Experimental investigation of performance, emission and combustion characteristic of C.I engine using Kusum biodiesel blended with diesel at different injection pressures

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Abstract - Biodiesel as alternative fuel has been widely studied due to its merits such as lower sulfur, lower aromatic hydrocarbon and higher oxygen content. Kusum seed oil is extracted from the germ and inner husk of the kusum and is not a common source of non edible oil. The aim of this paper is to study the effect of injection pressure on the emission characteristics of a single cylinder diesel engine using diesel and the blends of diesel and kusum biodiesel, B100 and Diesel D100 , B20 (80% diesel + 20% kusum biodiesel) and B40 (60% diesel + 40% kusum biodiesel) B60(40%diesel +60 % kusum biodiesel) . The injection pressure is varied from 180 bar to 200 bar with an interval of 220 bar. The exhaust gas emissions such as carbon monoxide (CO), hydrocarbon (HC), oxides of nitrogen (NO_X), carbon dioxide (CO_2) and smoke opacity are measured at the rated power and speed at different injection pressures. It is observed that the minimum CO, HC and smoke emissions are recorded at 220 bar. The NO_X, emissions are increased and CO_2 emissions decreased with the injection pressure. The optimum injection pressure is 220 bar and the blend is B20 with respect to emissions.

***Keywords*: Diesel engine, injection pressure, emissions**

1. INTRODUCTION

Developing countries have to depend on other countries to meet their petroleum demand. The energy demand is increasing day-by-day due to increase in population of vehicles leading to increased import bill. Due to its inherent advantages of better fuel economy and high part load efficiency diesel engines are preferred for transportation vehicles. With the increasing cost of petroleum a major part of foreign exchange is utilized for importing petroleum. This has forced the countries to search for alternative renewable fuel for diesel engines.

Recent studies and research have made it possible to extract bio-diesel at economical costs and quantities. The blend of Bio-diesel with diesel has many benefits like reduction in emissions, increase in efficiency of engine, higher Cetane rating, lower engine wear, low fuel consumption, reduction in oil consumption etc. It can be observed that the efficiency of the engine increases by the utilization of Bio-diesel. Therefore biodiesel will have a great impact on Indian economy [2]. 2008 have investigated the performance and emission characteristics on a single cylinder diesel engine using pongamia pinnata biodiesel and reported decrease in NOx and HC emissions.[3]

Haldar et al, 2008 have used 3 degummed non-edible vegetable oils (putranjiva, karanja and Jatropha) in a single cylinder diesel engine. Degumming is a chemical process in which impurities are removed by using concentrated phosphoric acid to improve its viscosity, Cetane number and combustion characteristics. They have reported that Jatropha gives better performance. The tests were conducted without any engine modification. Barnwal et al, 2005 have discussed about prospects of biodiesel production from vegetable oils in India. The y have also given the yield and production cost of various methyl esters, in general non-edible oils. The methyl esters of non-edible oil are much cheaper than petroleum diesel.[4]

The engine performance, power output, economy etc is greatly dependent on the effectiveness of the fuel injection system. The fuel injection system plays an important role in the combustion process [5]

Therefore the objective of this study is to investigate the performance, emissions and combustion characteristics of CI engine running with biodiesel [6]

Technical specification of Kirloskar oil Engines ltd, India

01	Manufacturer	Kirloskar oil engines ltd, India
02	Model	TV-SR, naturally aspirated.
03	Engine	Single cylinder ,DI
04	Type	4stroke, 1 cylinder, water cooled
05	Bore	87.5mm
06	Stroke	110 mm
07	Compression ratio	16.5:1
08	Rated Power	5.2kW @1500rpm
09	Fuel	Diesel

2. Experimental setup and methodology

The experiments are conducted for variable loads like 0., 1,2,3,4 and 5.2 KW at rated speed, with different injection pressure of 180bar, 200bar and 220bar cooling water exit temperature at 65ºC. Three blends of all types of vegetable oils such as 20%, 40%, 60% and 100% kusum seed biodiesel are used in this experimentation. The non edible oils and their blends with methanol are heated externally to a required temperature as stated earlier before injecting into the test cylinder. The engine was sufficiently warmed up and stabilized before taking all the readings. All the observations recorded were replicated thrice to get a reasonable value. The performance parameters such as brake thermal efficiency, brake specific fuel consumption (BSFC), exhaust gas temperature (EGT) and volumetric efficiency. Emission parameters such as carbon monoxide (CO), carbon dioxide (CO2),un-burnt hydro carbon (UHC), nitrogen oxides (NOx) and Smoke are evaluated .These performance and emission parameters of kusum seed biodiesel blends are compared to those of pure diesel.

. Fig 3.7 photograph taken from the IC engine laboratory, PDA College of Engineering shows engine connected with controlling unit. Fig 3.8 shows schematic diagram of engine, dynamometer, controlling unit smoke meter and exhaust gas analyzer. Table 3.3 shows the specification KIRLOSKAR oil Engines.

Fig:-1 Engine connected with dash board

2.1 The Properties of Diesel fuel and Kusum biodiesel

The different properties of diesel fuel and kusum seed biodiesel are determined and shown in table.3.2. After transesterification process the fuel properties like kinematic viscosity, calorific value, and density, flash and fire point get improved in case of biodiesel. The calorific value of kusum seed biodiesel is lower than that of diesel because of oxygen content. The flash and fire point temperature of biodiesel is higher than the pure diesel fuel this is beneficial by safety considerations which can be stored and transported without any risk.

Fuel samples Properties	Diesel	Kusum biodiesel	Apparatus used
Fuel density in $\frac{kg}{m^3}$	830	880	Hydrometer
Kinematic viscosity at 40ºC in cst	2.90	40.75	Say bolt
Flash point in ºC	64	147	Ables apparatus
Fire point in ºC	75	158	Ables apparatus
Calorific value in $\frac{kJ}{kg}$	45184	38529	Bomb calorimeter

