characteristics of combustion, performance and emission for neem oil biodiesel alongside a consistent flow of compressed natural gas (CNG) and Exhaust gas recirculation. By compounding biodiesel mixes with a relentless stream of CNG on a compression ignition engine, performance, emission and combustion characteristics are evaluated in examination with neat diesel operation.

2. Materials and Methods

2.1. Neem oil Methyl ester production

Sarva roga nivarani (medicine for all disease) is the other name for Neem oil owing to its properties. A Neem tree can produce 9-90 kg seeds per year and widespread in South Asia. Neem seed are also commercially traded for lamps fuel, drug remedy and soup making. Neem seed is displayed in Figure 1 and composition given in the Table 1. Figure 2 delineates the process of generation of NME biodiesel. Generally the free fatty acid concentration (FFA) of oil is very high as 20% FFA [12, 37]. Therefore, before transesterification process, the karanja oil is subject to acid esterification for bringing down the FFA concentration to less than 1%.

Table 1: Composition of Neem oil

Acid Content	%
Oleic	50 - 60
Palmitic	13 - 15
Stearic	14 - 16
Linoleic	8 - 16
Arachidic	1 - 3

Fig. 1. Neem seed and Neem oil

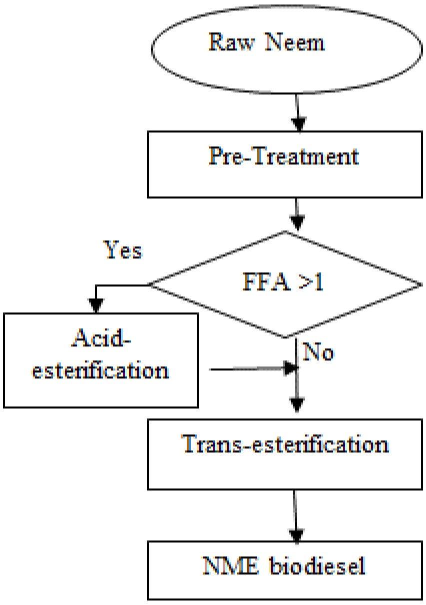


Fig. 2. Process flow of generation of NME biodiesel

2.2. Pre-treatment and Acid Esterification

The untreated neem oil is subject to screening and afterward pretreated to eject water and other contaminants. Acid esterification process begins by treating the resulting oil with H2SO4 as a catalyst [13]. In the event that neem oil is straightforwardly given for transesterification, the base catalyst utilized along would cause soap formation. The entire process is embraced in a round flask. A consistent temperature of 50°C is sustained for the acid and oil mixture with a ratio of 1 %w/w for 1 hour in the round flask [14]. This mixture is heated and stirred by the aid of a hot plate in conjunction with a magnetic stirrer. Over the span of time, FFA concentration keep on dwindling alongside concentration is measured time after time. When FFA turns out to be within 1%, the process is halted and permitted to be exploited for transesterification. On the off chance that the FFA is less than 1%, this process is bypassed and unswervingly conditioned for transesterification.

2.3. Transesterification

The transesterification process tapers the kinematic viscosity of FFA reduced neem oil eradicating the controversies labeled from fuel injection, combustion and atomization. A base catalyst of NaOH is put forth for speeding up the process whereas methanol is utilized as alcohol. For decreasing acid concentration to less than 1%, methanol to oil proportion is maintained to 55 wt. %.

2.4. Generation of Compressed Natural Gas (CNG)

As handling gaseous fuel may prompt hazardous risk, care must be taken while integrating safety measures in drafting CNG [8, 14]. Devices such as fire and flame arrester and filter are integrated with the intake manifold for incorporating safety measures. The underneath Figure 3 delineates the generation of CNG. The CNG cylinder is regulated a pressure valve alongside of it to supply a constant flow of CNG of pressure of 3 bar [15]. For measuring gas pressure, a pressure gauge is linked to CNG flow line next to cylinder. In addition to this a rotameter is connected to measure the flow rate of gas. A CNG injector whose specification is described in Table 2 is used for inducting the CNG with an injection pressure of 3 bar into the incoming air at a constant rate of 30% of the aggregate fuel which was in aggrement with Patil and Arakerimath [16, 35].

