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The Effects of Exhaust Gas Recirculation on Exhaust Emission and Combustion Characteristics of a CI engine operated on Diesel and WCO Biodiesel

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Abstract:- Biodiesel has come to a forefront to be an alternative fuel to diesel in CI engines to reduce the diesel consumption and reduce the environmental degradation. The objective of this work is to elicit the problem with Biodiesel usage results in higher NOx emissions when compared to Diesel Engines and to reduce the NOx emissions with the help of Exhaust Gas Recirculation (EGR). CO, HC, NOx and smoke concentration of the exhaust gas were measured to estimate the emissions characteristics of a single cylinder four stroke air cooled direct injection (DI) diesel engine. Detailed analysis of various blends of biodiesel and diesel was made, to elicit the precise benefits of its extensive usage in CI engines. This analysis showed results indicating reduction in NOx emissions with the help of EGR with little compromise in power output.

Keywords:- Transesterification , Waste cooking oil (WCO), Exhaust emission, Diesel Engine, Exhaust Gas Recirculation (EGR), Combustion characteristics, Pressure crank angle.

I. INTRODUCTION

Today World Is In The Age Of Industrialization And Excessive Need Of Fuel Has Compelled It, To Confront With Twin Crisis Of Fossil Fuel Depletion And Environmental Degradation. Indiscriminate Extraction And Lavish Consumption Has Led To Reduction Of Carbon Resources[1]. While Fossil Fuels Are Still Being Created Today By Underground Heat And Pressure, They Are Being Consumed More Rapidly Than They Are Created. For That Reason, Fossil Fuels Are Considered Non-Renewable: That Is They Are Not Replaced As Soon As We Use Them [2-3]. Hence, Alternative Energy Resources Such As Biodiesel From Various Edible And Non-Edible Oils Such As Soya Beans, Jatropha (Jatropa Curcas), Sunflower And Karania (Pongamia Pinnata) Has Started Attracting Significant Attention From Researchers, Governments , And Industries As A Renewable, Biodegradable, And Non-Toxic Source.

Rudolf Diesel invented the diesel engine, he demonstrated it at the 1990 world exhibition in Paris, employing peanut oil as fuel and said “The use of vegetable oils for engine fuels may seem insignificant today, but such oils may become in course of time as important as petroleum and the coal tar products of the present time” [4]. Bio fuels has been considered as a potential alternative fuel for internal combustion engines [1,4-7]. It has been found that it is not only renewable, but has zero net production of CO2 gas on global context. Moreover, thermodynamic tests based on engine performance evaluations, have proved their low volatility and high cetane number which makes them hold immense promise as alternative fuels. Many researchers have found that diesel engines run successfully for longer durations and the performance and emission characteristics are quite comparable to petroleum diesel engines [8-10]. Kalligeros et al. conducted test with biodiesel produced from sunflower oil and olive oil in a single cylinder stationary diesel engine and found lower particulate matter, carbon monoxide, hydrocarbons and nitrogen oxide emissions with a slight increase in volumetric fuel consumption [11]. Altiparmak et al. conducted tests with tall oil methyl ester in direct injection diesel engine and found lower CO emissions, lower sulphur content, higher torque and engine power output at higher engine speeds[12]. But the usage of edible and non-edible vegetable oil makes the process of production of bio fuels very expensive and also puts immense pressure on feedstock. The feedstock includes almost 75% of the cost of production of biodiesel. So keeping this aspect in mind a new though easily yet viable source is found that is waste cooking oil.

In automobiles with compression ignition engines, fuel like diesel are preferred prime movers due to excellent drivability and higher thermal efficiency. Besides their advantages, they emit large amounts of exhaust gases which contain green house gases and other gases like NOx, CO and smoke etc which cause damage to people’s health. Due to these effects, human beings may suffer from various diseases, such as lung cancer, breathing difficulties, poisoning and skin cancer etc. Hence, there is a need of controlling diesel engine emissions[13].