3. RESULTS AND DISCUSSIONS

3.1 Performance characteristics of diesel, blends of Kusum biodiesel on diesel engine 180 bar

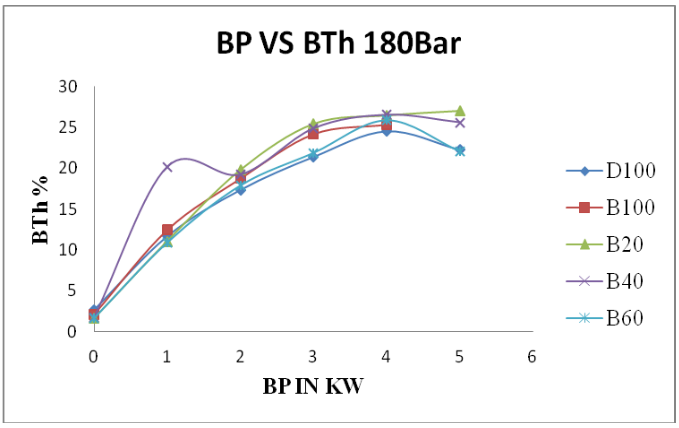

Fig:- 3.1 Variation of brake thermal efficiency with brake power for 180 bar

Provides for the correlation between those brake warm effectiveness of the motor the point when run for biodiesel What's more with diesel. The brake warm effectiveness will be plotted similarly as an capacity about brake control (kW). It need been watched that those brake warm effectiveness expands when those motor may be run with biodiesel. That greatest esteem for brake warm effectiveness for diesel & immaculate diesel will be toward 22 % and 25 %. The brake warm effectiveness will be practically consistent the middle of reach for 24 % should 30 %, Furthermore it declines pointedly with further build To a limited extent load. Brake warm effectiveness of biodiesel is more level over diesel.

3.2 Specific fuel consumption

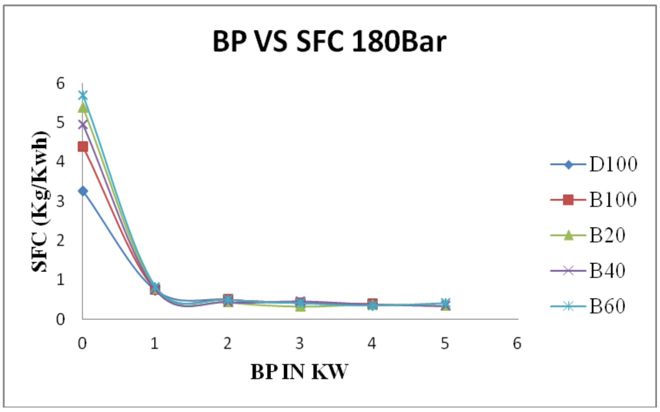

Fig:-3.2 Variation of specific fuel consumption with brake power for 180 bar

The fig 4.3 demonstrates the variety of the brake particular fuel utilization versus brake control when diesel is utilized as fuel and it is contrasted and brake particular fuel utilization when biodiesel is utilized as fuel. This might be because of the lower calorific value of kusum bio diesel contrasted with the diesel esteem. fuel utilization of biodiesel is higher, as load increments biodiesel practically identical with that of diesel. The variation of specific fuel consumption with brake power for diesel and blends kusum seed biodiesel are shown in figure 3.2, as the power developed increases the specific fuel consumption decreases for all the tested fuels. The specific fuel consumption of kusum seed biodiesel blends are higher than diesel because of lower calorific value and high density of biodiesel. From the graph it is clear that the specific fuel consumption is more for initial loads and further it is almost constant for remaining

3.3 Exhaust Gas Temperature

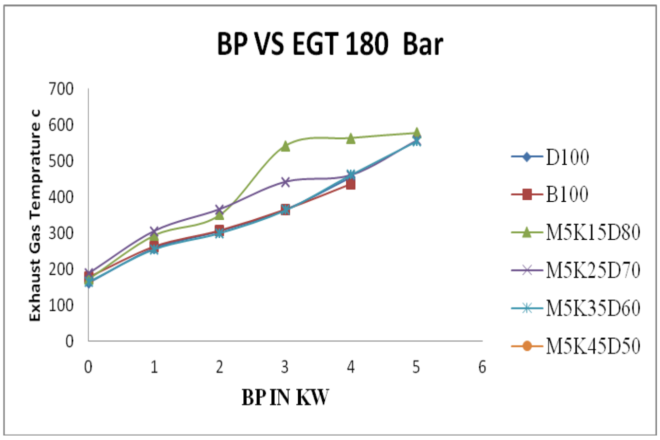

Fig:-3.3Exhaust Gas Temperature with brake power

The fumes gas temperature enemy every one of the energizes tried increment with increment in the brake control .Exhaust gas temperature of immaculate biodiesel and every one of the mixes is higher when contrasted with diesel .The Maximum EGT occur at full load .Maximum EGT of unadulterated biodiesel is 561 ^{0}C against 543 ^{0}C for that of diesel on ordinary moto.blend B20 Gives highest EGT 576.87 ^{0}C.compare to diesel.

3.4 Emission characteristics

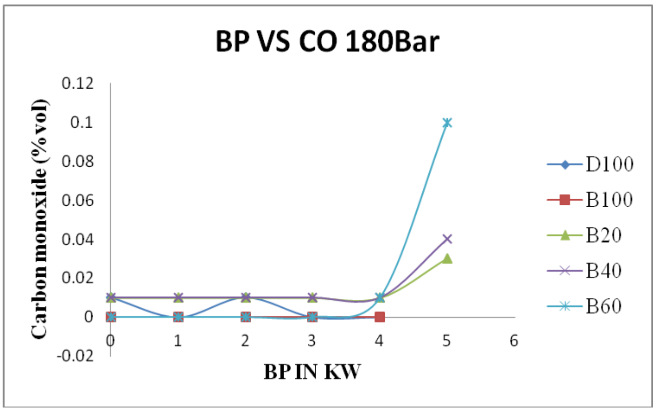

Fig:-3.4 Variation of carbon monoxide with brake power for 180 bar

Figure 3.4 shows variety of carbon monoxide discharge (CO) with brake control for diesel and biodiesel, for part heap of the motor. It is watched that the biodiesel emanates less sum CO than diesel at all heap condition. The level of CO emanation is as appeared in separately. CO emanation is 0.03 for diesel and biodiesel is 0.01 separately lower than diesel at part stack condition because of poor splash qualities and despicable blending. At full load CO emanation of diesel is 0.03%.

3.5 unburnt Hydrocarbon

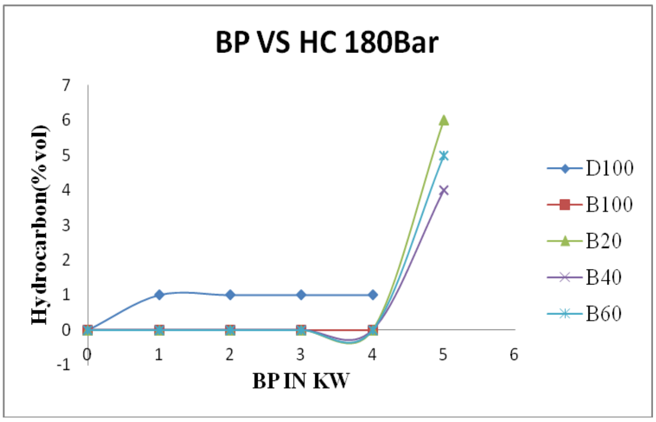

Fig: 3.5 Variation of hydrocarbon with brake power for 180 bar

Demonstrates the variety in the amount of unburnt hydrocarbons with change in brake control. It is seen from the assume that for B100% biodiesel mixes the emanation of HC is not as much as that of the diesel. Unburnt hydrocarbon outflow is the immediate aftereffect of fragmented ignition. A purpose behind the lessening of HC discharges with biodiesel is the oxygen content in the biodiesel atom, which prompts more entire and cleaner ignition.

