

EFFECT OF EXHAUST GAS RECIRCULATION ON EMISSION CHARACTERISTICS OF COMPRESSION IGNITION ENGINE WITH COTTONSEED BIODIESEL

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ABSTRACT

The present investigation was to study the compression ignition (CI) engines with cottonseed biodiesel along with different percentage of exhaust gas recirculation (EGR) for analyzing the emission characteristics. In this experiment, the EGR percentage was varied from 0% to 30% in a four-stroke, air-cooled, single cylinder, diesel engine capable of developing 4.4 kW-rated power to study its emission characteristics, which were clearly compared with diesel fuel. From the experiment, it is observed that the increase in EGR percentage in fresh mixture which intern resulted in reduction in oxides of nitrogen emissions. The maximum percentage reduction in oxides of nitrogen, when compared to neat diesel operation, is 65.86%. Even though there is an increase in carbon monoxide and hydrocarbon emission for various EGR rate.

Keywords: Emission characteristics, Alternate fuels, Cottonseed oil, NO_x emission.

INTRODUCTION

Compression ignition (CI) engines are most widely used in heavy-duty vehicles. Commonly used fuel for CI engine is diesel. Diesel has increasing demand among developing countries like India due to increasing in a number of automobiles. Important considerations to look up with performance and emission characteristics of diesel engines are emissions of carbon monoxide (CO), hydrocarbon (HC), CO₂, NO_x, and smoke opacity. Since diesel engines reported for high emission rates and environmental impacts, alternative fuels have been suggested to blend with diesel. A lot of researches have been conducted in CI engines, and various engine parameters are analyzed by employing with biodiesel. Diesel engine will release more amount of oxides of nitrogen and smoke emissions. In recent, researchers are focusing on reducing the emissions of oxides of nitrogen and smoke. This research work particularly focuses exhaust gas recirculation (EGR) technique to reduce the emission of oxides of nitrogen in diesel engine.

A recent study carried out by researchers revealed that 25% of cars and trucks are causing about 90% of air pollution throughout the world. One of the major contributors is passenger vehicles which account for greater amounts of nitrogen oxides, CO, and other pollution. In 2015, about half of the nitrogen oxides and CO and one-fourth of the hydrocarbons emitted by automobiles into the air. Burning fuel in an engine gives the power to move a car. Pollution produced from the cars comes from by-products of this combustion process (exhaust) and also from evaporation of the fuel itself.

Nature has made two things available, one is carbon, and another one is hydrogen. Both petrol and diesel fuels contain hydrogen and carbon atoms. In an ideal engine, oxygen present in the air would convert all the carbon present in the fuel to carbon dioxide and all the hydrogen present in the fuel to water. However, nitrogen present in the air would remain unchanged. The combustion process cannot be ideal in practical and tends to emit various types of pollutants. The most common types of exhaust pollutants are nitrogen oxide, hydrocarbons, CO, and carbon dioxide.

Emissions due to combustion have been minimized by changing the quality of fuels. Biodiesel is the better alternative to both gasoline and diesel fuels. Biodiesel can be employed in engine either directly

or can be blended with diesel fuel. Biodiesel results in greater amount of reduction in emissions of CO, nitrogen oxides, particulate matters, and sulfates compared to gasoline and diesel fuels. Biodiesel when blended with diesel fuel, reductions in emissions are directly proportional to the amount of biodiesel present in the blend. Biodiesel is usually preferred as it is safer to handle than diesel fuel due to its low volatility.

In general, biodiesel feedstock extracted from several types of agricultural crops. This contributes greater significant benefits to farmers and farming communities. Cottonseed oil is one of the important vegetable oils which have a greater possibility of using as biodiesel because of its good lubricating properties.

