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Modeling and Experimental Investigation of Diesel- Bio-Diesel Fuelled DI Diesel Engine with Various EGR Ratios

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Abstract

The EGR system is a very effective technique for reducing NOx emission from a diesel engine, particularly at the high load of engine operation condition where the engine emits more NOx than at other conditions. In this study, the biodiesel produced from cottonseed oil was prepared by a method of trans esterification and its blends of 20%, 40%, 60%, 80% and 100% in volume, and standard diesel fuel separately. In this project, experimental work is carried out in three different phases. During the first phase, performance and emission characteristics of diesel and bio diesel (cotton seed) are analysed. In second phase the bio-diesel with various % of blends is used without EGR, the formation of NOx and smoke is high. So in the third phase we are implementing the engine with Hot EGR. The blend B60 shows the better performance in the engine emission. The result with the EGR shows the NOX and other emissions are reduced.

Keywords: Biofuels, Efficient , EGR,Emission, Engine

I. INTRODUCTION

All these year there have always been some IC engines fuelled with non-gasoline or diesel oil fuels. Because of the high cost of petroleum products, some developing countries are trying to use alternate fuels for their vehicles. Another reason motivating the development of alternate fuels for the IC engine is the concern over the emission problems of gasoline and diesel engines. If a 35% improvement made over a period of years, it is to be noted that during the same time the number of automobiles in the world increases by 40%, thereby nullifying the improvement. However more improvements are needed to bring down the ever-increasing air pollution due to automobile population.

Diesel emission regulations continue to be tightened in many countries, necessitating diesel engines with the least possible emissions. Exhaust gas recirculation (EGR) is one of the most effective methods for reducing the emissions of nitrogen oxides (NOx) of diesel engines. EGR system has already been used to mass - produced diesel engines, in which EGR is used at the low and medium load of engine operating condition, resulting in effective NOx reduction. In order to meet future emission standards, EGR must be done over wider range of engine operation, and heavier EGR rate will be needed. It is especially important for EGR to be done in a high engine load range since the amount of NOx is larger than the other engine operation conditions.

II. POLLUTION ANALYSIS

The major forms of pollution are listed below along with the particular contaminant relevant to each of them:

1. **Air pollution**

   The release of chemicals and particulates into the atmosphere. Common gaseous pollutants include carbon monoxide, sulphur dioxide, chlorofluorocarbons (CFCs) and nitrogen oxides produced by industry and motor vehicles. Photochemical ozone and smog are created as nitrogen oxides and hydrocarbons react to sunlight.

2. **Light pollution**

   Includes light trespass, over-illumination and astronomical interference.

3. **Littering**

   The criminal throwing of inappropriate man-made objects, unremoved, onto public and private properties.

4. **Noise pollution**

   Which encompasses roadway noise, aircraft noise, industrial noise as well as high-intensity sonar?

5. **Soil contamination**

   Occurs when chemicals are released by spill or underground leakage. Among the most significant soil contaminants are hydrocarbons, heavy metals, MTBE, herbicides, pesticides and chlorinated hydrocarbons.

6. **6.Radioactive contamination**

   Resulting from 20th century activities in atomic physics, such as nuclear power generation and nuclear weapons research, manufacture and deployment. (See alpha emitters and actinides in the environment.)

III. EXHAUST GAS RECIRCULATION (EGR)

Instead of using after treatment systems to comply with exhaust emission legislation, it is also possible to avoid the formation of emissions during the combustion. The raw emissions are reduced and thus no after treatment is needed. It is common practice nowadays, to use EGR to reduce the formation of NOX emissions. A portion of the exhaust gases is recirculated into the combustion chambers. This can be achieved either internally with the proper valve timing, or externally with some kind of piping, Figure 1 shows this schematically.