3.6 Nitrogen oxide

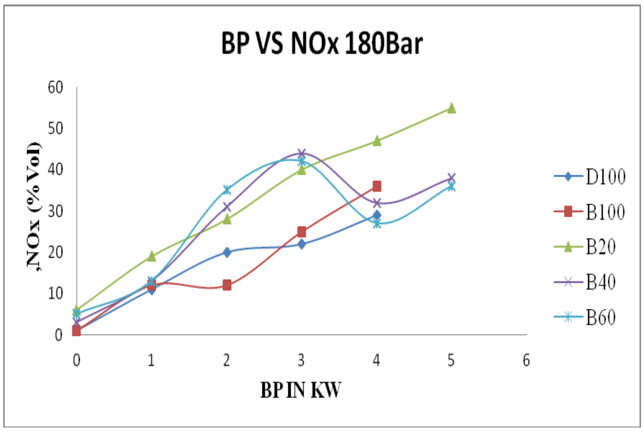

Fig:- 3.6 Variation of NOx with brake power for 180 bar

Demonstrates the variety of nitrogen oxides emanation with brake control yield for diesel and kusum seed biodiesel mixes in the test motor are appeared in figure .7 The NOx outflows for B20 and B40 B60 are higher than that of diesel. B20 are high NOx discharge contrast with diesel.

3.7 Smoke

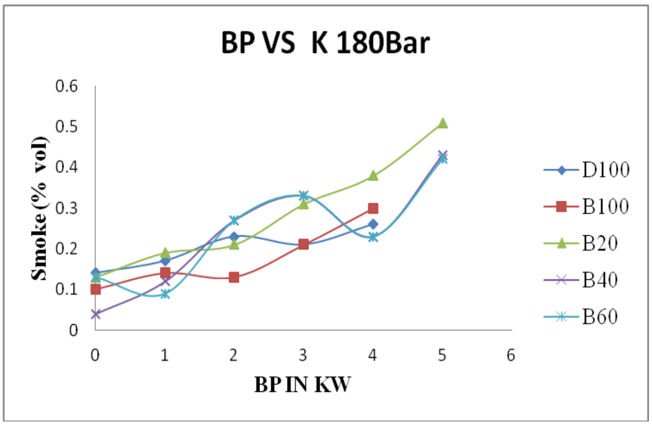

Fig:-3.7 Variation of exhaust smoke with brake power for 180 bar

Smoke arrangement happens at the outrageous air lack. Air or oxygen insufficiency is locally present inside the diesel motors. It increments as the air to fuel proportion diminishes. Test comes about show that smoke discharges are expanded with increment in the part stack as the arrangement of smoke is unequivocally subject to the heap. Fig 3.7 shows variety of smoke outflows with biodiesel and diesel with the part stack. Since at higher part stacks better burning may occur inside the motor chamber attempting to lessen the smoke emanations. Fig 3.7 demonstrates the smoke estimations of diesel and biodiesel at part stack operation. For diesel operation the smoke esteems diminished as a result of the nuclear limited oxygen which helps in better ignition, in this manner lessening the smoke.

3.8 Combustion characteristics

Cylinder pressure with Crank angle

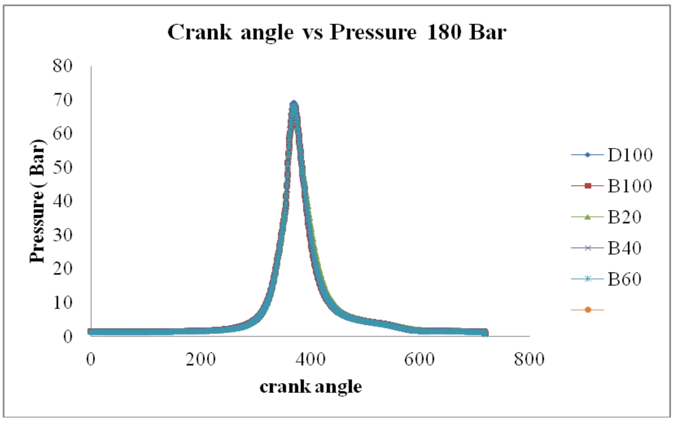

Fig:- 3.8 Variation of cylinder pressure with crank angle for 180 bar

Fig: 3.8 show the test results comparison of cylinder pressure v/s crank angle. The cylinder pressure was found significantly higher for sole fuel. This is due to the low heat rejection to the cylinder walls. The increase in cylinder pressure is due to increase in trapped gas temperature in the combustion chamber. Further for diesel the pressure rise pure biodiesel 67.78 @370 deg diesel 69.10@ 370 deg and which B60 68.34 @370 deg having Highest and nearest to diesel a pressure of bars at varying load

3.9Heat Release Rate with Crank Angle

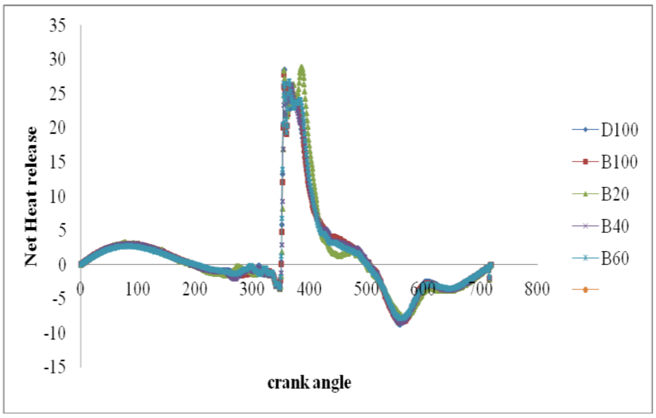

Fig:- 3.9 Variation of heat release rate with crank angle for 180 bar

The variation of net heat release rate with crank angle is shown in fig 3.9 The net heat release rate in more for biodiesel as compared to the diesel fuel. Diesel has high net heat release rate of 28.49 kJ at 357 degree CA compared to biodiesel of 27.87 at 356 degree CA. This is due to higher calorific value, Cetane number and good atomization because of low viscosity and B20 28.92 kj @386 deg nearest to the diesel.

