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Analysis of Combustion on Compression Ignition Diesel Engine fuelled with blends of Neem Biodiesel

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Abstract - *Neem (Azadirachta Indica) oil is a non-edible oil which is used for production of neem biodiesel (NBD). Neem biodiesel produced by transesterification process & it's used as alternative fuel in compression ignition diesel engine without any prior modification. Neem biodiesel used in diesel engine in various blends such as NBD5, NBD15, NBD25, NBD35 & NBD45. The combustion parameter such as cylinder pressure, rate of pressure rise, neat heat release, cumulative heat release, mass fraction burned, mean gas temperature & ignition delay were studied & compare all blends combustion parameters with neat diesel fuel (D100).*

Key Words: Transesterification, Neem Biodiesel, Compression Ignition Diesel Engine, , Cylinder Pressure, Rate of Pressure Rise, Net Heat Release, Ignition Delay.

1.INTRODUCTION

Energy is the most important part of human life & being an essential input for every activity. Global energy demand will grow to continues, other end fossil fuels depletion day by day & environmental pollution rise. World energy demand grow by one-third from 2011 to 2035 & demand grows for all forms of energy such as Coal by 17%, Natural gas by 48%, Oil by 13%, Renewable by 77% & Nuclear by 66%. World population will grow about 1.7 billion from 2011 to 2035 & reach about 8.7 billion in 2035. World primary energy demand will grow from 2011 about 13070 million tonnes of oil equivalent (Mtoe) to 15025 Mtoe in 2020 to 17387 Mtoe in 2035. The oil demand grows from 86.7 million barrels per day (mb/d) in 2011 to 101.4 mb/d in 2035. World energy related CO_2 emissions rise by 20% from 2011 to 2035 & the CO_2 emissions about 31.2 gigatonnes in 2011 to reach about 34.6 gigatonnes in 2020 to 37.2 gigatonnes in 2035. [1]
As per population, energy demand & emissions increases, the new sources of energy that can full fill the energy demand is required. The required energy sources have renewable, clean & pollution free. Vegetable oils have the greatest potential as alternative fuels for diesel engines to replace the diesel fuel partially or totally. The use of neat vegetable oil cause some problems in engine such as problems in pumping, combustion & atomization in the injector systems of a diesel engine because the neat vegetable oil have many times higher viscosity than neat diesel fuel. For long time operation, vegetable oils normally introduce the development of gumming, the formation of injector deposits & ring sticking in diesel engine. The viscosity of neat vegetable oils reduced by converted it into esters by transesterification process. Biodiesel is a source obtained from vegetable oils, animal fats & waste cooking oils. It is a secured & self reliant fuel. It reduces carbon & sulphur emissions. It can be used as a fuel to produce electricity. In transesterification process, triglyceride converted into biodiesel which have almost similar properties of diesel fuel. Biodiesel is the most promising & eco-friendly alternative fuel for diesel engine because it is renewable, biodegradable, non-toxic & has almost similar properties of conventional diesel fuel. Biodiesel also consists of 12% oxygen which enables complete combustion & produce less emission. [2-4]

1.1 NEEM

Neem is known as Azadirachta indica & Neem is generic name in english used throughout the world. Neem is a tree which have general smaller (5-10 meter), can reach 30 meter & live 2 centuries. [5] Neem seed, a non-edible & non food feedstock for second generation of fuels has native of India, Burma, Sri Lanka, Pakistan, Indonesia, Malaysia, Japan & Australia. Neem seed is being used as medicine, pesticides, organic fertilizers & this tree has both traditional & religious values & considered as divine tree. This tree can be grow in almost any kind of land including clay, saline stony & alkaline soils. In India, availability, of neem seed is estimated to be 0.5 million tonnes per annum & production of neem oil as 30000 tons per annum. [6] India has about 80-100 million hectares of wasteland, which can be used for Neem plantation. India is the largest producer of Neem oil & its seed contains 30% oil content. [7] Neem tree needs little water & plenty of sunlight. The tree grows naturally in areas where the rainfall is in the range of 450 to 1200 mm. The harvesting period is between June-August. A mature Neem tree produces 30-50 kg seed. [8,9] Figure 1 shows the Neem plant, fruits & seeds.

Fig -1: Neem plant, fruits & seeds

2. MATERIAL AND METHODOLOGY

Neem non-edible vegetable oil purchased from Churu district in Rajasthan. Methanol (CH_3OH) 99.9% pure & Catalyst Potassium Hydroxide (KOH Pellets) purchased from nearest chemist in Bikaner district in Rajasthan. These are material used for transesterification process. Conventional diesel fuel purchased from nearest petrol pump in Bikaner to used for generate the baseline data for comparison other blends of Neem biodiesel.

Neem non-edible crude vegetable oil converted into biodiesel by transesterification process. Transesterification process is widely acceptable process to reduce the viscosity of vegetable oil by separation of glycerol from vegetable oil. Vegetable oil consists of 97% triglycerides & 3% both diglycerides & mono glycerides. Transesterification process is also called alcoholysis & this process is similar to hydrolysis. In this process displacement of alcohol from an ester by another alcohol. Figure 2 shows the general transesterification chemical reaction process.

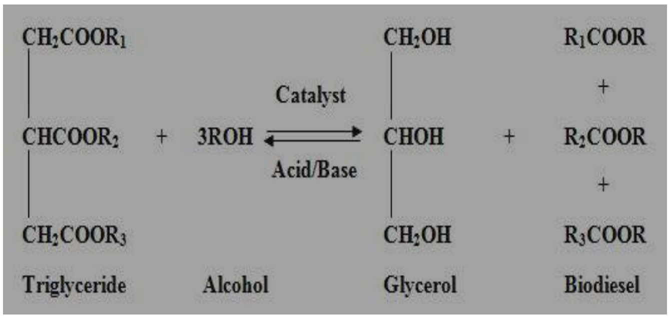

Fig -2: General transesterification reaction

For vegetable oil conversion into biodiesel, a transesterification kit is used which have hot plate magnetic stirrer mechanism. The hot plate mechanism is consists of a power switch, a temperature & speed controller. This kit also need some apparatus such as magnetic stirrer, beaker, stirrer rod, a vessel for reaction, temperature sensor etc. Figure 3 shows the transesterification kit for Neem oil biodiesel production.

Fig -3: Transesterification kit

The magnetic stirrer is used for stir the vegetable oil at different speed by adjust speed controller. The magnetic stirrer contain into the reaction vessel. 1 liter of Neem crude vegetable oil taken into reaction vessel & put it on to the hot plate for preheating process of Neem crude oil for removing moisture in it. 250 ml excess methanol taken into the beaker & 1% (approx. 10 gm) catalyst KOH pellets taken as by volume of Neem crude vegetable oil. This KOH pellets mixing with excess methanol in beaker with stirrer rod till pellets of KOH properly dissolved in the excess methanol. This solution of methanol & KOH called methoxide solution. This methoxide solution pour into the preheated Neem oil in reaction vessel & start the magnetic stirrer. The reaction temperature maintain at 60°C, stirrer speed maintain at 250 rpm & reaction time kept about 90 minute. After completion of this process the solution pour into bottle & settle down for 24 hour. After 24 hour, two layers was observed in the bottle. The upper low dense layer was Neem methyl ester (biodiesel) & lower high dense layer was glycerol. Neem biodiesel & glycerol shown in figure 4.

Fig -4: Separation layers of neem biodiesel & glycerol

Now this transesterified Neem crude vegetable oil become Neem biodiesel & this biodiesel have similar properties of diesel fuel. Table 1 shows the properties of Neem oil, Neem biodiesel & diesel fuel.

Table -1: Properties of Neem oil, biodiesel & diesel

Properties	Neem oil	Neem biodiesel	Diesel
Density (Kg/m³)	0.955	0.890	0.830
Kinematic Viscosity @ 40°C (Centistokes)	38.00	4.40	2.75
Cloud point (°C)	14.4	12	-5
Pour point (°C)	11	8	-12
Flash point (°C)	180	160	57

Fire point (^{0}C)	210	175	64
Calorific value (MJ/Kg)	36.00	38.15	42.00
Cetane number	47	52	47

Now, this Neem biodiesel blends manually with different volume proportions in neat diesel fuel. These different blends used for analysis of combustion characteristics of unmodified diesel engine. These combustion characteristics of blends compared with neat diesel fuel. The fuel specification shown in table 2 & figure 5 shows the different blends of neem biodiesel diesel (NBD5, NBD15, NBD25, NBD35, NBD45).

