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Effect of Cooled EGR in Combustion Characteristics of a Direct Injection CI Engine Fuelled with Biodiesel Blend

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***Abstract*—**As the demand and prices of various petroleum products have been on the rise in recent years, there is a growing need for alternative fuels. Biodiesel, which consists of alkyl monoesters of fatty acids from vegetable oils and animal fats, is considered as an alternative to petroleum diesel. Biodiesel has comparable performance with that of diesel and has lower brake specific fuel consumption than diesel with significant reduction in emissions of CO, hydrocarbons (HC) and smoke with however, a slight increase in NO_X emissions. This paper analyzes the effect of cooled exhaust gas recirculation in the combustion characteristics of a direct injection compression ignition engine using biodiesel blended fuel as opposed to the conventional system. The combustion parameters such as cylinder pressure, heat release rate, delay period and peak pressure were analyzed at various loads. The maximum cylinder pressure reduces as the fraction of biodiesel increases in the blend the maximum rate of pressure rise was found to be higher for diesel at higher engine loads.

***Keywords*—**Cylinder pressure, delay period, EGR, heat release.

I. Introduction

A large number of studies has shown that biodiesel is one of the promising renewable, alternative and environmentally friendly bio-fuels that can be used in diesel engine with little or no modification in the engine [1]-[5]. The stringent emission laws, the depletion of fossil fuels and relation of fuels with politics have forced the world to find alternatives to fossil fuels. Numerous vegetable oil esters (biodiesel) have been investigated for use in internal combustion engines and have been shown to have higher potential to reduce CO_2 emission [6], [7]. The effects of different fuels on the performance characteristics of engines have been extensively reported.

The common engine parameters on which effects have been quantified include brake specific fuel consumption, brake effective power and thermal efficiency. Many researchers have compared the performance of engines running with biodiesel and its blends with engines running with normal diesel. It has been reported by a large number of researchers that the use of biodiesel results in higher brake specific fuel consumption and higher thermal efficiency when compared to the use of diesel in an engine [8]-[11]. However, use of different biodiesels in an engine results in variations in engine performance and emission due to variation in various physical and chemical characteristics of biodiesel [12]. The effects of these physio-chemical properties on fuel supply system such as fuel pump, fuel filter and air-fuel mixing cylinder have already been reported [13]. To improve the performance and emission characteristics of the engine running with biodiesel and to understand the effects of physical properties of the fuel on the engine performance and emissions a detailed investigation is required on the underlying combustion and heat release characteristics. The heat released and resulting pressure and temperature fields affect the performance and emission characteristics. However most of the researchers so far have correlated the performance and emission characteristics of biodiesel against test parameters such as biodiesel fraction blend, engine speed, engine load, injection timing, injection pressure and engine compression ratio. However, there are very few works that have been reported on the engine combustion characteristics and heat release phenomena corresponding to different biodiesels and its blends [14]. Therefore, the objective of this study is to investigate the combustion characteristics and heat release rate phenomena of a compression ignition engine running with biodiesel blend.

Zhang and Van Gerpan [15] investigated the combustion characteristics of turbo charged direct-injection diesel engine using blends of methyl, isopropyl and winterized methyl ester of soybean oil with diesel as a fuel. They investigated the combustion characteristics at the maximum torque engine speed and for 20% and 100% engine load. They found that all fuel blends except isopropyl ester had similar combustion behavior. Fuel injection starts earlier for high engine loads. The cetane number was higher for biodiesel and its blends in comparison with diesel. All blends had a shorter ignition delay and a lower premixed burn fraction than diesel. Senatore *et al.* [16] reported that with the rapseed oil methyl ester, heat release always took place earlier than diesel, because fuel injection starts earlier for biodiesel blends owing to their higher density, leading to a higher peak cylinder temperature. McDonald *et al.* [17] investigated soybean oil methyl ester as a fuel on a Caterpillar indirect-injection diesel engine and found that overall combustion characteristics were quite similar to those of diesel except for a shorter ignition delay for