3.10 Cumulative Heat Release Rate with Crank Angle

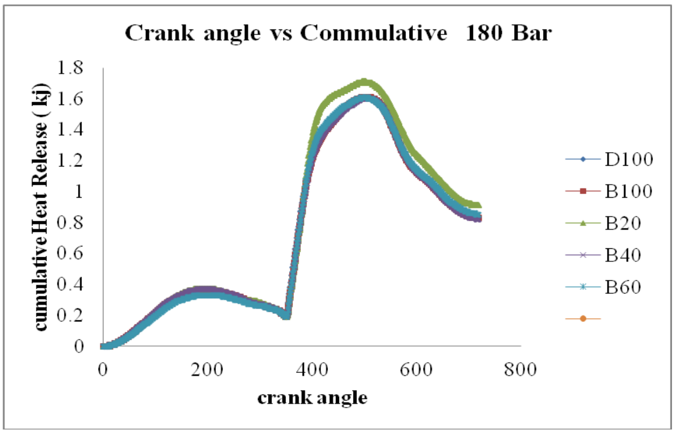

Fig:- 3.10 Variation of cumulative heat release rate with crank angle 180 bar

Variation of cumulative heat release rate with crank angle is shown in the fig 3.10 from the graph it is observed that diesel fuel has higher cumulative heat release rate compared to biodiesel. This is due to the cumulative effect of slight delay in start of dynamic fuel injection and a longer ignition delay compared to neat biodiesel. Maximum cumulative heat release rate for biodiesel is recorded as 1.61 kJ at 505 degree and diesel 1.61kj @505 CA. B20 has maximum cumulative heat release rate of 1.71 kJ at 500 degree CA

Performance characteristics of diesel, blends of Kusum biodiesel on diesel engine 200 bar
BTh

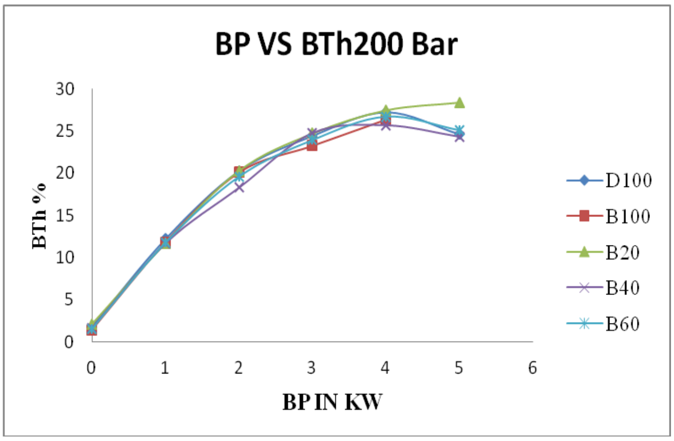

Fig:-3.11Variation of brake thermal efficiency with brake power for 200 bar

Provides for the correlation between those brake warm effectiveness of the motor the point when run for biodiesel What's more with diesel. The brake warm effectiveness will be plotted similarly as a capacity about brake control (kW). It need been watched that those brake warm effectiveness expands when those motor may be run with biodiesel. That greatest esteem for brake warm effectiveness for diesel & immaculate diesel will be toward 22 % and 25 %. The brake warm effectiveness will be practically consistent the middle of reach for 25 % should 28 %, Furthermore it declines pointedly with further build To a limited extent load. Brake warm effectiveness of biodiesel is more level over diesel.

3.12 SFC

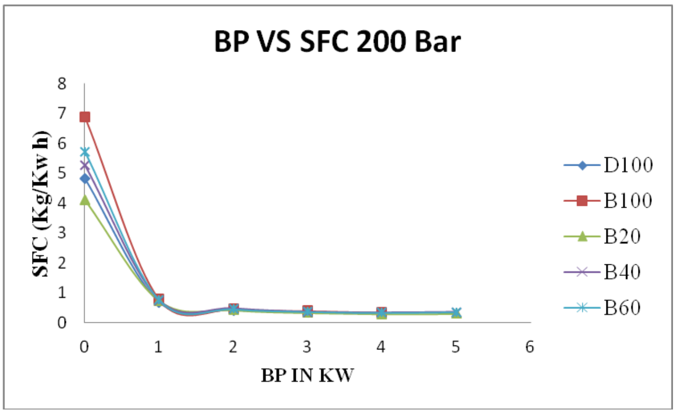

Fig:-3.12.Variation of specific fuel consumption with brake power for 200 bar

The fig 3.12 demonstrates the variety of the brake particular fuel utilization versus brake control when diesel is utilized as fuel and it is contrasted and brake particular fuel utilization when biodiesel is utilized as fuel. This might be because of the lower calorific value of kusum bio diesel contrasted with the diesel esteem. Fuel utilization of biodiesel is higher, as load increments biodiesel practically identical with that of diesel. The variation of specific fuel consumption with brake power for diesel and blends kusum seed biodiesel is shown in figure 3.12, as the power developed increases the specific fuel consumption decreases for all the tested fuels. The specific fuel consumption of kusum seed biodiesel blends are higher than diesel because of lower calorific value and high density of biodiesel. From the graph it is clear that the specific fuel consumption is more for initial loads and further it is almost constant for remaining.

3.13 Exhaust Gas Temperature

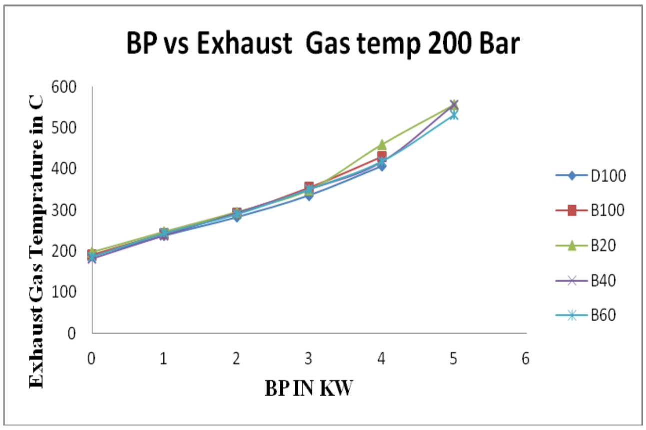

Fig:-3.13 Exhaust Gas Temperature with break power

The fumes gas temperature enemy every one of the energizes tried increment with increment in the brake control .Exhaust gas temperature of immaculate biodiesel and every one of the mixes is higher when contrasted with diesel .The Maximum EGT occur at full load .Maximum EGT of unadulterated biodiesel is 583.45 ^{0}C against 521.29 ^{0}C for that of diesel on ordinary moto.