Table -2: Specification of fuel composition

Fuel	Fuel blends
100% (1000 ml) pure diesel + 0% (0 ml) neem biodiesel	D100
95% (950 ml) diesel + 5% (50 ml) neem biodiesel	NBD5
85% (850 ml) diesel + 15% (150 ml) neem biodiesel	NBD15
75% (750 ml) diesel + 25% (250 ml) neem biodiesel	NBD25
65% (650 ml) diesel + 35% (350 ml) neem biodiesel	NBD35
55% (550 ml) diesel + 45% (450 ml) neem biodiesel	NBD45

NBD5 contains 50 ml neem biodiesel & 950 ml neat diesel in 1000 ml of fuel. Same as NBD 15 contains 150 ml neem biodiesel, NBD25 contains 250 ml neem biodiesel, NBD35 contains 350 ml neem biodiesel & NBD45 contains 450 ml neem biodiesel in diesel fuel.

Fig -5: Different blends of neem biodiesel in diesel

2.1 EXPERIMENTAL SETUP AND PROCEDURE

The computerized combustion analysis of diesel engine experimental setup shown in figure 6. The experimental have different apparatus (component) such as an engine, eddy current dynamometer, calorimeter, water pump, pressure transducer, thermocouples, rpm encoder, crank angle encoder, engine & calorimeter rotameter, control panel & data acquition system. The engine have single cylinder, four stroke, compression ignition diesel engine & its specifications tabulated in table 3.

Fig -6: Diesel engine experimental setup

The eddy current dynamometer is connected at the engine flywheel end & using for apply the different load on engine. The calorimeter have a function for heat balance in the exhaust gas temperature with calorimeter water flow & pipe in pipe type calorimeter is used. The water pump is used for supply the water from water tank to engine, calorimeter & dynamometer cooling purpose. The pressure transducer installed in the combustion chamber of the engine to analysis the combustion characteristics of the engine such as pressure inside the engine combustion chamber & gas temperature. The thermocouples is used for measure the temperatures & attached various section of the set-up such as water inlet of engine & calorimeter, water outlet of engine & calorimeter, at the exhaust of the engine & calorimeter. The function of rpm encoder is measure the speed of engine in rpm. Crank angle encoder is used for analyzed the combustion characteristics of engine versus crank angle & it measured the crank angle in degree. The function of engine & calorimeter rotameter to set the water flow in liter per hours by the application of control valves.

Table -3: Specification of diesel engine setup

Description	Specifications
Make & Model	Legion brothers, Bangalore (India), TV1 (Kirloskar)
Type	Single cylinder, four-stroke, direct injection, vertical, water cooled, naturally aspirated diesel

	engine
Power	5.2 kW & 7 BHP
Rated speed	1500 rpm governed speed
Compression ratio	17.5:1
Cubic capacity	661.45 cc
Cylinder bore	87.5 mm
Stroke length	110 mm
Connecting rod length	234 mm
Injection pressure	203 bar
Method of loading	Eddy current dynamometer
Inlet valve open	4.5 deg. BTDC
Inlet valve close	35.5 deg. ABDC
Fuel injection start	23 deg. BTDC
Exhaust valve open	35.5 deg. BBDC
Exhaust valve close	4.5 deg. ATDC
Method of starting	Manual crank angle
Overall dimensions	W2000 x D2500 x H1500 mm^3

The control panel consists of various indicator such as temperature indicator, load indicator, rpm indicator, loading knob, air flow manometer, fuel measuring burret & fuelcock. The loading knob is used for adjust the load for engine through dynamometer. The data acquisition system is inside the control panel box & the components of data acquisition systems include appropriate sensors that converts any measurement parameter to an electrical signals, which is acquired by data acquisition hardware. It is collect the important data & store it on a personel computer for offline analysis.

The extensively experiment was performed firstly with the neat diesel fuel to obtained base line data & then with five different blends (NBD5, NBD15, NBD25, NBD35, NBD45) of every neem biodiesel diesel fuel. The experiment procedure are described as:

- Firstly the fuel tank was filled with neat diesel fuel.
- Initially check the fuel line pipe was properly filled with diesel fuel & no air bubbles are there.
- All the connections were checked properly & then electric supply was started.
- After setting the water supply from the water tank, by the water pump, the cooling water for engine flow & calorimeter flow was set up at 90 liter per hour & 50 liter per hour respectively.
- Start the computer & open the IC Engine combustion analysis software.
- Now open the fuelcock supply from burette & start the engine with manual cranking.
- The engine is run at no load condition about 10 minutes then after start the reading with software.
- Now log on to the IC Engine combustion software control panel & save the data given a file name with a specify folder.
- Now change the load and again log on to the software control panel.
- Same procedure is applied for different load & other blends of biodiesel.

3. RESULT AND DISCUSSION

The extensive experimental investigations were conducted with neat diesel fuel & neem biodiesel blends for combustion analysis of compression ignition diesel engine. The various combustion parameter of diesel engine such as cylinder pressure, rate of pressure rise, mass fraction burned, net heat release, cumulative heat release, mean gas temperature & ignition delay were analyzed.

3.1 CYLINDER PRESSURE

Cylinder pressure versus crank angle data over the compression & expansion strokes of the engine operating cycle can be used to obtain quantitative information on the progress of combustion. Chart 1 to 6 are shown the cylinder pressure history versus crank angle from 300°CA to 450°CA at 0%, 20%, 40%, 60%, 80% & 100% load conditions of engine.

The in cylinder pressure increases according to load increase on engine. The chart predicted that the in cylinder pressure are almost similar trends for both neat diesel fuel (D100) & neem biodiesel diesel blends (NBD5, NBD15, NBD25, NBD35, NBD45). The in cylinder pressure at ideal load (0% load) was found to be 48.70 bar at 371°CA for diesel fuel, 48.94 bar at 370°CA for NBD5, 49.30 bar at 369°CA for NBD15, 48.11 bar at 370°CA for NBD25, 45.39 bar at 371°CA for NBD35 & 46.74 bar at 371°CA for NBD45.

