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Experimental Investigation of CRDI Engine fuelled with Jatropha curcas biodiesel for various EGR rates

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Abstract

Present experimental work investigated the influence of EGR, biodiesel blends for variable speed CRDI diesel engine for performance, emissions and combustion characteristics. Biodiesel blends of B10, B20 and B30 with EGR rates of 10%, 20% and 30% at constant load were tested. Performance parameters such as brake thermal efficiency (BTE) and emission characteristics like smoke opacity, oxides of nitrogen (NOx), Hydrocarbon (HC) and carbon mono-oxide (CO) were measured and analyzed. The results revealed about the improvement in performance with minimal effect emissions among the different fuels operation. The reduction of smoke, HC, CO with slight increase of NOx emissions was observed with usage of biodiesel blends. In summary, it is optimized that engine running on biodiesel blend of B20 with 20% EGR rate culminates into NOx reductions without affecting engine efficiency and other emissions like smoke opacity, hydrocarbon and carbon mono-oxide.

Keywords: CRDI Engine; Biodiesel; EGR; In-cylinder pressure; Emissions.

1. INTRODUCTION

Diesel engines are extensively used in public transportation and power generating sectors compared to gasoline engines. It is popular due to higher thermal efficiency, durability, and low specific fuel consumption. It is well known fact that diesel engines churn out harmful and hazardous emissions like particulate matter (PM) and nitrogen oxides (NOx) [1]. The increased vehicles fleet due to rapid population growth in developed country coupled with high rate of urbanization and industrialization has caused serious air pollution and global warming problems. Winkelmann et al. [2] in his recent article stated that rise of global temperature will meltdown Antarctic ice sheet mainly due to generation of pollution from the combustion of available fossil fuels. Loss of Antarctic ice sheet may result in increase of ocean levels globally that may perhaps sink the whole seaside inhabitants. Great efforts have been oriented towards solving dual problems of shortage of crude oil sources and environmental pollution by reformulating of conventional diesel fuel which can be done by adding bio-origin renewable fuels produced from locally available resources such as vegetable oil, biodiesel or alcohols. Production of biodiesel from edible oil is not an affordable solution for country like India because of large population, edible oil may require for human consumption. Therefore, instead, non-edible oil like Jatropha curcas oil methyl ester can be considered as good choice as it is one of the best options in non-edible category [3].

The main advantages of biodiesel include (i) Renewable, sustainable and are environmental friendly (ii) The fuel-bound oxygen helps proper combustion and affects combustion temperature and emission formation [4-6]. (iii) Higher cetane number, lower sulfur content, and lower aromatic content (iv) Increased lubricity decreases wear of fuel injection system [7]. The use of biofuels will also balance the climatic changes due to reduced greenhouse gas emissions [8]

1.1 Low Temperature Combustion

Presumably futuristic emission norms would be more stricter hence diesel vehicle manufacturers has to switch more innovative methods which radically reduce the particulate matter (PM) and NOx emissions. Among newer technologies in-cylinder strategies are emerging to be top contender even though there is enormous scope for after-treatment devices. The modern research on in-cylinder strategies for total emissions controlling and improving efficiency has mainly attentive on tactics to reduce in cylinder combustion temperatures, such a combustion concept is known as low-temperature combustion (LTC). In LTC approaches, the combustion temperatures are reduced by dilution effect of the in-cylinder combustible charges, by creating fuel-lean mixtures using excess charge or with varying flow rates (low to high levels) of Exhaust Gas Recirculation's (EGR) [9].

External exhaust gas recirculation (EGR) is a most preferred in-cylinder technique in current direct injection (DI) automotive C I engine for controlling NOx emissions. Lower peak combustion flame temperature achieved through this technique is a result of several effects mentioned below when the inlet charge is diluted by exhaust gases.

The dilution or oxygen displacement effect: oxygen mass fraction is reduced because of the replacement of fraction of the oxygen by recirculated exhaust gases during fresh intake air charge using inert gases and causes a spatial broadening of the flame resulting in reduction of local flame temperature.

Thermal effect, specific heats of gases involving in combustion process play pivotal role, charge entering engine cylinder is now a mixture of recirculated gases and fresh air which mainly contains CO_2 and H_2O species which have greater specific heat than that of intake air, hence average specific heat capacity of a charge increases.