3.14 Emission characteristics
Carbon monoxide

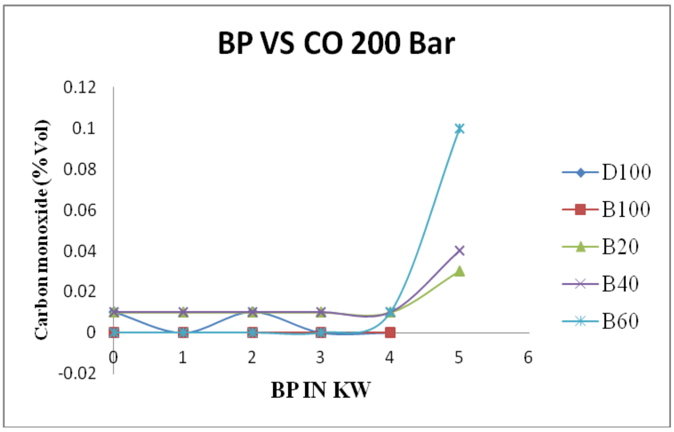

Fig:-3.14 Variation of carbon monoxide with brake power for 200 bar

Figure 3.14 shows variety of carbon monoxide discharge (CO) with brake control for diesel and biodiesel, for part heap of the motor. It is watched that the biodiesel emanates less sum CO than diesel at all heap condition. The level of CO emanation is as appeared in separately. CO emanation is 0.02 for diesel and biodiesel is 0 separately lower than diesel at part stack condition because of poor splash qualities and despicable blending. At full load CO emanation of diesel is 0.02%.

3.15 unburnt Hydrocarbon

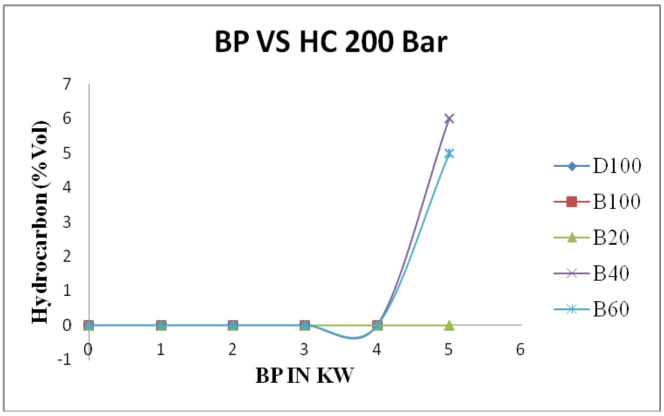

Fig: 3.15 Variation of hydrocarbon with brake power for 200 bar

Demonstrates the variety in the amount of unburnt hydrocarbons with change in brake control. It is seen from the assume that for B20 biodiesel mixes the emanation of HC is not as much as that of the diesel. Unburnt hydrocarbon outflow is the immediate aftereffect of fragmented ignition. A purpose behind the lessening of HC discharges with biodiesel is the oxygen content in the biodiesel atom, which prompts more entire and cleaner ignition.

Fig: 3.16 Nitrogen oxide

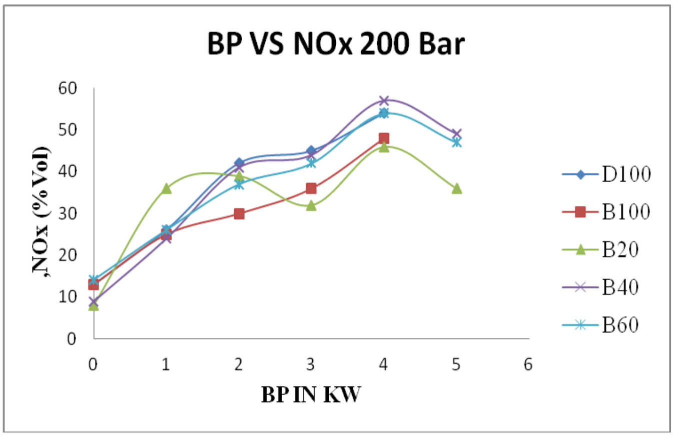

Fig: 3.16 Variation of NOx with brake power for 200 bar

Demonstrates the variety of nitrogen oxides emanation with brake control yield for diesel and kusum seed biodiesel mixes in the test motor are appeared in figure 3.1.7 The NOx outflows for B40 are higher than that of diesel.

Fig: 3.17 Smoke

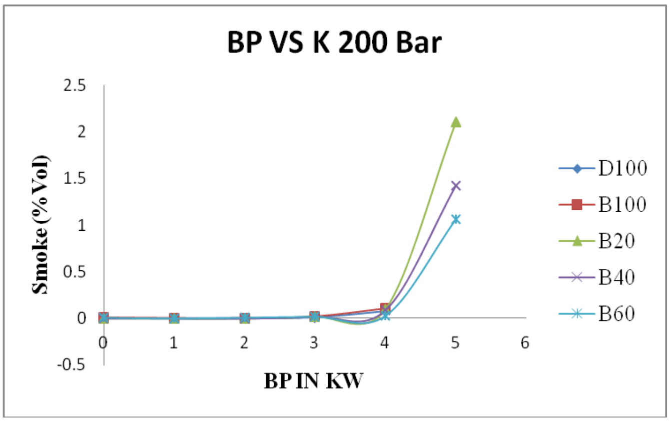

Fig: - 3.17 Variation of exhaust smoke with brake power for 200 bar

Smoke arrangement happens at the outrageous air lack. Air or oxygen insufficiency is locally present inside the diesel motors. It increments as the air to fuel proportion diminishes. Test comes about show that smoke discharges are expanded with increment in the part stack as the arrangement of smoke is unequivocally subject to the heap. Shows variety of smoke outflows with biodiesel and diesel with the part stack. Since at higher part stacks better burning may occur inside the motor chamber attempting to lessen the smoke emanations demonstrates the smoke estimations of diesel and biodiesel at part stack operation. For diesel operation the smoke esteems diminished as a result of the nuclear limited oxygen which helps in better ignition, in this manner lessening the smoke.