Research on alternative fuels shows Bio-diesel has a promising effect on reducing emissions of CO, CO2 and UBHC for all biodiesel and its blends without any modification on current diesel engines [13,14-15].

This is due to the fact that biodiesel has oxygen in its structure and it burns cleanly for the fuel. But it was reported that NOx emissions are slightly high in biodiesel and its blends. Availability of high flame temperature and abundant oxygen in the combustion chamber is the basic reason behind higher NOx emissions [17]. To reduce this higher Nox emission, Exhaust Gas Recirculation (EGR) can be considered a viable method. Exhaust gas is the one gas that is readily available for engine use. Exhaust gas recirculation (EGR) is done by ducting some of the exhaust flow back into the intake system, usually immediately after the throttle. This is probably the simplest and practical method of reducing maximum flame temperature that is to dilute the air-fuel mixture with a non-reacting parasite gas. This gas absorbs energy during combustion without contributing any energy input. Hence, using EGR a lower flame temperature can be achieved.

CO2 and Argon gases also can be used in this concept. Due to lack of availability of these gases generally, the exhaust gases having larger specific heats are generally preferred. One prominent advantage of using EGR is that it doesn't alter the air-fuel ratio of the fuel, hence there is no change in the combustion characteristics. This method is adapted in the modern automobile and other medium sized and large engines.
However, technologies like Exhaust gas Recirculation (EGR), soot traps and exhaust gas after treatment are vital to cater to problems posed by stringent environmental emission rules [17]. EGR is where a part of exhaust gas is recirculated to intake so as to decrease the amount of oxygen available for nitrogen and also to reduce flame temperatures which results in reduction in NOx emissions. The specific heat of the EGR is much higher than fresh air, hence EGR increases the heat capacity (specific heat) of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber. Even though EGR application results in higher specific fuel consumption, it is the most effective way of reducing NOx emissions from compression ignition (CI) engines and is widely used in order to meet the emission standards.

The objective of the present work is to investigate the effect of exhaust gas recirculation with WCO and diesel fuel on the reduction of NO_x emissions and also to investigate the pressure crank angle, combustion characteristics, heat release and emission characteristics of a diesel engine with biodiesel as fuel with and without EGR at percentage like 30%EGR under the same load conditions.

II. BIODIESEL PREPARATION

A. Retrieving the WCO

WCO was collected from different hotels, restaurants, canteen and cafeterias. The sample was allowed to settle for 2-3 days and vacuum filtration was done to separate unnecessary impurities and food residues.

B. Pre-heating WCO

Before transesterification process, to ensure that the oil contained very little amount of water droplets in it , the filtered WCO was subjected to pre-heating to 100 degree Celsius for 15 minutes with continuous stirring using magnetic stirrer. This helped in drying the oil.

C. Neutralization of free fatty acids

In the accumulated WCO, neutralization of free fatty acids (FFA) needs correct amount of catalyst for avoidance of soap formation. To determine the correct amount of catalyst required , a titration was performed on the oil to be transesterified. The sample was tested with pH paper and pH was kept to between 8-9. KOH of weight 1 gram was measured using electronic weighing balance and its solution with 10ml water (solution A). Another solution of 10 ml of iso-propyl alcohol and 1 ml of oil sample was made (solution B). Then, solution A was added drop wise into solution B to achieve pH between 8-9 to determine the equivalents of KOH required to neutralize FFA.

D. Alkali catalysed transesterification of WCO

The alkali catalyzed transesterification was performed due to presence of majority of free fatty acids in WCO. For transesterification of WCO in laboratory, oil was heated in a flat bottom conical flask upto 60 degree Celsius. To ensure the prevention of methanol to reach its boiling point (78deg C), the optimum reaction temperature was set to be 60 degree C. Equivalent of KOH determined from the neutralization of FFA process was added to the standard KOH value to get the required KOH weight in grams that is to be added to the reaction vessel. This KOH weight in grams was dissolved in 200 ml of water (Solution C).
Now, 1litre of filtered WCO is poured into the reaction vessel and is stirred and simultaneously heated with the help of magnetic stirrer apparatus. Once the temperature of reaction reaches 60 degree C, 120ml of solution C is poured in reaction vessel and is stirred for one hour maintaining constant temperature (60 degree Celsius).