The chemical effect: Dissociation of CO_2 and H_2O takes place due to endothermic chemical in combustion zone which will results in decrease of combustion temperature [10].

2. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Analysis of fuel properties

Fuel droplet size, the size distribution, fuel evaporation, spray characteristics, combustion zone and emissions depend on fuel properties. Hence a careful analysis of various fuel properties such as kinematic viscosity, flash and fire point, lower calorific value are determined as per ASTM standards prior to experimentation and listed in Table 1.

The engine experimental test setup shown in Figure 1 consists of two cylinder four stroke CRDI engine connected to eddy current type dynamometer for loading. Combustion pressure and crank-angle measurements were done with standard instruments provided, which are interfaced to computer through engine indicator for pressure vs crank angle diagrams. The setup has panel box consisting of air box, manometer, fuel tank, fuel measuring unit, transmitters for air, fuel flow measurements and for process, load and engine indicator. Rotameters are provided for measuring water flow rate which is supplied for cooling of engine, dynamometer and calorimeter. This experimental test rig facility allows online data recording using Labview based software package “Enginesoft”. Engine details are shows as in Table 2.
The emissions namely carbon monoxide (CO), nitric oxide (NO_x) and unburnt Hydrocarbons (UBHC) were measured using an AVL DI Gas 444 five gas analyser. CO is determined as percentage volumes and NOx, HC were in ppm. Smoke opacity was measured using the AVL 415SE smoke meter which measures soot concentration. The engine performance and emissions characteristics were recorded at different speeds ranging from 2000 to 3500 rpm in step of 500 rpm at a constant load of 5 bar BMEP. Blending of Jatropha curcas biodiesel has been done by volume basis in which 10% referred as B10, similarly B20 and B30. Along with blends, 10% 20% and 30% exhaust gas recirculation ratio are applied. Averages of three set of reading were taken for performance as well as for emission characteristics after achieving steady state condition.

Table 1. Various properties for different fuel blends of biodiesel

Diesel and Fuel Blends	**Calorific Value**	**Flash Point**	**Fire Point**	**Kinematic Viscosity**	**Density**
	(MJ/kg)	(^{0}C)	(^{0}C)	cSt	(kg/m^3)
Diesel	42.000	74	81	3.45	830
Jatropha curcas biodiesel	39.800	201	215	4.21	875
B10	40.650	80	86	3.70	841
B20	40.300	84	89	3.85	847
B30	40.030	89	96	4.05	852

Table 2. Engine Details

Parameter	**Details**
Engine make and Model	Mahindra, Maxximo
Type	Twin Cylinder, four stroke
Stroke x Bore	83 x 84 mm
Power Rating	18.4KW at 3600 rpm
Compression ratio	18.5
Injection Type	CRDI with ECU
Speed	3600 rpm max, variable
Aspiration	Natural aspiration
Cooling system	Water cooled
Dynamometer	Eddy current with loading unit

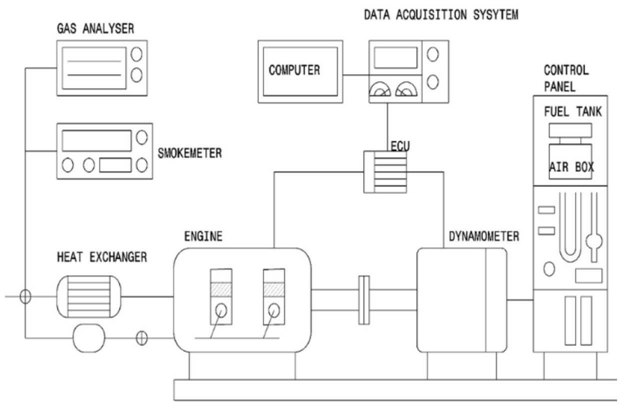

Figure 1. Schematic layout of an experimental setup

3. RESULTS AND DISCUSSION

The first set of experiments are carried out with diesel as a reference fuel and then second set of experiments are continued for B10, B20 and B30 biodiesel blends with application of 10%,20% and 30% EGR rate. Speed varied from 2000 rpm to 3500 rpm at constant load of 5 bar BMEP for both sets. First and second set of experimental outcome are compared against each other to obtain results in the form of change in percentage for performance, emission characteristics and presented here.

3.1 Brake Thermal Efficiency (BTE)

Brake thermal efficiency results against
various speeds is as shown in figure 2, An improvement in the performance is observed with usage of biodiesel B10 and B20 blend ratios. The improvement in BTE for lower blend concentration may be due to the presence of oxygen molecules in the biodiesel which helps in improving the combustion.