3.18 Combustion characteristics

Cylinder pressure with Crank angle

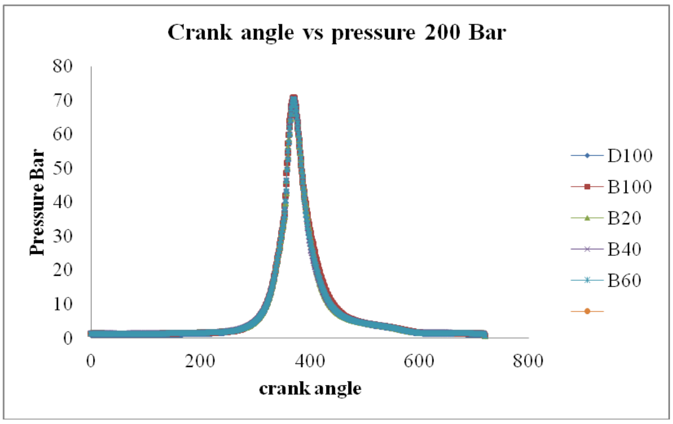

Fig:-3.18 Cylinder pressure with Crank angle

Fig: 3.18 show the test results comparison of cylinder pressure v/s crank angle. The cylinder pressure was found significantly higher for sole fuel. This is due to the low heat rejection to the cylinder walls. The increase in cylinder pressure is due to increase in trapped gas temperature in the combustion chamber. Further for diesel the pressure rise is found to be when compared with biodiesel which is having a 70.81 @370 deg and diesel having 69.19 @ 370.

3.19 Heat Release Rate with Crank Angle

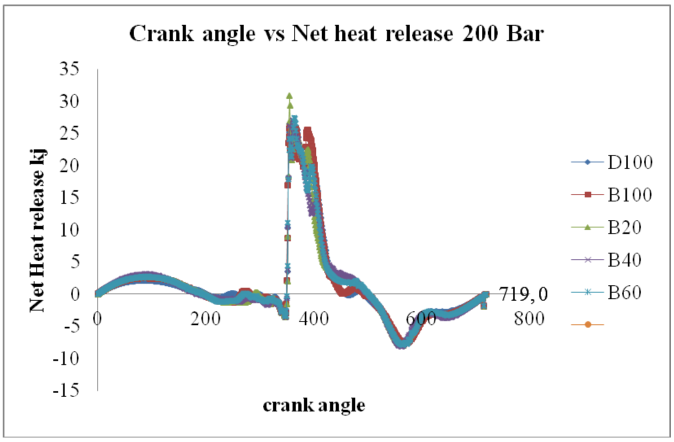

Fig:-3.19 Heat Release Rate with Crank Angle

The variation of net heat release rate with crank angle is shown in fig 3.19 the net heat release rate in more for biodiesel as compared to the diesel fuel. Diesel has high net heat release rate of 25.78 kJ at 368 degree CA compared to biodiesel of 25.74 at 354 degree CA. This is due to higher calorific value, Cetane number and good atomization because of low viscosity. Blend B20 Having 30.38 @355 deg has high heat release. Compare to diesel.

3.20 Cumulative Heat Release Rate with Crank Angle

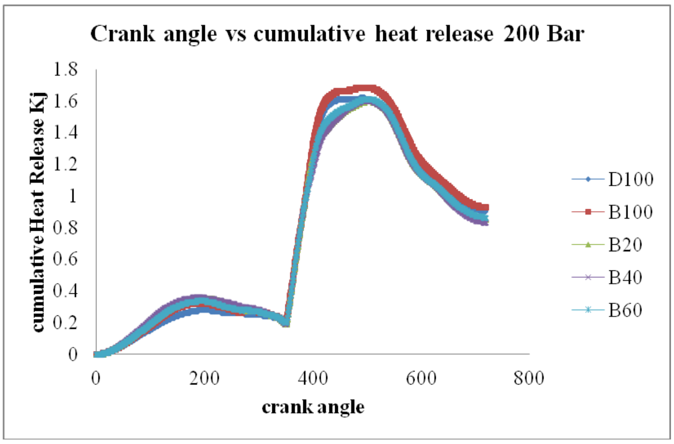

Fig:-3.20Cumulative Heat Release Rate with Crank Angle

Variation of cumulative heat release rate with crank angle is shown in the fig 3.20 from the graph it is observed that diesel fuel has higher cumulative heat release rate compared to biodiesel. This is due to the cumulative effect of slight delay in start of dynamic fuel injection and a longer ignition delay compared to neat biodiesel. Maximum cumulative heat release rate for biodiesel is recorded as 1.68 kJ at 493.0 degree CA. Diesel has maximum cumulative heat release rate of 1.62 kJ at 492 degree CA.

3.21 Performance characteristics of diesel, blends of Kusum biodiesel on diesel engine 220 bar

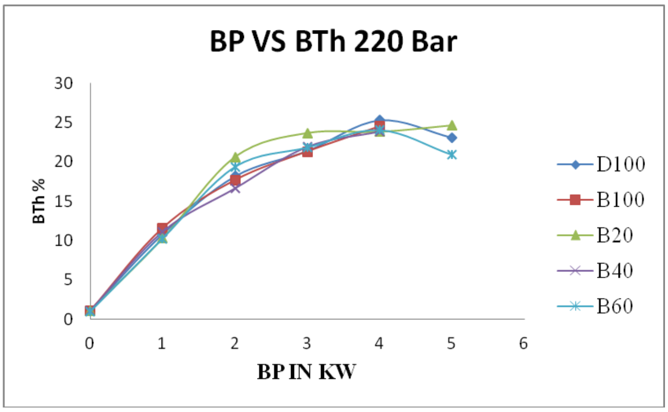

Fig:-3.21 Variation of brake thermal efficiency with brake power for 220 bar

Provides for the correlation between those brake warm effectiveness of the motor the point when run for biodiesel What's more with diesel. The brake warm effectiveness will be plotted similarly as An capacity about brake control (kW). It need been watched that those brake warm effectiveness expands when those motor may be run with biodiesel. Those greatest esteem for brake warm effectiveness for diesel & immaculate diesel will be toward 23.45 % bio diesel having 21.17% and Blend B20 having 24.64 % higher than the diesel .

3.21 SFC

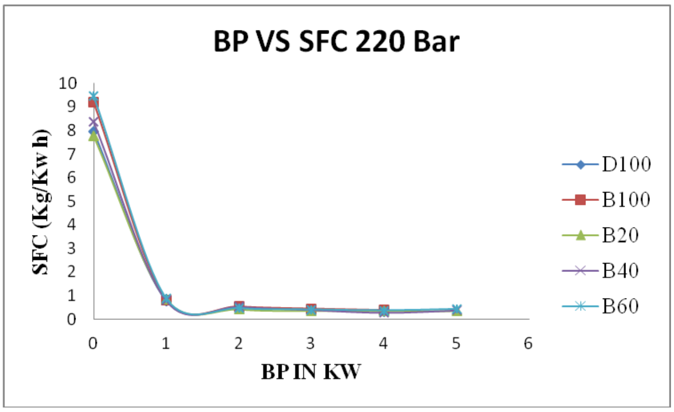

Fig:-3.21.Variation of specific fuel consumption with brake power for 220 bar

The fig3.21 demonstrates the variety of the brake particular fuel utilization versus brake control when diesel is utilized as fuel and it is contrasted and brake particular fuel utilization when biodiesel is utilized as fuel. This might be because of the lower calorific value of kusum bio diesel contrasted with the diesel esteem. Fuel utilization of biodiesel is higher, as load increments biodiesel practically identical with that of diesel. The variation of specific fuel consumption with brake power for diesel and blends kusum seed biodiesel are shown in figure 3.21, as the power developed increases the specific fuel consumption decreases for all the tested fuels. The specific fuel consumption of kusum seed biodiesel blends are higher than diesel because of lower calorific value and high density of biodiesel. From the graph it is clear that the specific fuel consumption is more for initial loads and further it is almost constant for remaining.