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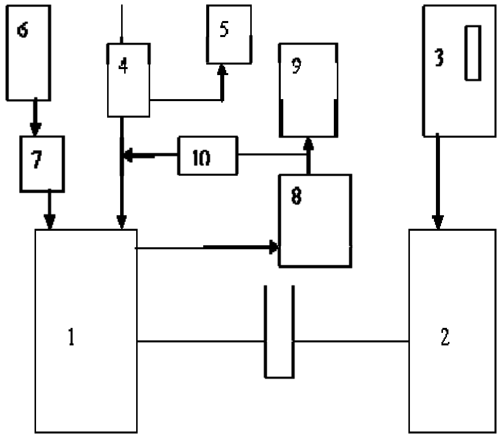
soybean methyl ester. Kumar *et al.* [18] found that, for jatropha oil methyl ester, ignition delay was longer than diesel in a constant speed diesel engine.

II. Experimental Program

A. Experimental Setup



1. Diesel Engine 2. Electrical Dynamometer 3. Dynamometer Controls 4. Air Box 5. U Tube Manometer 6. Fuel Tank 7. Fuel Measurement 8. Exhaust Gas Analyzer 9. AVL Smoke Meter 10. EGR Control Valve

Fig. 1 Experimental setup

Fig. 1 shows the schematic representation of the experimental setup used in this study.

A swinging field electrical dynamometer is used to apply the load on the engine. This electrical dynamometer consists of a 5-kVA AC alternator (220V, 1500 rpm) mounted on bearings and on a rigid frame for the swinging field type loading. The output power is obtained by accurately measuring the reaction torque by a strain gauge type load cell. A water rheostat with an adjustable depth of immersion electrode is provided to dissipate the power generated.

TABLE I
Specifications of the Engine used in this Study

Make	Kirloskar
Model	TAF 1
Type	Direct injection, air cooled
Bore x stroke (mm)	87.5 x 110
Compression ratio	17.5:1
Cubic capacity	0.661 lit
Rated power	4.4 KW
Rated speed	1500 rpm
Start of injection	23.4º bTDC
Injector operating pressure	200-205 bar

TABLE II
Properties of Biodiesel Blended Fuels (B20)

Property	*ASTM Method*	*Limits*	*Units*
Flash Point	D93	53 minimum	°C
Kinematic Viscosity, 40°C	D445	1.9 – 4.1^	mm^2/sec
Cetane	D613	40 minimum	
Distillation, T90 AET	D86	343 maximum	°C
Oxidation Stability	EN 15751	6 minimum	hours

C = Celsius, mm = millimeter, sec = seconds

B. EGR System

A piping arrangement is made to tap the exhaust gases from the exhaust pipe and to connect it to the inlet air flow passage. Flow rate of the exhaust gases through the pipe is controlled by a control valve. This control valve regulates the exhaust gases and the mixture of fresh air and exhaust gases are sent to the inlet manifold. The exhaust gases are tapped after passing through 10m of exhaust pipe and a pulse reducer tank. After tapping, it travels 8m in the piping arrangement which reduces the temperature of tapped exhaust gases as equal to the ambient air and it does not cause any change in the temperature of the inlet air before admitting in to the combustion chamber.

C. Testing Procedure

Tests are conducted on the engine fuelled with biodiesel blend. The tests are conducted at constant speed equal to the rated engine speed of 1500 rpm at various loads starting from no load to 100% of the rated load condition and at each load, combustion parameters were measured. NO_x emission is measured with MRU1600 exhaust gas analyzer and the smoke concentration is measured with AVL smoke meter.