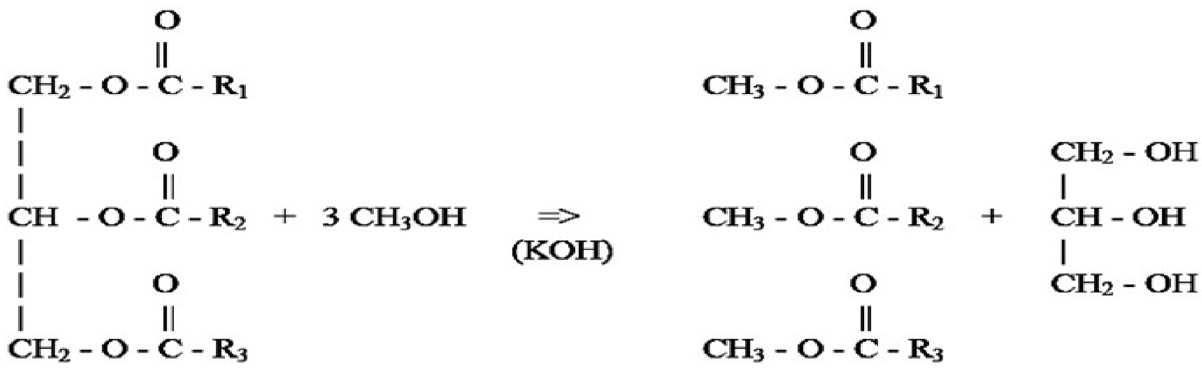

Fig. 1: Transesterification Reaction

The reaction products were poured into a separating funnel and kept for approx. 6 hours for gravity separation of glycerol with WCO methyl esters. The glycerol forms a lower layer due to higher density, which is separated out. This oil recovered from the separating funnel was again subjected to same procedure with 80 ml of solution C to remove the traces of glycerol and retrieve better quality of bio diesel from the WCO.

This biodiesel is then blended with petroleum diesel and various blends such as B20, B40, B80 and B100 are prepared for conducting CI engine experiment for performance and emission characteristics. Proper characterization of biodiesel blends and petroleum diesel is also done in laboratory as per ASTM norms. Specific gravity of blends and kinematic viscosity is measured using Red Wood Viscometer.

Table I: Fuel properties

S. NO	**Fuel**	**Viscosity (at 50^0C) ($Nsec/m^2$)**	**Density (Kg/m^3)**	**Flash point (^0C)**	**Fire point (^0C)**
1	B20	0.007516	860	62	68
2	B40	0.009657	865	66	72
3	B80	0.009398	875	76	85
4	B100	0.008439	900	80	89
5	Diesel	0.007270	840	78	86

- **EXPERIMENTALSETUP**

A four stroke single cylinder air cooled diesel engine typically used in utility vehicles was used for conducting the engine performance tests. The specifications of the engine are given in the table 2. The engine was coupled with AVL PRESSURE transducer GH14D/AH01, AVL INDIMICRA 602-T10602A , AVL digas 444 (five gas analyser) and AVL 437C Smoke meter for simulating the testing conditions. Data for engine speed (rpm), exhaust gas temperature, smoke meter reading, voltage , current etc. was collected from different types of sensors. Load was varied with the help of current variations.

Exhaust gas emissions were measured by the exhaust gas analyser. It measured CO, HC, CO2, O2, NOx and Air/fuel mixture. The exhaust gas smoke opacity was measured by AVL 437C Smoke meter.

Table II: Specifications of Engine

Type of engine	Four stroke, Vertical air cooled diesel engine
Number of cylinder	Single
Bore/Stroke	87.5/110
Compression ratio	17.5:1
Rated power	4.4 KW
Rated speed	1500 rpm
Injection timing	23^0
Injection pressure	200 bar

The experiment was carried out and repeated for every blend for the injection timing 23degrees, , injection pressure 200 bar and same mass flow rate for WCO. The pressure crank angle was also recorded and analysed.