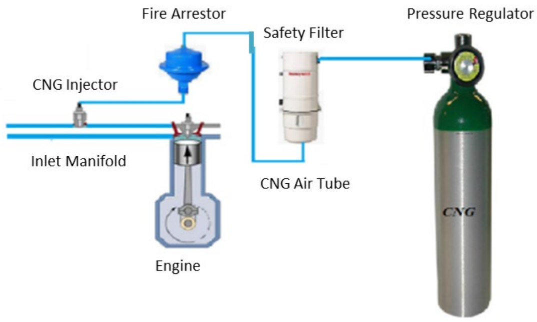


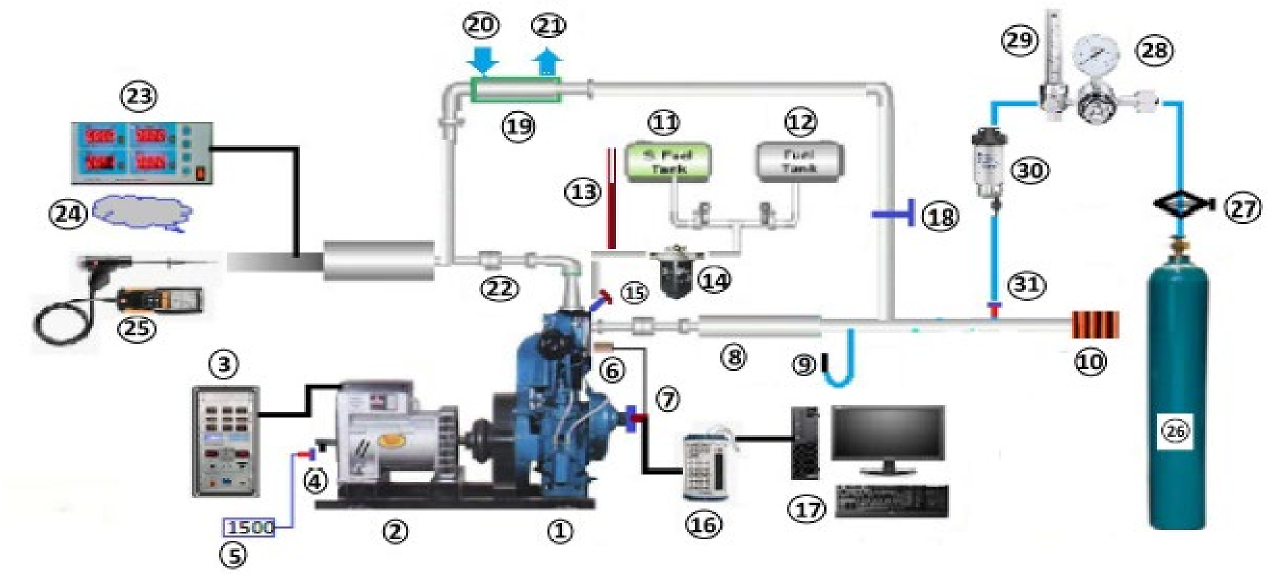
Fig.3. CNG injection circuit

Table. 2 Specification of CNG Injector

Parameter	Specification
Type	Top-Feed Port Fuel Injector
Operating Voltage	8V DC ~ 16V DC
Avalanche Energy	7.2 mJ
Max. Operating Press.	3.45 Bar
Working Pressure	1.03 ~ 3.45 Bar
Dynamic Flow Rate	2.00 g/sec (CNG) @ 50 PSI, 27 Hz 85% Duty Cycle x 15V
Coil Resistance	13.4 Ohms
Inductance	7.16 mH

3. Experimental setup and Procedures

Figure 4 and 5 depict the schematic diagram and photographic view of the whole test setup. A single cylinder, four strokes compression ignition engine with a specification given in Table.3 is utilized as a test engine. The test engine is affiliated to an alternator and an electrical loading device. A constant rate of CNG is introduced to the intake manifold via CNG injector shown in figure. The CNG pressure regulator as appeared in figure controls the pressure to 3 bar throughout the process. The air-flow is measured utilizing U-Tube manometer. The specification of emission gas analyzer is depicted in Table.4.



1	Diesel engine	7	Cam Position sensor and Crank encoder	13	Burette	20	Cooling water in	27	Flow valve
2	Generator			14	Diesel filer	21	Cooling water out	28	Pressure Regulator
3	Electrical loading device	8	Intake manifold	15	Diesel fuel injector	22	Exhaust manifold	29	Rotameter
4	RPM sensor	9	U-Tube manometer	16	Data acquisition system	23	Exhaust gas analyse	30	Fire arrestor & Filter
5	RPM digital meter	10	Intake air filter	17	Computer	24	Exhaust gas out		
6	Pressure sensor	11	Diesel tank 1	18	EGR valve	25	Smoke meter	31	CNG Injector
		12	NME tank	19	EGR unit	26	CNG Cylinder		

Fig.4. Schematic experimental layout

Fig.5. Photographic view of Experimental layout

The pressure in the combustion chamber is analyzed with help of Kistler piezoelectric sensor of sensitivity 15.2 pc/bar. The charge generated from the pressure transducer is amplified by Kistler charge intensifier. The information related to the sign of the amplified charge is depicted as flag from crank point encoder and it is stored in the computer. Exhaust gas analyzer and smoke meter is used for reckoning the emission trend of the exhaust gas. The exhaust gas recirculation (EGR) unit is furnished with a cooling facility.

Table.3. Test Engine Specification

Parameter	Specifications
Make and model	Kirloskar, AV1
Bore and stroke	80 X 110 mm
Swept Volume	553 cc
Compression ratio	16.5: 1
Clearance volume	36.87 cc
Rated output	3.7 kW @ 1500 rpm
Injection timing	24° bTDC
Combustion chamber	Hemispherical open type
Weight of flywheel	33 kg
Connecting Rod length	235 mm
Valve dia and max lift	33.7 mm and 10.2 mm
Injection nozzle	Bosch, 3 hole nozzle, 116° spray angle

Table.4 Specification of Emission gas analyzer

Parameters	Specification
Supplier	Horiba
Product	Automatic Emission analyzer
Model	Mexa -584 L
Measured / displayed components	CO : 0.00 % vol to 10.00 % vol HC : 0 ppm vol to 10000 ppm vol CO_2: 0.00 %vol to 20.00 % vol AFR : 10.00 to 30.00 Lambda : 0.000 to 9.999 O_2 : 0.00 %vol to 25 %vol NO : 0 ppm vol to 5000 ppm vol
Display resolution	CO : 0.01 % vol, HC : 1 ppm vol l, CO_2: 0.02 %vol, AFR : 0.1, Lambda : 0.001, O_2 : 0.01%vol NO : 1 ppm vol

4. Results and discussion

4.1. Performance analysis

4. 1. 1. Brake thermal efficiency (BTE)

Brake Thermal efficiency (BTE) is the measure of combustion quality of an engine [6]. The Figure 6 demonstrates the pattern of brake thermal efficiency in light of different brake mean effective pressure (BMEP) for different biodiesel blends with CNG. The brake thermal efficiency increases in line with the BMEP and load conditions. This is because, as the power increases the heat loss is reduced thereby increasing the BTE. The BTE for neat diesel is 11.81% at least load and 29.42% at maximum load whereas the BTE for biodiesel blends is 11.55% and 11.40% at minimum load respectively for N10 (10% NME + 90% diesel) and N20 (20% NME + 80% diesel) and these reduction is an account of more viscosity of biofuel and insufficient mixing at lower load [17, 18, 36]. At maximum load BTE is observed 30.38% and 31.54% respectively for N10 and N20.