III. Results and Discussion

A. Cylinder Pressure at Various Loads

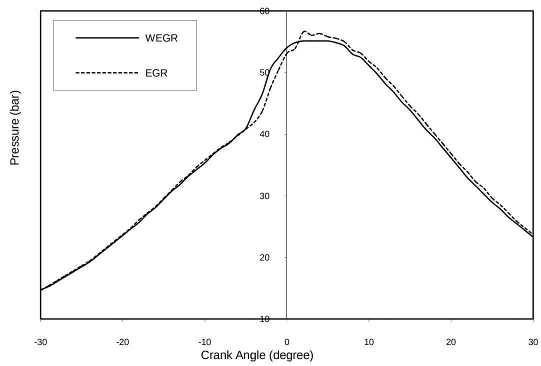


Fig. 2 Variation of cylinder pressure at 0% load

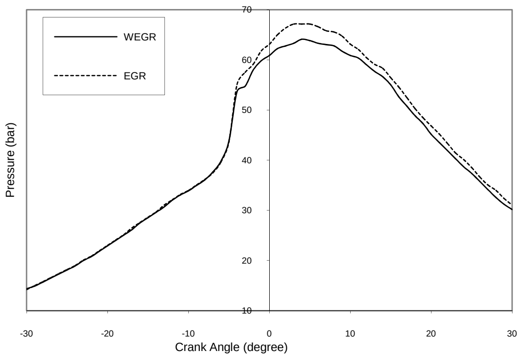


Fig. 3 Variation of cylinder pressure at 50% load

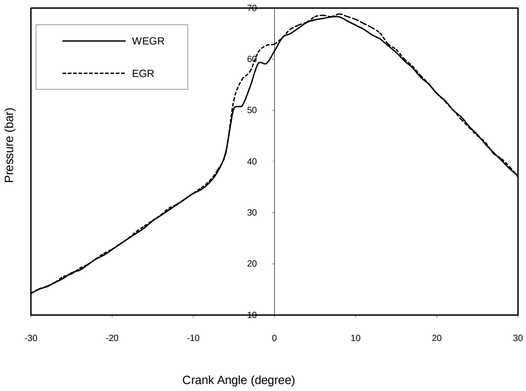


Fig. 4 Variation of cylinder pressure at 100% load

Figs. 2, 3 and 4 show the variation of cylinder pressure at various crank angles for different loads. The oxygen concentration is changed when the exhaust gas is recycled to the intake for the control of the emissions of oxides of nitrogen. As the oxygen concentration is decreased, the ignition delay period becomes longer. So, longer the delay, the more rapid and higher is the pressure rise. *The average cylinder pressure with EGR is found to be 1.54% greater than that without EGR.*