3.22 Exhaust Gas Temperature

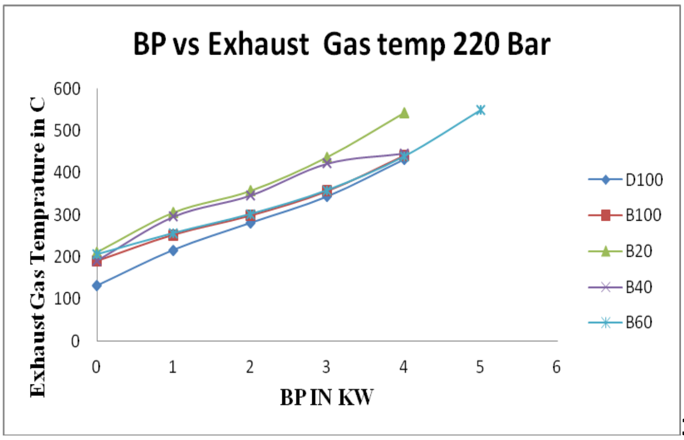

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Fig:-3.22 Exhaust Gas Temperature with brake power

The fumes gas temperature enemy every one of the energizes tried increment with increment in the brake control .Exhaust gas temperature of immaculate biodiesel and every one of the mixes is higher when contrasted with diesel .The Maximum EGT occur at full load .Maximum EGT of unadulterated biodiesel is 548.09 0C against 534.7 ^{0}C for that of diesel on ordinary Moto and blends B20 gives highest 573. 92 ^{0} C EGT.

3.23 Emission characteristics

Carbon monoxide

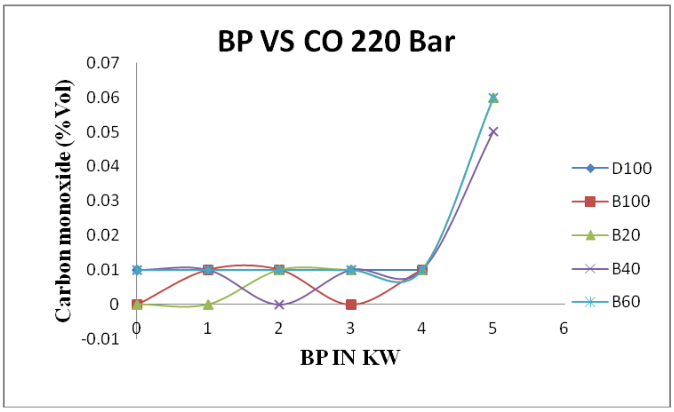

Fig:- 3.23 Carbon monoxide with brake power

Figure 3.23 shows variety of carbon monoxide discharge (CO) with brake control for diesel and biodiesel, for part

Heap of the motor. It is watched that the biodiesel emanates less sum CO than diesel at all heap condition. The level of CO emanation is as appeared in fig4.3.1 separately. CO emanation is 0.01 for diesel and biodiesel is 0 separately lower than diesel at part stack condition because of poor splash qualities and despicable blending. At full load CO emanation of diesel is 0.01%,

3.24 unburnt Hydrocarbon

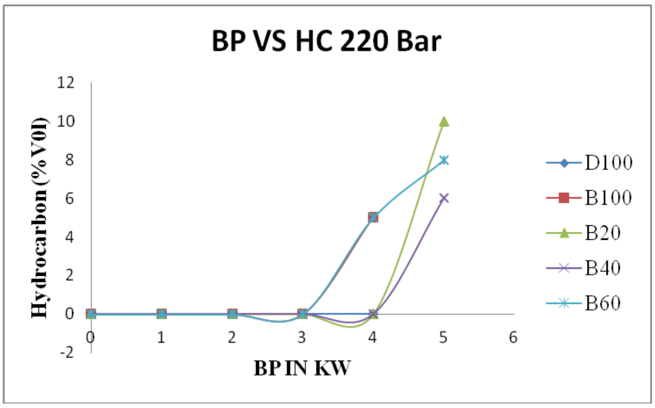

Fig:-3.24 unburnt Hydrocarbon with brake power

Demonstrates the variety in the amount of unburnt hydrocarbons with change in brake control. It is seen from the assume that B20 biodiesel mixes the emanation of HC is not as much as that of the diesel. Unburnt hydrocarbon outflow is the immediate aftereffect of fragmented ignition. A purpose behind the lessening of HC discharges with biodiesel is the oxygen content in the biodiesel atom, which prompts more entire and cleaner ignition.

3.25 Nitrogen oxide

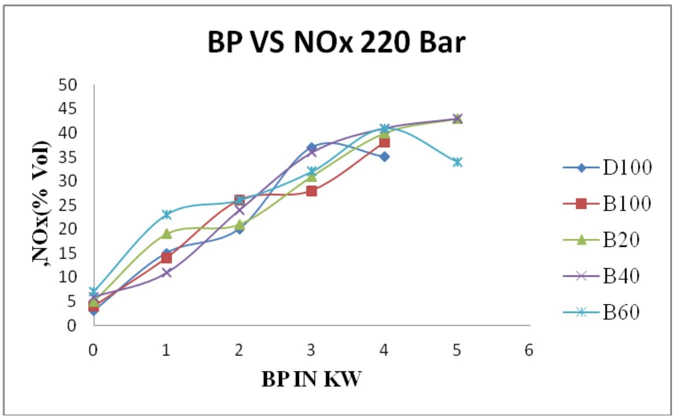

Fig:-3.25 Nitrogen oxide with brake power

Demonstrates the variety of nitrogen oxides emanation with brake control yield for diesel and kusum seed biodiesel mixes in the test motor are appeared in figure .7 The NOx outflows for B20 and B40 Equal to than that of diesel.