A lot of researches done on implementing cottonseed oil as a biodiesel and one of which concluded that the possibility of CO emission happens due to the presence of vegetable oil content in the fuel [1]. Furthermore, CO and HC emissions are more for cottonseed oil blended with methanol than hippie oil blended with methanol [2]. It was reported that smoke opacity rate reduces sufficiently and NO_x emission rates increase marginally in preheated cottonseed oil and diesel mixture compared to the neat mixture of cottonseed oil [3]. This study showed that CO and HC emissions are lower in all the biodiesel blends compared to mineral diesel [4]. In this study, biodiesel blends show higher NO_x rates than diesel as it is mainly due to high O₂ content and high temperature in cylinders [5]. This study showed that autoignition is retarded due to increase in EGR ratio and results in combustion for longer period and also results in decrease in absolute heat release rate [6]. In this study, it was shown that cooled EGR tends to increase in emission levels of CO and HC, and at the same time, there is a significant reduction in NO_x emission rates.[7] This study reveals the investigation of pilot injection strategy effects on combustion and emission characteristics of diesel engine with medium EGR rate and showed that increase in the level of CO and HC emission levels [8]. It was concluded that spark timing could be advanced by 8 crank angle degrees with addition of 12% EGR and also it reduces fuel consumption up to 4.1% at 7.0 bar IMEP [9]. This study showed that change in EGR has significant effects on indicated thermal efficiency and also emission levels of CO, NO_x, and HC. EGR change also causes variation in fuel properties and oxygenated structures [10]. It was reported that change in EGR reduces mean charge temperature and NO_x emissions reduce at higher percentage of EGR and at the same time increase HC and CO emission levels [11]. In this study, it was

stated that 20% increase in EGR reduces NO_x emission rates up to more than 65% with increase in HC and CO emission levels [12]. This study revealed the increasing trend in NO_x emissions with increasing biodiesel ratio in the fuel blend [13]. This study showed that the use of biofuel blends is certainly beneficial as it experiences NO_x emission increased with increase in the percentage of biodiesel in the blend, while PM, CO, and HC decreased with increase in the percentage of biodiesel in the blend [14]. In this study, it was reported that CO and CO₂ emission rates were considerably reduced with the increase in load for biodiesels compared to petro diesel [8]. This study showed that there was a sufficient reduction in CO and CO₂ emission characteristics for all the biodiesels than ordinary diesel [15]. This study highlights the decreasing trend in CO and HC emissions with increasing load for all biofuel blends compared to diesel fuel, and average NO_x emissions are higher for the former [16]. In this study, for all compression ratios (CR), CO and HC emission rates with biodiesels are lower than that of diesel fuel [17]. This study suggested that biodiesel made with a fish oil as a good option as it has good emission characteristics such as low CO emission, low PM and smoke opacity, and high NO_x rates [18]. In this study, 20% of polanga blends shows the highest brake thermal efficiency (BTE) for all the injection timings [19]. This study showed that NO_x increased marginally with the increase in the percentage of mahua (biodiesel) in the blends and could be safely blended with 20% of diesel used as a suitable alternative fuel for diesel [20]. In this study, except NO_x, the other emission characteristics such as HC, CO, and CO₂ are sufficiently decreased due to preheating of the fuel [21]. This study showed that significant reduction in NO_x and smoke emissions achieved with fuel consumption about 12% higher when compared to ordinary diesel using EGR technique [22]. In this study, there occurs a reduction in smoke levels and NO_x emissions in premixed gasohol and ethanol-fueled diesel when compared to direct injected diesel fuel [23]. This study concluded that smoke levels are reduced in cottonseed oil and neem oil blends when compared to conventional diesel [24]. In this study, it was stated that CO and hydrocarbons emission rates reduced in greater amounts in cottonseed oil blends with orange peel when compared with conventional gasoline [25]. This study showed that all the emission levels on the biodiesel are comparatively less when compared to conventional diesel fuel and concluded that orange peel and cottonseed oil are more optimum compared to diesel [26].

Table 1: Test engine specifications

Engine specifications	
Engine make and model	Kirloskar and TAF-I
Type of chamber	Hemispherical open combustion chamber
Number of cylinders	1
Type of cooling	Air cooled
Bore	87.5 mm
Stroke	110 mm
CR	17.5
Engine capacity	660 cc
Nozzle opening pressure	200 bar
Injection timing	23° bTDC
Rated power	4.4 kW at 1500 rpm
Rated speed	1500 rpm
Lubricating oil	SAE 40
CR: Compression ratios	

Table 2 Properties of diesel and cottonseed oil

Property	Diesel	Cottonseed oil
Calorific value (kJ/kg)	43000	39648
Flashpoint (°C)	44	200
Fire point (°C)	49	230
Viscosity (poise)	0.278	2.52
Density (kg/m ³)	835	850
Cetane number	49	52

EXPERIMENTAL SETUP

A direct injection, single cylinder, and four-stroke cycle diesel engine of 662 cm³ of displacement is used as the test engine. Kistler pressure transducer was used to measure the cylinder pressure.

