Experimental Determination of Performance Characteristics for Cotton-seed oil Biodiesel with Cerium Oxide Nanoparticles

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Abstract— The current research is focusing on the effect of cotton seed oil biodiesel with cerium oxide nanoparticles used along with diesel in various concentrations of B6 up to B36 and 35ppm of nano-particles in each of them. The experiment was carried out on a single cylinder variable compression ratio diesel engine for compression ratios of 16 and 18 and the results were validated with reference research which were carried before. There is an increase in brake thermal efficiency at peak load with biodiesel, wherein B30 has the maximum value of 28.86%. The maximum exhaust gas temperature was noted for B30 with the value 405^{0}C at CR-16 and 389.05^{0}C at CR-18. Also, the increase in NOx emissions was less as compared to diesel and biodiesel mixture due to the addition of cerium oxide nanoparticles. While considering all characteristics, B30 is found to be the optimum blend among all.

Index Terms- Cottonseed biodiesel, cerium oxide, brake thermal efficiency, emissions.

I. INTRODUCTION

For any country, transportation plays the key role in development of economy. Currently, the issue for worldwide transportation sector is the energy supply, which is mostly fulfilled by fossils fuels majorly. Globally, an average consumption of energy in transport sector is increased by 1.1% per year due to the development in automobile industry. It has been reported that out of the total global liquid fuel consumption from year 2010-2040, only the transportation sector has a share of 63%. In India, transportation consumes close to 70% of total diesel supply, 66% of which is used by passenger and commercial vehicles. India is already the fifth largest greenhouse gas emitter in the world and is estimated to go to the third position in upcoming 2-3 years. Transport sector considerable contribution in greenhouse emission especially in developing and developed countries. The maximum amount of greenhouse gases added to the atmosphere are from electricity and transportation whose contribution is 34% and 27% respectively. Also, the population is increasing day by day and especially in India, the growth rate of automotive sector is one of the largest in the world.

Diesel engines are blessed with high thermal efficiency and hence widely used in automobiles. However, diesel engines are one of the major contributors to the emissions such as hydrocarbons, particulates, nitrogen oxides, and Sulphur oxides. It is very important to mention that, there are about 22% of global GHG (greenhouse gas) emission comes only from the transportation sector. Not only the International Energy Agency (IEA) predicted the emissions of GHG (carbon dioxide) from transport sector will be increased by 92%. [1] These emissions are very harmful to human beings and also responsible for acid rain and photochemical contamination and hence subject to strict environmental legislation. Thus, wide use of diesel engines leads to harmful threat of nitrogen oxide and hydrocarbon emissions. Improvement in the performance of diesel engines is an important challenge to be addressed, in the current era due to the fast depletion of fossil fuel resources as well as due to the harmful hydrocarbon and nitrogen oxide emissions. In this regard, various studies have been done on addition of catalytic particles along with fuel blends in engines so as to reduce such emissions. Commonly used additives are titanium oxide, aluminum oxide, cerium oxide, copper particles etc. These particles, when added in nano-sized phase, improve the performance of fuel blends further, reduce the NOx emissions and soot formation.

As the calorific value of biodiesel is lower than that of diesel, use of biodiesel and blends in engine reduces engine power and increases fuel consumption slightly, but if has positive impact on emissions such as hydrocarbons, carbon monoxide, particulate matter. As the exhaust gas temperature increases by adding biodiesel, NOx emissions are more, however, it can also be further reduced by adding to it certain additives. It was observed that biodiesel combustion leads to an increase in NOx emissions within a range of 16.7 to 38% [3].