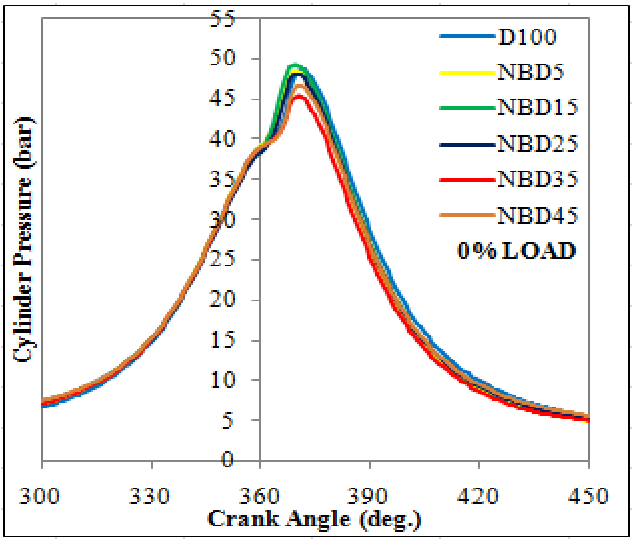

Chart -1: Cylinder pressure at 0% load

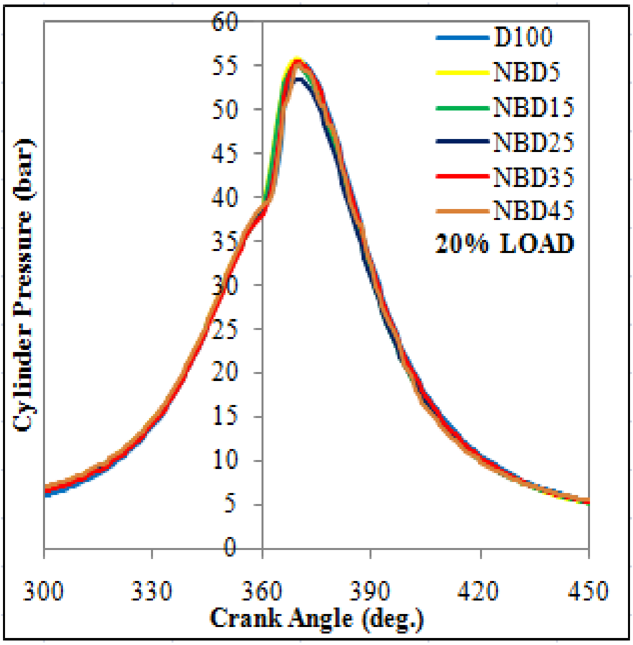

Chart -2: Cylinder pressure at 20% load

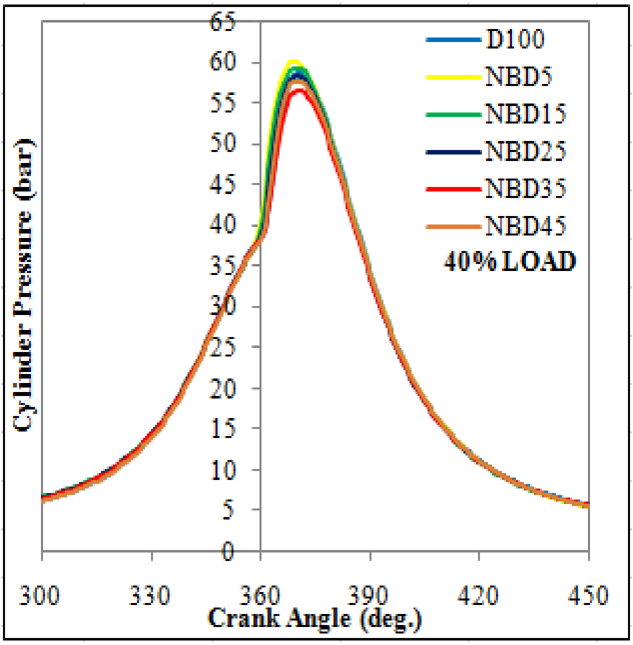

Chart -3: Cylinder pressure at 40% load

At full load condition (100% load), the in cylinder pressure was found to be 67.31 bar at 373°CA for diesel fuel, 69.34 bar at 371°CA for NBD5, 67.89 bar at 372°CA for NBD15, 67.62 bar at 372°CA for NBD25, 65.92 bar at 373°CA for NBD35 & 64.43 bar at 373°CA for NBD45. Lower concentration of neem biodiesel diesel blends shows slightly higher in cylinder pressure because lower concentration of neem biodiesel blends have complete combustion of the fuel. The neem biodiesel have already oxygen molecular & higher cetane number than neat diesel which leads complete combustion of the blends fuel. When concentration of neem biodiesel increases then in cylinder pressure goes down than neat diesel fuel because the kinematic viscosity & density of fuel increases which leads some proper atomization of blends of neem biodiesel in diesel. The NBD5 fuel shows higher in cylinder pressure than other blends & neat diesel fuel. Its shows about 2.93% higher in cylinder than neat diesel fuel. The rise in cylinder pressure also safe & efficient for neem biodiesel diesel blends because it takes place after TDC (360°CA). Otherwise, in cylinder pressure occurring very close to TDC or before that cause severe engine knock problem & thus affects engine durability. From in cylinder pressure results conclude that the use of neem oil biodiesel in diesel engine is safe & reliable.

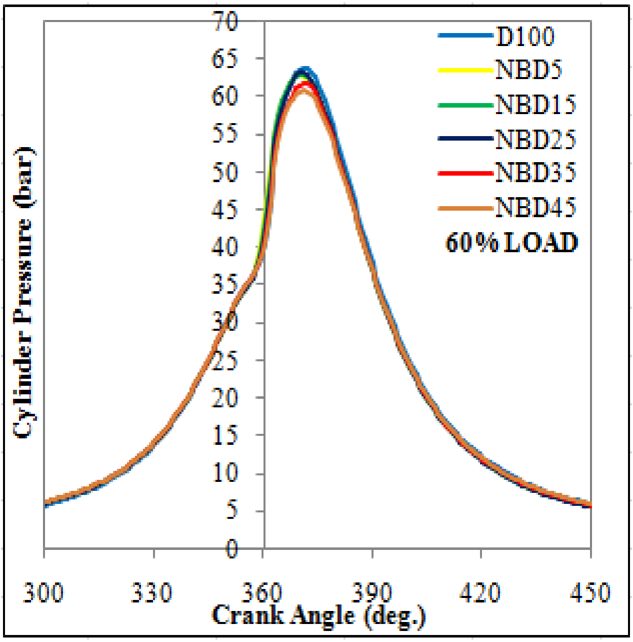

Chart -4: Cylinder pressure at 60% load

3.2 RATE OF PRESSURE RISE

Chart 7 to 12 are shown the variation of rate of pressure rise with respect to crank angle from 285°CA to 435°CA at 0%, 20%, 40%, 60%, 80% & 100% load condition on engine. The rate of pressure rise for neem biodiesel shows similar trends as diesel fuel. The rate of pressure rise at 60% load was higher than other loads.

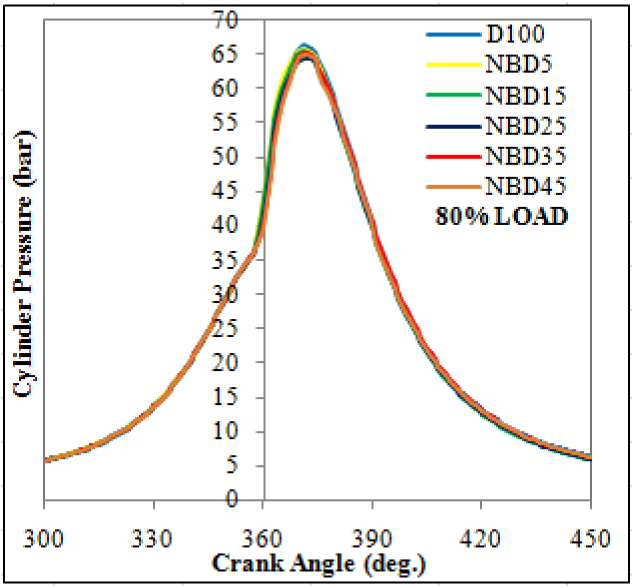

Chart -5: Cylinder pressure at 80% load

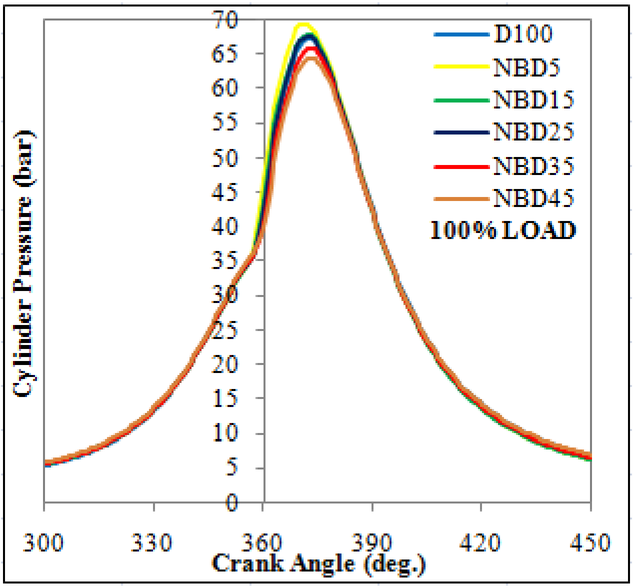

Chart -6: Cylinder pressure at 100% load

The rate of pressure rise at ideal load (0% load) condition was found to be 1.88 bar/°CA at 365°CA for diesel fuel, 1.81 bar/°CA at 363°CA for NBD5, 2.06 bar/°CA at 363°CA for NBD15, 1.83 bar/°CA at 363°CA for NBD25, 1.81 bar/°CA at 364°CA for NBD35 & 1.86 bar/°CA at 363°CA for NBD45. At full load (100% load) condition, rate of pressure rise was found to be 4.31 bar/°CA at 358°CA for diesel fuel, 4.22 bar/°CA at 358°CA for NBD5, 4.11 bar/°CA at 359°CA for NBD15, 3.96 bar/°CA at 359°CA for NBD25, 3.73 bar/°CA at 360°CA for NBD35 & 3.68 bar/°CA at 360°CA for NBD45. Therefore, rate of pressure rise increases according to load increase on engine. The rate of pressure rise for neat diesel fuel was obtained higher than other blends of neem biodiesel in diesel fuel. At full load condition maximum lower pressure obtained for NBD45 that was 14.62% lower than neat diesel fuel. The lower rate of pressure rise for neem biodiesel because it has higher viscosity, higher density & lower volatility than conventional diesel fuel.

