EXPERIMENTAL INVESTIGATION OF CI ENGINE CHARACTERISTICS FUELLED WITH CAMPHOR BLENDED CALOPHYLLUM FUEL WITH HYDROGEN INDUCTION

A PROJECT REPORT

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Certified that this project report titled **"EXPERIMENTAL INVESTIGATION OF CI Engine Characteristics fuelled with Camphor blended Calophyllum Inophyllum fuel with Hydrogen Induction"** is the bonafide work of **"GOWRI SHANKAR C N [Reg No: RA1711002010381], NIDHISH NANDAN V [Reg No: RA1711002010330]"**, who carried out the project work under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form any other project report or dissertation based on which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

The project deals with the experimental analysis of a bio-fuel blend consisting of 50% Calophyllum Inophyllum oil (CI) and 50% camphor oil (CMO) along with Hydrogen (H_2) Induction of 4,6 and 8 lpm. All the four blends of pure diesel, CI50CMO50, CI50CMO50 + 4lpm H_2, CI50CMO50 + 6lpm H_2 and CI50CMO50 + 8lpm H_2were tested for performance, emission characteristics using a direct-injection single-cylinder 5.2kW Kirloskar diesel engine which is run at a constant rpm of 1500. The engine is attached to an eddy current dynamometer. The objective of this study was to test the properties of Calophyllum Inophyllum oil and camphor Oil blend along with different flow rates of Hydrogen Induction and its result on the efficiency of diesel engine, and various other parameters. It was inferred that there was a considerable decrease in Volumetric Efficiency of the engine along with increase in NOx emissions. There was minimal difference seen in the BTE, BSFC and BSEC between the different blends. There was also a considerable decrease in CO, CO_2 and HC emissions.

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LIST OF SYMBOLS AND ABBREVIATIONS

kW	Kilowatt
Rpm	Revolutions per minute
mm	Millimeters
cc	cubic centimeters
kg	Kilogram
vol	Volume
g/cm3	Grams per Cubic Centimeters
kJ/kg	Kilo Joules per Kilogram
MJ/kg	Mega Joules per Kilogram
CST	Centistoke
ρ	Density
A/F	Air fuel ratio
LHV	Latent Heat of Vaporization
BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
BSEC	Brake Specific Energy Consumption
CI	Compression Ignition
η	Dynamic viscosity
°C	degree Celsius

1. INTRODUCTION

Fossil fuels are one of the important sources of energy production, but they are non-renewable and are depleting at a much rapid rate than its restoration. An Alternative can be to switch towards the production and consumption of alternative fuels like bio fuels which are renewable. Combustion of fuels produces by products which are harmful and polluting in nature. It is also a thermally in efficient process.

Liquefied or gaseous Hydrogen is a carbon-free alternative fuel. Hence, formation of carbon monoxide, carbon dioxide, unburned hydrocarbon, nitrogen oxides and sulphur oxides emissions during combustion can be completely avoided. On burning liquified Hydrogen water is the only by-product. Here Hydrogen Induction is done directly through the use of fuel injector connected to the intake manifold and the flow rate is controlled using a flow meter. When hydrogen is used as an additive or alternative in SI or CI engines, volumetric efficiency of the engine decreases as the lower heat value (LHV) 120 MJ/kg of H2 is higher than that of diesel and gasoline petrol. This reduction in volumetric efficiency will reduce engine power and torque.

Bio Fuels can be an alternative to fossil fuels as they renewable or can be extracted from plant products and are thus in exhaustible. Bio fuels are produced from various kinds of organic matter such as sugarcane, corn seed, cotton seed oil, biomass etc. India is also a huge importer of crude oil, the second largest in the world. Almost one third of our total imports are accounted from crude oil. Hence switching to bio fuels can be advantageous for a country like India.

Our project involves the experimental analysis of performance, combustion and emission parameters with the aid of graphs and readings of the bio fuel consisting of 50% Calophyllum Inophyllum Oil, 50% camphor oil with Hydrogen Induction. The experiment was conducted by using four blends of:

- Diesel oil-100%
- Calophyllum Inophyllum oil-50%, Camphor oil-50%
- Calophyllum Inophyllum oil-50%, Camphor oil-50% with 4lpm H2 Induction
- Calophyllum Inophyllum oil-50%, Camphor oil-50% with 6lpm H2 Induction
- Calophyllum Inophyllum oil-50%, Camphor oil-50% with 8lpm H2 Induction

Calophyllum Inophyllum or Tamanu is a plant that has been historically used for timber in shipbuilding. Its fruit kernels can be used to extract oil. This project uses Calophyllum Inophyllum as one of the components of the fuel blend. Camphor is usually extracted and processed from the bark of camphor tree. It can be used as a flammable product to start fire as its fire point is very low. It also has medicinal properties and is used as a component in balms like Vicks etc. Oil from it can also be used as bio fuel.

On using Calophyllum (Punnai or Tamanu) oil as a fuel in fuel injected diesel engine leads to combustion that is incomplete and thus it lowers the brake thermal efficiency. It happens viscosity of the oil is high. To overcome this problem, it can be mixed with camphor oil which has lower viscosity and flash and fire points. Camphor oil has a lower viscosity than tamanu oil, which could help with fuel atomization, evaporation, and air/fuel mixing. Although, because camphor oil has a lower cetane index, it can increase nitrogen oxide emissions when used in CI engines.

2. LITERATURE SURVEY

Ilker Turgut et al. concluded that the low compression ratio test yields highest cylinder pressure, highest amount of heat release, highest amount of pressure raises and ringing intensity. Combustion duration increases however ignition duration delays fluctuate with hydrogen enrichment. Firstly, hydrogen enrichment increases but decreases the BTE of engine with the low compression ratio. Ringing intensity increases with increase in engine load and hydrogen amount. As the hydrogen ratio increases BTE decreases.

M Senthil Kumar et al. investigated the effects of hydrogen induction on the performance, emissions, and combustion behaviour of a diesel engine that runs on an emulsion of used palm oil (pilot fuel) and hydrogen (primary fuel). With the use of hydrogen induction, dual fuel operation helps to reduce pollution, which is nothing but emissions from the engine. At 40% load, hydrogen induction helps to lower the thermal efficiency. Hydrogen induction performs better at high power output and vice versa.

N Saravanan et al. discovered a solution to improve brake thermal efficiency while lowering specific energy consumption in diesel engines with hydrogen enriched air systems. With 90.1 percent hydrogen enhancement at 70.1 percent engine load, nitrogen oxide emissions are reduced from 2763 to 514 ppm. When the load is full, nitrogen oxide emissions are lowered, and particulate matter emissions are reduced by 50% when compared to diesel operation. With 30% hydrogen augmentation, the brake thermal efficiency increases from 22.78 percent to 27.9 percent. As a result, diesel engines with hydrogen-enriched air emit less pollution and operate better.

Nithyanandhan Kamaraj et al. studied on maximizing fuel economy and decreasing greenhouse gas emissions from vehicle resource. He used a diesel engine running on diesel fuel with hydrogen induction. He concluded that the fuel efficiency and carbon di oxide emissions increases while carbon mono oxide emissions decrease by injecting hydrogen into the intake manifold of diesel engine. Combustion Analysis did not show any significant improvement of the in-cylinder pressure. This study also compared different flow amounts of hydrogen induced in the engine to the nitrogen oxides emissions and established the optimal hydrogen flow amounts.

V Vigneshwar et al. investigated the impact of higher alcohols, antioxidants, and nano particles on the yield of calophyllum inophyllum biodiesel at varied concentrations. The entire impact of modifying injection timing, injection pressure, and compression ratio during calophyllum inophyllum biodiesel fuel operations is critically discussed.

B Ashok et al. investigated the possibility of using 100 percent calophyllum inophyllum methyl ester as a future fuel source. A plan reveals how to reduce nitrogen oxide emissions from a calophyllum inophyllum bio-diesel-fueled diesel engine by adjusting the injection time to 21 degrees, 23 degrees, and 25 degrees TDC and acknowledging exhaust gas recirculation at rates of 10%, 20%, and 30%. It demonstrates that nitrogen oxide emissions are lowest with 10% exhaust gas recirculation.

G. Kasiraman et al. researched the effectiveness of using cashew nutshell oil as a CI engine alternative fuel. After testing the given oxygenate blends, we could observe that the blends with diethyl ether had a superior performance than the blends with dimethyl carbonate. During a full load operation, diesel fuel (30.14%) and DEE30 (29.68%) have similar brake thermal efficiency.

L.Tarabet et al. examines the experimental investigation of a direct injection diesel engine that runs on eucalyptus biodiesel and natural gas in dual fuel mode. According to combustion study, using biodiesel in dual fuel mode enhances combustion stability, particularly under greater engine load levels. Under high engine loads, the BSFC in dual fuel operation is lowered. At up to 70% of the engine's maximum load, the dual-fuel mode emits less NOx than the traditional diesel fuel mode.

R Sushant Krishna et al. investigated Calophyllum inophyllum or tamanu oil with a 20% bio diesel blend. In a common-rail direct injection engine, it looked at several injection techniques and EGR. On various fuel injection systems, it resulted in greater brake thermal efficiency, but no increase was shown when EGR was included. The combination of a 15% pilot injection rate and a 10% exhaust gas recirculation resulted in enhanced performance and emission characteristics.