Lot of research has been carried out to investigate the effects of biodiesels blended with diesel fuel and the results are enhanced when additives are used along with this. It was found that the bulk modulus of fuels tends to affect the injection timing, which in turn, affects directly the NOx emissions. It is also evident that carbon chain length, degree of unsaturation and oxygen content all together affect the NOx emissions [1]. In some research experiments, it was observed that HC and CO emissions were reduced by increasing load and CR, whereas NOx emissions were observed to be increasing with load and CR [2]. It was also found that biodiesel combustion leads to an increase in NOx emissions within a range of 16.7 to 38%. Biodiesel-NOx penalty is a multi-parametric effect which arises because of changes in fuel properties, engine characteristics and operating conditions. In some research cases, the thermal efficiency with biodiesel was obtained less as compared to that with neat diesel. They linked this reduction with poor spray characteristics, higher viscosity, higher volatility and lower calorific value of biodiesel blends. Also, for biodiesel blends, brake specific fuel consumption was found to be higher than diesel. [6] The addition of nanoparticles has also been proved to be beneficial from performance point of view. Nano particles increase better combustion because of micro explosion phenomenon. It is also concluded that addition of nanoparticles improves the cetane number, however, the viscosity, flash point and density of fuel are increased. With dosing nanoparticles, brake specific fuel consumption is decreased due to catalytic oxidation and complete combustion of fuel. In case of brake thermal efficiency, however, the results obtained are generally positive. [8]

II. EXPERIMENTAL SETUP AND METHODOLOGY

The setup consists of single cylinder, four stroke, Multi-fuel, research engine connected to eddy current type dynamometer for loading. Set up is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. The setup has standalone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and hardware interface.

Fig. 1: Actual engine setup of 4 stroke VCR testing

The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. Labview based Engine Performance Analysis software package "Enginesoft" is provided for on line engine performance evaluation.

Table 1 Engine Specifications

Make	Kirloskar
Type of engine	Single cylinder, 4 stroke Diesel Engine
Stroke	110 mm
Bore	87.5 mm
Capacity	661 cc
Power	3.5 kW at 1500 RPM
Compression ratio range	12:1 to 18:1
Dynamometer	Eddy current type, water cooled with loading unit

The blends used in this experiment are- B6, B12, B18, B24, B30 and B36 with CeO2 quantity of 35 ppm in each case.
Ge properties of cerium oxide nanoparticles are as below:

Table 2 Properties of cerium oxide nanoparticles

Purity	99%
Average particle size	50-200nm
Phase	Cubic

III. RESULTS AND DISCUSSION

The experiments were conducted on the variable compression ignition engine to evaluate the performance and emission characteristics of diesel and different blends of biodiesel with and without the addition of cerium oxide nanoparticles. Following results were obtained-

Performance Parameters

1) *Brake thermal efficiency*

Brake Thermal Efficiency (BTE) is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value. Figure 2 and 3 show the variation of brake thermal efficiency with load for CR 16 and 18.

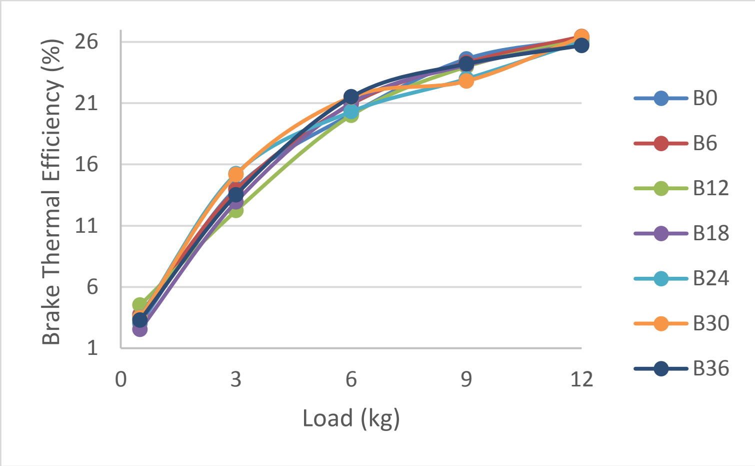

Fig. 2: Brake thermal efficiency Vs. Load at CR-16

The reading of brake thermal efficiencies for all blends for compression ratio 16 and 18 are shown in the graphs above. It is observed that the BTE is increasing with increase in load for all blends, because at high loads, less part of the developed power is vanished. For both compression ratios, diesel shows the maximum efficiency, and among the blends, B30 has maximum brake thermal efficiency.