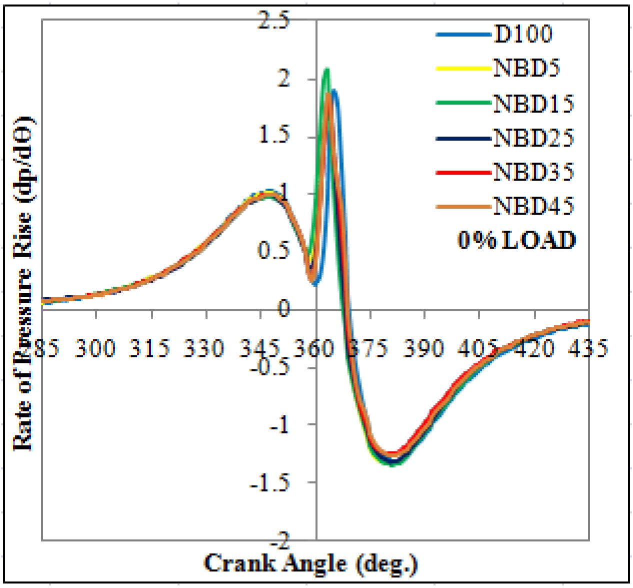

Chart -7: Rate of pressure rise at 0% load

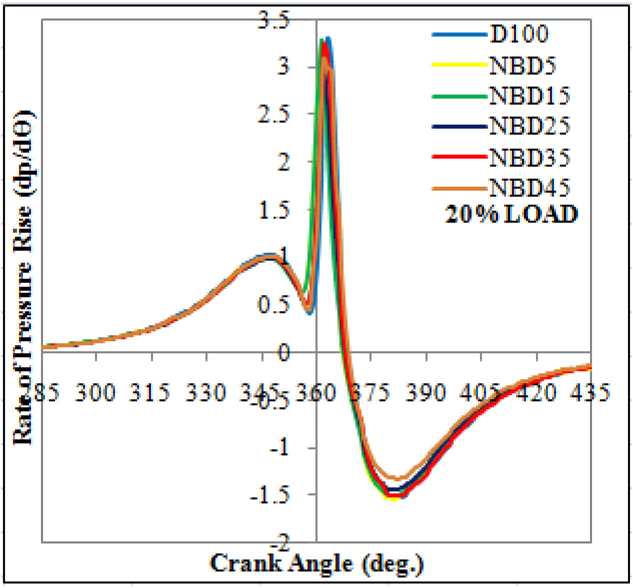

Chart -8: Rate of pressure rise at 20% load

3.3 NET HEAT RELEASE

Graph 13 to 18 shows the trends of net heat release versus crank angle from 350°CA to 400°CA at 0%, 20%, 40%, 60%, 80% & 100% load conditions on engine.

The net heat release was obtained at 60% load higher than other loads. The net heat release for diesel was found higher than neem biodiesel blends at every load conditions because conventional diesel fuel have higher calorific value. The net heat release at ideal load (0% load) condition was found to be 29.96 J/deg. at 366°CA for diesel fuel, 25.00 J/deg. at 364°CA for NBD5, 26.60 J/deg. at 363°CA for NBD15, 26.20

J/deg. at 364°CA for NBD25, 22.41 J/deg. at 366°CA for NBD35 & 25.71 J/deg. at 366°CA for NBD45.

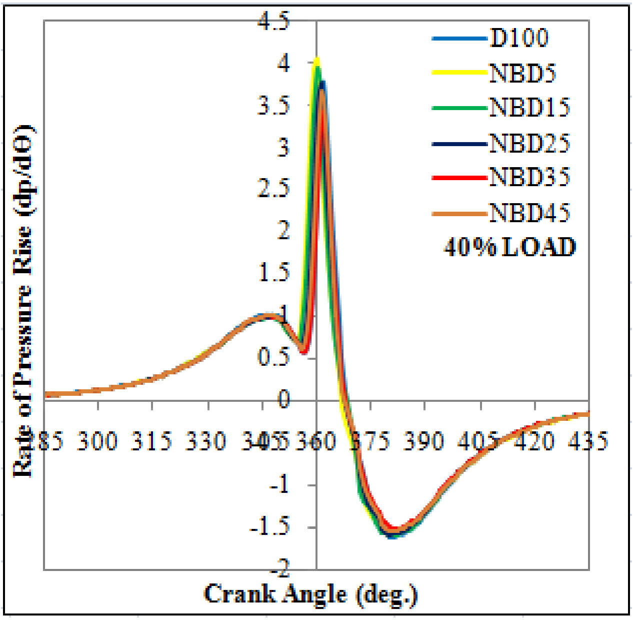

Chart -9: Rate of pressure rise at 40% load

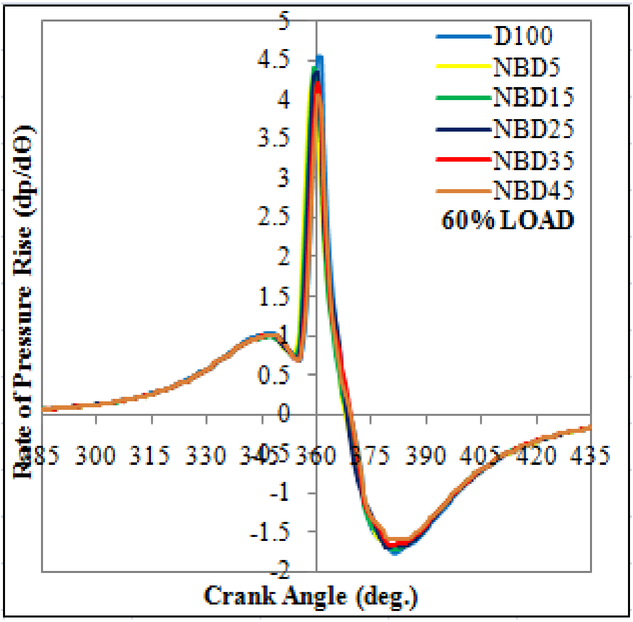

Chart -10: Rate of pressure rise at 60% load

At full load (100% load) condition, the net heat release rate was found to be 41.23 J/deg. at 360°CA for diesel fuel, 39.04 J/deg. at 358°CA for NBD5, 39.38 J/deg. at 359°CA for NBD15, 37.96 J/deg. at 359°CA for NBD25, 37.33 J/deg. at 360°CA for NBD35 & 34.58 J/deg. at 361°CA for NBD45. The net heat release for neem biodiesel was lower than neat diesel. The concentration of neem biodiesel increases in neat diesel fuel than net heat release decreases correspondingly. The lower net heat release was obtained for NBD45 that have about 16.13% decrease than neat diesel fuel.

3.4 CUMULATIVE HEAT RELEASE

Graph 19 to 24 are shows the variation of cumulative heat release versus crank angle from 0°CA to 720°CA at 0%, 20%, 40%, 60%, 80% & 100% load conditions on engine. Graph shows that the cumulative heat release increase according to load increase on engine. The cumulative heat release at ideal load (0% load) condition was found to be 1.21 kJ at 528°CA for neat diesel fuel, 1.12 kJ at 530°CA for NBD5, 1.17 kJ at 523°CA for NBD15, 1.15 kJ at 522°CA for NBD25, 1.12 kJ at 524°CA for NBD35 & 1.21 kJ at 523°CA for NBD45.

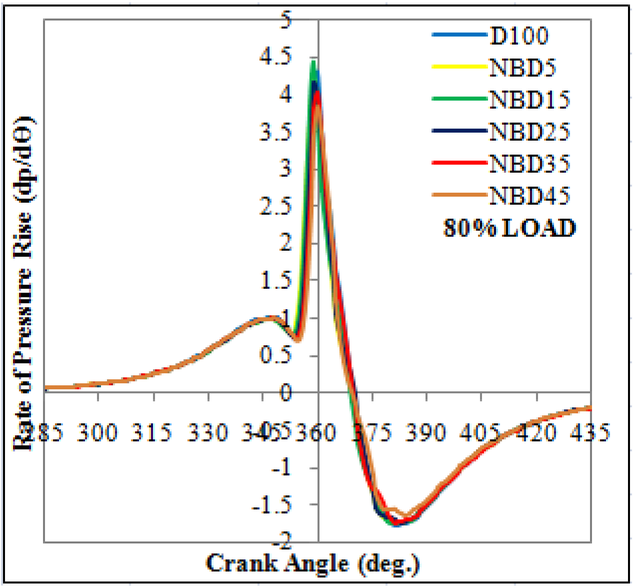

Chart -11: Rate of pressure rise at 80% load

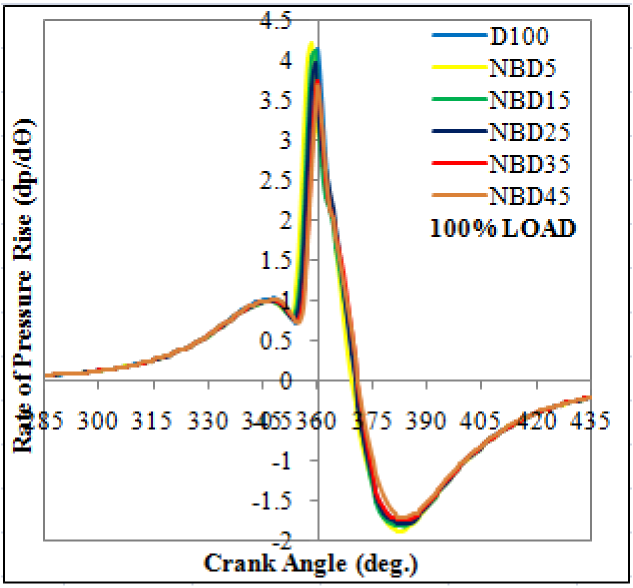

Chart -12: Rate of pressure rise at 100% load

At full load (100% load) condition, the cumulative heat release was found to be 1.50 kJ at 512°CA for neat diesel fuel, 1.39 kJ at 505°CA for NBD5, 1.37 kJ at 508°CA for NBD15, 1.44 kJ at 512°CA for NBD25, 1.42 kJ at 509°CA for NBD35 & 1.50 kJ at 512°CA for NBD45. The cumulative heat release was found for diesel fuel higher at every load condition because diesel have higher heating value & high volatile fuel. The cumulative heat release was obtained for NBD15 lower than other blends, it's about 8.67% lower than conventional diesel fuel.