The sensing element consists of a metal diaphragm, which deflects under pressure. This deflection is a converted voltage signal, which is proportional to the cylinder pressure. The charge amplifier further amplifies the voltage signal from the pressure transducer. The crank position is determined using crank angle encoder. The encoder pulse and cylinder pressure signal are fed into the data acquisition system. The port fuel injector is mounted on the intake port for achieving homogeneous charge.

EXPERIMENTAL PROCEDURE

The total fuel consumption for diesel and biodiesel for various EGR rate. CO_x, UHC, and CO emissions will be measured using an exhaust gas analyzer. The smoke intensity will be measured using Bosch smoke meter. The test engine will be maintained at a speed of 1500 rpm throughout the experiments. Finally, the biodiesel results were compared with neat diesel for validation.

Uncertainty analysis

All physical quantity measurements are usually tended to produce uncertainties. Uncertainty analysis or error analysis is usually carried out to check accuracy in experiments. Root mean square method was used to get the magnitude of error and realistic error limits for the computed results.

The uncertainty in the computed values such as BTE, brake power, and flow measurements of fuel was estimated. The uncertainties in the measured parameters, voltage (ΔV) and current (ΔI), estimated by the Gaussian method, are ± 3 V and ± 0.14 A, respectively. For fuel time (Δt_r) and fuel volume (Δt), the uncertainties are taken as ± 0.2 s and ± 0.1 cc/s, respectively.

1. Temperature measurement

Uncertainty in temperature is $\pm 1\%$ ($T > 150^\circ\text{C}$), $\pm 2\%$ ($150^\circ\text{C} < T < 250^\circ\text{C}$), and $\pm 3\%$ ($T > 250^\circ\text{C}$).

2. Percentage of uncertainty for the measurement of speed, mass flow rate, NO_x, hydrocarbon, smoke, and pressure are given as follows:

1. Speed: 1.1
2. Mass flow rate of air: 1.3
3. Mass flow rate of diesel: 1.0
4. NO_x: 1.1
5. Hydrocarbon: 0.01
6. CO: 0.8.

RESULTS AND DISCUSSION

CO emission

CO is an in-between product in the combustion of hydrocarbons. It is formed as a result of insufficient combustion, which is attenuated by a lack of oxidants, temperature, and residence time. Some of the carbon in the fuel ends up as CO due to lack of O₂ required for oxidation. Even at sufficient oxygen level, dissociation caused by high peak temperatures.

During the expansion stroke, dissociated CO may freeze. Maximum CO emission usually occurs during engine startup when the engine is in condition to withstand poor fuel evaporation. The percentage of CO of cottonseed oil was lower than diesel fuel at no load conditions. This was because better combustion took place in the engine fueled with cottonseed oil fuel. However, the level of CO emission rate gradually increases for cottonseed oil. At maximum load, cottonseed oil emits 33.3% higher CO rate than diesel fuel.