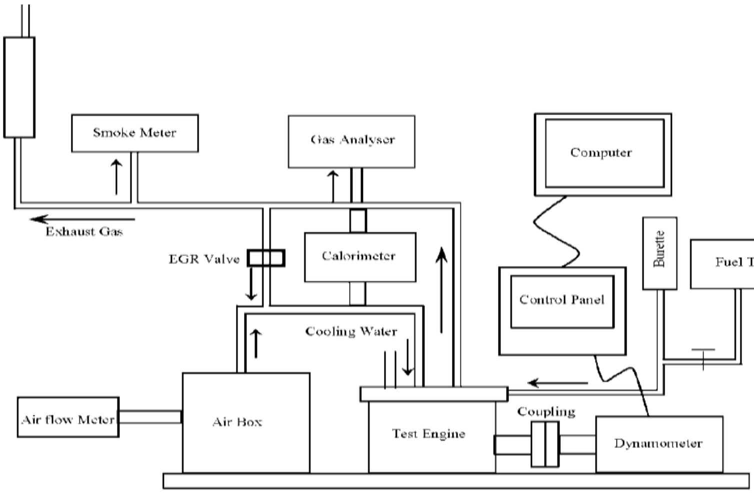

Fig. 2: Schematic diagram of experimental setup

Engine tests were conducted according to Indian Standard Codes [15-17]. According to this, engine performance parameters such brake power efficiency, smoke opacity, emissions etc. were measured for each blend. The engine was operated at 1500 rpm and data collections for combustion parameter, emission and performance was done. This data was recorded at various loads of 0, 25, 50, 75 and 100%. The average of three readings was reported in this paper.

The basis of this is the amount of flow can be only as high as 30% of the total intake. EGR combines with the exhaust residual left in the cylinder from the previous cycle to effectively reduce the maximum combustion temperature. Two blends with EGR 30%, B100 and pure diesel at different engine loads are run under the specified engine and the results are tabulated and the resultant pressure-crank angle graphs are plotted accordingly.

Fig. 3: Actual Engine setup

III. EXPERIMENTAL INVESTIGATION

A. Nitrous oxide (NO_x) emissions

NOx content in exhaust is highly toxic and EGR is mainly focused on reducing this emissions. Figure2 shows it's emissions for various blends with and without EGR at various loads. Emissions increases with increasing loads. This might be due to higher amounts of fuel needed at higher loads and higher flame temperatures. A drastic decrease in emissions in case of B100+EGR30% was noticed when compared to B100 without EGR. The reason for the reduction of NOx emissions is that EGR system dilutes the fresh charge and decreases the flame temperature. Another interesting aspect is that both B100 and diesel with EGR show similar emission characteristics at any load and the question of alternate fuel is judged here.

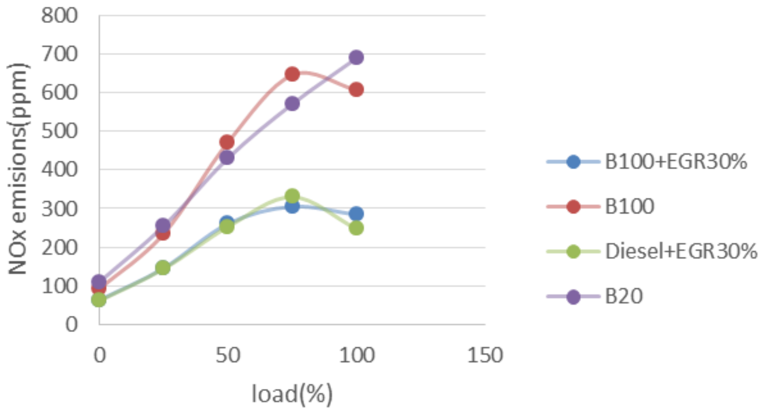

Fig. 4: Nitrous oxide emission at various loads

B. Unburnt hydrocarbons (HC)

One of the side effects of EGR is increase in amount of unburnt hydrocarbons. Figure 2 shows the variations of HC emissions with change in loads. It was observed that HC emissions increases with increase in load. As the load increases, the amount of fuel injected also increases and due to this, the corresponding rise in emissions can also be noticed. HC emissions are higher with increase in EGR rate as oxygen availability decreases. B20 is having low HC emission since adding biodiesel increases presence of molecular oxygen in biodiesel and hence full combustion occurs reducing HC emissions.