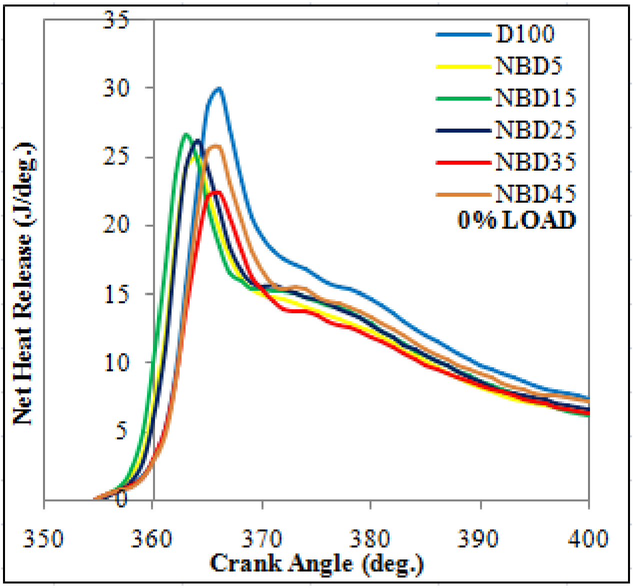

Chart -13: Net heat release at 0% load

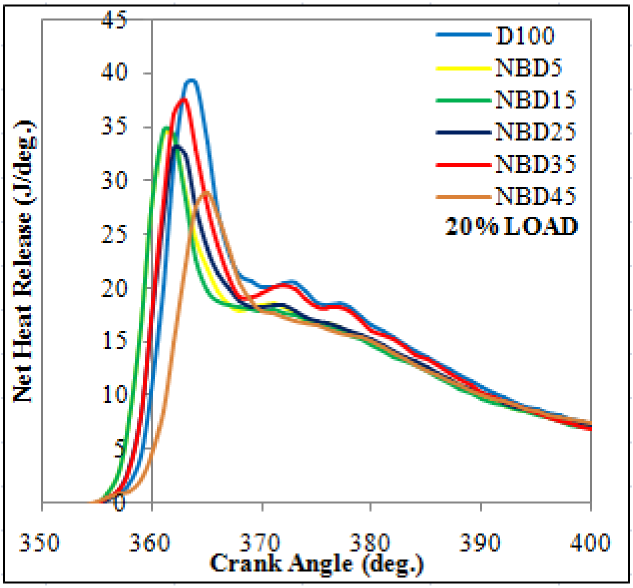

Chart -14: Net heat release at 20% load

3.5 MASS FRACTION BURNED

Graph 25 to 30 are shows the mass fraction burned trends with respect to crank angle during compression & expansion process at 0%, 20%, 40%, 60%, 80% & 100% load conditions on engine. The mass fraction burned is a phenomenon of fraction of charge mass (air/fuel mixture) burned with respect to time history of crank angle. The mass fraction burned data are tabulated in table 4 at full load (100%) condition on engine. The mass fraction burned was found almost similar trends for neem biodiesel blends as conventional diesel fuel. The neem biodiesel blend NBD45 shows slightly late mass fraction burned & it obtained about 9.12% late 90% mass fraction burned than conventional diesel fuel. The neem biodiesel have higher viscosity & density than conventional diesel fuel which tends to increase the time history of crank angle to mass fraction burned.

Table -4: Mass fraction burned at full load condition

Mass fraction burned (%)	D100	NBD5	NBD15	NBD25	NBD35	NBD45
5%	-1.01°CA	-2.58°CA	-1.83°CA	-1.65°CA	-0.94°CA	-0.51°CA
10%	0.12°CA	-1.50°CA	-0.73°CA	-0.51°CA	0.24°CA	-0.80°CA
50%	9.03°CA	7.45°CA	-8.65°CA	8.17°CA	9.38°CA	10.30°CA
90%	23.23°CA	21.12°CA	23.60°CA	21.11°CA	23.55°CA	25.56°CA

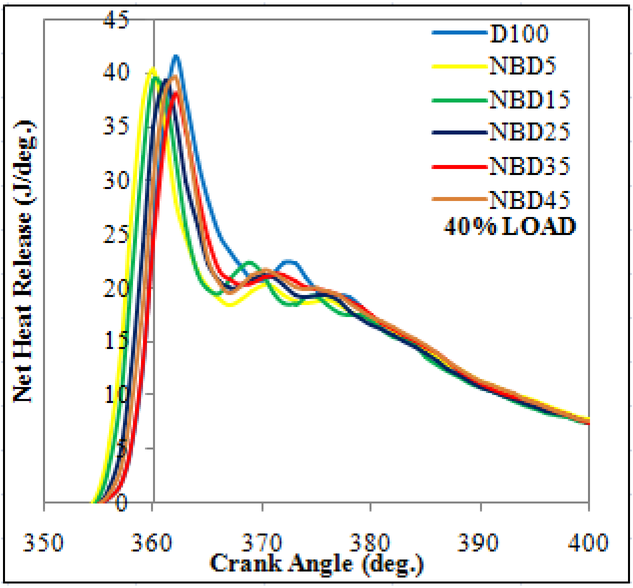

Chart -15: Net heat release at 40% load

3.6 MEAN GAS TEMPERATURE

Graph 31 to 36 are shows the variation of mean gas temperature from 0°CA to 720°CA at 0%, 20%, 40%, 60%, 80% & 100% load conditions on engine. The mean gas temperature increase according to load increase on engine & it's in cylinder gas temperature phenomenon.

The mean gas temperature at ideal load (0% load) condition was appear before TDC because at 0% load, fuel taken by engine very less quantity than other loads. The mean gas temperature was obtained at ideal load to be 1142.02°C at 198°CA for diesel fuel, 1230.84°C at 187°CA for NBD5, 1225.23°C at 181°CA for NBD15, 1187.80°C at 181°CA for NBD25, 1217.49°C at 180°CA for NBD35 & 1255.85°C at 180°CA for NBD45.

At full load (100% load) condition, the mean gas temperature was found to be 1638.98°C at 386°CA for neat diesel fuel, 1631.37°C at 385°CA for NBD5, 1619.18°C at 386°CA for NBD15, 1629.87°C at 386°CA for NBD25, 1618.58°C at 387°CA for NBD35 & 1618.82°C at 387°CA for NBD45. Mean gas temperature for neat diesel was obtained higher because diesel fuel have higher calorific value than blends of neem biodiesel. The lowest temperature found for NBD35, it's was about 1.25% lower than neat diesel fuel at full load condition.

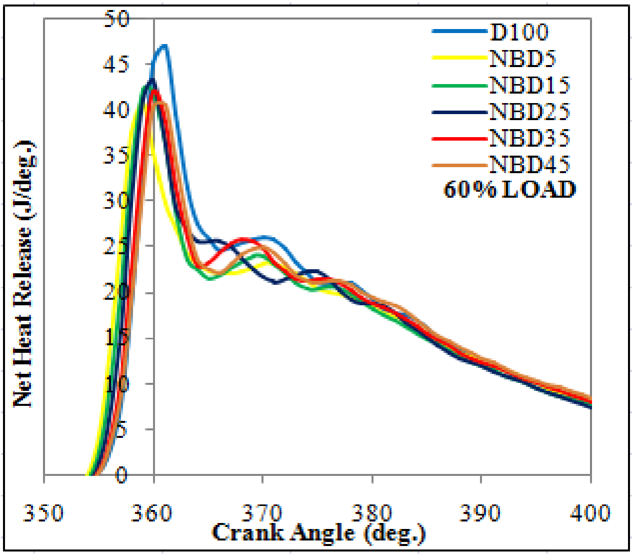

Chart -16: Net heat release at 60% load

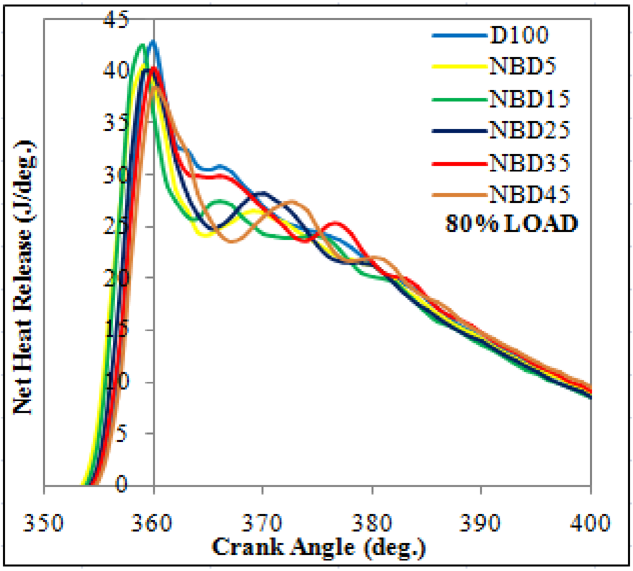

Chart -17: Net heat release at 80% load

3.7 IGNITION DELAY

Chart 37 shows the variation of ignition delay at different loads (0%, 20%, 40%, 60%, 80% & 100%) conditions on diesel engine for neat diesel (D100) & different blends of neem biodiesel.