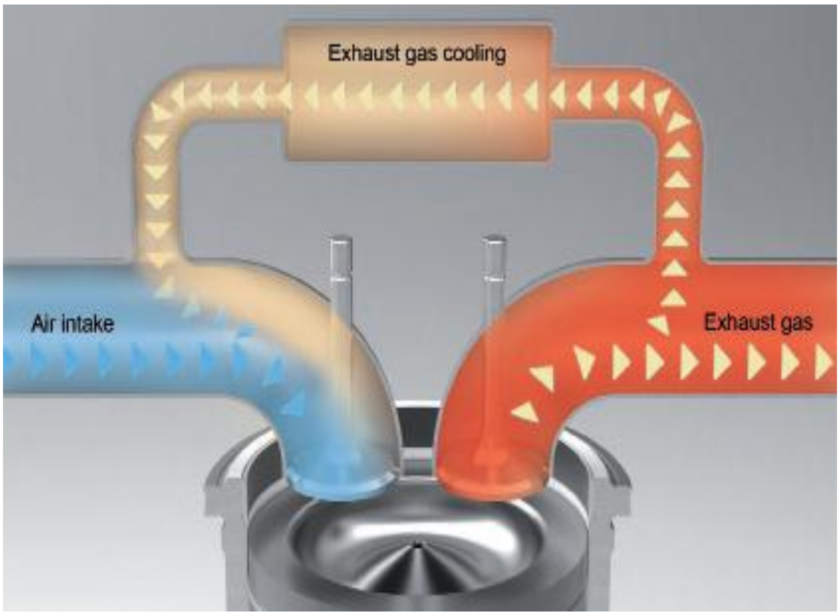


Figure 1: EGR - Exhaust Gas Recirculation

The exhaust gas acts as an inert gas in the combustion chamber, it does not participate in the combustion reaction. This leads to a reduction of the combustion temperature by different effects. The fuel molecules need more time to find a oxygen molecule to react with, as there are inert molecules around. This slows down the combustion speed and thus reduces the peak combustion temperature, as the same amount of energy is released over a longer period of time. The energy is also used to heat up a larger gas portion than it would without EGR. As the air is diluted with exhaust gas, the mass of a gas portion containing the needed amount of oxygen gets bigger. Another effect is the change in heat capacity. Exhaust gas has a higher specific heat capacity than air, due to the CO_2- molecule's higher degree of freedom. So for the same amount of combustion energy a gas mass containing EGR will get a lower temperature than pure air. The lower combustion temperature directly reduces the NOx formation, as the NOx formation rate is highly temperature dependent, Figure 2.

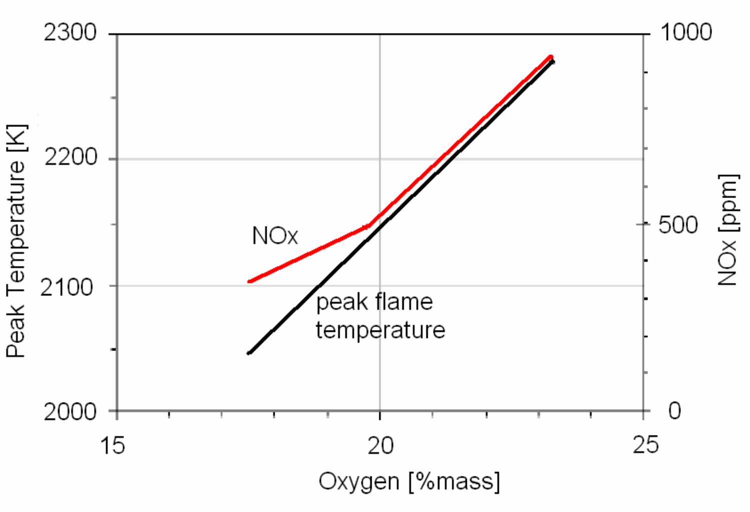


Figure 2: Temperature dependency of NOx formation

The X-axis shows the mass-percentage of oxygen. This is a way to express the amount of EGR that is recirculated. More EGR leads to a lower oxygen concentration. Several difficulties have to be taken into account when EGR issued. When the exhaust gas is taken out of the exhaust system upstream of the turbocharger, the energy of this gas is lost for the turbocharger. This decreases the useable exhaust energy for compressing the intake air and thus the amount of air that gets into the cylinder. This amount of air is directly coupled to the amount of EGR that the engine can run, because the limiting factor is the air/fuel ratio in the cylinder. Another problematic area is the control of emissions during transients. As it is desirable to get a maximum acceleration, the EGR is usually shut off when the load is increased, to provide the maximum amount of available air. This strategy leads to NOx peaks in the transient parts of the MNEDC as can be seen in Figure 3.