3.26 Smoke

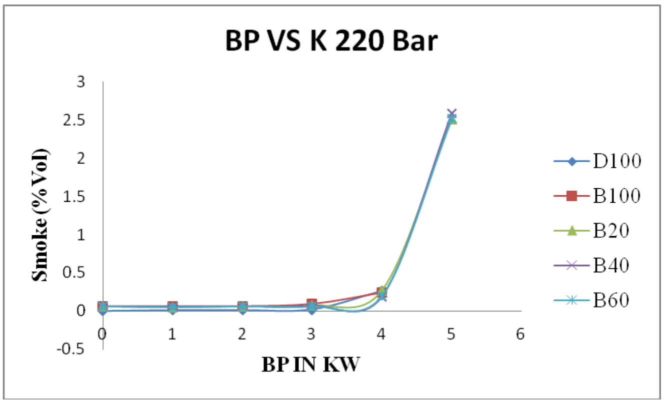

Fig:-3.26 Smoke with brake power

Smoke arrangement happens at the outrageous air lack. Air or oxygen insufficiency is locally present inside the diesel motors. It increments as the air to fuel proportion diminishes. Test comes about show that smoke discharges are expanded with increment in the part stack as the arrangement of smoke is unequivocally subject to the heap. Shows variety of smoke outflows with biodiesel and diesel with the part stack. Since at higher part stacks better burning may occur inside the motor chamber attempting to lessen the smoke emanations. Demonstrates the smoke estimations of diesel and biodiesel at part stack operation. For diesel operation the smoke esteems diminished as a result of the nuclear limited oxygen which helps in better ignition, in this manner lessening the smoke.

3.27 Combustion characteristics

Cylinder pressure with Crank angle

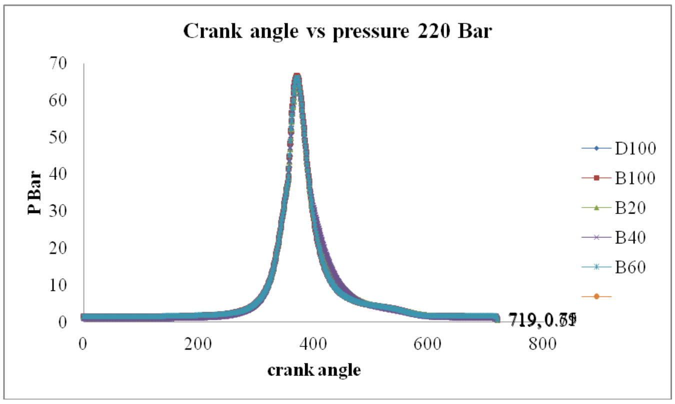

Fig:-3.27 Cylinder pressure with Crank angle

Pressure v/s crank angle. The cylinder pressure was found significantly higher for sole fuel. This is due to the low heat rejection to the cylinder walls. The increase in cylinder pressure is due to increase in trapped gas temperature in the combustion chamber. Further for diesel the pressure rise is 65.15 @372 deg and biodiesel pressure rise 66.64 @371 deg hence biodiesel highest pressure

3.28 Heat Release Rate with Crank Angle

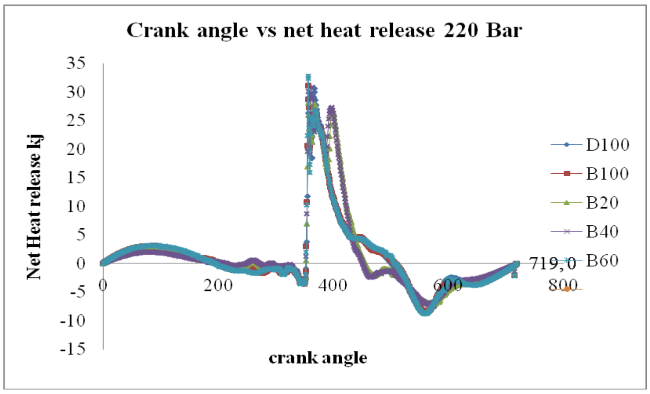

Fig:-3.28 Heat Release Rate with Crank Angle

The variation of net heat release rate with crank angle is shown in fig 3.28 the net heat release rate in more for biodiesel as compared to the diesel fuel. Bio Diesel has high net heat release rate of 31.15 kJ at 357 degree CA compared to diesel of 30.55 at 367 degree CA. This is due to higher calorific value, Cetane number and good atomization because of low viscosity. And highest B60 like 32.78 @ 357 deg compare to diesel.

3.29 Cumulative Heat Release Rate with Crank Angle

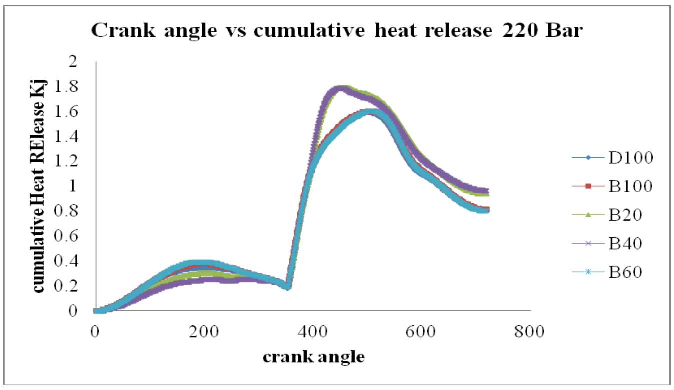

Fig:-3.29 Cumulative Heat Release Rate with Crank Angle

Shown in the fig 3.29 from the graph it is observed that diesel fuel has higher cumulative heat release rate compared to biodiesel. This is due to the cumulative effect of slight delay in start of dynamic fuel injection and a longer ignition delay compared to neat biodiesel. Maximum cumulative heat release rate for biodiesel is recorded as 1.67 kJ at 507 degree CA. Diesel has maximum cumulative heat release rate of 1.59 kJ at 500 degree CA. and B20 has highest like 1.79 kj @ 455.

CONCLUSION

The engine was made to run on diesel fuel mode, and kusum oil-diesel mode.The experiments were conducted at 3 different fuel injection pressures of 180 bar, 200 bar and 220 bar. The performance and emission of the engine at full load were investigated. The following results were obtained. The engine was able to run on 180 bar, 200 bar and 220 bar fuel injection pressures on diesel fuel mode and kusum oil -diesel mode

- The brake thermal efficiency of the engine for kusum oil - diesel blend of operations is high compared to diesel mode at 180, 200 and 220 bar.
- The exhaust gas temperature of kusum oil - diesel blend mode is less compared to diesel mode at fuel injection pressures of 180, 200 and 220 bar.
- HC emissions of kusum oil -diesel blend mode is higher compared to that of diesel fuel mode at all fuel injection pressures.
- CO emissions of kusum oil -diesel blend mode is higher compared to that of diesel fuel mode at all fuel injection pressures.
- NOX emissions of kusum oil -diesel blend mode is higher compared to that of diesel fuel mode at all fuel injection pressures

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