The ignition delay is defined as the period between the start of fuel injection into the combustion chamber to onset of the combustion. The ignition delay reduces accordingly to load increasing on engine because more in cylinder heated continuously when increasing load then rapidly gasification occurs inside the cylinder. The improves ignition delay for neem biodiesel blends because neem biodiesel have already oxygen molecular which atomized the fuel rapidly to burn faster rate. The ignition delay at ideal load (0% load) conditions was found to be 13°CA for neat diesel fuel, 13°CA for NBD5, 12°CA for NBD15, 11°CA for NBD25, 11°CA for NBD35 & 10°CA for NBD45. The ignition delay at full load (100% load) conditions was found to be 9°CA for neat diesel fuel, 8°CA for NBD5, 8°CA for NBD15, 7°CA for NBD25, 7°CA for NBD35 & 6°CA for NBD45. NBD45 shows the maximum reduces ignition delay than other blends & neat diesel because oxygen molecular increases with blends increase in neat diesel fuel which leads burning combustion rate.

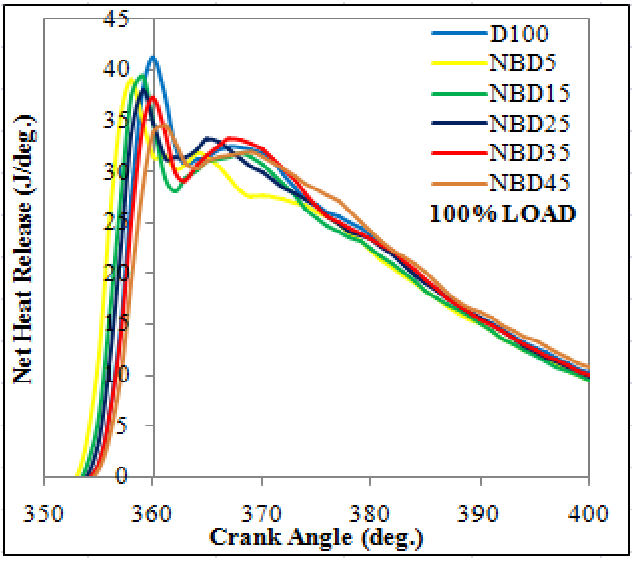

Chart -18: Net heat release at 100% load

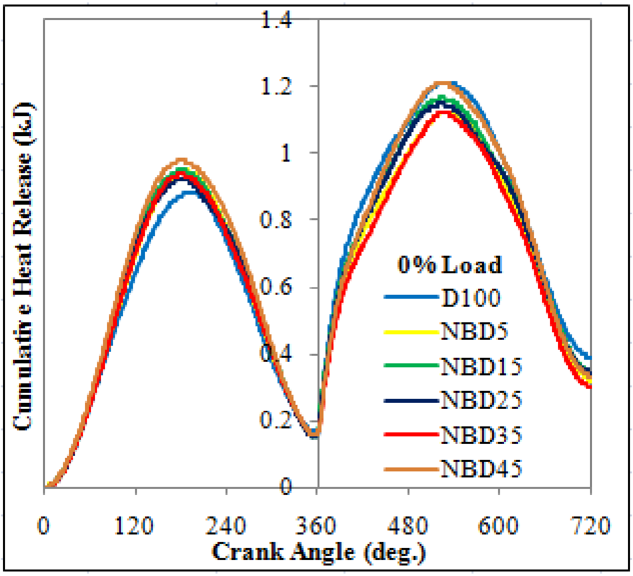

Chart -19: Cumulative heat release at 0% load

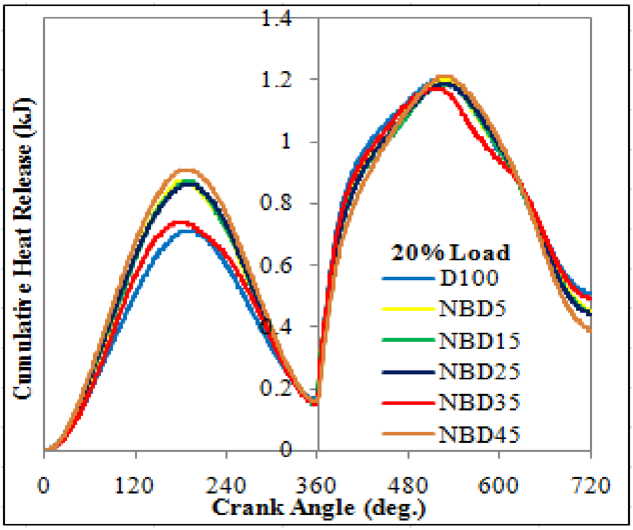

Chart -20: Cumulative heat release at 20% load

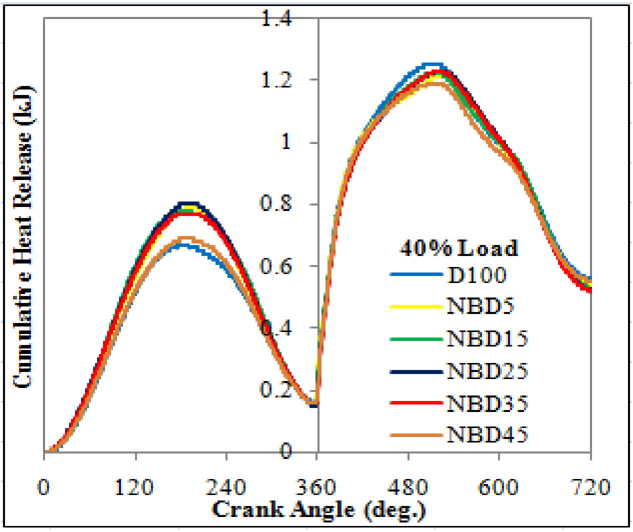

Chart -21: Cumulative heat release at 40% load