B. Heat Release at Various Loads

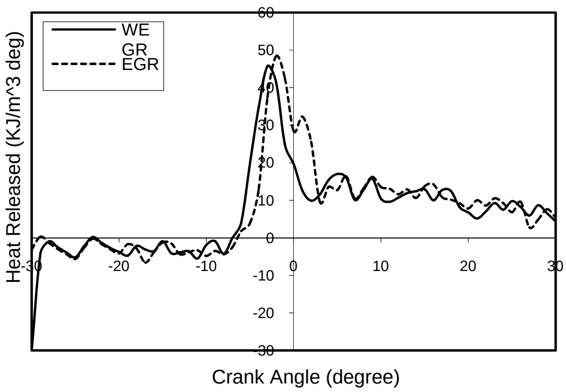


Fig. 5 Variation of rate of heat release at 0% load

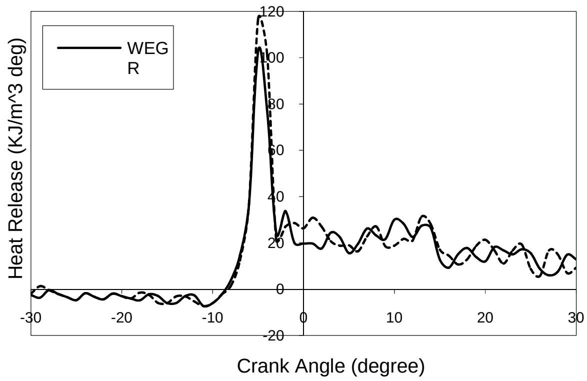


Fig. 6 Variation of rate of heat release at 50% load

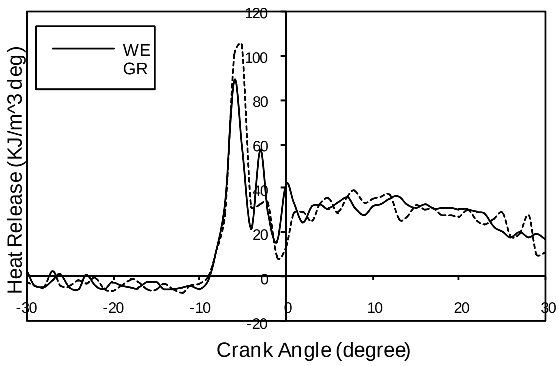


Fig. 7 Variation of rate of heat release at 100% load

Figs. 5, 6 and 7 show the variation of heat release rate at various crank angles for different loads. The introduction of exhaust gases increases the heat released during rapid combustion phase. This is due to the utilization of un-burnt fuel particles which releases heat during combustion process. So, the net heat released with EGR is greater than the heat released without EGR. *The average heat release in the cylinder with EGR is found to be 5.7% greater than that without EGR.*

C. Ignition Delay

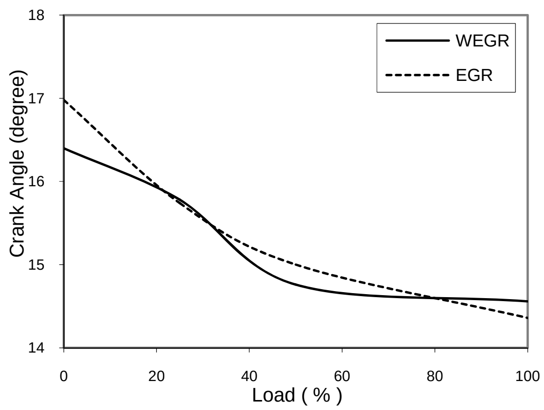


Fig. 8 Variation of ignition delay

Fig. 8 compares the ignition delay of the biodiesel blend with and without EGR. At no load conditions, the ignition delay is more for with EGR. This is due to the more time available during start of injection and start of combustion. As the load increases, the ignition delay increases. In case of without EGR there is a significant decrease in the ignition delay at 50% load. At full load, delay is less when compared to without EGR. *The average ignition delay with EGR is found to be 0.95% longer than that without EGR.*

D. Peak Pressure at Various Loads

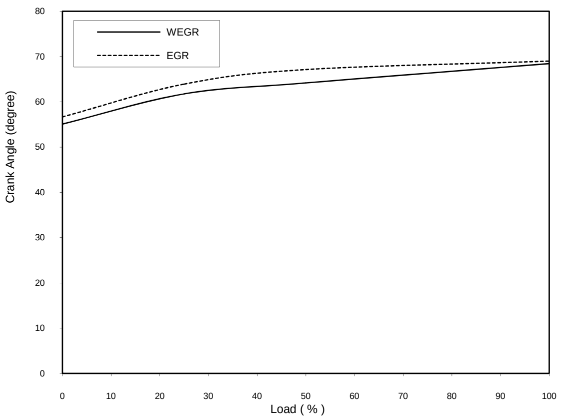


Fig. 9 Variation of peak pressure

Fig. 9 compares the effect of EGR on peak pressure at different loads. Introduction of EGR shows a significant increase in peak pressure for all loads. The increase in ignition delay causes the pressure rise due to the presence of more fuel particles in the cylinder during the delay period. *The average peak pressure in the cylinder is found to be 2.89% more when EGR is used than without EGR.*

IV. CONCLUSION

In this work cooler EGR was introduced into the combustion chamber to investigate the combustion parameters and the following conclusions were drawn.

- The cylinder pressure is increased by 1.54% due to the increase in the ignition delay period.
- The net heat release rate is higher by 5.7% due to the utilization of un-burnt fuel particles which releases heat during combustion process.
- Ignition delay period is longer at no load conditions but gradually decreases at full load conditions. The delay period is 0.95% longer.
- Peak pressure significantly increases at all loads since the burning of the first few droplets is delayed and therefore a greater quantity of fuel accumulates in the chamber. When the actual burning commences it causes a rapid rate of pressure rise. On an average it increases by 2.89%.

ABBREVIATIONS USED

EGR – Exhaust Gas Recirculation
WEGR – Without Exhaust Gas Recirculation
CI – Compression Ignition
CO – Carbon Monoxide
CO_2 – Carbon dioxide
HC – Hydrocarbons
NO_x – Oxides of Nitrogen

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