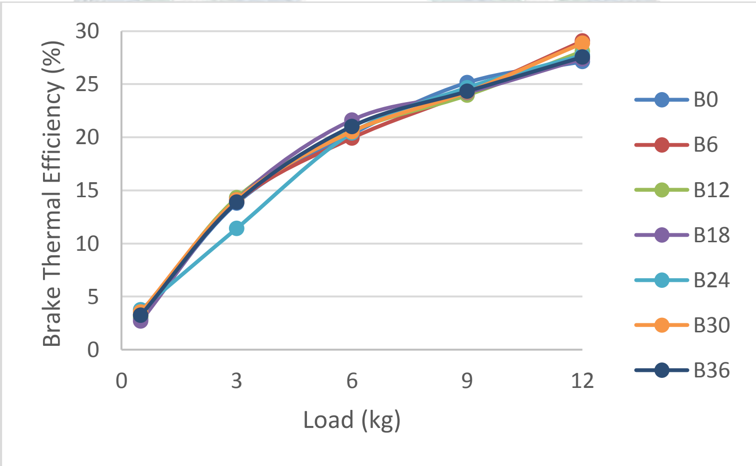

Fig. 3: Brake thermal efficiency Vs. Load at CR-18

Diesel has higher calorific value as compared with biodiesel blends, so it has maximum efficiency, and as concentration of cerium oxide is increased, being an oxygen buffering agent, the efficiency goes on increasing. This may be attributed to the higher efficiency of B30. Though the efficiency of B30 is less than diesel, it is well comparable with it in value as well. Brake thermal efficiency is also found to be increased with load as well as with compression ratio. Higher brake thermal efficiency at higher compression ratio is because of better combustion and intermixing of fuel with air.

2) Brake specific fuel consumption

As brake thermal efficiency and brake specific fuel consumption are like inverse proportion, diesel, being a fuel of higher calorific value than biodiesel blends, requires least amount of fuel. As shown in figure 4 & 5, at both compression ratios, BSFC for blends is quite higher than diesel. The increase in BSFC in blends is not very high because of addition of cerium oxide nanoparticles which provides extra oxygen. The cerium oxide nanoparticles put a stop to the formation of the carbon deposits which leads to decrease the frictional power of the cylinder and results in to reduce the fuel consumption.