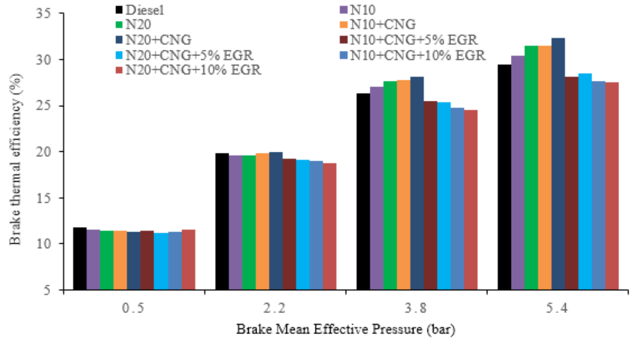


Fig. 6. Trend of Brake thermal efficiency with brake mean effective pressure for different fuel blends.

This increase is in lieu of fuel borne oxygen exist in neem oil. With constant CNG, the BTE is slightly decreased to 11.30% and 11.35% at minimum load for N10+CNG and N20+CNG respectively due to lean burn and poor air utilization and at higher load increased to 31.49 % and 32.37% for N10 and N20 respectively. This increase is due to increase in injection rate to maintain 30% energy share and improved mixture strength. When higher blends biodiesel is given alongside CNG, the engine quit running due to substantial smoke and knocking condition. This impact is due to the fact that the biodiesel has comparably greater viscosity and poor volatility which builds poor atomization and air-fuel mix in that way causing incomplete combustion inside the combustion chamber and lessening the thermal efficiency [19]. The addition of varying EGR rates slightly reduces the BTE to up to 6.5% for full load operation for N20 and 10% EGR with respect to diesel operation.

4. 1. 2. Brake Specific Energy Consumption (BSEC)

BSEC is the energy consumption per unit power for a given time [20]. Figure 7 depicts the trend of BSEC for different fuel combinations under varying EGR esteems..

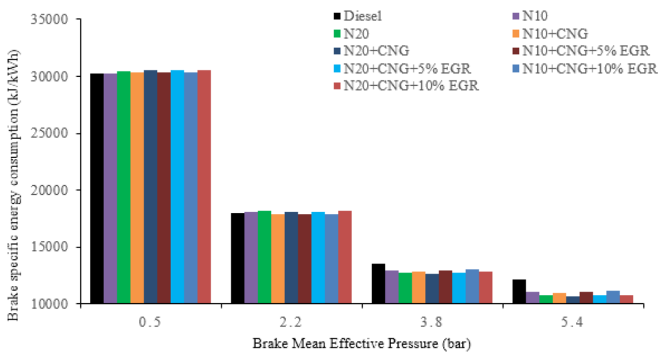


Fig.7. Variation of Brake specific energy consumption for different fuel blends based on break mean effective pressure

When a constant share (30%) of CNG is injected into the suction line of the biodiesel fuelled diesel engine, the BSEC of the engine were observed as 30300 and 30520 kJ/kWh which is slightly more by 0.32% and 1.05% at minimum load, 10980 and 10706 kJ/kWh which is less by 9.41% and 11.67% at maximum load conditions for blend N10 and N20 respectively based the neat diesel operation where the BSEC was 30203 and 12120kJ/kWh at minimum and maximum load respectively. This decrease is due to improved mixture strength and the higher heating value of the natural gas [21]. With the addition of EGR system, increases the BSEC by 10.84% at full load for N20+CNG+10% EGR compared to base diesel.

4.2. Combustion analysis

Combustion is the process where fuel and oxidants react thereby producing heat energy and makes the engine to run. Appropriate percentage of blending of fuel and oxygen prompt efficient burning of fuel and empowers good combustion characteristics. These characteristics are assessed based on the parameters such as pressure, temperature, heat release rate, mass fraction burned.

4.2.1. In-cylinder pressure

The cylinder pressure is the measure of pressure in the engine cylinder during its four strokes. At the compression stroke, the pressure achieves its maximum towards the top dead center. Figure 8 demonstrates the pattern of in-cylinder pressure based on crank angle with a steady flow of CNG into biodiesel blends under full load condition. The peak pressure is noted as 50.4, 46.8, 46.1, 46.4, 45.9, 46.0, 45.3, 44.52 and 43.12 bars at crank angles 375°, 372°, 370°, 373°, 371°, 375° and 377°, for neat diesel, N10+CNG, N20+CNG, N10+CNG+5%EGR, N20+CNG+5%EGR, 10+CNG+19%EGR and N20+CNG+10%EGR respectively. As the percentage of biodiesel blends increases, the pressure inside the cylinder becomes lower compared to the neat diesel because of the poor volatility and higher viscosity of the biodiesel blends [19].