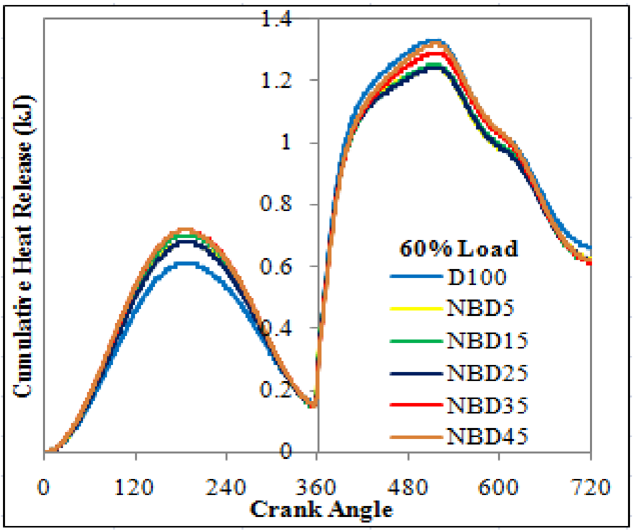

Chart -22: Cumulative heat release at 60% load

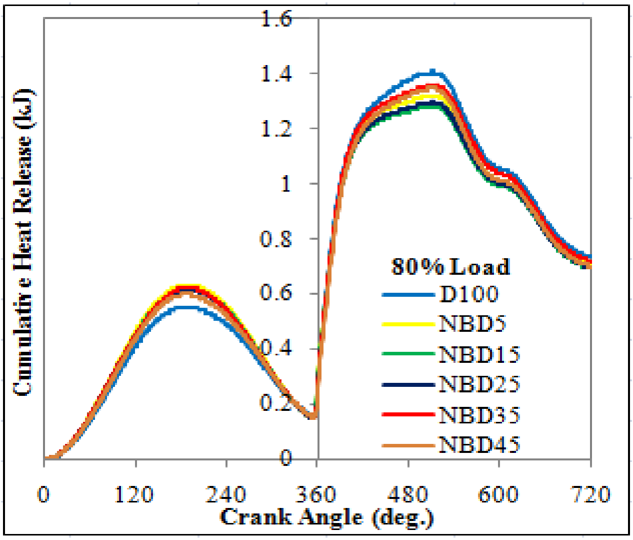

Chart -23: Cumulative heat release at 80% load

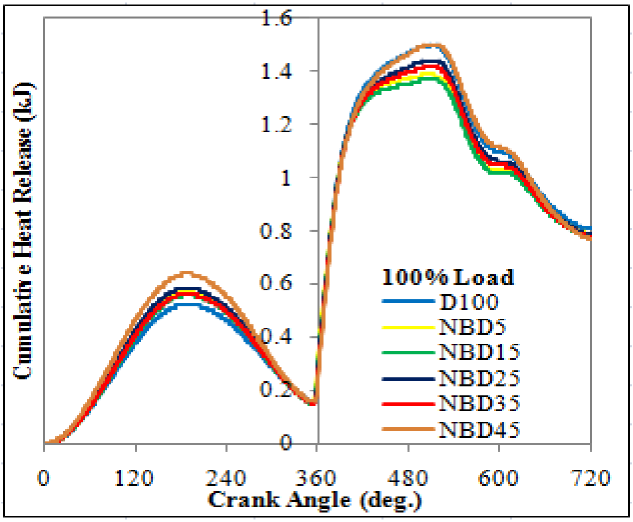

Chart -24: Cumulative heat release at 100% load

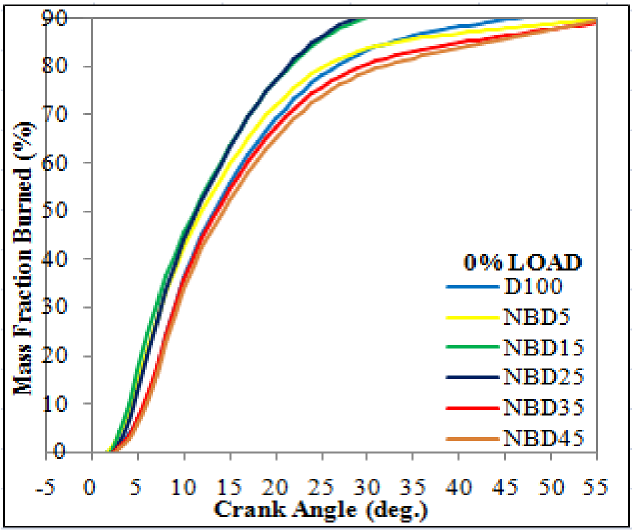

Chart -25: Mass fraction burned at 0% load

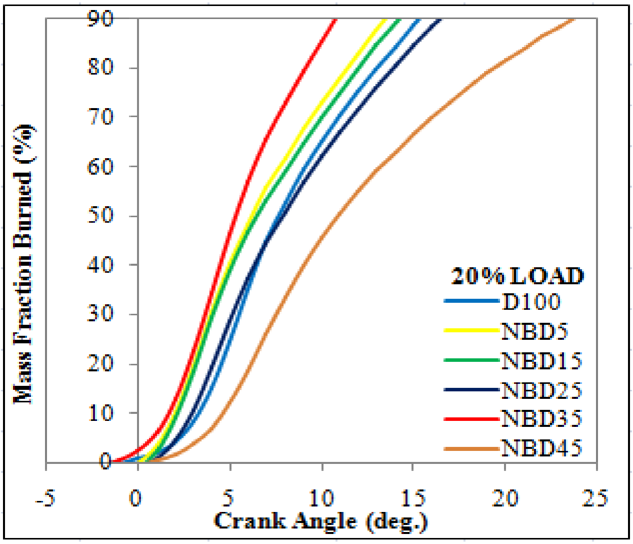

Chart -26: Mass fraction burned at 20% load

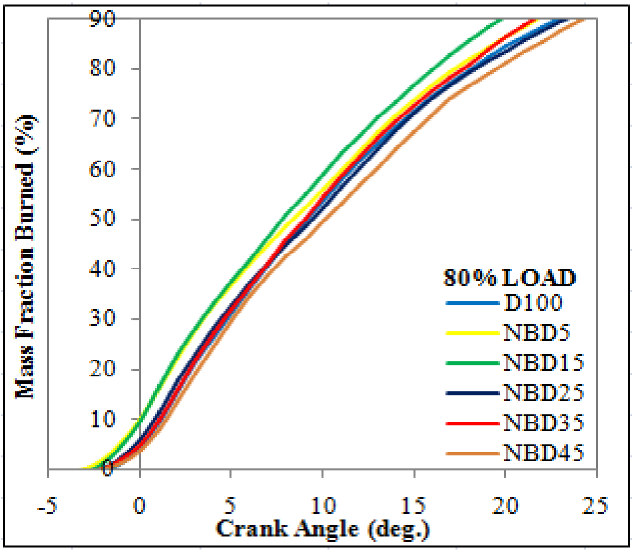

Chart -29: Mass fraction burned at 80% load

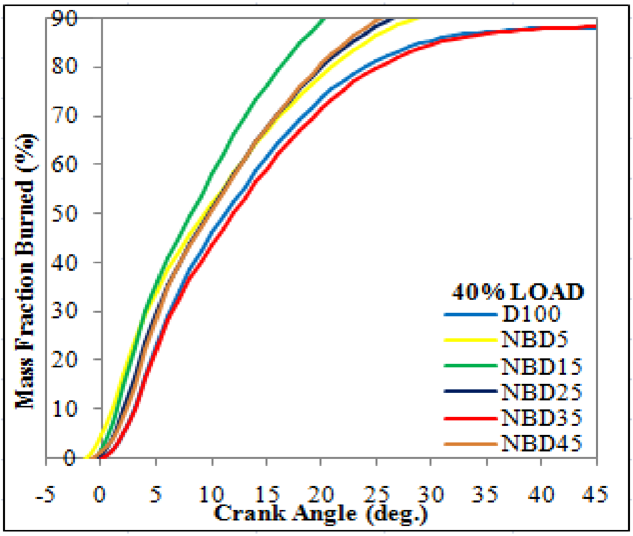

Chart -27: Mass fraction burned at 40% load

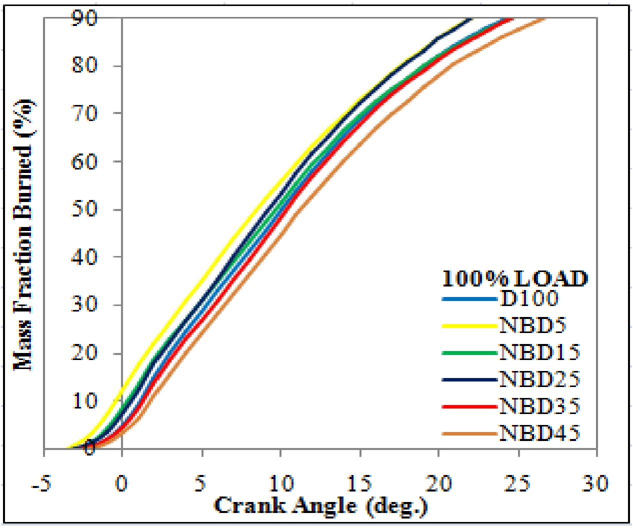

Chart -30: Mass fraction burned at 100% load

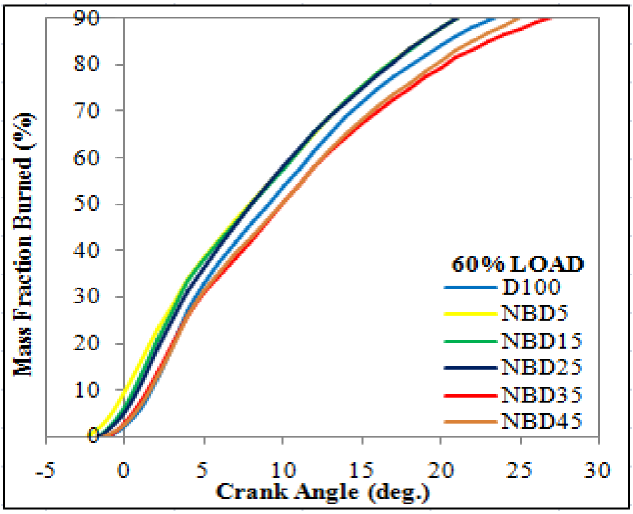

Chart -28: Mass fraction burned at 60% load

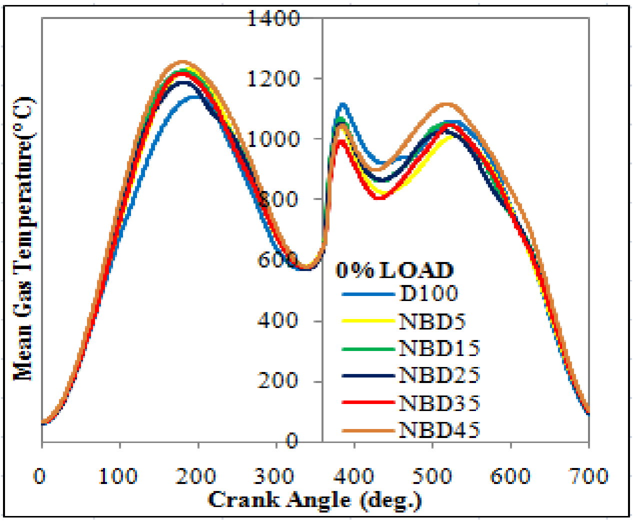

Chart -31: Mean gas temperature at 0% load

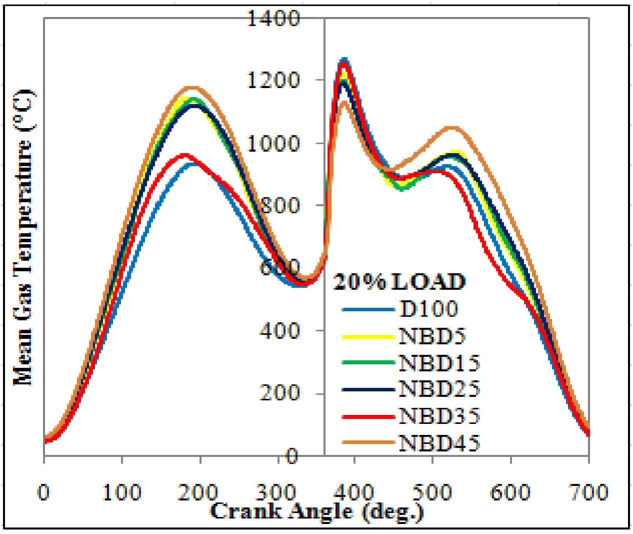

Chart -32: Mean gas temperature at 20% load

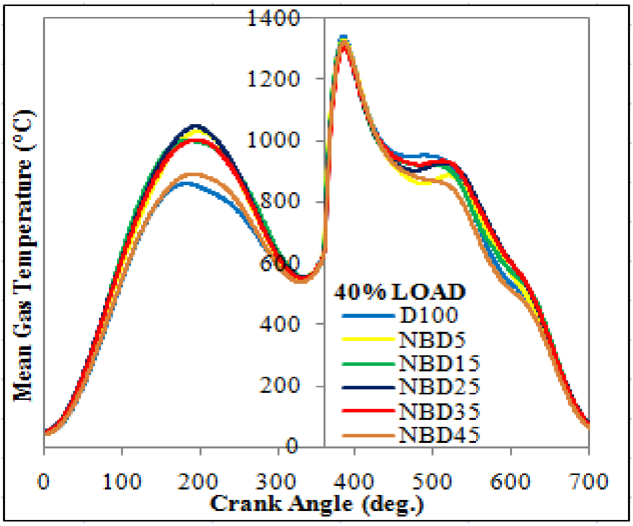

Chart -33: Mean gas temperature at 40% load

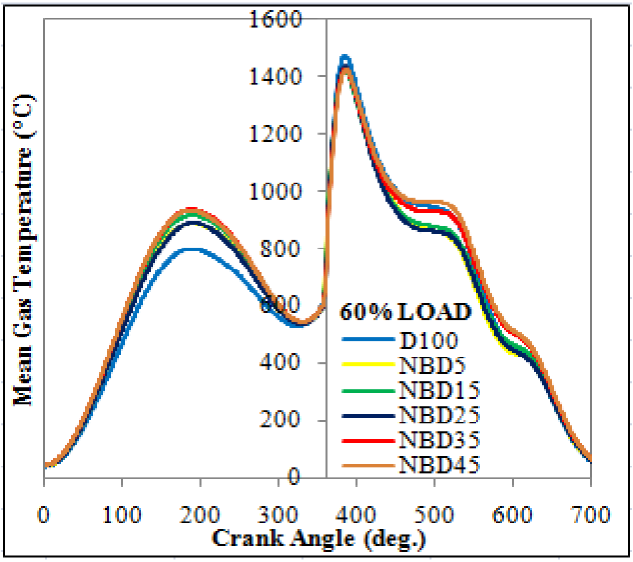

Chart -34: Mean gas temperature at 60% load

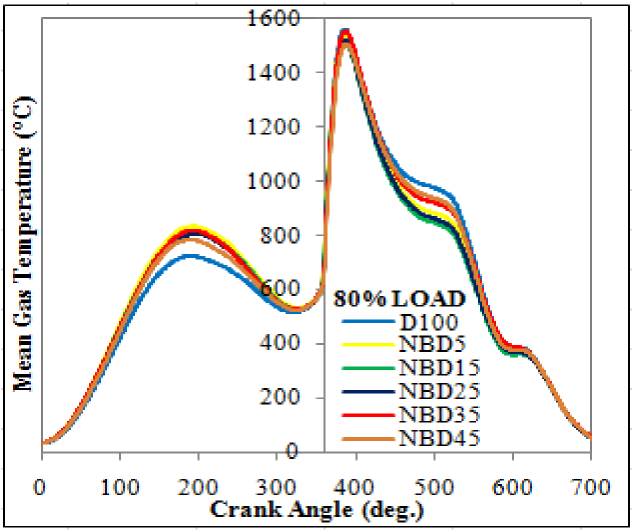

Chart -35: Mean gas temperature at 80% load

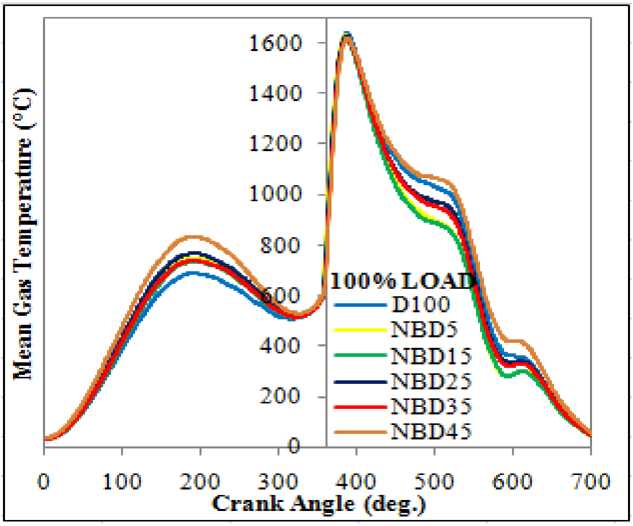

Chart -36: Mean gas temperature at 100% load

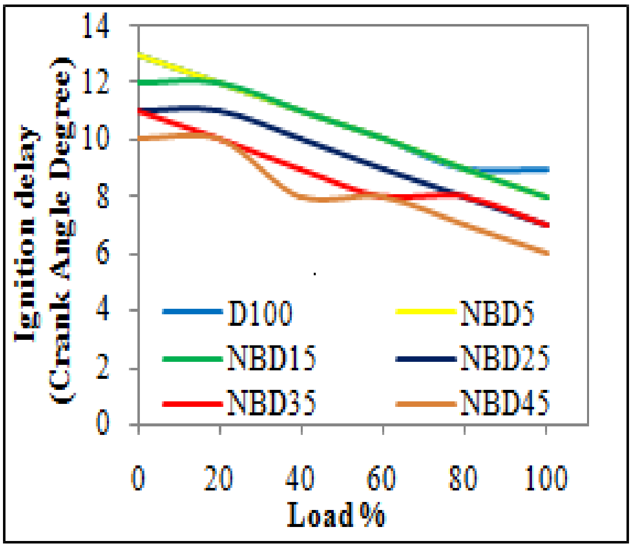

Chart -37: Ignition delay

4. CONCLUSIONS

The NBD5 fuel shows higher in cylinder pressure than other blends & neat diesel fuel. Its shows about 2.93% higher in cylinder than neat diesel fuel at full load condition. At full load condition maximum lower pressure obtained for NBD45 that was 14.62% lower than neat diesel fuel. The lower net heat release was obtained for NBD45 that have about 16.13% decrease than neat diesel fuel at full load condition. The cumulative heat release was obtained for NBD15 lower than other blends, it's about 8.67% lower than conventional diesel fuel at full load condition. The neem biodiesel blend NBD45 shows slightly late mass fraction burned & it obtained about 9.12% late 90% mass fraction burned than conventional diesel fuel at full load condition. The lowest mean gas temperature found for NBD35, it's was about 1.25% lower than neat diesel fuel at full load condition. NBD45 shows the maximum reduces ignition delay than other blends & neat diesel fuel.

Therefore, above results shows that the use of neem biodiesel in diesel engine as alternative fuel was efficient & reliable. The combustion parameter of compression ignition diesel engine does not highly effected but it's slightly effected. The ignition delay problem with neat diesel fuel improves with neem biodiesel blends. Henceforth, neem biodiesel is good alternative substitute in compression ignition diesel engine in future.

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