Liu et al. examined how diesel fuel injection pressure affects the performance, emissions, and combustion of a six-cylinder common rail diesel engine that runs on diesel/methanol fuel. The combustion period became shorter, the maximum cylinder pressure increased, and the peak heat release rate increased. As the diesel injection pressure was increased, smoke emissions fell and NOx levels climbed.

S K Nayak et al. investigated the effects of combining calophyllum inophyllum or tamanu oil with babul-derived gas. A turbocharged diesel engine in dual fuel mode was used in the test. The turbocharged engine with other fuels was tested at varied load circumstances with the gas flow rate fixed at 21.58kg/h. In order to compare it to standard diesel fuel, the effort also included altering the gas flow rate with varied engine parameters to examine performance, emission, and combustion behaviour. As a result, both diesel fuel consumption and pollutants were reduced.

H.Kasiraman et al. study the improvements in performance, combustion and emission of cashew nut oil mixed with camphor oil which is run on a single-cylinder direct injection diesel engine. Camphor oil is added to cashew nutshell oil to improve its performance as a fuel in a DI diesel engine. Camphor oil has a lower viscosity and is more ignitable than other oils. Atomization, vaporisation, and mixing must all be improved. The addition of camphor oil resulted in incomplete combustion.

3. METHODOLOGY

DIESEL	Diesel oil-100%
CI50CMO50	Calophyllum Inophyllum oil-50%, Camphor oil-50%
CI50CMO50 + 4lpm H2	Calophyllum Inophyllum oil-50%, Camphor oil-50% with 4lpm H2 Induction
CI50CMO50 + 6lpm H2	Calophyllum Inophyllum oil-50%, Camphor oil-50% with 6lpm H2 Induction
CI50CMO50 + 8lpm H2	Calophyllum Inophyllum oil-50%, Camphor oil-50% with 8lpm H2 Induction

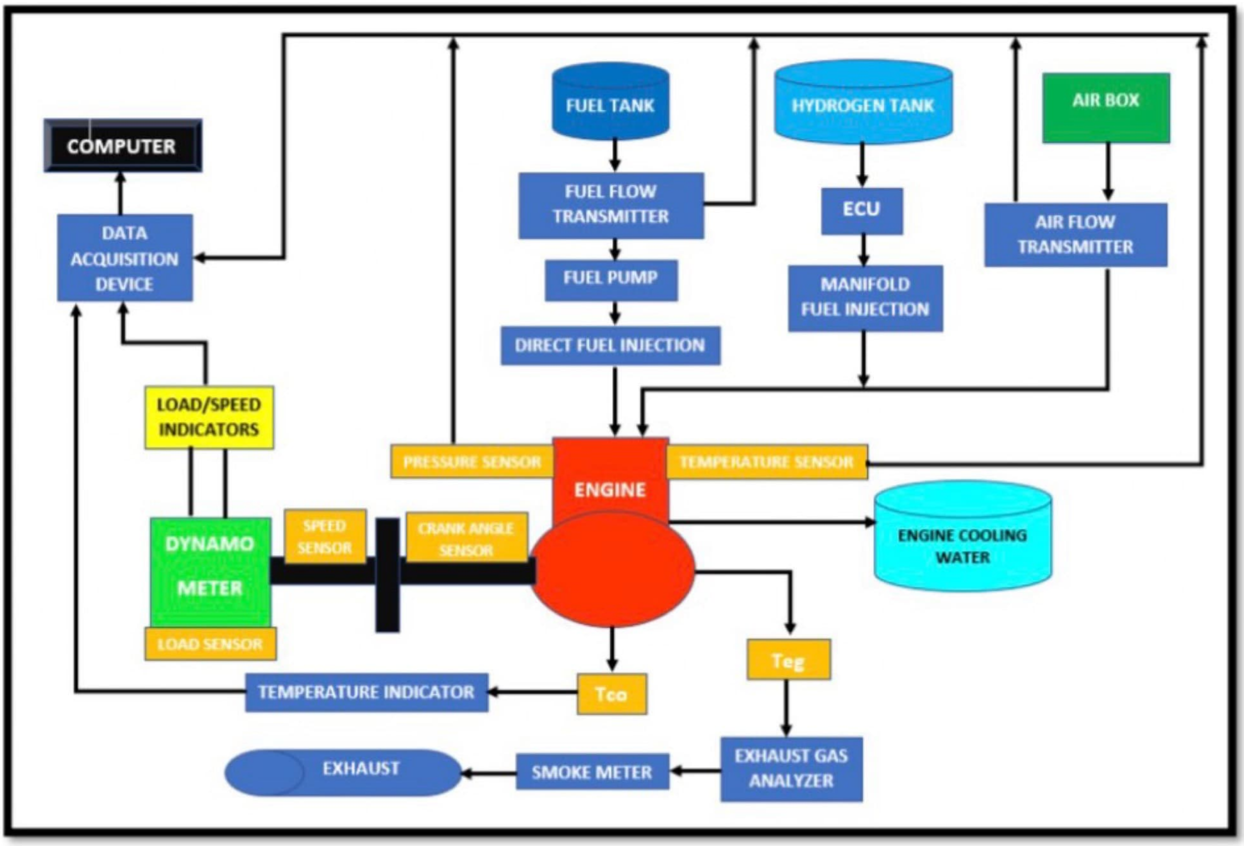
We used Calophyllum Inophyllum oil and Camphor oil to make the required blends of fuel. The blends are as follows:

Diesel fuel is also used to acquire the results which are further used to compare the results obtained when the different blends are run. We used a Kirloskar Engine TV 1 to run the blends to obtain various performance and emission characteristics which had the following specification:

Table 3.1: Engine specifications

Type	1 cylinder, 4 stroke, diesel
Make	Kirloskar
Model	TV1
Rated Power (kW)	5.2
Cooling	Water
Volume (cc)	661
Bore (mm)	87.5
Stroke (mm)	110
Compression Ratio	17.5:1
Rated-Speed (rpm)	1500

Figure 3.1: Engine setup



An Eddy current dynamometer is connected to the diesel engine. Three sensors were connected to the dynamometer: a load cell sensor, a speed sensor, and a crank angle position sensor.

Table 3.2: Eddy current dynamometer specifications

Make	Techno Mech
Model	TMEC-10
Maximum Power (kW)	7.5
Rated Speed (rpm)	1500-1600
Dynamometer Arm Length (mm)	185

A load cell sensor converted the load readings or force into electrical impulses (range 0-50 kg, type strain gauge). The crank angle was measured with a crank-angle sensor with a resolution of 1 degree and a range of 5000 PSI at a speed of 5500rpm with a TDC pulse, while the rpm was measured with the speed sensor. Other sensors utilized were a piezo-sensor with a low noise wire for measuring pressure or stress and strain and a temperature sensor for sensing temperature changes.

The Fuel was used to store the fuel while testing each blend. After the testing of one blend is over the fuel tank is emptied and the fuel is replaced with the next blend. A fuel flow transmitter (DP transmitter) with a range of 0-500mm WC was connected to the fuel tank which indicated the amount of fuel flow into the cylinder.

To monitor temperature readings, the temperature transmitter of two-wire types with an input RTD PT100 having a range of 0-1000 and input thermocouple with a range of 0-12000C, which give output in a range of 4-20mA is linked to a temperature sensor at the engine's intake and outlet valves. Temperature transmitter is also connected to the Rotameter (Engine cooling 40400 LPH; Calorimeter 25250 LPH) through the temperature sensor near the intake. The Rota meter's job is to determine the fuel's volumetric flow rate.

The DAQ (Data Acquisition) is linked to the Engine software ("Engine soft"), a software used to analyze engine performance, which is connected to all of the sensors.
The amount of smoke produced was measured using a smoke meter.

Table 3.3: Smoke meter specifications

Type	AVL 437C Smoke-Meter
Opacity – 0-100%	0.1%
Absorption (K value)	0-99-99/m, 0.01/m
Measurement Data	Resolution

Table 3.4: Gas analyser specifications

Type	AVL DI GAS 444 N
Measurement Data	Resolution
CO2 - 0-20%Vol	0.1% Vole
CO - 0-15%Vol	0.000% Vol
O2 - 0-25%Vol	0.01% Vol
HC - 0-20000 ppm Vol	1 ppm/10 ppm
NOx 0-6000 ppm Vol	1 ppm Vol
Type	AVL 437C Smoke-Meter
Opacity – 0-100%	0.1%
Absorption (K value)	0-99-99/m, 0.01/m
Measurement Data	Resolution

Property Testing:

Various properties like viscosity, flash point, fire point and density of the oils were tested. Density was tested using a hydrometer, flash point and fire point of each oil were tested using Cleveland Apparatus and Redwood Viscometer was used to test both absolute and kinematic viscosity of the oils. The various properties of each oil are as follows:

Table 3.5: Properties of Oil

Property	Diesel	Camphor Oil	Calophyllum Inophyllum Oil	CI50CMO50
Chemical Formula	C12H23	C10H16O	C48H90O6	--
Molecular Weight	167	252	762	--
Cetane Number	48	5	52	28
Calorific Value (kJ/kg)	42500	38200	39000	38600
Density (g/cm3)	0.840	0.890	0.910	0.900
Kinematic Viscosity (cST @ 40°C)	4.5	2	35	18
Dynamic Viscosity (cPoise @ 40°C)	3.78	1.78	31.85	16.2
Flash point (°C)	52	54	228	.72
Fire Point (°C)	78	58.	270	76