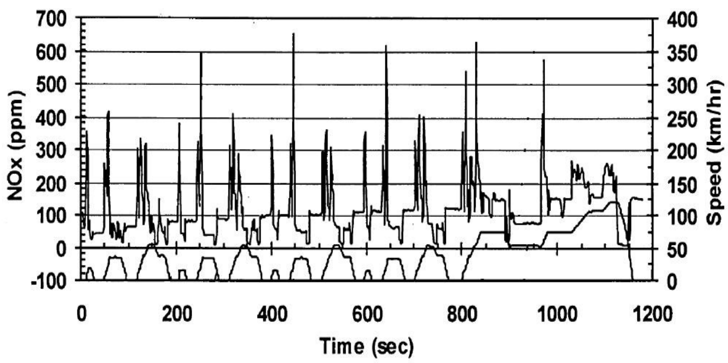


Figure 3: NOX formation

IV. TRANSESTERIFICATION

In organic chemistry, transesterification is the process of exchanging the alkoxy group of an ester compound by another alcohol. The reactions are often catalyzed by an acid or a base. Transesterification is crucial for producing biodiesel from bio lipids. The transesterification process is the reaction of a triglyceride with a bio-alcohol to form ester and glycerol. The details of the process of transesterification and biodiesel are given in following paragraphs.

Cotton seed oil have undergone the process of transesterification to be usable in internal combustion engine. Biodiesel is the product of the process of transesterification. Biodiesel is biodegradable, non-toxic and essentially free from sulphur; it is renewable and can be produced from agriculture and plant resources. Biodiesel is an alternative fuel, which has a correlation with sustainable development, energy conservation, management, efficiency and environmental presentation.

Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol. Alcohol combines with the triglycerides to form glycerol and ester. A catalyst is usually used to improve the reaction rate and yield. Since the reaction is reversible, excess alcohol is required to shift the equilibrium to the product side. Among the alcohols that can be used in the transesterification process are methanol, ethanol, propanol, butanol and amyl alcohol. Potassium hydroxide (KOH)-catalyzed transesterification is much faster than acid-catalyzed transesterification and is most often used commercially.

The process of transesterification brings about drastic change in viscosity of cotton seed oil. The biodiesel thus produced by this process is totally miscible with mineral diesel in any proportion. Biodiesel viscosity comes very close to that of mineral diesel hence no problems in the existing fuel handling system. Flash point of the biodiesel gets lowered after esterification and the cetane number gets improved. Even lower concentration of biodiesel act as cetane number improver for biodiesel blend.

Calorific value of biodiesel is also found to be very close to mineral diesel. Some typical observations from the engine tests suggested that the thermal efficiency of the engine generally improves; cooling losses and exhaust gas temperature increases, smoke opacity generally gets lower for biodiesel blends. Possible reason may be additional lubricity properties of thebiodiesel; hence reduced frictional losses. The energy thus saved increases thermal efficiency, cooling losses and exhaust losses from the engine. The thermal Efficiency starts reducing after a certain concentration of biodiesel, Flash point, density, pour point, cetane number, calorific value of biodiesel comes range to that of mineral diesel.

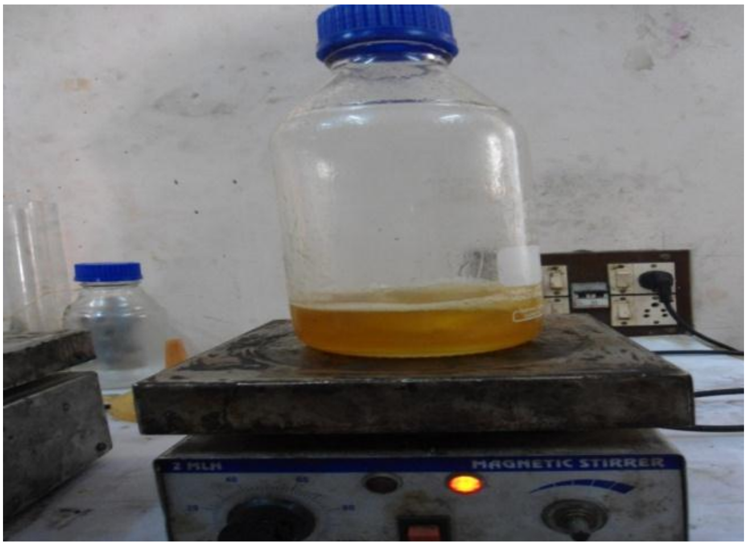


Figure 4: A sample of diesel and biodiesel mixed with catalyst in magnetic stirrer