Further increasing in biodiesel concentration to 30% in diesel, the reduction in thermal efficiency is observed. The decrement at B30 blend may be due to lower heating and higher density, viscosity values of the blend as listed in Table 1.

With the application of different EGR rate along with the blends, improvement in performance is observed compared to neat diesel fuel operation for 10% and 20% EGR rates, this is mainly due to re-burning of unburnt hydrocarbons during combustion which are entered into combustion chamber by mixing with fresh air. At 30% EGR rate, the reduction in efficiency is noticed and this reduction is due to the fact that the exhaust gases may contain higher amounts of CO_2, which limits the peak combustion temperature in the combustion chamber along with the oxygen availability. Hence the remarkable re-burning of HC is not achieved.

A maximum positive change in performance is observed to be at 2500 rpm by 8.5% for B20 blend with 20% EGR rate. Also maximum decrement is found by 9.6% for 3500 rpm with 30% EGR rate and B30 blend.

3.2 Nitrogen Oxides (NO_x) Emissions

Higher nitrogen oxides in engine exhausts are due to higher oxygen molecule level in the biodiesel and elevated combustion temperatures. Nitrogen Oxides (NOx) emission is directly proportional to the biodiesel blend ratio. However, NOx formation decreases moderately with the application of EGR rate. This is owing to the fact that EGR dilutes oxygen concentration inside the cylinder, thereby limiting the flame temperature which reduces the NOx evolution as shown in figure 3. An oxides of nitrogen compared with normal diesel is increased by 32% at 2500 RPM for B30 blend. With the application of EGR rate, NOx level decreased and the reduction rate is proportional to EGR rate. For same speed it is decreased by 38% for 30% EGR for B10 Blend ratio.

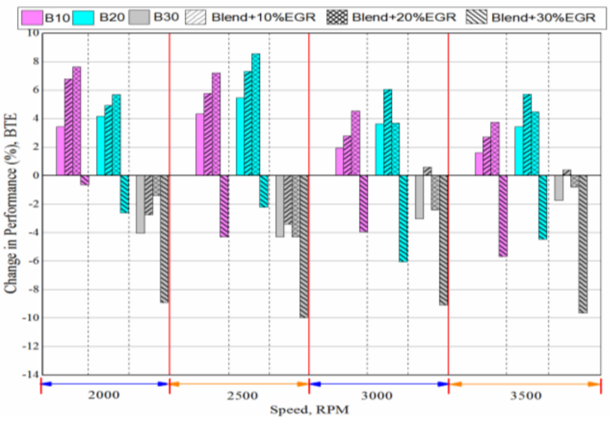

Figure 2. Variation of BTE for Different speeds

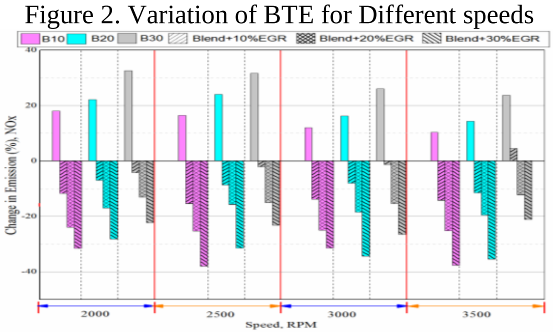

Figure 3. Variation of NO_x for Different speeds

3.3 Smoke Opacity

From the experimental study it is observed that with the usage of biodiesel blend in diesel engine, the smoke opacity emission trend is lower than that of diesel. It is decreased by around 36% for B30 biodiesel blend ratio at 2500 rpm condition without EGR application. This is due to more oxygen concentration with lower carbon to hydrogen ratio in biodiesel and also an absence of aromatics in biofuel is added advantage for lower smoke.

With the application of EGR rates 10%, 20% and 30%, smoke opacity in the exhaust is slightly increased compared with the biodiesel blend ratios but it is still lower than the diesel operating condition for 10%, 20% EGR rates. But at 30% EGR, the opacity value is observed to be higher than diesel by 25% on an average. This is due to the fact that exhaust gas recirculated reduces the oxygen required for proper combustion of fuel inside the combustion chamber leading higher origination of smoke as shown in figure 4.