4.FORMULAE

Brake Power (kW)

$$BP = \frac{2\pi NT}{60 \times 1000}$$

$$T = Rmg$$

Where;

- R = Radius of the Drum (0.185m)
- M = mass of the load applied on the engine (kg)
- g = acceleration due to gravity (9.81m/s^2)
- T = Torque (Nm)
- N = Speed of the Engine (1500rpm)

Without Hydrogen Induction:

$$TFC = \dot{m}_f = \rho_f \times \frac{10}{10^6 \times t}$$

$$Q_i = \dot{m}_f \times CV$$

Brake Thermal Efficiency (BTE):

$$BTE = \frac{BP}{Q_i} \times 100$$

Brake Specific Fuel Consumption (BSFC):

$$BSFC = \frac{\dot{m}_f \times 3600}{BP}$$

Brake Specific Energy Consumption (BSEC):

$$BSEC = \frac{CV \times \dot{m}_f \times 3600}{BP}$$

With Hydrogen Induction:

$$\dot{m}_f = \rho_f \times \frac{10}{10^6 \times t}$$

$$\dot{m}_{H_2} = \rho_{H_2} \times \dot{V}_{H_2}$$

$$\rho_{H_2} = \frac{Pm}{RT}$$

$$TFC = \dot{m}_f + \dot{m}_{H_2}$$

$$Q_i = \left(\dot{m}_f \times CV_f\right) + \left(\dot{m}_{H_2} \times CV_f\right)$$

Brake Thermal Efficiency (BTE):

$$BTE = \frac{BP}{\left(\dot{m}_f \times CV_f\right) + \left(\dot{m}_{H_2} \times CV_{H_2}\right)} \times 100$$

Brake Specific Fuel Consumption (BSFC):

$$BSFC = \frac{\left(\dot{m}_f + \dot{m}_{H_2}\right) \times 3600}{BP}$$

Brake Specific Energy Consumption (BSEC):

$$BSEC = \frac{\left\{\left(\dot{m}_f \times CV_f\right) + \left(\dot{m}_{H_2} \times CV_{H_2}\right)\right\} \times 3600}{BP}$$

Where;

- R = Universal Gas Constant (8.314 J/molK)
- T = Temperature of Hydrogen (300K)
- P = Pressure of Hydrogen (1 bar)
- m = molar mass of Hydrogen (2)
- ρ_{H_2} = Density of Hydrogen (kg/m^3)
- ρ_f = Density of Fuel (kg/m^3)
- t = Time taken for 10cc of fuel (s)
- $\dot{m}_f$ = mass flow rate of fuel (kg/s)
- $\dot{m}_{H_2}$ = mass flow rate of Hydrogen (kg/s)
- CV_f = Calorific Value of Fuel (kJ/kg)
- CV_{H_2} = Calorific Value of Hydrogen (1,20,000kJ/kg)
- Q_i = Heat Input (J)

5. GRAPHS, RESULTS AND DISCUSSION

The following performance, emission, and combustion parameters were graphically examined based on the engine runs.

5.1: PERFORMANCE TEST ANALYSIS

5.1.1: Brake Specific Energy Consumption

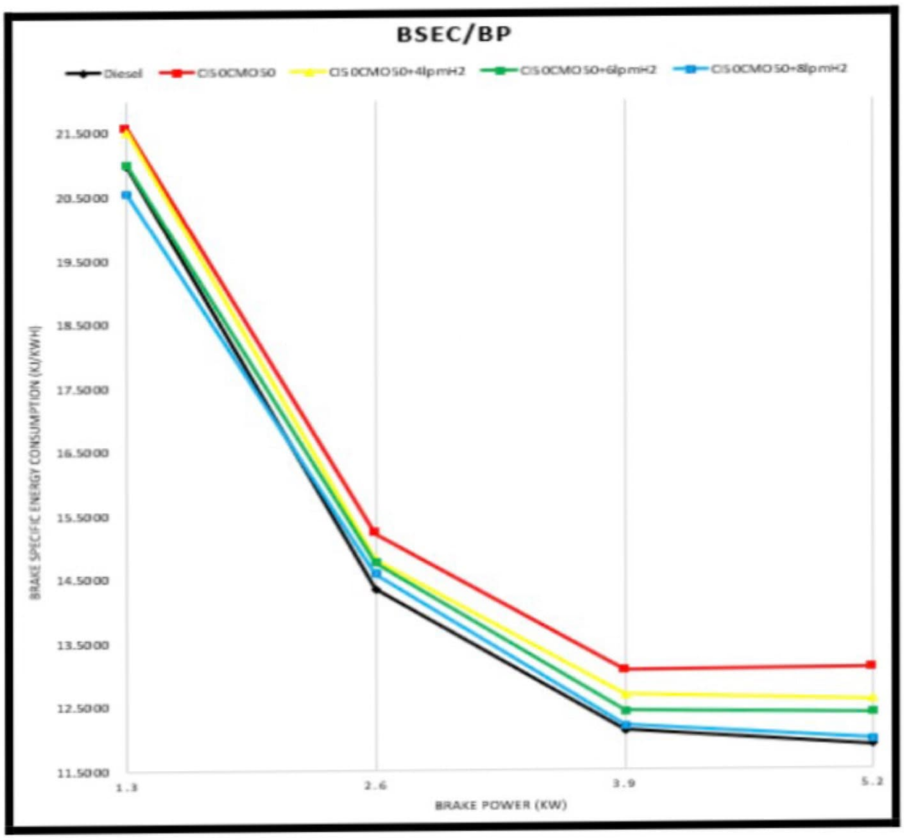


Figure 5.1.1

By observing Figure 5.1.1 we can analyse that diesel is having the least brake-specific energy conception during every loading condition. The addition Hydrogen has decreased the energy consumption throughout the load range, at lower loads the change is not very much but once the load is increased there is a significant decrease in energy consumption. The blends with more concentration of camphor oil also show a high thermal efficiency comparatively. CI50CMO50 + 8 lpm H2 has the most consistent fuel consumption over the load range and it is comparable to diesel graph. At 0% load condition it has lower specific energy consumption than diesel.

5.1.2: Brake Specific Fuel Consumption

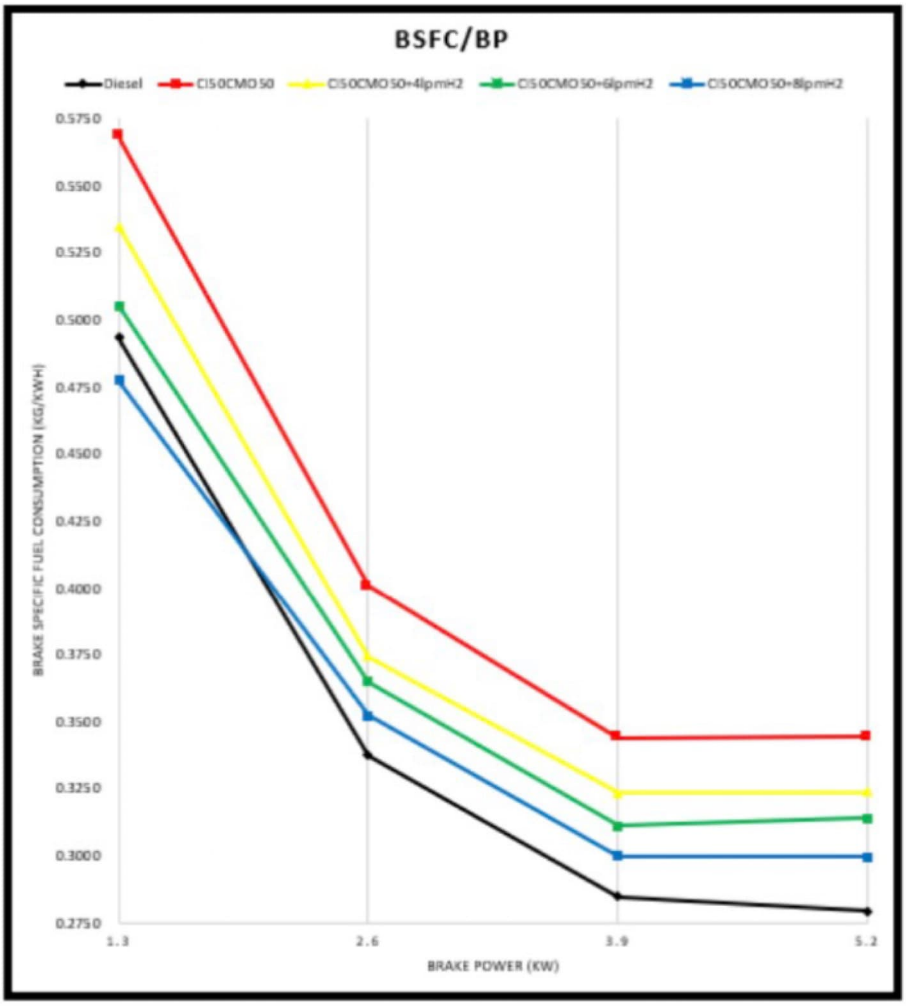


Figure 5.1.2

By observing Figure 5.1.2 we can analyse that diesel is having the least brake-specific fuel conception during every loading condition. The addition of Hydrogen has decreased the fuel consumption throughout the load range, at lower loads the change is not very much but once the load is increased there is a significant decrease in fuel. The blends with more concentration of Hydrogen also show a lower Specific Fuel Consumption comparatively. CI50CMO50 + 8lpm H2 has the most consistent fuel consumption over the load range as it has higher concentration of Hydrogen and at 0% load condition 8lpm blend has lower Specific Fuel Consumption than diesel.

