stated that 20% increase in EGR reduces NOx emission rates up to more than 65% with increase in HC and CO emission levels [12]. This study revealed the increasing trend in NOx 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 NOx 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 CO_2 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 CO_2 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 NOx 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 NOx 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 NOx 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 NOx, the other emission characteristics such as HC, CO, and CO_2 are sufficiently decreased due to preheating of the fuel [21]. This study showed that significant reduction in NOx 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 NOx 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 cm^3 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. COx, 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 (Δtr) 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 ±1% (T>150° C), ±2% (150°C<T<250°C), and ±3% (T>250°C).

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

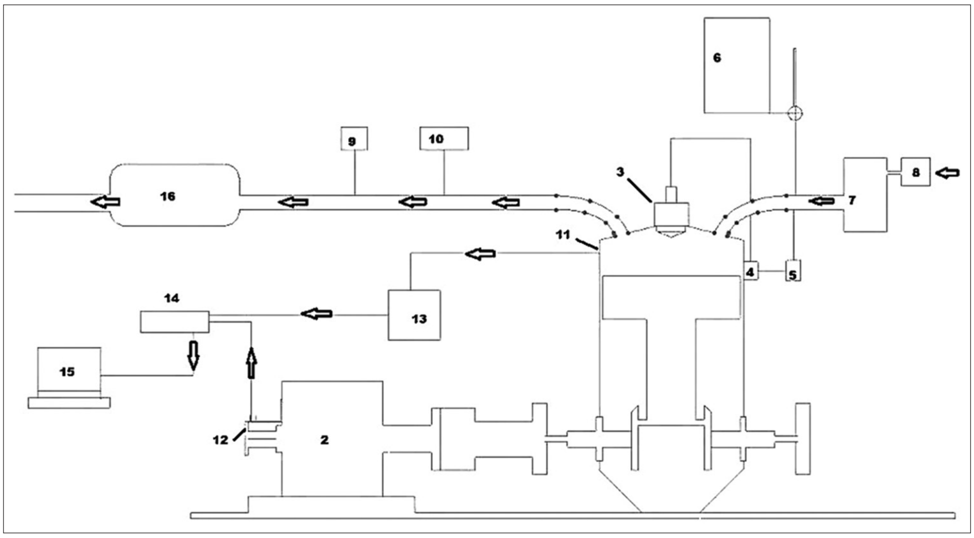
1. Speed: 1.1
2. Mass flow rate of air: 1.3
3. Mass flow rate of diesel: 1.0
4. NOx: 1.1
5. Hydrocarbon: 0.01
6. CO: 0.8.

RESULTS AND DISCUSSION

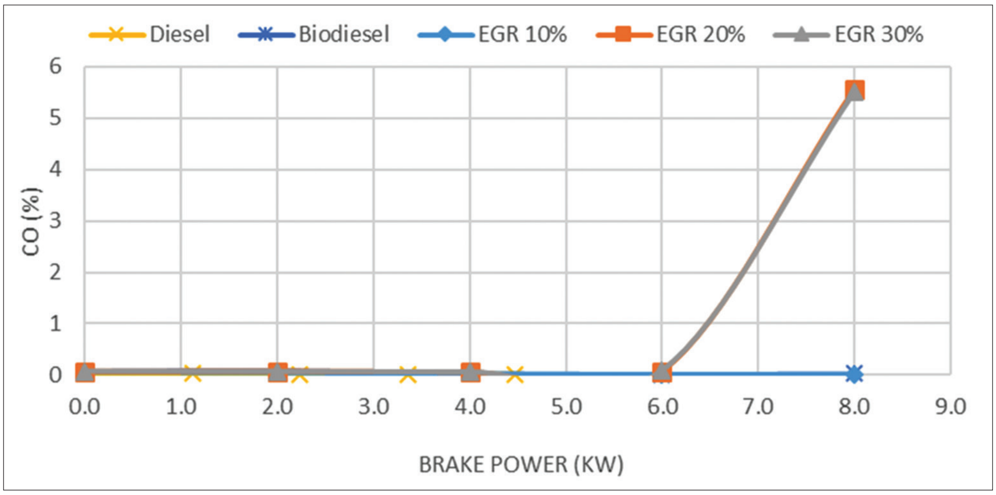
CO emission

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 O_2 required for oxidation. Even at sufficient oxygen level, dissociation caused by high peak temperatures.