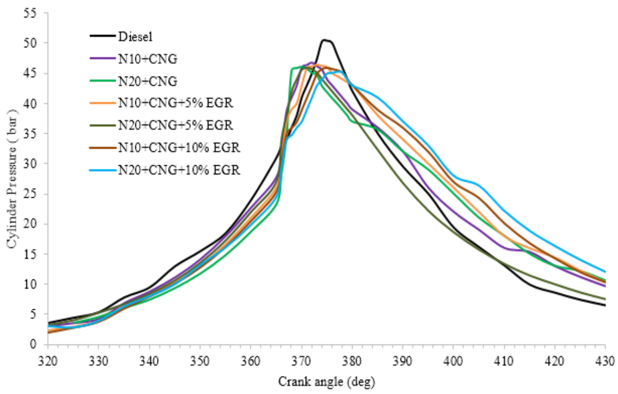


Fig.8. In-cylinder pressure with crank angle for diesel + Bio diesel + CNG with varying EGR

At maximum load, the peak pressure increases with increasing engine loads, as more amount of fuel is consumed and burned at higher loads. At lower loads, a delay in start of pressure rise with increasing biodiesel blends compared to the neat diesel is seen. However, pressure rise timing is almost similar to other fuel modes at higher loads [22]. The pressure further brings down on applying a constant flow of CNG into the suction line. The reason is the natural gas – air blend exhibit higher specific heat capacity contrasted with diesel, accordingly slows down the combustion and reduces the pressure in the cylinder [23].

4.2.2. Heat Release Rate (HRR)

Heat release rate conveys how much heat energy is discharged in the combustion chamber in the course of the combustion of fuel. The Figure 9 shows the pattern of HRR with crank angle for different fuel combinations at maximum load. The peak HRR is marked as 55.1, 52.1, 51.5, 51.2, 50.6, 51.0 and 49.8 J/crank angle for neat diesel, biodiesel blend N10+CNG, biodiesel blend N20+CNG, biodiesel blend N10+CNG+5%EGR, biodiesel blend N10+CNG+10%EGR biodiesel blend N20+CNG+5%EGR, biodiesel blend N20+CNG+10%EGR respectively. The peak HRR value is lower for biodiesel blends contrasted with neat diesel because of the lower calorific value of biodiesel enables reduced peak heat release rate [23, 24].

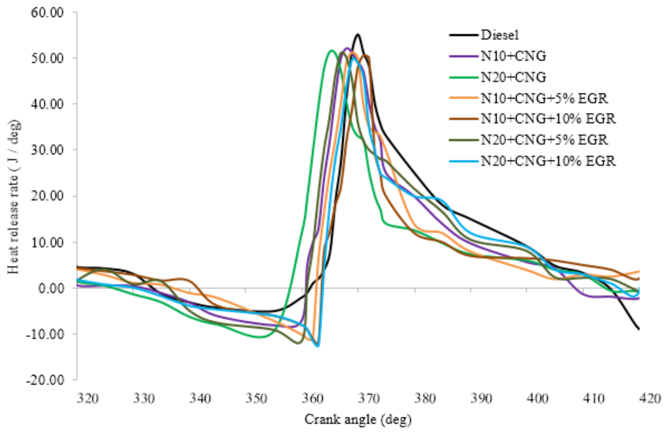


Fig. 9. Variation of HRR with crank angle for CNG + biodiesel with varying EGR

However, HRR is practically comparative during late combustion stage on account of the presence of excess oxygen left over at the time of earlier combustion stage. Further reduction in the measure of heat released with addition of CNG is witnessed, due to the low premix combustion; however this effect is very feeble. The addition of EGR system into the tri-fuel mode of operation further delays the start of combustion and reduces the heat release rate.

4.3. Emission analysis

4.3.1. Oxides of nitrogen

The Figure 10 shows the emission pattern of NO_x gas with brake mean effective pressure for different biodiesel blends with constant flow of CNG and varying EGR. It is noted from the graph that the increase in release of NO_x gas to 21.50% (3.75g/kWh) and 25.33% (3.87g/kWh) for biodiesel blends N10 and N20 in 40% partial load condition compared with neat diesel (3.09g/kWh). When a constant flow of CNG is added along biodiesel blends reduces the emission to 7.93% (2.86g/kWh) and 5.74% (2.93g/kWh) at least load and 16.81% (2.10g/kWh) and 12.75% (2.21g/kWh) at extreme load for blends N10 and N20 with CNG compared to neat diesel respectively(3.12 and 2.53g/kWh for minimum and maximum load). By further including EGR, diminishes the emission of NO_x gas up to 20.81% for N10+CNG+10% EGR compared with the neat diesel. It is obvious that the addition of biodiesel blends enhances ensures complete combustion and increases the combustion temperature. Due to this increase in temperature, the emission of NO_x gas also got increased. In contrast, the injection of CNG into the suction line reduces the peak temperature in the chamber thereby reducing the emission of NO_x gas. The combined effect of biodiesel and CNG influences a tradeoff between the emission of NO_x gas and the reduced cylinder temperature enables a reduction of this emission. Further including EGR reduces the emission of NO_x gas to a controlled manner. Similar outcome is seen with the addition of ethanol by Carlucci et al. [24].