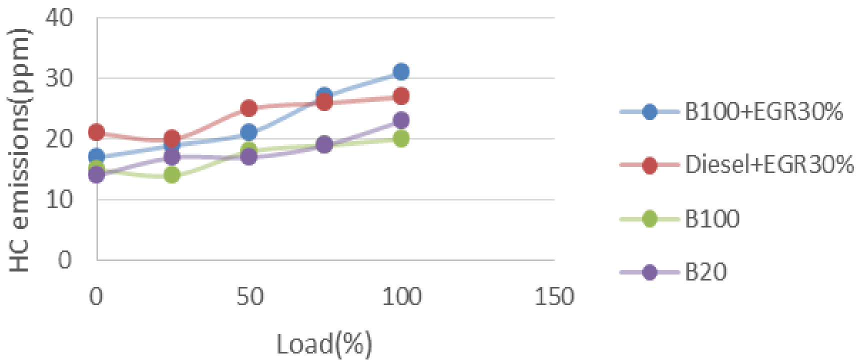

Fig. 5: Hydro carbon (HC) at various loads

C. Smoke emission characteristics

Smoke opacity also increases with respect to all loads due to dissociation of gases. Figure 4 shows the variation of emissions with load. Due to lack of sufficient oxygen in fresh charge mixture, incomplete combustion occurs hence emissions are higher in case of EGR. B100 is giving considerable emissions at all loads when compared to that of diesel+ EGR 30% which gives more emissions at higher loads.

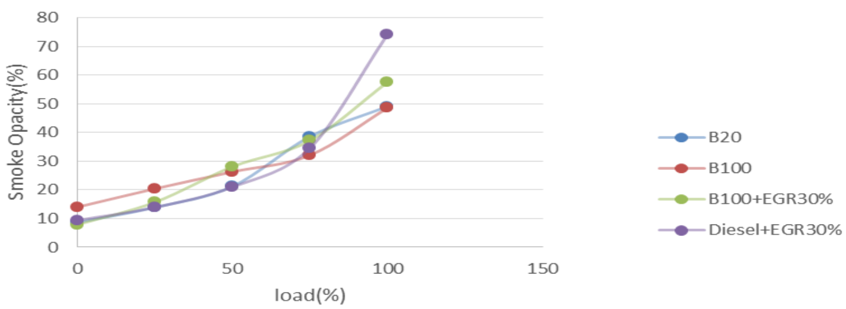

Fig. 6: Smoke opacity at various loads

D. Carbon monoxide emissions (CO)

Figure 7 shows the variation of CO emissions at various loads. CO emissions increases with increase in load as shown and similar to hydro carbon emissions, CO emissions increases with EGR. Again these emissions are due to lack of oxygen availability which results in partial combustion and inhaling this causes brain damage and sometimes even death. CO emissions of B20 is lower than diesel at all loads and this is due to the availability of oxygen in biodiesel blend when compared to that of diesel.