Figure 5: Separation of biodiesel and glycerol

V. EXPERIMENTAL INVESTIGATION

1. Experimental Results

The test engine is a single cylinder, direction injection, water cooled Compression Ignition engine. The experimental setup is shown in figure. The EGR system consists of a piping system taken from the engine exhaust pipe. The amount of exhaust gas recycling into the inlet manifold is controlled by means values. The recirculated exhaust gas floes through orifice with manometer for measuring the flow rate, before mixing with the fresh air. Cold EGR is attained by cooling the recirculated exhaust gas. The exhaust gas recirculation line is connected to a heat exchanger having water as the cold fluid. Thermocouples are connected to inlet and exit of the cold and hot fluids in the heat exchanger. Diesel engine was directly coupled to an eddy current dynamometer. The dynamometer was interfaced to a control panel. The emission like CO, HC, CO_2, O_2 and NOx, were measured in the exhaust gas analyzer and density was measured in the smoke meter.

TABLE 1: Specification of the Test Engine

Type	Vertical, Water cooled, Four stroke
Number of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1
Maximum power	5.2 Kw
Speed	1500 rev/min
Dynamometer	Eddy current
Injection timing	23° before TDC
Injection pressure	220 kgf/cm²

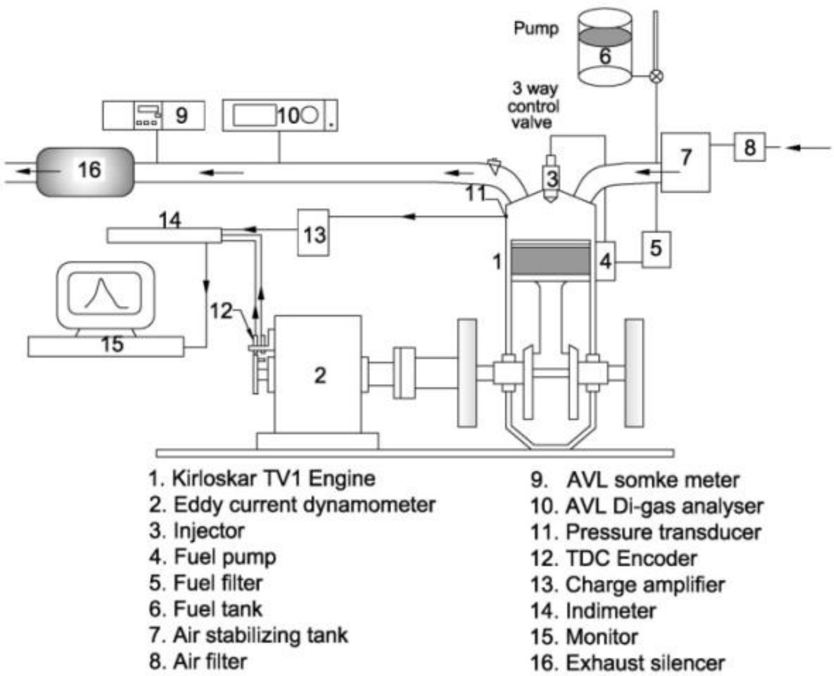


Figure 6: The layout of the engine test bench

2. Test Procedure

Details of the engine are given in table. Fuel flow rate is obtained on the gravimetric basis and the airflow rate is obtained on the volumetric basis. NOX emission is obtained using an AVL di-gas analyzer working on electro chemical principle. AVL 444 smoke meter is used to measure the smoke capacity, in terms of Hart ridge smoke unit (HSC). All the measurement were obtained and recorded by a data acquisition system. A burette is used to measure the fuel consumption for a specified time interval. During this interval of time, the fuel consumption is measured, with the help of the stopwatch.

The engine was allowed to run with sole fuel at a constant speed at 1500 rpm for nearly 5 minutes to attain the steady state condition at the lowest possible load the following observation were made twice for averaging / concordance . The test at various load ranges were conducted on the engine at a constant speed at 1500 rpm to obtain parameters such as fuel consumption, brake thermal efficiency, smoke density, NOx, and hydrocarbons.