5.1.3: Brake Thermal Efficiency

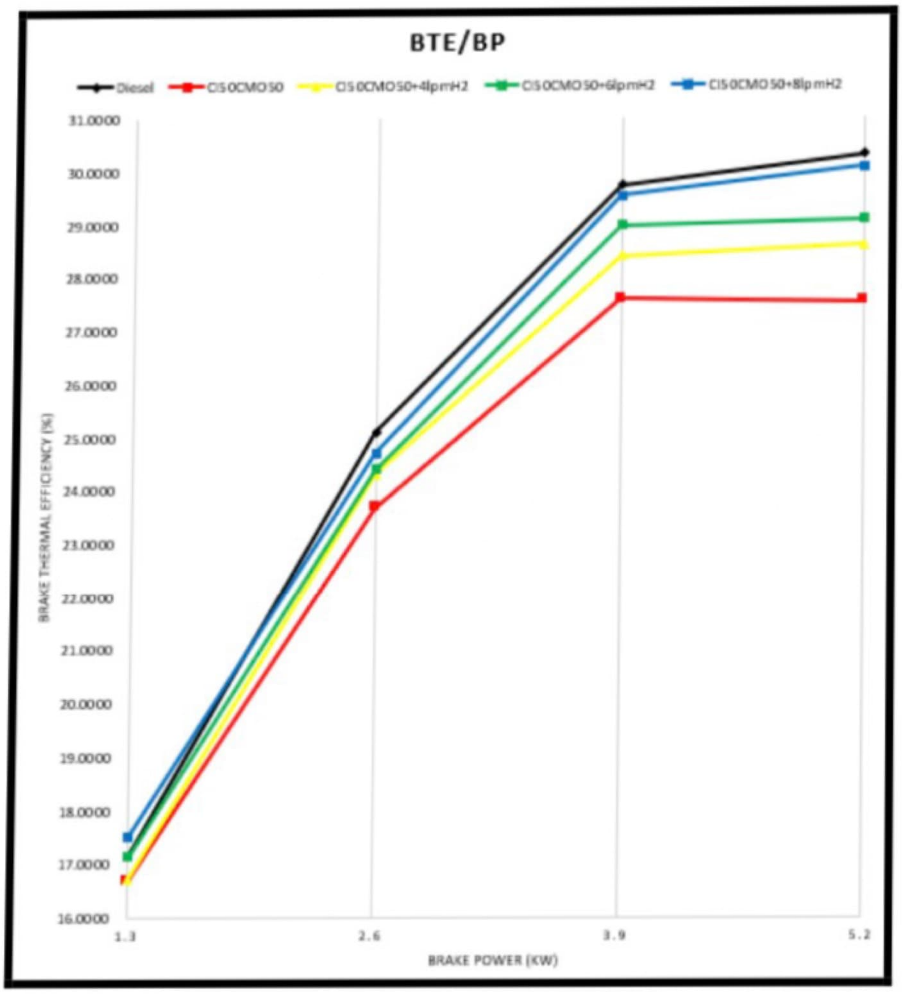


Figure 5.1.3

By observing Figure 5.1.3 we can analyse that diesel is having the highest brake thermal efficiency during every loading condition. The addition of H2 has increased the brake thermal efficiency throughout the load range, at lower loads the change is not very much but once the load is increased there is a significant increase in thermal. The blends with more concentration of Hydrogen also show a high thermal efficiency comparatively. CI50CMO50+8lpmH2 has the most consistent efficiency over the load range as it has a higher concentration of hydrogen and at 0% loading condition it has higher brake thermal efficiency than even diesel.

5.2: EMISSION ANALYSIS

5.2.1: Carbon Monoxide Emission

As indicated by Figure 5.2.1 the presence of Camphor oil has increased the amount of Carbon Monoxide emission at a lower load and this is also more than that produced by diesel. The addition of H2 has shown a reduction in the emission of CO throughout the load range. The main reason for the emission of CO is improper combustion of fuel which is prominently visible in the blends with Calophyllum oil composition. During increased loading conditions the amount of CO emission gradually decreases but at higher loads, it is increased further. Blends with of H2 as additive have managed to keep the amount of CO emission under control even less than that of diesel between 25% and 75% load conditions

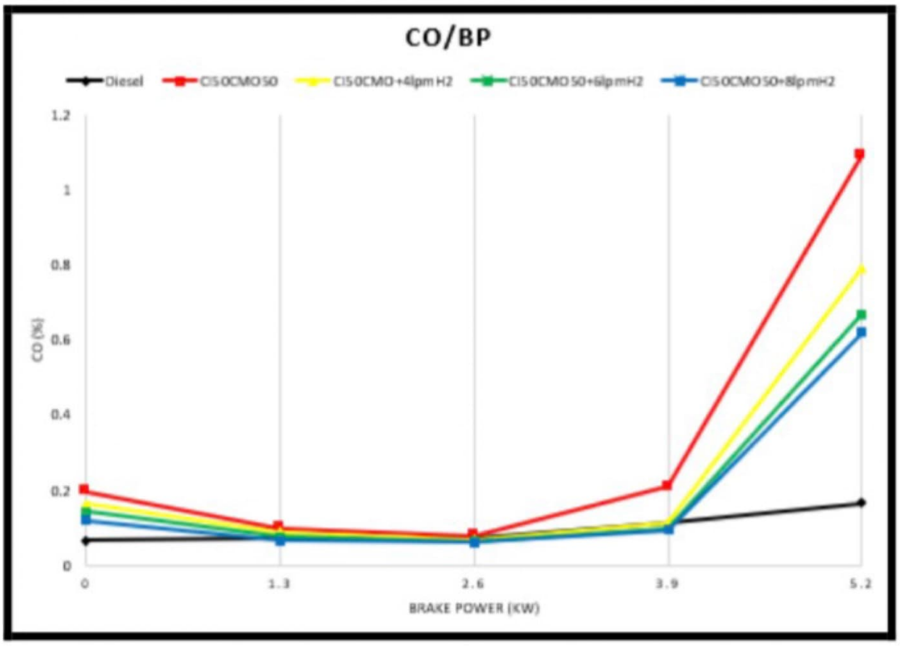


Figure 5.2.1

5.2.2: Carbon Dioxide Emissions

Figure 5.2.2 shows that at lower loads diesel is having more Carbon Dioxide emission compared to other blends, the increase in the concentration of Calophyllum fuel has shown a significant increase in Carbon Dioxide emission which reduces with the addition of Hydrogen. As the load decreases, Carbon Dioxide emission is further reduced. At higher loads Camphor blended Calophyllum fuel concentration shows more Carbon Dioxide emissions than diesel. CI50CMO5O+8lpmH2 is having a lower amount of Carbon dioxide emission than diesel across all load ranges.