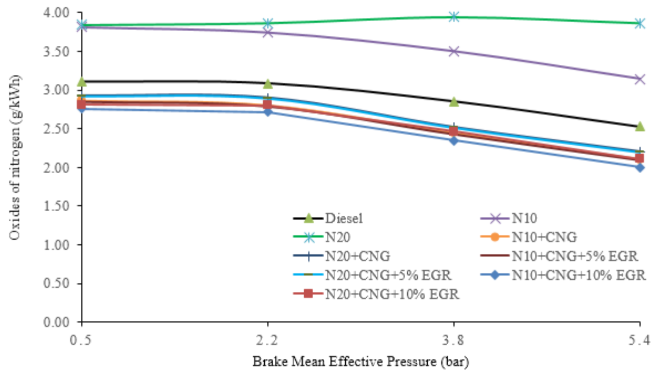


Fig.10. Variation in oxides of nitrogen with brake mean effective pressure

4.3.2. Unburnt Hydrocarbon (UHC) and Carbon Monoxide (CO)

The unburnt hydrocarbon (UHC) and carbon monoxide (CO) are harmful gases that are exhausted out due the incomplete combustion of the fuel. In general, the emission of these gases reduces with respect to the brake mean effective pressure. This is on the grounds that the pressure inside the cylinder tends to increment with increasing load conditions which enhancing complete combustion and reduces the emission. As the supply of oxygen is adequate with the addition of biodiesel, a stable and further oxidization of carbon and carbon monoxide is possible. Similar results are noted by Agarwal and Rajamanoharan, [25] in the trial conducted in single cylinder agricultural diesel engine with fuel as karanja oil and its blends. The addition of steady flow of CNG counteracts the performance by increasing both the emissions as CNG causes incomplete burning. Nevertheless, the association of biodiesel and constant flow of CNG enables a reduced emission of UHC and CO compared to the neat diesel. Figure 11 and 12 demonstrate the emission pattern of UHC and CO for different fuel combinations under varying load conditions. It is observed that the emission of UHC and CO is increased with the biodiesel blends N10 and N20 with CNG to about 10.11% (0.2g/kWh) and 5.75% (0.18g/kWh) at least load and 14.05% (0.14g/kWh) and 12.37% (0.11g/kWh) at maximum load conditions for UHC and 1.2% (9.23g/kWh) and 1.0% (8.28g/kWh) at least load and 3.5% (3.86g/kWh) and 2.7% (3.06g/kWh) at maximum load conditions for CO compared to the only N10 (UHC :0.12 and CO :3.73g/kWh at full load) and N20 (UHC:0.1 and CO:2.98g/kWh at full load) operation respectively, however these emissions are lesser than the neat diesel operation. Further increase in emission of UHC and CO is observed with the addition of EGR system due to the inadequacy of oxygen during the combustion and the same is at par with the neat diesel level.

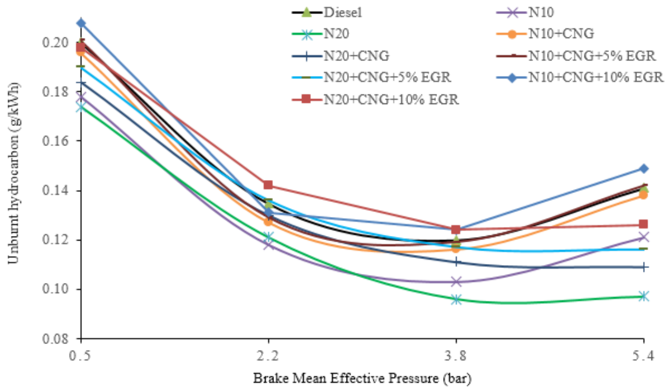


Fig.11. Variation in unburnt hydrocarbon with brake mean effective pressure

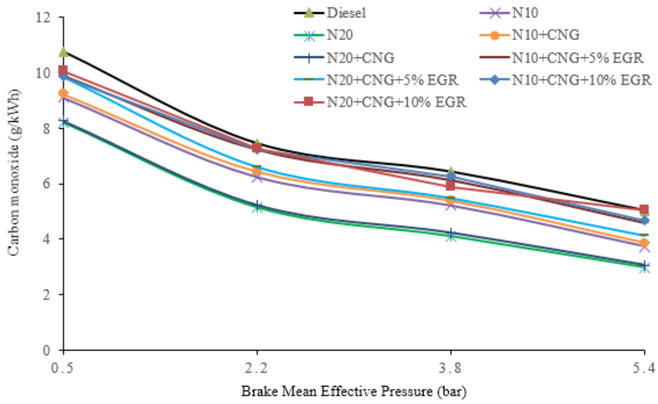


Fig.12. Variation in carbon monoxide with brake mean effective pressure

4.3.3. Carbon Dioxide (CO_2)

The emission of CO_2 results from the complete combustion of fuel, which is the most obvious cause for global warming. The emission of CO_2 is traded off with the combustion performance of the engine. This is due to the fact that on complete combustion, the amount of unburnt components like UHC and CO reduces with more supply of oxygen and along these lines the emission of CO_2 becomes high. Due to enriched level of oxygen in biodiesel, the discharge got increased whereas the initiation of steady flow of CNG reduces this release to the intended level due to lesser carbon to hydrogen ratio. An emission pattern of CO_2 different fuel combinations under varying brake mean effective pressure and EGR is depicted in Figure 13. It is marked from the plot that the emission of 1336 g/kWh and 1412 g/kWh at minimum load to 696 g/kWh and 908 g/kWh at full load conditions for blends N10 and N20 which is greater than that of neat diesel (1198 and 636 g/kWh for minimum and maximum load respectively). When conditioning with a steady flow of CNG with biodiesel blends, the CO_2 lessened as 943 g/kWh and 952 g/kWh at minimum load to 464 g/kWh and 497 g/kWh at full load conditions for blends N10 and N20 is seen. Further augmenting with EGR the reduction of this emission of around 20% is attained with respect to diesel operation and 5% with respect to biodiesel+ CNG operation.