3. Load Test

1. The water flow is started and maintained constant through the experiment.
2. The load, speed and temperature indicators were switched on.
3. The engine is allowed to run at the rated speed of 1500 rpm for a period of five minutes to reach the steady state.
4. The fuel consumption is measured by a stop watch.
5. Smoke readings were measured using the AVI Smoke meter at the exhaust outlet.
6. The amount of NOx was measured using exhaust AVL di gas analyzer.
7. The exhaust temperature was measured at the indicator by using a temperature sensor.
8. Then the load is applied by adjusting the knob, which is connected to the eddy current dynamometer.
9. Experiments were conducted using diesel and biodiesel (cottonseed oil) blend at various ratio on B20, B40, B60, B80 and B100 the above procedure is adopted.

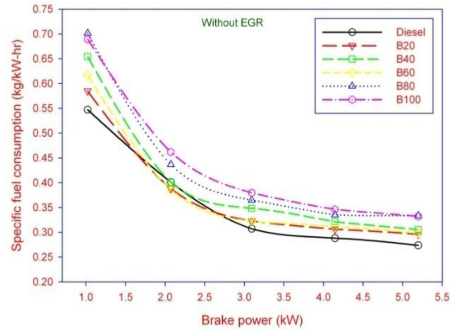
Figure 7: A schematic view of TV I Engine with Hot EGR

VI. RESULT AND DISCUSSION

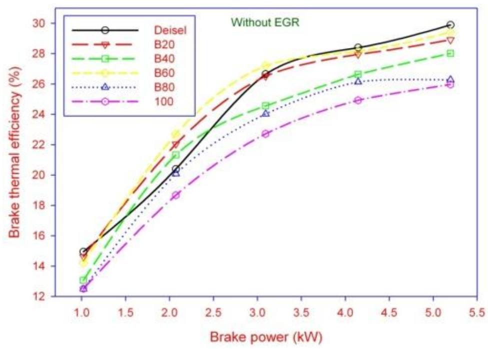
The modern diesel engine even though efficient are not able to meet the future emission norms .The reduction of emission from the existing engine though they are able to meet the present emission regulation will not be able to meet future standards. Some of the innovative methods for satisfying the norms are usage of alternative bio based diesel fuels, exhaust gas recirculation (EGR) and the combination of different blends of bio diesel with variying proportion of EGR.

1. Comparison of Performance with Various Blends of Biodiesel without EGR.

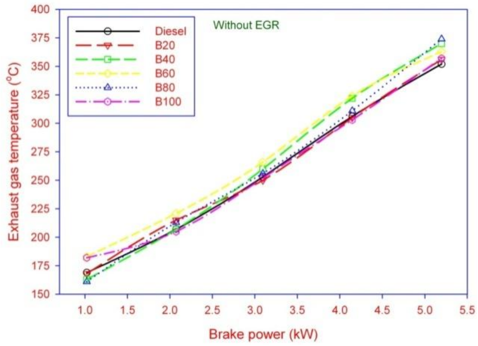
It is clear from the previous discussions that the biodiesel performance is better in the emission point of view. But the availability of the bio diesel is still uncertain and moreover the cost of preparation of a liter of bio diesel is still expensive. As in practice the world over the fuel supplement is better than fuel substitute. Hence analyses were conducted with various blends of diesel (D100) and Biodiesel (B100), in the ratio of 20% Biodiesel and 80 & Diesel (B20), 40 % biodiesel and 60% Diesel (B40), 60 % biodiesel and 40% Diesel (B60), and 80 % biodiesel and 20% Diesel (B80).