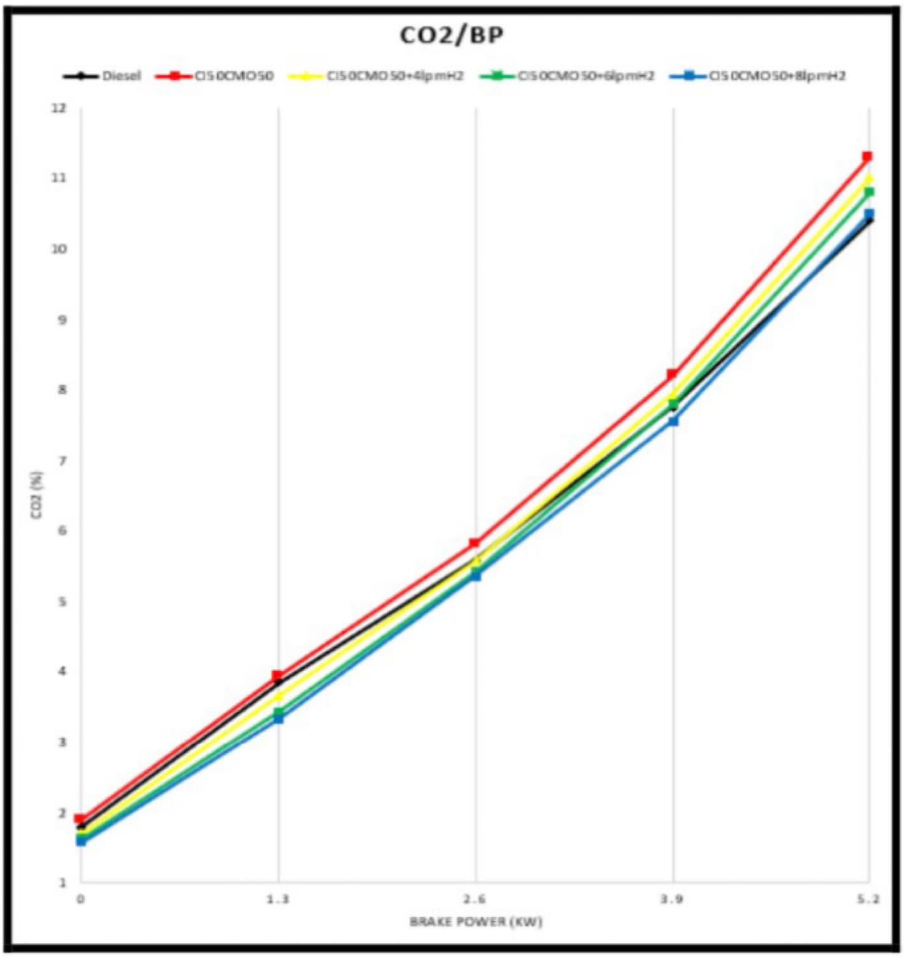


Figure 5.2.2

5.2.3: Unburnt Hydrocarbon Emissions

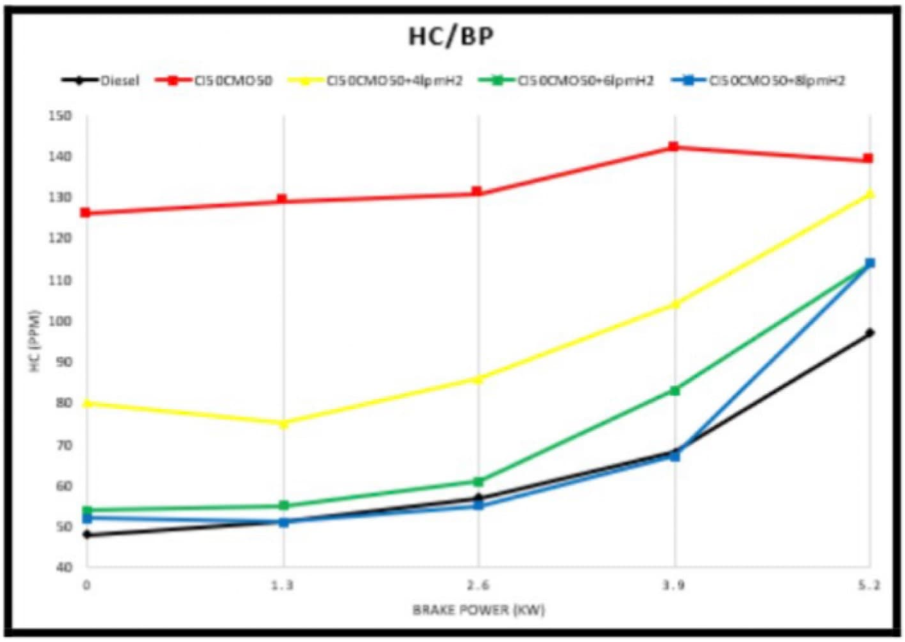


Figure 5.2.3

As indicated by Figure 5.2.3 diesel is having very less unburnt hydrocarbon emission throughout the different loading conditions which indicates the proper burning of fuel. On the other hand, CI50CMO50 is having a very high amount of unburnt hydrocarbon emission at all loading conditions. As the concentration of hydrogen is increased the emission of unburnt hydrocarbon is reduced and stays similar to that of diesel. It must have happened as higher amount of hydrogen in the combustion chamber increases the temperature which burns the fuel completely leaving lesser unburned hydrocarbon emissions. 8lpm variant fuel blend also has lower hydrocarbon emissions than even diesel between 25% to 75% load conditions.

5.2.4: Smoke Opacity

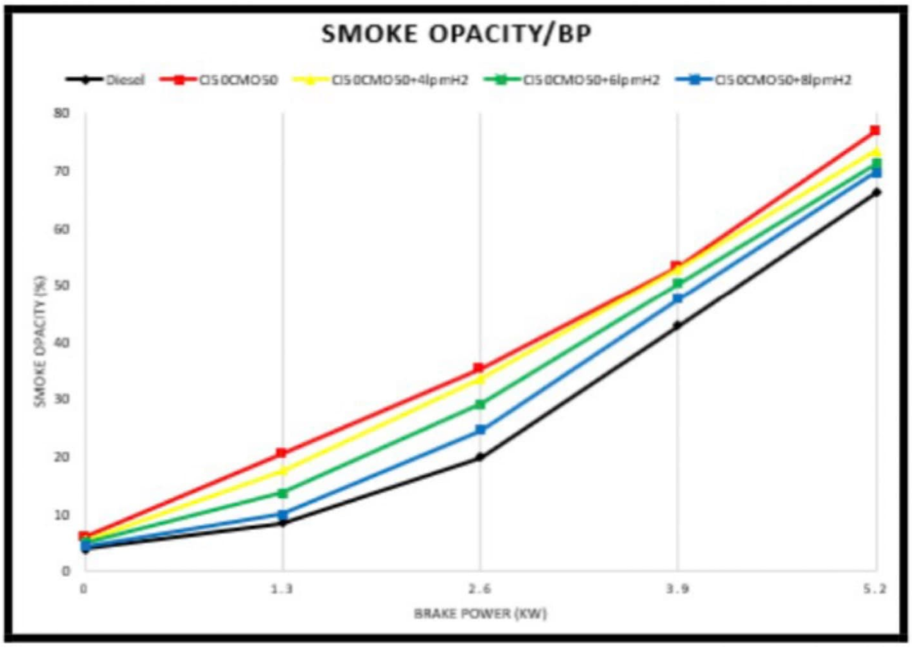


Figure 5.2.4

Figure 5.2.4 shows the comparison of smoke opacity and brake power. The comparison shows that CI50CMO50 has higher smoke emission than diesel throughout the load range except for and zero load where it is comparable to diesel which has slightly lower smoke opacity. Increase in Hydrogen concertation in the blends reduces the smoke emissions and 8 lpm variant though higher than diesel is better comparable to the rest.

5.2.5: Oxides of Nitrogen Emission

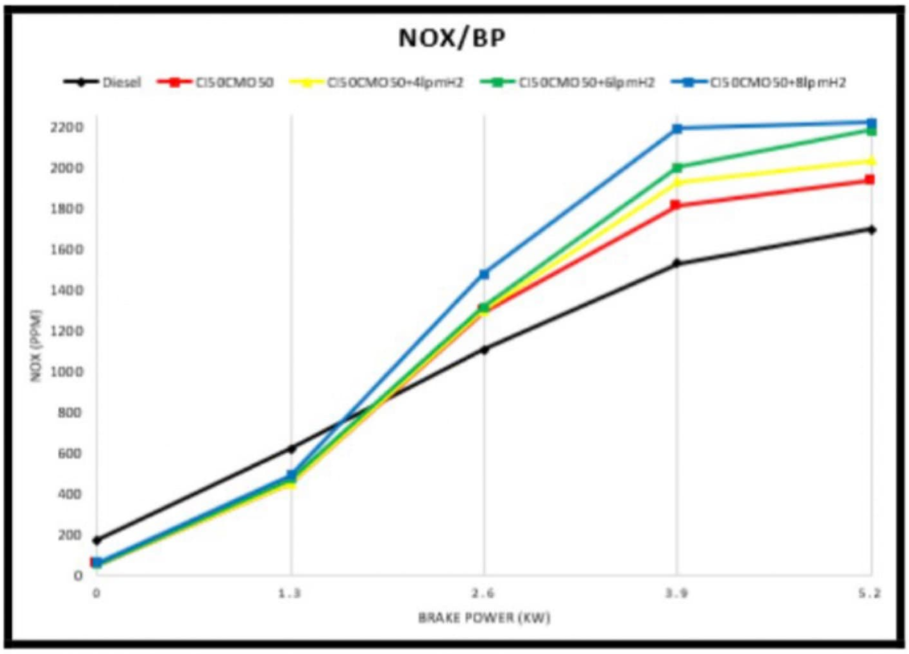


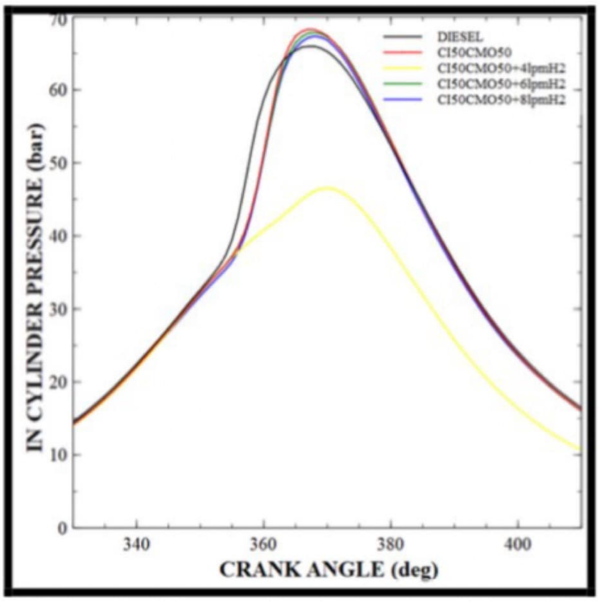
Figure 5.2.5

Figure 5.2.5 show the of emission of oxides of nitrogen and brake power. The presence of hydrogen increases the nitrogen oxides emission as it increases the combustion chamber temperature. Oxides of Nitrogen are formed at higher combustion temperatures. This shows that diesel has a higher emission of oxides of nitrogen compared to all other blends at the lower load range. At a lower load, incomplete combustion of fuel must have reduced the amount of NOx emitted, the addition of Hydrogen at higher load range increases the amount of NOx emission as seen in the graph.

Here CI50CMO50+lpmH2 has the highest Nitrogen oxide emissions across all blends because of the higher amount of hydrogen in the fuel.