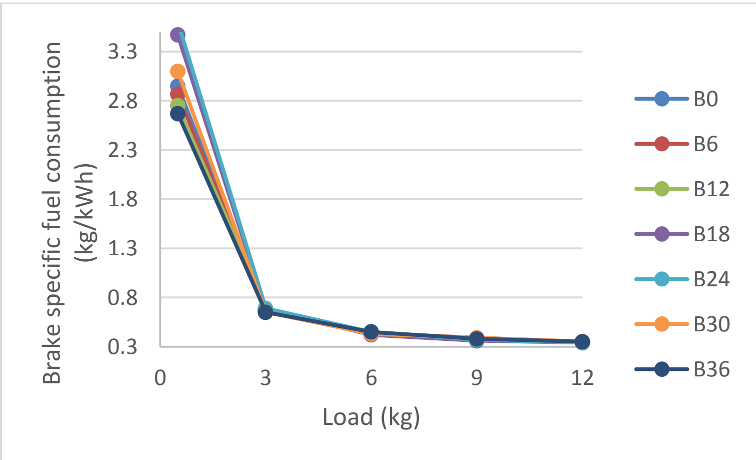

Fig. 4: Brake specific fuel consumption Vs. Load at CR-16

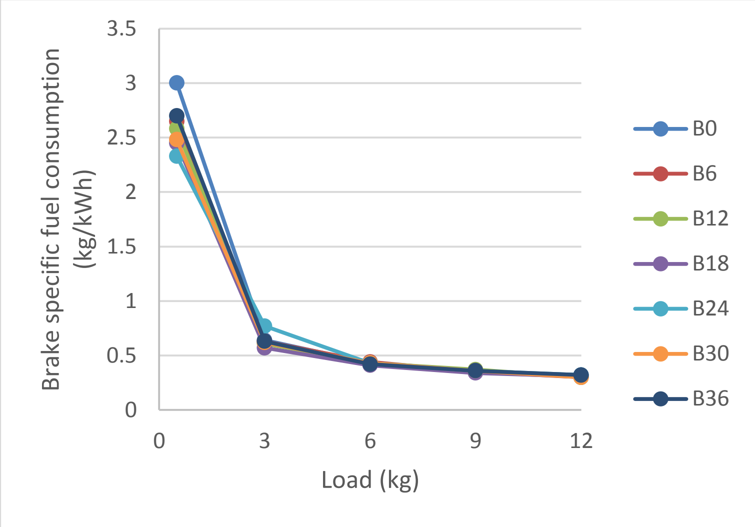

Fig. 5: Brake specific fuel consumption Vs. Load at CR-18

3) Exhaust gas temperature

The exhaust gas temperature graphs are shown above in fig.6 and fig7. It was observed experimentally that exhaust gas temperature of all the biodiesel blends included nanoparticle blends found to be more than pure diesel. Exhaust gas temperature of B30 was seen maximum among the all fuels. This is due to the higher amount of oxygen molecules in the ester form which takes part in the combustion process. It raises the combustion chamber temperature resulting in increased the exhaust gas temperature. The exhaust gas temperature was observed in increasing trend for all the fuel as the load was increased and maximum temperature was attained at full load. This is due to the more fuel burnt to maintain the constant speed. But after the addition of cerium oxide nanoparticles in the biodiesel blends improving trend was observed. The exhaust gas temperature was also observed to be increased with load and compression ratio also.