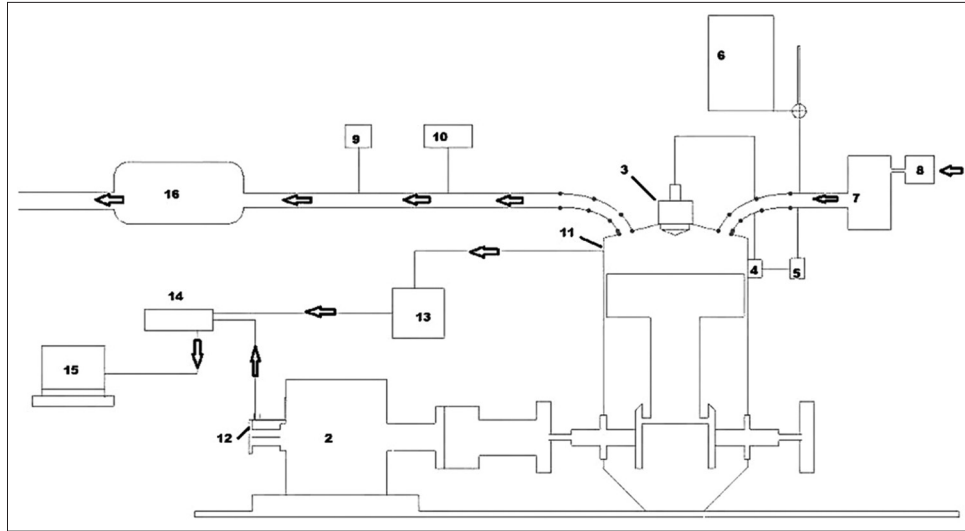


Fig. 1: Experimental setup. 1 - Kirloskar TV1 engine, 2 - Eddy current dynamometer, 3 - Injector, 4 - Fuel pump, 5 - Fuel filter, 6 - Fuel tank, 7 - Air stabilizing tank, 8 - Air filter, 9 - AVL smoke meter, 10 - AVL di-gas analyzer, 11 - Pressure transducer, 12 - TDC encoder, 13 - Charge amplifier, 14 - Indi meter, 15 - Monitor, 16 - Exhaust silencer