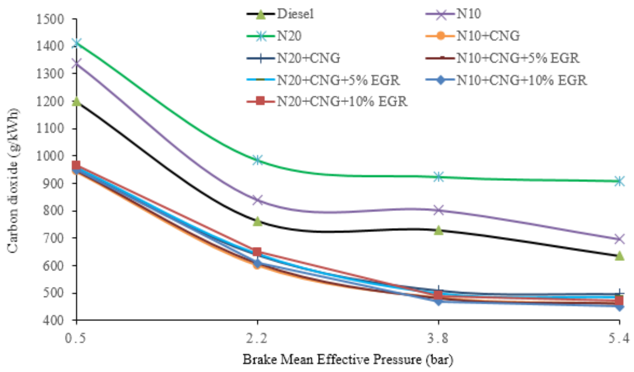


Fig.13. Variation in carbon-dioxide with brake mean effective pressure

4.3.4. Smoke density

Smoke density comprises of unburnt carbon contents left over during combustion. As the CNG causes incomplete combustion, more unburnt particles settle around the walls of cylinder. Because of the fact that the aromatic hydrocarbons possess more prominent boiling point and thermal stability, higher discharge of smoke is possible [26, 27]. Since the Neem used here does not have any aromatic components and restrain the carbon contents from soot formation thereby reducing smoke emission. It is pinpointed that lubricating oil also increases the smoke emission.

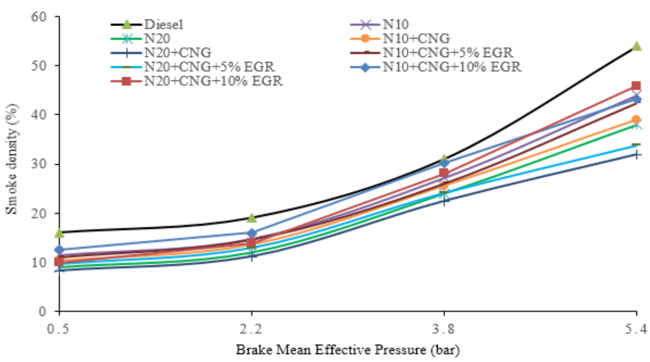


Fig.14. Variation in Smoke density with brake mean effective pressure

Further conditioning with CNG, slightly reduces the emission because methane, the prime component of CNG is a lower member paraffin family which basically reduces the formation of smoke density. A slight increase in smoke emission is observed when EGR system is incorporated. This is due to the fact that with the addition of EGR the oxygen supply will be diminished that prompt increased PM emission [28, 29]. Figure 14 shows the pattern of discharge of smoke for different brake mean effective pressure and different fuel combinations. The decrease in smoke emission observed as 10.4 % and 8.3% at low load and 13.7% and 11.2% at full load conditions for biodiesel blends N10 and N20 with CNG compared to the neat diesel operation (16% and 54% at minimum and maximum load respectively). Addition of EGR marginally builds the smoke compared to the biodiesel and CNG combinations however this increase is still below the neat diesel level.

4.4. Trade off study

4.4.1. Trade off study between BSFC vs. NOx

The Figure 15 delineates the variation of brake specific energy consumption with respect to oxides of nitrogen for various fuel operations at full load. The emission of NO_x is lower for biodiesel blends with constant CNG on comparison with neat diesel and sole biodiesel blend. With the addition of EGR substantial drop down in emission of NO_x with slight increase in BSEC is witnessed. An optimum of 5% EGR with N20 biodiesel blend with CNG will deliver an acceptable scope of performance [30, 34].

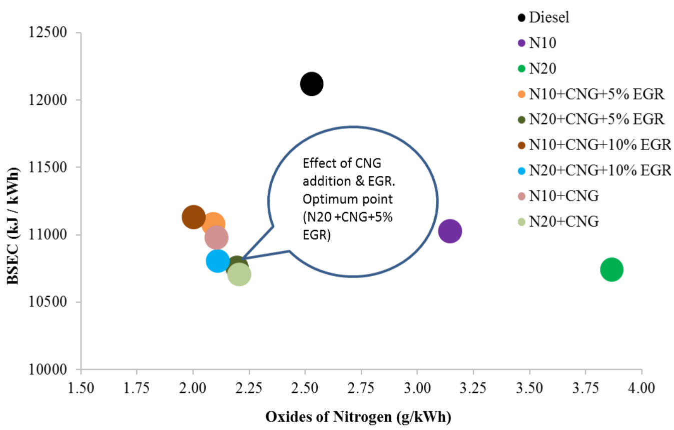


Fig. 15. Pattern of Brake specific Energy Consumption with Oxides of nitrogen with different fuel combinations

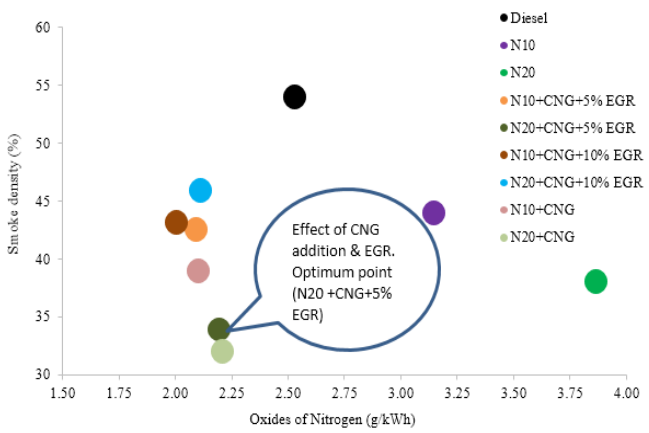


Fig. 16. Variation of smoke density with oxides of nitrogen for different fuel combinations

4.4.2. Trade off study between Smoke density vs. NOx

The Figure 16 demonstrates the change in smoke density based on changing oxides of nitrogen (NO_x) for various fuel combinations at full load. From the tradeoff study the smoke emission is lesser with a reduction in emission of oxides of nitrogen NO_x for biodiesel with CNG compared with sole biodiesel and neat diesel. Indeed, even with the addition of EGR, smoke emission is slightly controlled in comparison with biodiesel and neat diesel. An optimum of 5% EGR with N20 biodiesel blends with CNG would deliver better emission characteristics [31, 33].