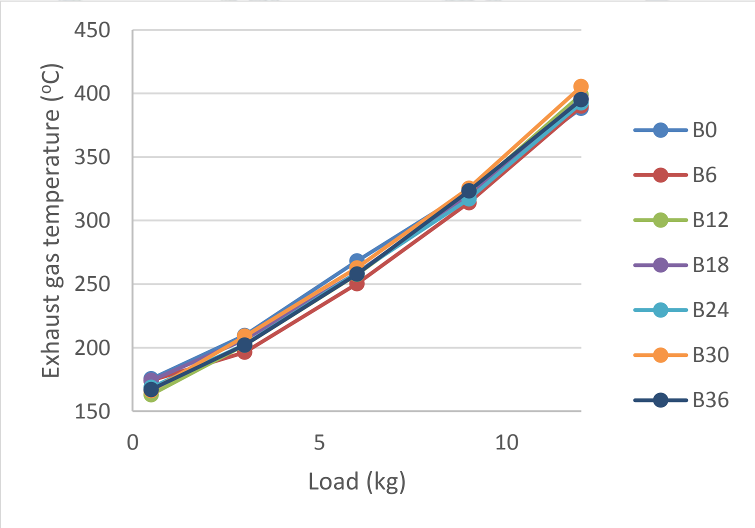

Fig. 6: Exhaust gas temperature Vs. Load at CR-16

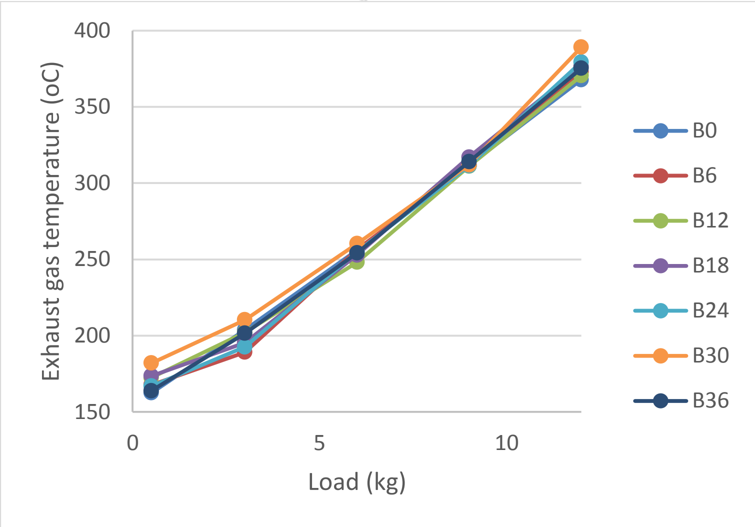

Fig. 7: Exhaust gas temperature Vs. Load at CR-18

Emission Parameters

I. Carbon monoxide

From literature, it can be concluded that CO emissions mostly reduce as we replace more diesel with biodiesel. The outcomes of this research for CO emissions are represented in graphical form in fig no.8 & 9. It is observed that, at both compression ratios, there is decreasing trend in the CO emissions as we go from B00 to B36. Out of all blends, B36 showed maximum reduction of 49% in CO emissions as compared with neat diesel at CR-16, while at CR-18, B36 has 44.7% reduction in CO as compared with B00.

Also, there is a decreasing trend of CO emissions with engine load. This is because the increase in load leads to increase in combustion temperature which may lead to more complete combustion of fuel. [3] As biodiesel concentration increases, there is an increase in oxygen content of fuel. The inherent oxygen content of biodiesel leads to complete combustion, which leads to less CO emissions. Another factor responsible for this is the inclusion of nano-additive i.e. cerium oxide. Cerium oxide, being in nano-form, increases catalytic activity due to its higher surface-volume ratio and improves fuel-air mixing in the combustion chamber. [11]