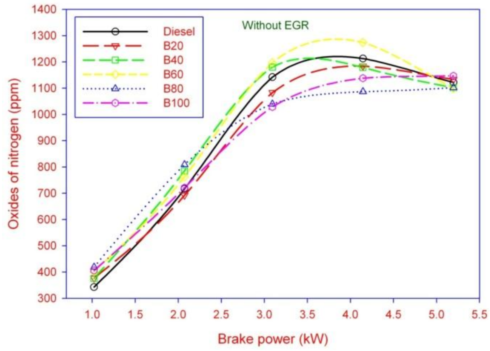
(a) Brake Specific Fuel Consumption



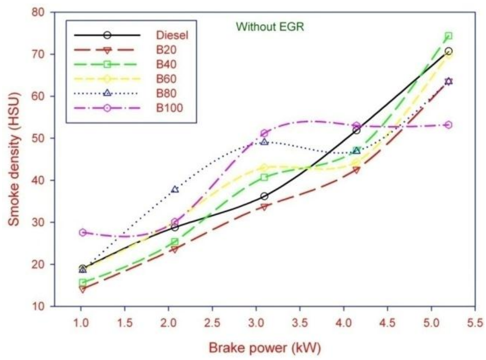
(b) Brake Thermal Efficiency



(c) Exhaust Gas Temperature



(d) Oxides of Nitrogen



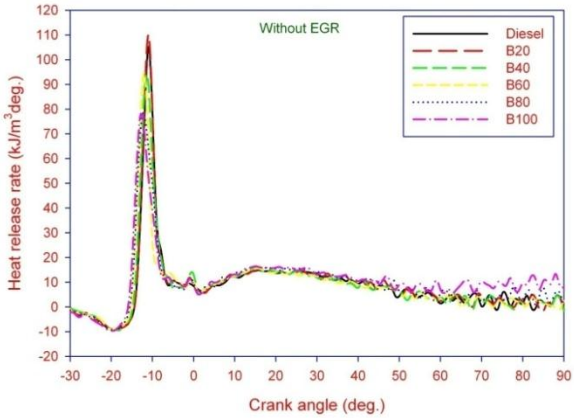
(e) Smoke Density

Figure 8: Comparison of Parameters at various loads for different combinations of Biodiesel and Diesel Blends

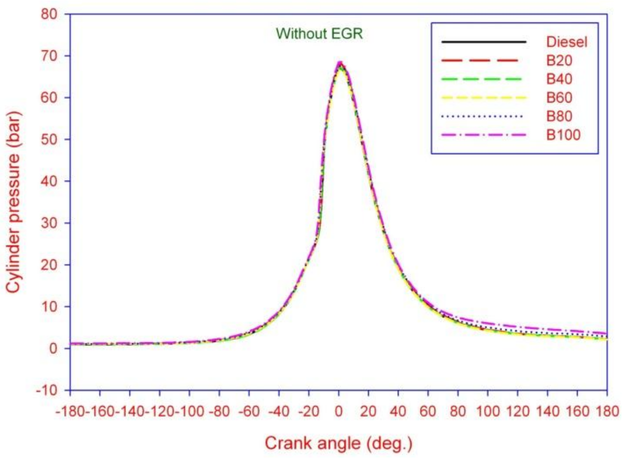
It is clear from the picture that while diesel (D100) gives better fuel economy and brake thermal efficiency the NOx emission is more than that of the combinations of diesel- biodiesel. While the emissions of B40 and B60 are more than that of diesel up to 60% load the trend is lower than diesel at loads at higher than 60%. This is so with B40. Whereas B60 consistently produces a higher NOx emission at all loads. Hence this blend is not suitable in the emission point of view also. Moreover the EGT is also high with this blend.

The only regime this blend performs better is at loads higher than 80% producing a better fuel economy and thermal efficiency. The B80 blend shows lower exhaust gas temperature and lower NOx emission at all loads while the fuel economy and thermal efficiency are only marginally lower than D100. Hence this blend is preferred over the other biodiesel blends. Regarding the smoke emission point of view the B20 combination consistently generate less smoke at all loads than all other combinations. The B80 which seems good on the other hand produces higher emissions till around 80 % load., but emission is lower above this point. Hence this blend again scores the other combinations which are conducive in the long haul running of the engine at maximum load.

Fig 9 compares the heat release rate and pressure generated inside the cylinder on cyclic basis.