5.3: COMBUSTION ANALYSIS

5.3.1: at 50% load



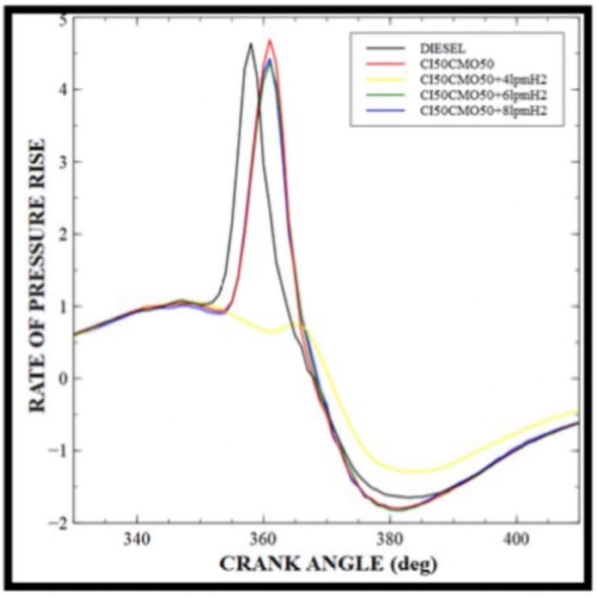
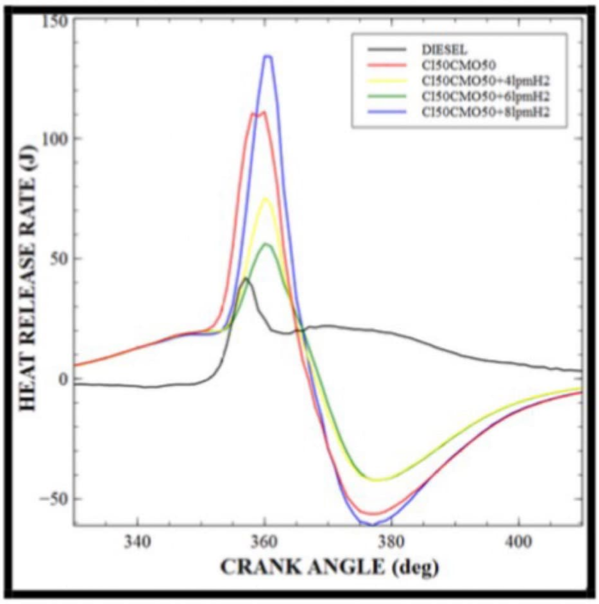


Figure 5.3.1a **Figure 5.3.1b**

Figure 5.3.1a & b shows in cylinder pressure and rate of pressure rise compared to crank angle at 50% load. at 365 CA C150CMO50 is having the greatest ignition with maximum peak pressure. The above graph also shows that C150CMO50+8lpmH2 and C150CMO50+6lpmH2 have a slightly delay in peak pressure .C150CMO50+4lpmH2 has low in cylinder pressure through all crank angle considerations compared other blends.



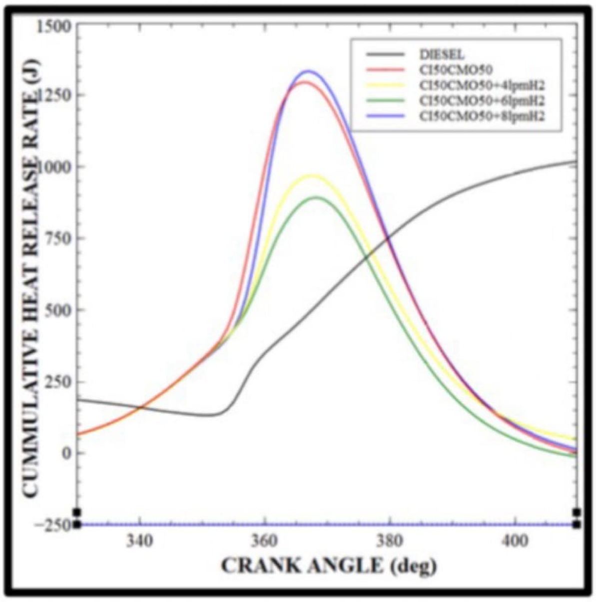
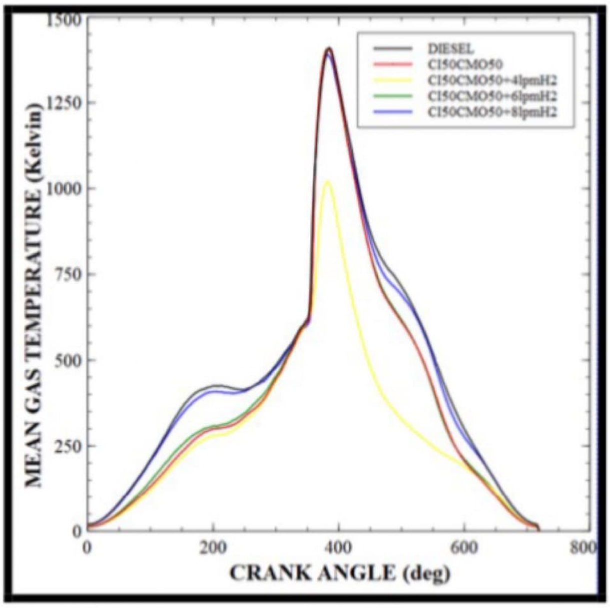


Figure 5.3.1c **Figure 5.3.1d**

Figure 5.3.1c and Figure 5.3.1d shows the diagram where the Net and Cumulative Heat Release rate is compared to the Crank angle at 50% load. With 360°CA C150CMO50+81pmH2 is having the highest heat release rate and cumulative heat release rate. The graph also shows that diesel has a delayed peak. C150CMO50+61pmH2 have the lowest peak with a minimal delay.



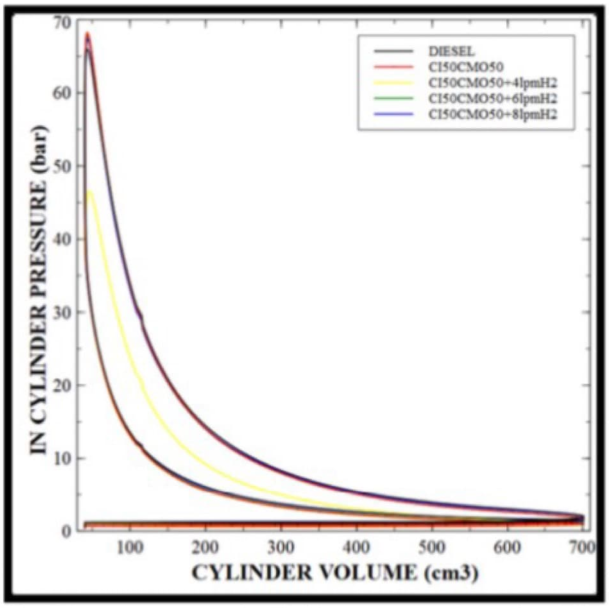


Figure 5.3.1e **Figure 5.3.1f**

Figure 5.3.1e depicts a graph that compares the Mean Gas Temperature to the Crank Angle at 50% load. The gas temperature for CICMO+8lpmH2 is the maximum at 400°CA. The C150CMO50+41pmH2 mix also has a lower peak mean gas temperature than other blends, as shown in the graph. C150CMO50+81pmH2 is comparable to diesel.

Figure 5.3.1f shows the PV diagram where a comparison of in-cylinder pressure and volume is compared at 50% load. Here rise in pressure is inversely proportional to the rise in volume at a constant temperature. Diesel is attaining the peak pressure in this PV Diagram. Pressure peak shows a higher temperature which in turn indicates the proper combustion taking place inside the cylinder. The figure shows the lowest pressure rise in the cylinder was experienced by C150CMO50. The delays in pressure rise experienced by the blends in previous loads have reduced to a very negligible amount.