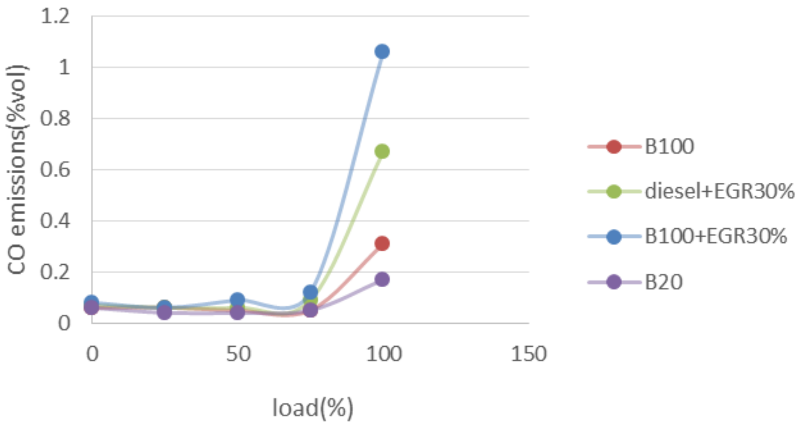

Fig. 7: Carbon monoxide emissions at various loads

E. Comparison of combustion characteristics

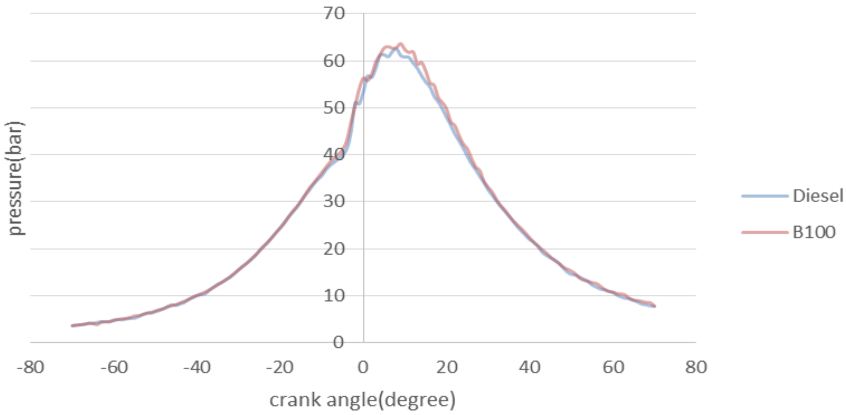

Fig. 7: Comparison of diesel and B100 with 30% EGR at 75% load

The whole combustion process in CI engine can be divided into four stages namely ignition delay, uncontrolled combustion phase, controlled combustion phase followed by after combustion phase. A comparative study between diesel and biodiesel at 75% load is done in figure 5 to analyse the combustion characteristics of pure biodiesel (B100) using EGR 30%.The path of phase1 (ignition delay) is found to be similar in both B100 and normal diesel. But the length of preparatory phase (ignition delay) in case of B100 is slightly more. In the phase of uncontrolled combustion, maximum pressure and maximum of rate of heat release is achieved.

Maximum pressure is achieved at 9^{o} after TDC in case of B100 and 8^{o} after TDC in case of diesel. Peak pressure is slightly more in case of B100. This is explained on the basis of ignition delay period. The longer the delay, the more rapid and higher the pressure rise since more fuel would have accumulated in the cylinder during the delay period. However, this rise is almost negligible and doesn't cause any significant change in the compression ratio and combustion characteristics. And moreover these changes are more likely to occur at higher loads only.

F. Comparison of pressure crank angle characteristics

As discussed earlier, EGR is the one which does not involve any change in the combustion characteristics of diesel engine but lower the flame temperature and reduces NOx emissions. A comparative study on biodiesel (B100) without EGR and with 30% EGR is done as shown in figure 8 and figure 9. The combustion characteristics is almost same with no rise in peak pressure and not much change in the heat release rate.