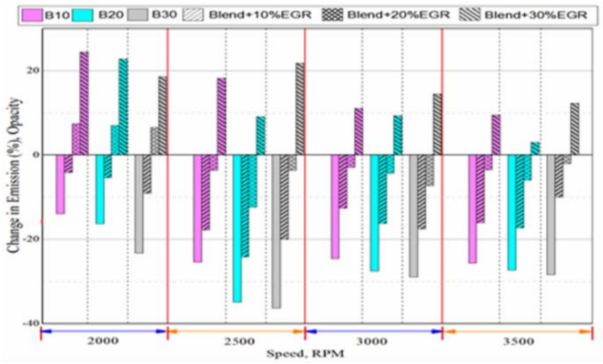

Figure 4. Variation of smoke opacity for Different speeds

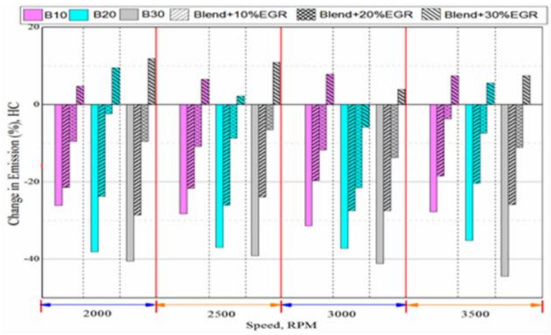

Figure 5. Variation of HC for Different speeds

3.4 Hydrocarbon (HC) and Carbon monoxide (CO)

Blending diesel with biodiesel decreases the HC and CO emissions, the decrease level vary with volume of blends. Higher the blend ratio, lower the emission compared to baseline diesel value. Hydrocarbon and carbon monoxide emissions level is reduced due to addition of blended fuel and this is the implication of adding oxygenate fuels which can decrease HC from the locally over rich mixture. Moreover oxygen enrichment is also favorable to the oxidation process of HC and CO during expansion and exhaust processes. HC and CO emissions are shown in Figure 5 & 6. Hydrocarbon and carbon monoxide emission is reduced by around 40% and 44% respectively for all speeds for B30 blend.

With the application of EGR rate, HC and CO emissions increase, however at 10%, 20% EGR rate HC and CO emissions are still lower than the neat diesel operation and this increasing trend is noticed to be higher by 10% and 8% respectively at 30% EGR rate. The increase at 30% EGR rate may due to lower excess oxygen presence during combustion and rich air-fuel mixture at different locations inside the combustion chamber is the consequence of this lower excess oxygen concentration. Hence, this non-homogeneous mixture does not combust accordingly and develops more HC and CO emissions.

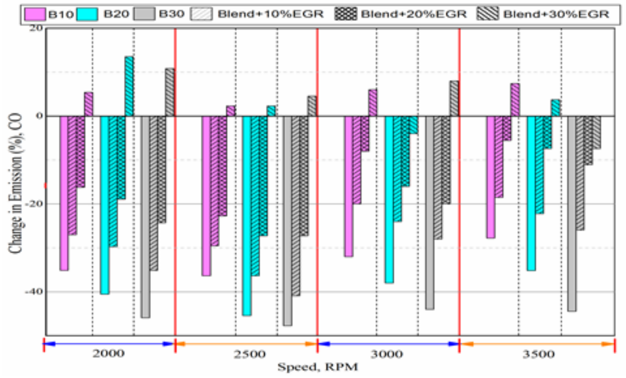

Figure 6. Variation of CO for Different speeds

4. CONCLUSION

Jatropha curcas biodiesel blends with various EGR rates tested in CRDI engine for performance, emission and combustion parameters in comparisons with fossil diesel fuel and following conclusions are obtained for this experimental study.

1) Jatropha curcas biodiesel and blends can be used as an alternative fuel for diesel engine without any major modifications.
2) Improvement in brake thermal efficiency for B20 blend is noticed compared to neat diesel operation.
3) CO, HC and opacity emissions decrease with the use of biodiesel blends but NOx emissions increase.
4) With the application of EGR, BTE improves upto 20% EGR rate and starts declining with the application of 30% EGR rate.
5) At EGR rate 20% there is substantial increase in HC, CO and opacity but still lesser than the diesel operation.
6) It is optimized that 20% EGR rate and B20 biodiesel blend gives better performance and lower emissions for CRDI diesel engine.

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