5. Conclusion

The extensive reconnaissance of performance, emission and combustion characteristics of biodiesel blends conditioned with a steady flow of CNG share under varying EGR rates by comparing to that of neat diesel was undertaken. A steady flow of 30% CNG injected by means of CNG injector into the suction line produced better outcome in the light of emission pattern of various parameters. By augmenting with CNG and EGR systems, considerable reduction in emission of oxides of Nitrogen is accomplished. In addition to this, biodiesel and CNG achieves a substantial reduction in the emission of smoke density and CO_2 compared to the neat diesel and sole biodiesel blends as well. The combination of biodiesel with CNG turns into a surpassing combo in rebating the issues related to environmental air pollution with a slight bargain in performance and combustion characteristics. Nevertheless, this detriment in performance and combustion characteristics overweighs the benefits procured from the minimization of emission characteristics as well as fuel economy. The biodiesel blend N20 along with steady flow of CNG with 5% of EGR rate is considered to be an optimum choice because the performance improved by decrease in BSEC by 11.7% and the emission parameters decreased by 17.4% , 18% ,27.5% and 21.3 % for NOx, CO , CO_2 and Smoke density respectively compared neat diesel operation.

Nomenclature	
BMEP	Brake Mean Effective Pressure
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CI	Compression Ignition
CAD	Crank Angle Degree
CNG	Compressed Natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
DI	Direct Injection
EGR	Exhaust Gas Recirculation
ID	Ignition Delay
NME	Neem oil Methyl Easter
NOx	Oxides of Nitrogen
SOC	Start of Combustion
SOI	Start of Injection
UHC	Unburnt Hydro-carbon

References

[1] V. Hariram, S. Seralathan, K. M. Dinesh, S. Vasanthaseelan and M. Sabareesh. "Analyzing the fatty acid methyl esters profile of palm kernel biodiesel using GC/MS, NMR and FTIR techniques" Journal of Chemical and Pharmaceutical Sciences, 9 (4), pp. 3122-3128. 2016.

[2] H. Venkatesan, S. Sivamani, T. Premkumar and P. Tharun. Reduction of exhaust emissions using a nanometallic enriched lemongrass biodiesel blend" Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 39 (21), pp. 2065-2071, 2017.

[3] B. Rudell, M. Ledin, U. Hammarstrom, N. Stjernberg, B. Lundback. And T. Sandstrom. "Effects on symptoms and lung function in humans experimentally exposed to diesel exhaust", Occupational and Environmental Medicine, 53(10), pp.658-662, 1996.

[4] S. Gangil, R. Singh, P. Bhavate, D. Bhagat and B. Modhera. "Evaluation of engine performance and emission with methyl ester of Karanja oil', Perspectives in Science 8(C) DOI:10.1016/j.pisc.2016.04.040, 2016.

[5] R. Papagiannakis and D. Hountalas. "Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot Diesel fuel and natural gas", Energy Conversion and Management, 45(18-19), pp.2971-2987, 2004.

[6] A. Paul, R. Panua, D. Debroy and P. Bose. "Effect of compressed natural gas dual fuel operation with diesel and Pongamia pinnata methyl ester (PPME) as pilot fuels on performance and emission characteristics of a CI (compression ignition) engine", Energy,68, pp.495-509, 2014.

[7] R. Senthilraja, V. Sivakumar, K. Thirugnanasambandham and N. Nedunchezhian. "Performance, emission and combustion characteristics of a dual fuel engine with Diesel–Ethanol – Cotton seed oil Methyl ester blends and Compressed Natural Gas (CNG) as fuel", Energy, 112, pp. 899-907, 2016.

[8] Y.H.Basavarajappa. "Performance and emission characteristics of a CNG-Biodiesel dual fuel operation of a single cylinder four stroke CI engine", To cite this article: IOP Conf. Ser.: Mater. Sci. Eng. 376 el, 2018.

[9] L. Tarabet, K. Loubar, M. S. Lounici, K. Khiari, T. Belmrabet and M. Tazerout. "Experimental investigation of DI diesel engine operating with eucalyptus biodiesel/natural gas under dual fuel mode", Fuel, vol. 133, pp. 129-138, 2014.

[10] D. Barik, S. Murugan, N. Sivaram, E. Baburaj. and P. Shanmuga Sundaram. " Experimental investigation on the behavior of a direct injection diesel engine fueled with Karanja methyl ester-biogas dual fuel at different injection timings", Energy, 118, pp.127-138, 2017.

[11] L. Rupesh Patel and C. D. Sankhavara. (2017). Biodiesel production from Karanja oil and its use

in diesel engine: A review", Renewable and Sustainable Energy Reviews,71, pp. 464-474 , 2017

[12] M. Naik, L. Meher, S. Naik and L. Das. "Production of biodiesel from high free fatty acid Karanja (Pongamia pinnata) oil. Biomass and Bioenergy", 32(4), pp.354-357, 2008.

[13] M. Nabi, S. Hoque and M. Akhter. "Karanja (Pongamia Pinnata) biodiesel production in Bangladesh, characterization of karanja biodiesel and its effect on diesel emissions', Fuel Processing Technology, 90(9), pp.1080-1086, 2009.