(a) Temporal Variation of Heat Release Rate for Various Blends



(b) Evolution of Pressure inside the Engine Cylinder on Crank Angle Basis

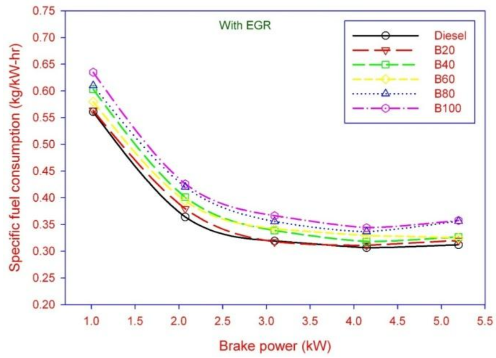
Figure 9: Comparison of Heat Release Rate Pattern and Pressure inside the Engine Cylinder on Crank angle Basis at Full Load for Various Blends at Full Load

Comparing Figures A11. a) and A.11b) it is evident that the Heat release pattern at full load by various blends less than the sole diesel (D100) fuel during the early stages of combustion whereas the late stage combustion by the blends shows a higher value than the sole fuel. As it can be clearly seen from the picture A.11.b) the various blends other than the sole diesel fuel producing a higher heat release value and hence a higher pressure after the crank angle 60 deg aTDC.

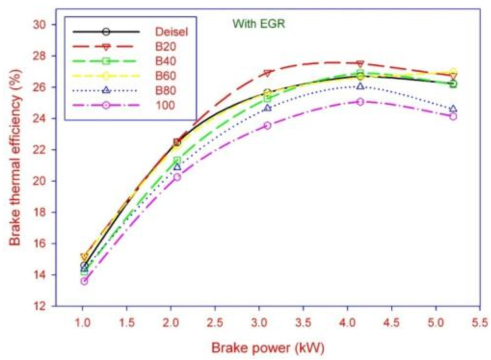
2 .Comparison of Performance with Various Blends of Biodiesel with EGR.

It is clear from the previous discussions that the biodiesel performance is better in the emission point of view. But the availability of the bio diesel is still uncertain and moreover the cost of preparation of a liter of bio diesel is still expensive. As in practise the world over the fuel supplement is better than fuel substitute. Hence analyses were conducted with various blends of diesel (D100) and Biodiesel (B100), in the ratio of 20% Biodiesel and 80 & Diesel (B20), 40 % biodiesel and 60% Diesel (B40), 60 % biodiesel and 40% Diesel (B60), and 80 % biodiesel and 20% Diesel (B80).

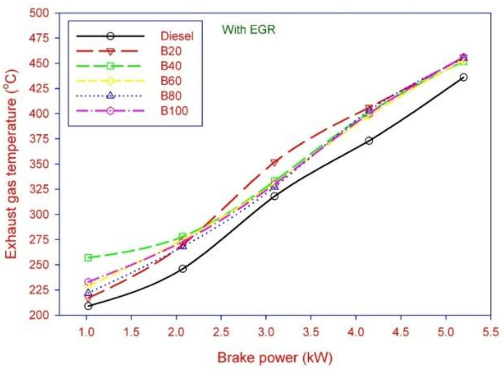
Figure 10 shows the comparison various parameters like BSFC, brake thermal efficiency, exhaust gas temperature and oxides of Nitrogen, smoke density without EGR.