5.3.2 At 75% Load

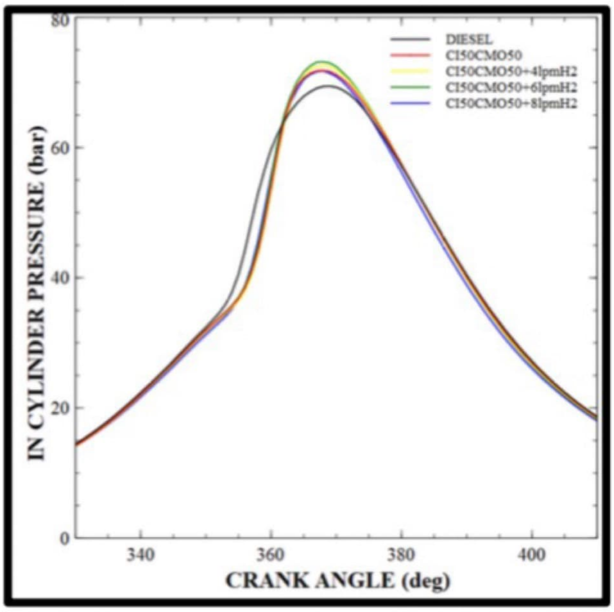


Figure 5.3.2a

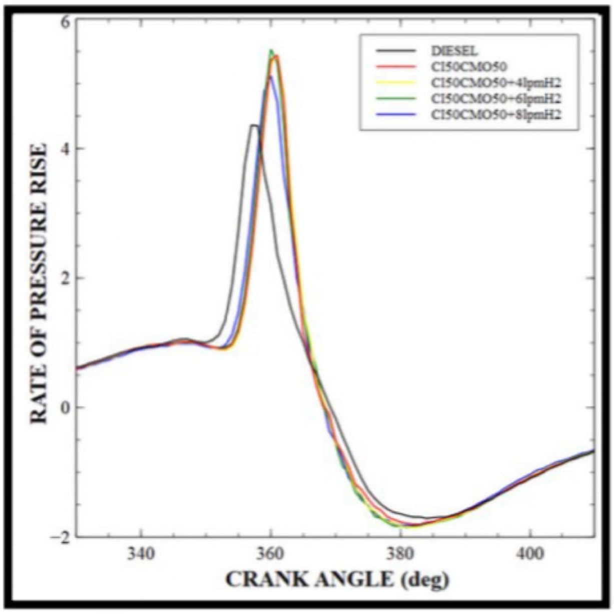


Figure 5.3.2b

Figure 5.3.2a and Figure 5.3.2b shows the P-Theta diagram where the Rate of Pressure rise and In-cylinder pressure is compared to the Crank angle at 75% load. With 370°CA, C150CMO50+61pmH2 is having the greater ignition with the maximum peak pressure. The graph also shows that C150CMO50+41pmH2, C150CMO50 and C150CMO50+81pmH2 have a delayed peak but which is similar to that of diesel.

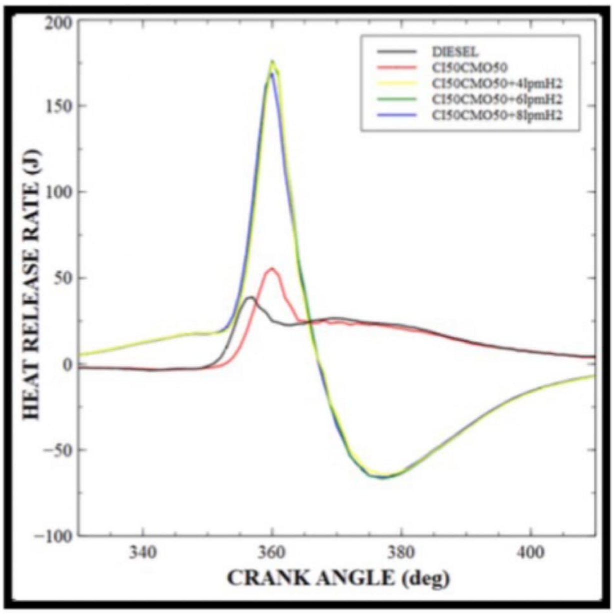


Figure 5.3.2c

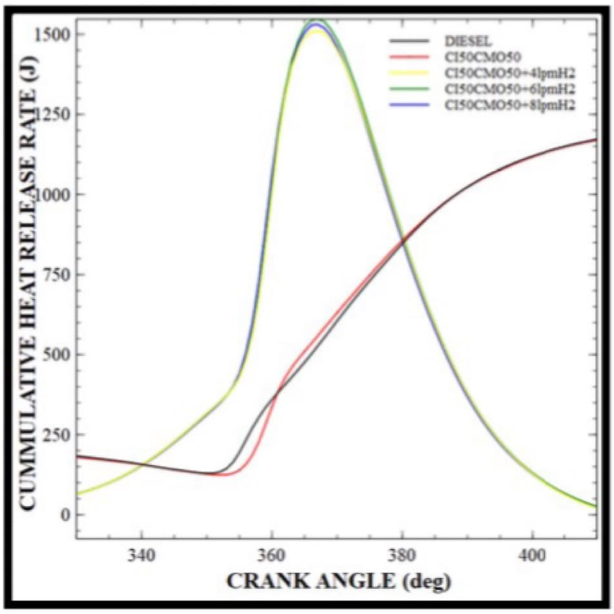
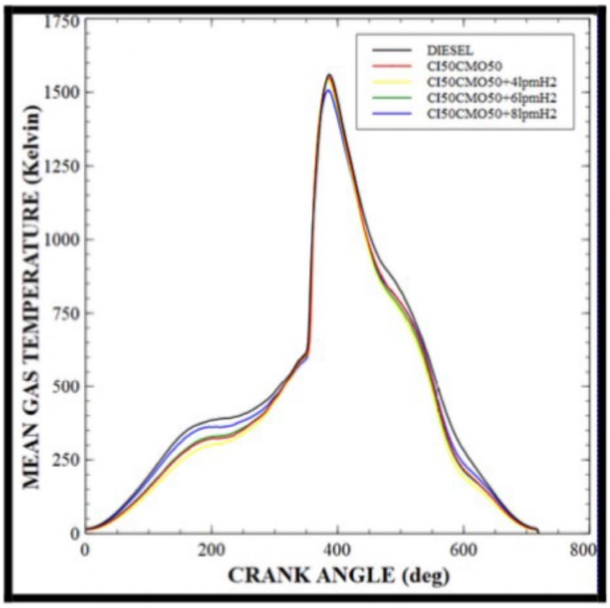


Figure 5.3.2d

Figure 5.3.2c and Figure 5.3.2d shows the diagram where cumulative heat release rate and net heat release rate are compared to crank angle. The graph indicates the highest peak in net heat release rate by C150CMO50+61pmH2 during combustion. Except for C150CMO50, all other blends have a higher peak than diesel for the net heat release rate. The graph shows the delays in attaining peak heat cumulative heat release experienced by each blend. C150CMO50 and diesel have a similar cumulative heat release rate.



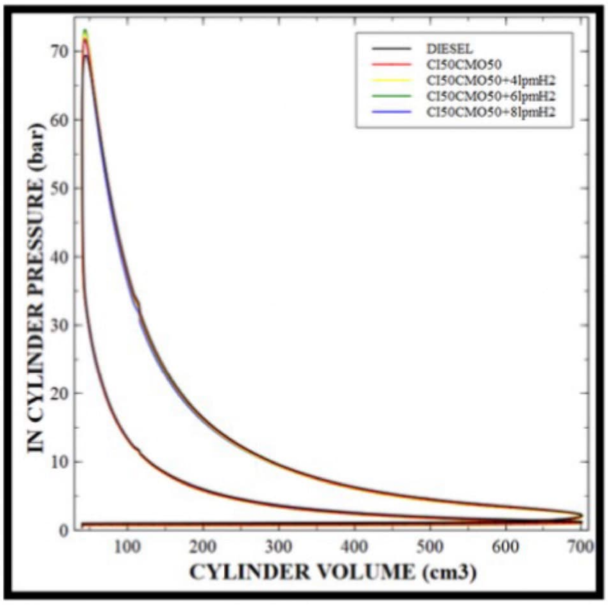
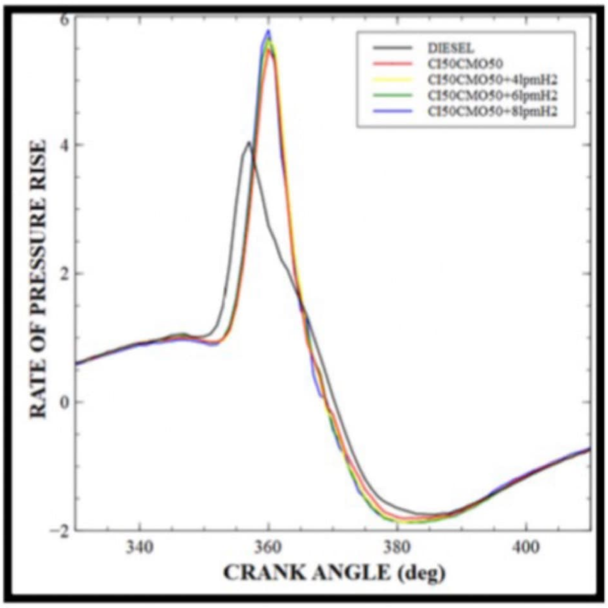


Figure 5.3.2e **Figure 5.3.2f**

Figure 5.3.2e shows the diagram where the Mean Gas Temperature is compared to the Crank angle at 75% load. With 1600 kelvin at 400CA, diesel and CI50CMO50 is having the greater mean gas temperature. CI50CMO50+8lpmH2 has the lowest mean gas temperature.

Figure 5.3.2f shows the PV diagram where a comparison of in-cylinder pressure and volume is compared at 75% load. Here rise in pressure is inversely proportional to the rise in volume at a constant temperature. CI50CMO50+6lpmH2 is attaining the peak pressure in this PV Diagram. Pressure peak shows a higher temperature which in turn indicates the proper combustion taking place inside the cylinder.