[14] H. Berchmans and S. Hirata. "Biodiesel production from crude Jatropha curcas L. seed oil with a high content of free fatty acids", Bioresource Technology, 99(6), pp.1716-1721, 2008.

[15] Firmansyah, A.R.A. Aziz and M. Heikal. "The combustion behavior of diesel/CNG mixtures in a constant volume combustion chamber", IOP Conference Series: Materials Science and Engineering, 100, p.012032, 2015.

[16] M. Rajasekaran, V. Hari Ram, M. Subramanian. "Multi-objective optimization of material layout for body-in-white using design of experiments", International Journal of Vehicle Structures and Systems, 8(1), pp.17-22, 2016.

[17] D. H. Qi, H. Chen, L.M. Geng and Y.Z.H. Bian. "Experimental studies on the combustion characteristics and performance of a direct injection engine fueled with biodiesel/diesel blends", Energy Convers Manage, 51: 2985–92, 2010.

[18] N.R. Banapurmatha, P. G. Tewari and R. S. Hosmath. "Performance and emission characteristics of a DI compression ignition engine operated on honge, jatropha and sesame oil methyl esters", Renew Energy, 33(9), 1982 –8, 2008.

[19] A. K. Agarwal and A. Dhar. "Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine", Renewable Energy, 52, pp.283-291,2013.

[20] C. Enweremadu and H. Rutto. "Combustion, emission and engine performance characteristics of used cooking oil biodiesel—A review", Renewable and Sustainable Energy Reviews, 14(9), pp.2863-2873, 2010.

[21] R. Papagiannakis and D. Hountalas. "Experimental investigation concerning the effect of natural gas percentage on performance and emissions of a DI dual fuel diesel engine", Applied Thermal Engineering, 23(3), pp.353-365, 2003.

[22] A. Dhar and A. K. Agarwal. "Performance, emissions and combustion characteristics of Karanja biodiesel in a transportation engine", Fuel, 119, pp.70-80, 2014.

[23] K. Nantha Gopal and R. Thundil Karupparaj. "Effect of pongamia biodiesel on emission and combustion characteristics of DI compression ignition engine", Ain Shams Engineering Journal, 6 (1), pp. 297-305, 2015.

[24] A. Carlucci, A. de Risi, D. Laforgia and F. Naccarato. (2008). "Experimental investigation and combustion analysis of a direct injection dual-fuel diesel–natural gas engine", Energy, 33(2), pp.256-263, 2008.

[25] A. K. Agarwal and K. Rajamanoharan. "Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine", Applied Energy, 86(1), pp.106-112, 2009.

[26] K. Bhaskar, G. Nagarajan and S. Sampath. "Optimization of FOME (fish oil methyl esters) blend and EGR (exhaust gas recirculation) for simultaneous control of NOx and particulate matter emissions in diesel engines", Energy, 62, pp.224-234, 2013.

[27] V. Hariram and K.G. Mohan. "The effect of injection timing on combustion, performance and emission parameters with AOME blends as a fuel for compression ignition engine". European Journal of Scientific Research, 79 (4), pp. 653-665, 2012.

[28] V. Hariram, A. Bose and S. Seralathan. "Dataset on optimized biodiesel production from seeds of Vitis vinifera using ANN, RSM and ANFIS", Data in Brief, 25, art. no. 104298. 2019.

[29] N. Saravanan and G. Nagarajan. "Performance and emission studies on port injection of hydrogen with varied flow rates with Diesel as an ignition source", Applied Energy, 87(7), pp.2218-2229, 2010.

[30] G. John, V. Hariram and S. Seralathan. "Emission reduction using improved fuel properties of algal oil biodiesel and its blends" Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 40 (1), pp. 45-53, 2018.

[31] V. Hariram and R. Bharathwaaj. "Extraction and optimization of biodiesel yield from wax esters of Apis melifera (Honey bee)" International Journal of ChemTech Research, 8 (9), art. no. A045, pp. 433-437, 2015.

[32] S. Dewang, S. Suriani, Hadriani, Diana, E. S. Lestari and Bannu. "Viscosity and calorie measurements of biodiesel production from Calophyllum Inophyllum L using catalyst and time variations for stirring in transesterification process" 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 734-738. 2017

[33] V. Hariram, S. Seralathan, Dinesh Kumar and S.Padmanabhan, "Effect of metallic-nanoadditive on combustion, performance and emission parameters of DI CI engine fuelled with Palm kernel methyl esters", International Journal of Vehicle structures and systems, 9 (2), pp. 103-9. 2017.

[34] S.A. Abd Allah. El-Gharabawy. "Cost Analysis for Biodiesel Production from Waste Cooking Oil Plant in Egypt" International Journal of Smart Grid, ijSmartGrid, 1(1), pp. 16-25. 2017.

[35] Y. Tominaga, M. Tanaka, H. Eto, Y. Mizuno, N. Matsui and F. Kurokawa. "Design Optimization of Renewable Energy System Using EMO" 2018 International Conference on Smart Grid (icSmartGrid), , pp. 258-263. 2018.

[36] R. Arslan and Y. Ulusoy. "Utilization of waste cooking oil as an alternative fuel for Turkey," 2016 IEEE International Conference on Renewable Energy Research and Applications, pp. 149-152. 2016.

[37] E.K. Çoban, C. Gençoğlu, D. Kirman, O. Pinar, D. Kazan and A.A. Sayar. "Assessment of the effects of medium composition on growth, lipid accumulation and lipid profile of Chlorella vulgaris as a biodiesel feedstock" 2015 International Conference on Renewable Energy Research and Applications (ICRERA), pp. 793-796. 2015.