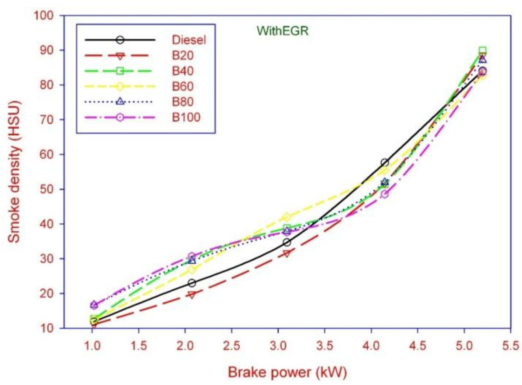
(a) Brake Specific Fuel Consumption



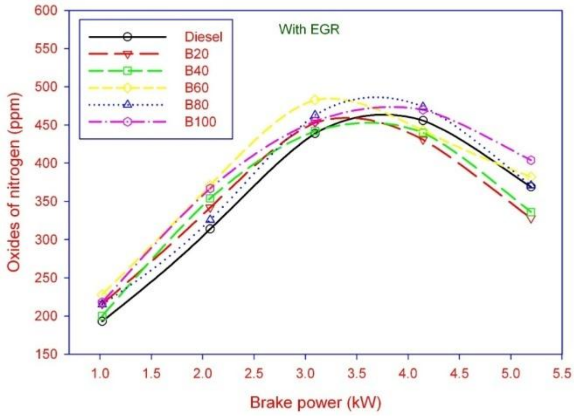
(b) Brake Thermal Efficiency



(a) (Exhaust Gas Temperature

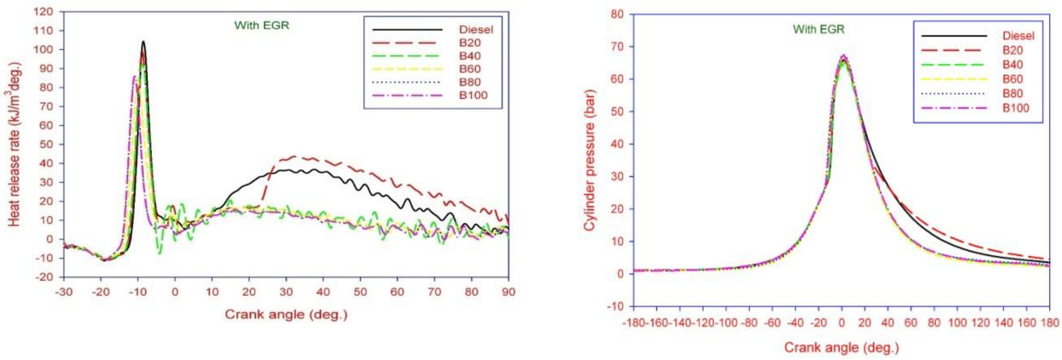


(b) Smoke Density



(e) Oxides of Nitrogen

Figure 10. Comparison of Parameters at various loads for different combinations of Biodiesel and Diesel Blends



a) Temporal Variation of Heat Release Rate for Various Blends

b) Evolution of Pressure inside the Engine Cylinder on Crank Angle Basis

Figure 11. Comparison of Heat Release Rate Pattern and Pressure inside the Engine Cylinder on Crank angle Basis at Full Load for Various Blends at Full Load

Comparing Figures 10 a) and 11 b) it is evident that the Heat release pattern at full load by various blends less than the sole diesel (D100) fuel during the early stages of combustion whereas the late stage combustion by the blends shows a higher value than the sole fuel. As it can be clearly seen from the picture A.12.b) the various blends other than the sole diesel fuel producing a higher heat release value and hence a higher pressure after the crank angle 60 deg a TDC.

3 Investigation of Flowfield Characteristic And Combustion For The KIRLOSKAR TV-1 Engine

In order to understand many of the sub-physical processes now a days CFD is used.

Hence the geometrical model of the engine is created complete with intake and exhaust ports and valves. Figure 12a) shows the CAD model of the engine and Fig. 12b) shows the discretized domain.

(a). CAD Model of the Engine (b). Discretized Domain

Figure 12: CAD Model of the Engine and the Discretized Domain Showing Valves and Ports

For the simulation of the engine sub processes like air intake, compression, combustion and expansion a commercially available CFD software STARCD is used. The piston and valve motion is simulated with moving mesh algorithm developed specifically for this case. This involves the addition and removal of cell layers. The fluid motion, spray and combustion are modelled by solving Navier-Stokes Equation with energy and species transport equation and equation of state. Fig A15 shows the flow field inside the engine cylinder during important stages of suction and compression.

CONCLUSION

Through the simulation and experiment of the EGR control strategy we know as follows:

(1) When the engine is idle, the combustion temperature is not high, NOx emissions is not, in order to make the engine idle stability, cut off the EGR.

(2) When the engine starts, in order to start the engine a smooth and stable operation, need to cut off the EGR; engine cooling water temperature is low, combustion instability, and the combustion temperature is lower, you need to cut off the EGR. With the cooling water temperature, increasing EGR; in minor or low-speed cruising speed, because less fuel injection, combustion volume becomes unstable, you can use a small amount of EGR, to reduce NOx emissions, while ensuring that the driver of good ; medium engine load, NOx emissions are high at this time a large EGR rate should be used to reduce NOx emissions. With the increase of load, EGR rate can be increased accordingly.

(3) When the engines require high power, high speed, in order to ensure better power, fuel injection quantity is large at this time, NOx emissions resultant reduced, and therefore can EGR or less without using EGR; in the intake air temperature is low, the combustion temperature inside the cylinder will be reduced, this time should reduce the amount of exhaust gas recirculation to the combustion process can be a good manner

ACKNOWLEDGEMENTS

An acknowledgement section may be presented after the conclusion, if desired.

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