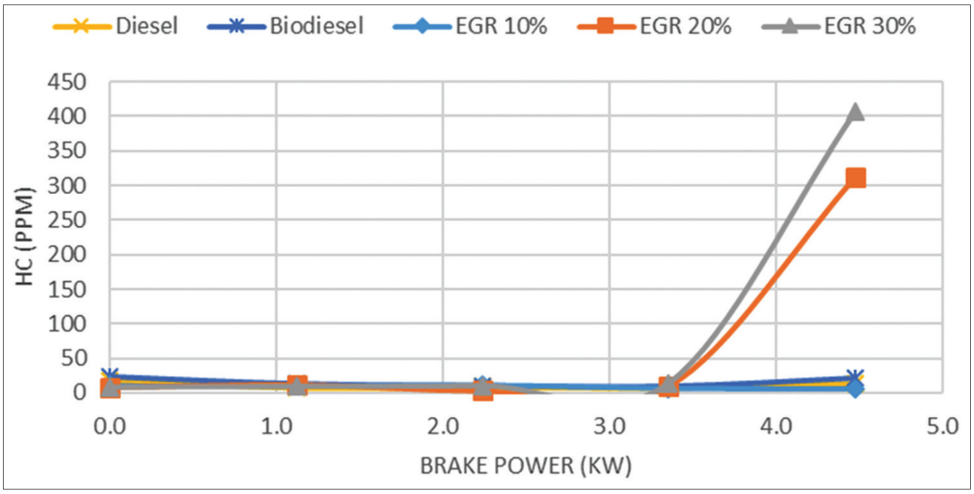
During the expansion stroke, dissociated CO may freeze. Maximum CO emission usually occurs during engine startup when the engine is in condition to withstand poor fuel evaporation. The percentage of CO of cottonseed oil was lower than diesel fuel at no load conditions. This was because better combustion 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.



AQ6 **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**



AQ6 **Fig. 2: Carbon monoxide**



AQ6 **Fig. 3: Hydrocarbon**

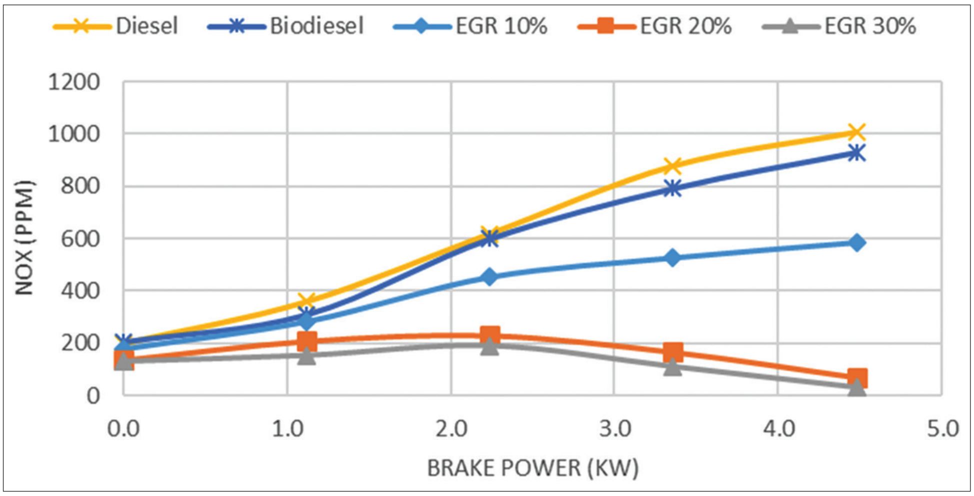


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Fig. 4: NOx

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

NOx 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 NOx. The main reason for higher NOx 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 NOx rate increases. At maximum load, diesel emits 7.56 % higher NOx than cottonseed oil. To minimize the NOx emitting rate further, EGR technique is employed with cottonseed oil as a fuel. EGR is an engine conditioning technique to control NOx 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 NOx rate to a minimal level. EGR 10%, 20%, and 30% emit level of NOx rate, namely, 41.7 %, 93.2%, and 97% less than of NOx 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.

- NOx emission for CSO fueled engine is 929 ppm and 1005 ppm for diesel-fueled engine. The increase in NOx 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 NOx 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 NOx rate, namely, 41.7%, 93.2%, and 97% less than of NOx emitted by diesel.

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