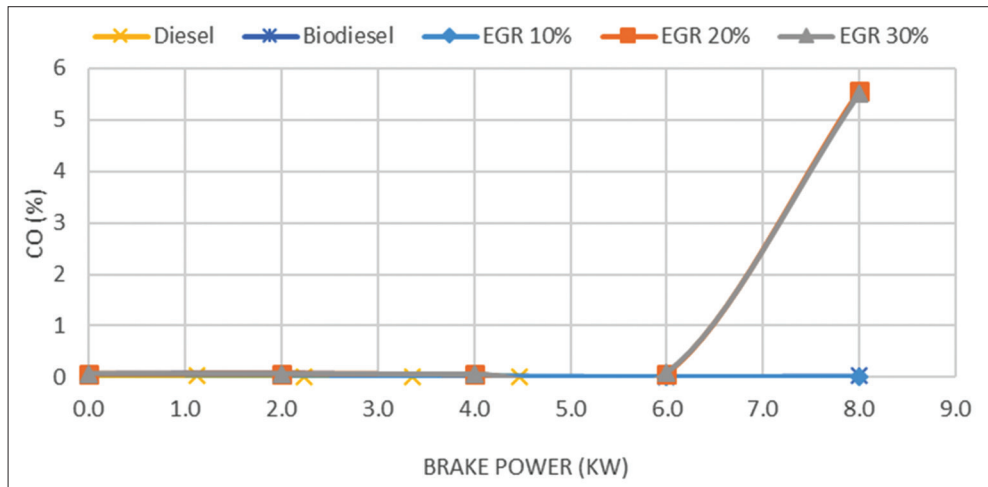


Fig. 2: Carbon monoxide

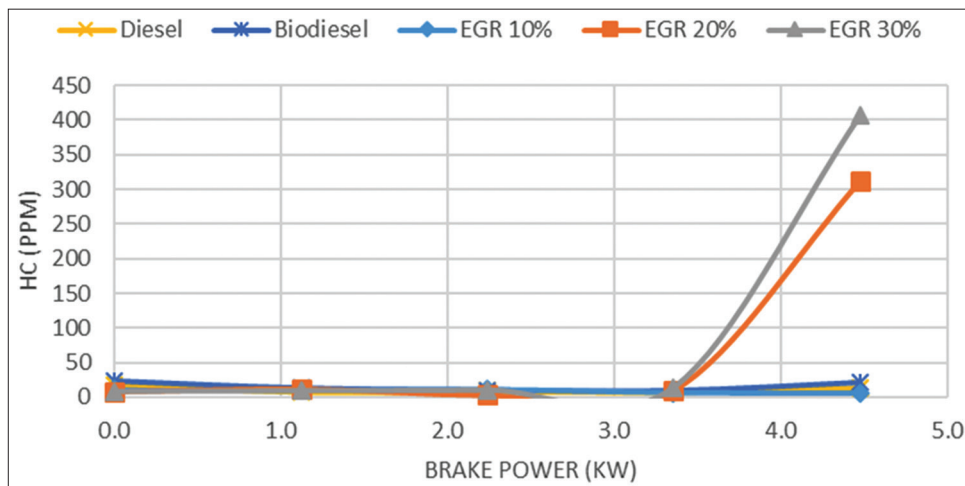


Fig. 3: Hydrocarbon

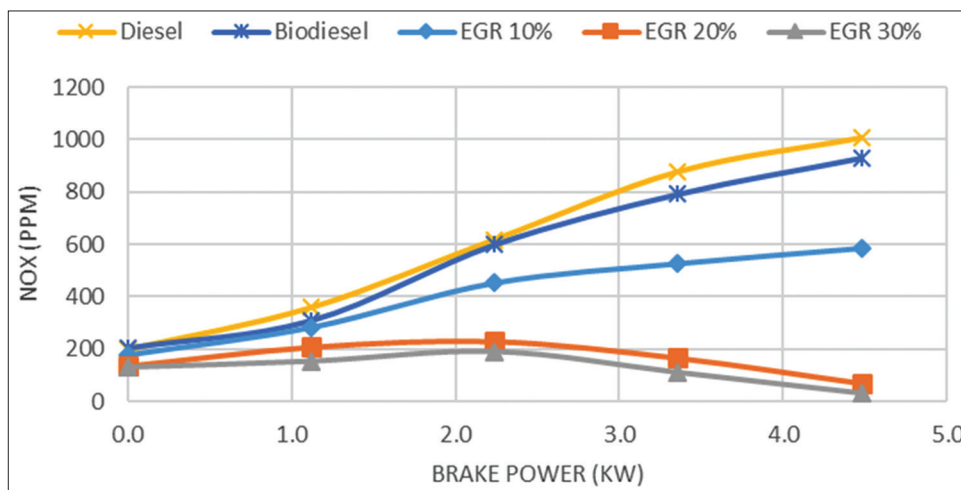


Fig. 4: NOx

HC emissions

High HC emission rate occurs as a result of over mixing of fuel and air beyond lean flammability limits during delay period and also due to undermixing of fuel injected toward the end of injection process, resulting in rich air-fuel ratios for complete combustion.

At maximum load, cottonseed oil emits 23.6% higher CO rate than diesel fuel. This can be mainly due to the higher viscosity of cottonseed oil than diesel fuel. This clearly states that there will be no possibility of uniform distribution with air, resulting in bigger fuel droplets.

Oxides of nitrogen emissions

NO_x is formed as a result of a combination of nitrogen and oxygen from the air under heat and pressure. More heat and pressure give you more NO_x. The main reason for higher NO_x production in diesel combustion is the temperature and duration of the combustion flame due to a burning of mixed fuel and air. Due to increase in applied load on the engine, emission of NO_x rate increases. At maximum load, diesel emits 7.56 % higher NO_x than cottonseed oil. To minimize the NO_x emitting rate further, EGR technique is employed with cottonseed oil as a fuel. EGR is an engine conditioning technique to control NO_x which works by re-circulating a portion of an engine's exhaust gas back to the cylinders of engines. This tends to decrease the amount of excess oxygen during combustion period. This gives better result in a reduction of NO_x rate to a minimal level. EGR 10%, 20%, and 30% emit level of NO_x rate, namely, 41.7 %, 93.2%, and 97% less than of NO_x emitted by diesel.

CONCLUSION

In this experimental analysis, it has confirmed that cottonseed oil with EGR can be used as a better alternative to diesel as it has better emission characteristics. The following conclusions are drawn based on the experimental results.

- NO_x emission for CSO fueled engine is 929 ppm and 1005 ppm for diesel-fueled engine. The increase in NO_x emission rate in diesel than the preheated CSO is mainly due to higher combustion temperature.
- CO and hydrocarbon emissions are higher for CSO-fueled engine than diesel-fueled engine due to insufficient combustion
- To control higher NO_x emission rates in diesel-fueled engine, the engine controlling technique known as EGR technique is employed with CSO.
- EGR gives greater results such as EGR 10%, 20%, and 30% which emit a level of NO_x rate, namely, 41.7%, 93.2%, and 97% less than of NO_x emitted by diesel.

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