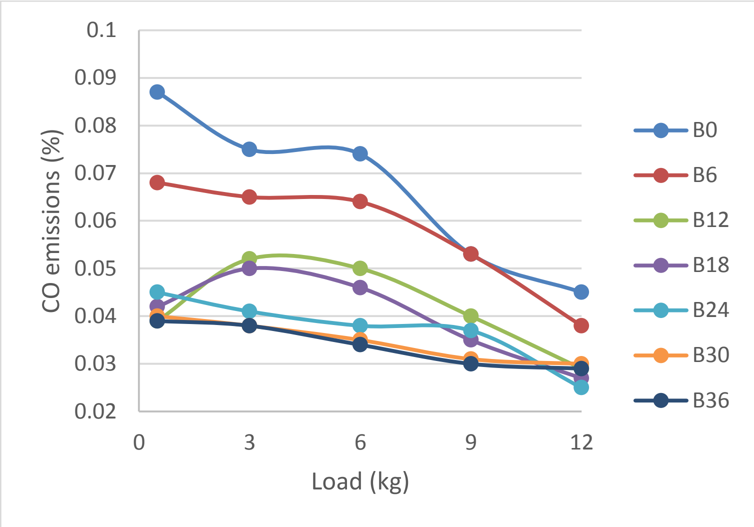

Fig. 8: Carbon monoxide emissions Vs. Load at CR-16

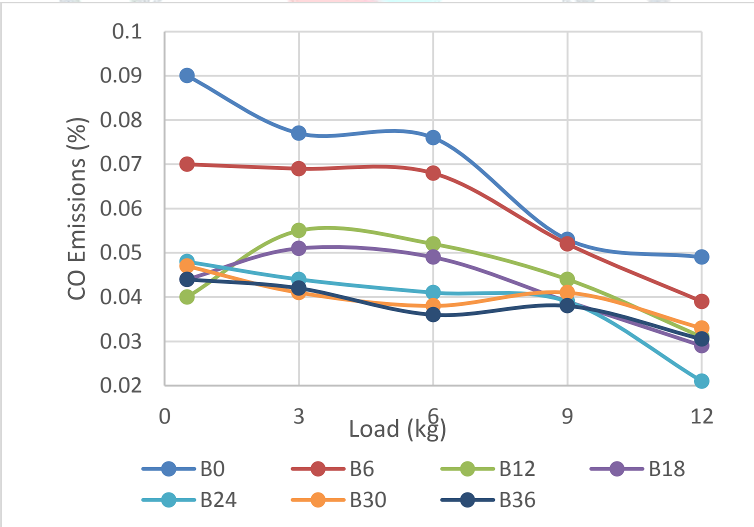

Fig. 9: Carbon monoxide emissions Vs. Load at CR-16

II. Nitrogen oxide

In most of the literature available, it is found that the use of biodiesel causes increase in NOx emissions. The possible causes for these higher NOx emissions than diesel include the effect of bulk modulus differences during injection, the effects of higher viscosity on spray characteristics, presence of fuel-bound oxygen which serves as an additional one for NOx kinetics, influence of cetane number on ignition delay and the absence of soot particles resulting in higher flame temperatures. [3]

In this research, there is an increase in NOx emissions with increase in biodiesel percentage. B36 shows the maximum increase in NOx emissions by 9.7% at CR-16 and 10.6% increase at CR-18. But, because of addition of cerium oxide nanoparticles, this increase is slightly lower as compared with the blends without nanoparticles. [8]. This is maybe because of the transformation of cerium oxide (CeO2) to cerous oxide (Ce2O3) viz a relatively low-energy reaction. Due to its high thermal stability, Ce2O3 remains active after enhancing initial combustion cycles and gets re-oxidized to CeO2 through the reduction of nitrogen oxide [9].

$$Ce_2O_3 + NO \qquad 2\,CeO_2 + \frac{1}{2} N_2 \longrightarrow$$

At peak load, B36 has NOx emissions 24% more than neat diesel at CR-16 as well as at CR-18. The NOx is observed to increase with load because higher creates higher fuel-air ratio, which increases average engine temperature.