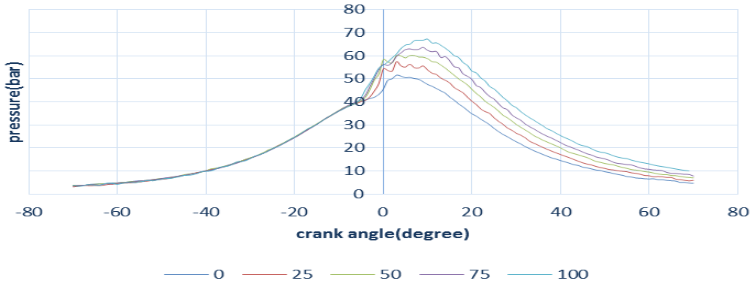

Fig. 8: Pressure crank angle diagram for B100+EGR 30% at different loads

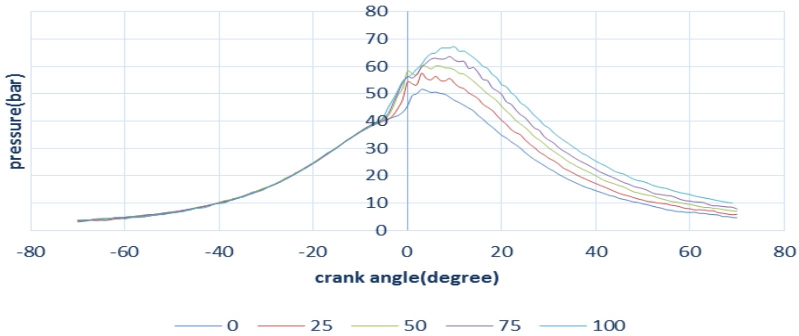

Fig. 9: Pressure crank angle diagram for B100 without EGR at different loads

G. Comparison of heat release

The below graph represents heat release rates between B100 and pure diesel with 30% EGR. It was observed that heat release for B100 was more than diesel. It can be clearly seen at highest peak in figure 8. The reason might be due to presence of small amounts of residual methanol in biodiesel, which burns and increases the heat release in the initial/middle stages of combustion. This can be also due to the improved combustion of biodiesel since it has highest cetane number delivering improved combustion characteristics. The same conclusion can be drawn for other blends also.

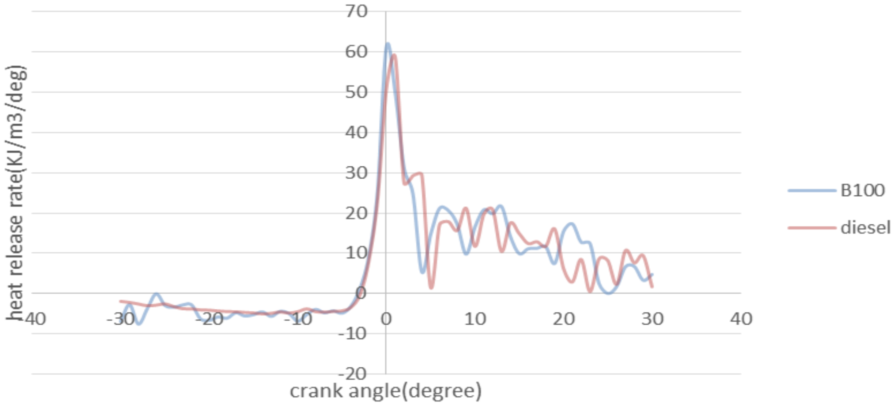

Fig. 10: Heat release rate diagram for diesel and B100 with 30% EGR

IV. CONCLUSIONS

In this study, the properties and combustion characteristics of biodiesel produced from waste edible oil has been determined and these are compared to normal diesel. Also a study on EGR is done on both pure biodiesel (B100) and diesel and the effects of various emission properties is determined. Following are some of the statistical results from the above discussion.

- Although NO_x emissions can be controlled using EGR process, a costly price of increased HC emissions and lowered thermal efficiency must be paid. However, there is a limit to this and recirculation up to 30% exhaust gas is considered safe.

- Pure biodiesel (B100) with EGR 30% has reduced NO_x emissions of 30% at lower loads to 51% at peak loads when compared to the emission properties of B100.
- As said CO and HC emissions are also increased by using EGR. However this increase is not magnified when compared to reduction in NO_x emissions.
- HC emissions are increased form 10 % at low loads to 30% at peak loads. CO emissions are increased at an average of 0.5%.

Apart from the above discussion, the need for alternate fuel is justified. Because, the combustion and emission characteristics of biodiesel (B100) and normal diesel with and without using EGR is found to be same. Hence, even pure biodiesel cans also be used as a substitution for diesel and EGR value from 10% to 30% can be used effectively to reduce emissions.

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