5.3.3: At 100% Load



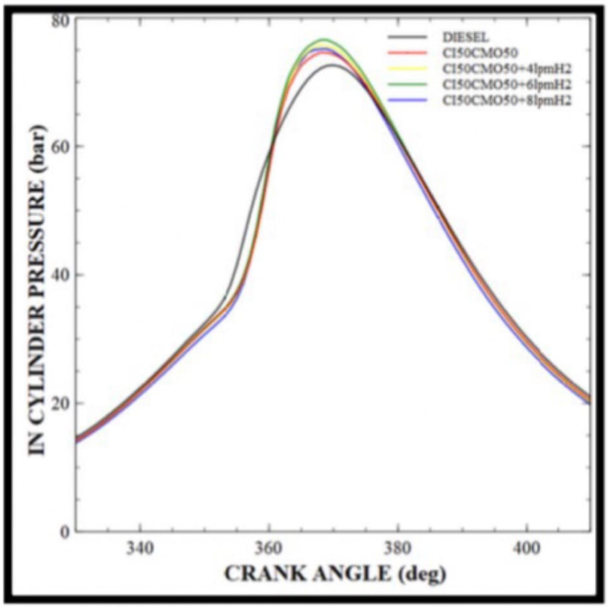
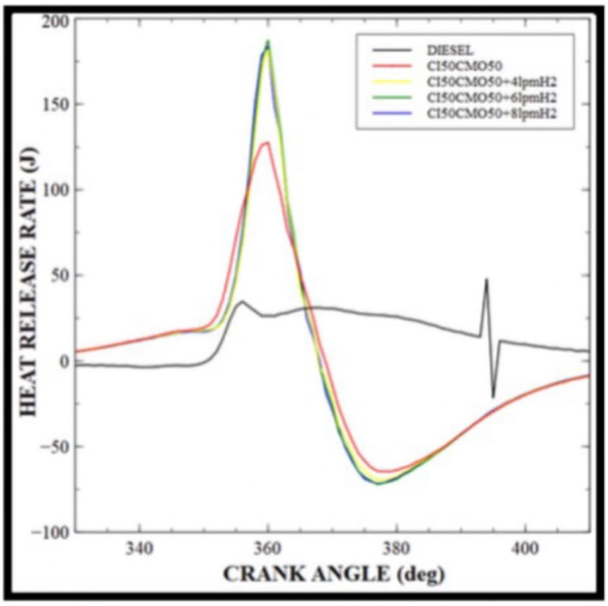


Figure 5.3.3a **Figure 5.3.3b**

Figure 5.3.3a and Figure 5.3.3b shows the P-Theta diagram where the Rate of Pressure rise and In-cylinder pressure is compared to the Crank angle at 100% load. At 360°CA the rate of pressure rise is around 6. C150CMO50+81pmH2 is having the greater ignition with the maximum peak pressure. All the bends have a delayed peak pressure compared to diesel. The graph also shows the C150CMO50, C150CMO50+41pmH2 and C150CMO50+61pmH2 have higher peak pressure in that order. Diesel has the lowest peak with a minimal delay.



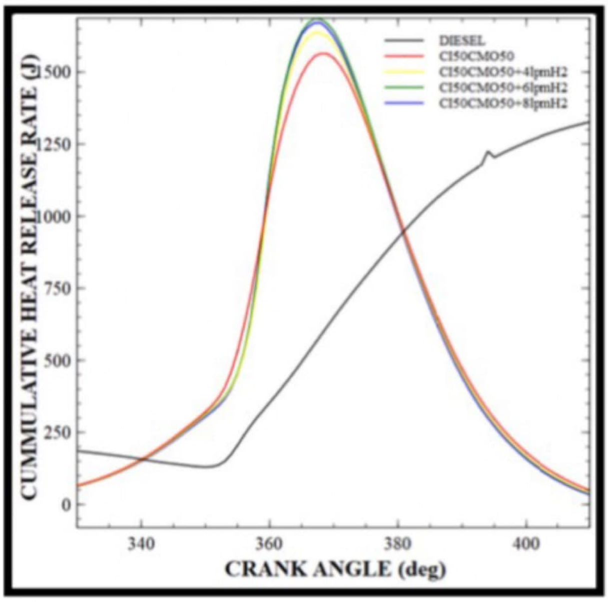
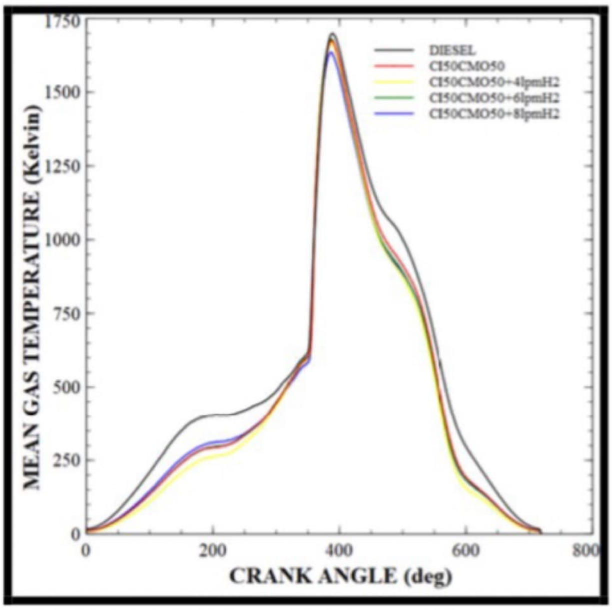


Figure 5.3.3c **Figure 5.3.3d**

Figure 5.3.3c and Figure 5.3.3d shows diagram where cumulative heat release rate and net heat release rate are compared to crank angle. The graph indicates the highest peak in net heat release rate by C150CMO50+61pmH2 and C150CMO50+81pmH2 during combustion. Diesel is having the lowest peak for the net heat release rate. The graph shows the delays in attaining peak heat cumulative heat release experienced by each blend. C150CMO50+61pmH2 has a higher peak for cumulative heat release rate than all other blends.



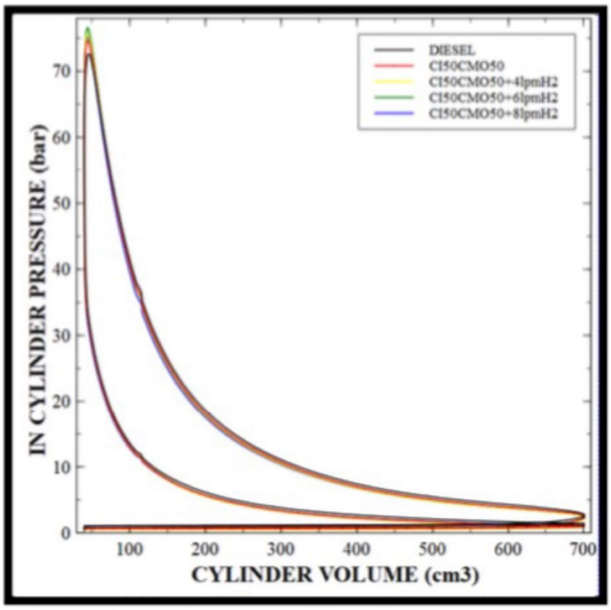


Figure 5.3.3e **Figure 5.3.3f**

Figure 5.3.3 e shows the diagram where the Mean Gas Temperature is compared to the Crank angle at 100% load. With 1680 kelvin at 450CA, diesel is having the greater ignition with the maximum mean gas temperature. The graph also shows that C150CMO50, C150CMO50+41pmH2, C150CMO50+61pmH2 CI50CMO50+8lmpH2 have lower peak mean gas temperature during combustion in that order respectively.

Figure 5.3.2 f shows the PV diagram where a comparison of in-cylinder pressure and volume is compared at 100% load. Here rise in pressure is inversely proportional to the rise in volume at a constant temperature. CI50CMO50+6lpm H2 is attaining the peak pressure in this PV Diagram. Pressure peak shows a higher temperature which in turn indicates the proper combustion taking place inside the cylinder.

6. CONCLUSION

Graphical Analysis of all the tests was analyzed for various blends of Camphor oil and Calophyllum Inophyllum with Hydrogen Induction. Tests include a performance test, emission tests and combustion tests. After the analysis various conclusions were formulated, which are as follows:

- Various property tests showed that Calophyllum Inophyllum oil has the highest viscosity and was very large compared to camphor oil and diesel. It also revealed that Calophyllum Inophyllum oil has a very high fire and flash point which made it very tough to undergo combustion.

- Performance tests revealed that diesel had the advantage over all the blends in all the tests. C150CMO50+8lpm H2 has comparable Brake Thermal Efficiency to diesel. We can witness higher Brake Thermal Efficiency and lower Brake Specific Fuel and Energy Consumptions as the flow rate of Hydrogen increases. The inclusion of H2 improved the BTE, BSFC, and BSEC results for all mixes.
- Emission test of C150CMO50+8lp H2 had shown better results than diesel in some tests like emission of CO emission, CO2 emission and unburnt HC emissions throughout the lower load range. The addition of Hydrogen to the blends had a serious impact in reducing emissions of CO and CO2. In between 0-25% load range we can see lower NOx emissions with all blends of CI50CMO50.

- Combustion Analysis showed diesel showed an overall better performance by having the maximum peak in-cylinder pressure during all the loading conditions. Even though, as the loading condition increased C150CMO50+81pmH2 showed improvement in net heat release rate which was more than that of diesel.

It may be stated that the brake thermal efficiency of CI50CMO50 + 8lpm H2 is comparable to that of diesel. It also shows greater Thermal Efficiency than diesel at lower load ranges. It also had lower CO, CO2 and unburned HC emissions than other blends and it also has lower emissions than diesel in the middle load ranges. It had higher NOx emissions than other blends and diesel but the lowest at 0% load range. Thus, it can be concluded that higher concentration of hydrogen increases the thermal efficiency and lowers carbon emissions.

However, it is to be considered that the experiment was conducted in an engine designed for diesel fuel. If an engine with a different method of injection for the additive were to be used, the results obtained might vary

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