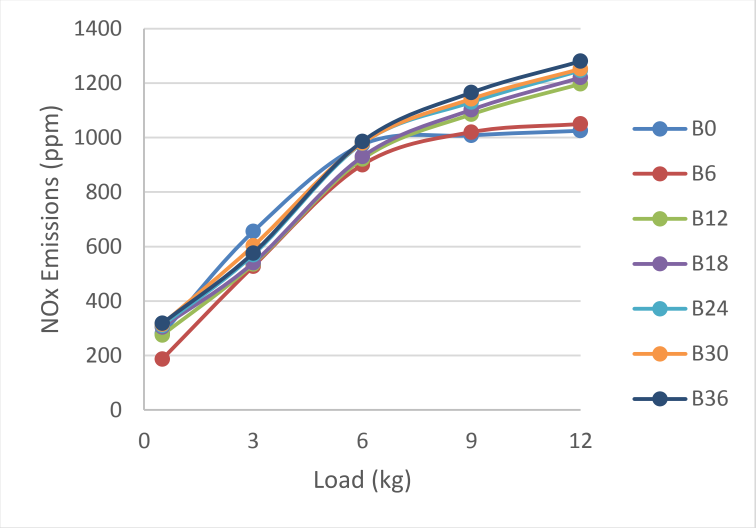

Fig. 10: Nitrogen oxide emissions Vs. Load at CR-16

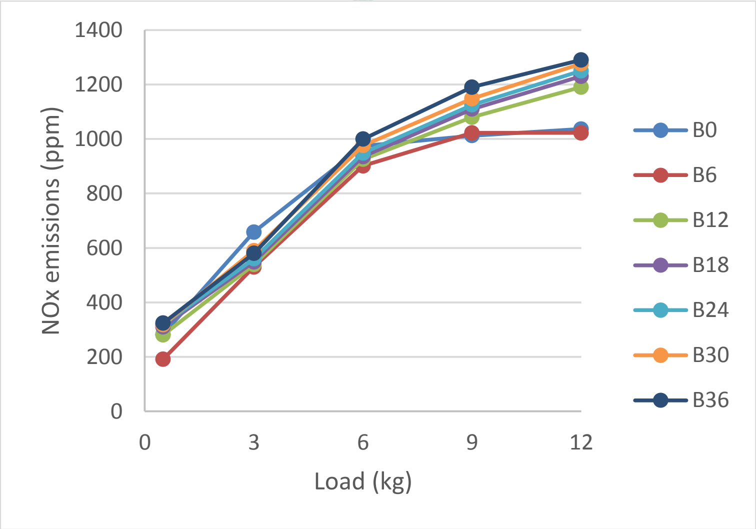

Fig. 11: Nitrogen oxide emissions Vs. Load at CR-18

III. Hydrocarbon emissions:

The fig 12& 13 show the variation of HC emissions with blends and load. HC emissions were reduced with increase in biodiesel content. Maximum average reduction of 40% was obtained by B36 as compared with diesel. The results can be attributed to higher cetane number of biodiesel and its inherent oxygen content. Along with this, the use of cerium oxide also has a key role in reduction of HC emissions. As cerium oxide transforms to cerium oxide, it supplies the oxygen for the reduction of hydrocarbons. [9]

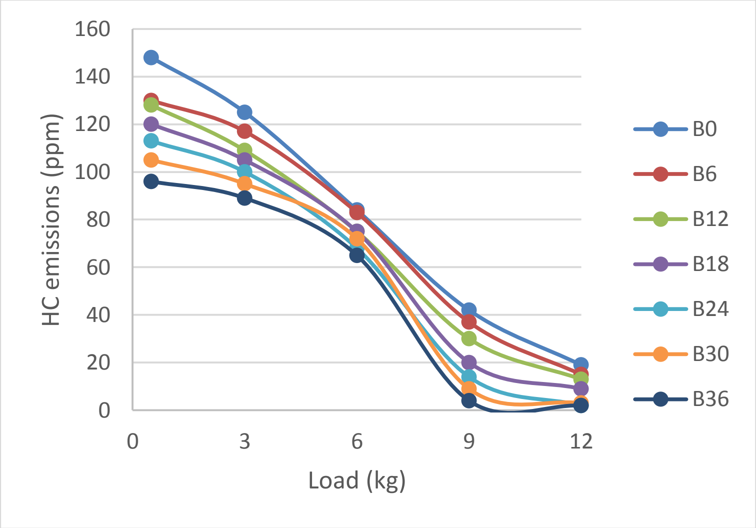

Fig. 12: Hydrocarbon emissions Vs. Load at CR-16

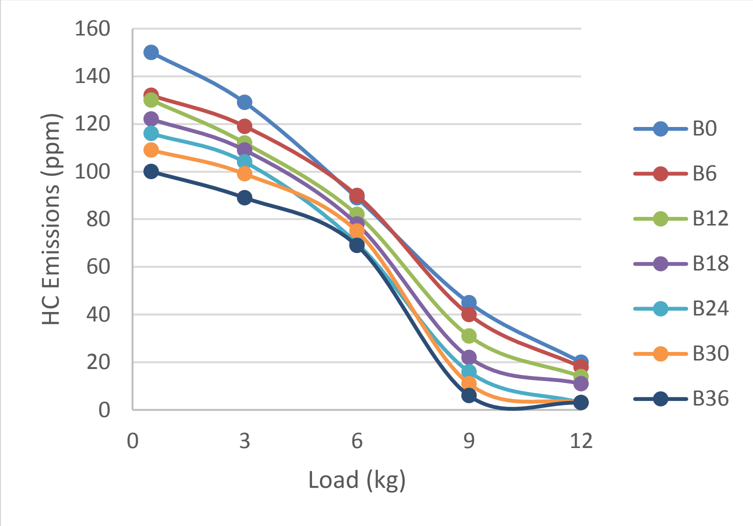

Fig. 13: Hydrocarbon emissions Vs. Load at CR-18

IV RESULT VALIDATION

Brake thermal efficiency

The brake thermal efficiency data of current research is validated with those with another research with blends of cottonseed biodiesel. The nature of both graphs is observed to be similar with load. The difference in the values of brake thermal efficiency is because of use of cerium oxide nanoparticles in the current research.

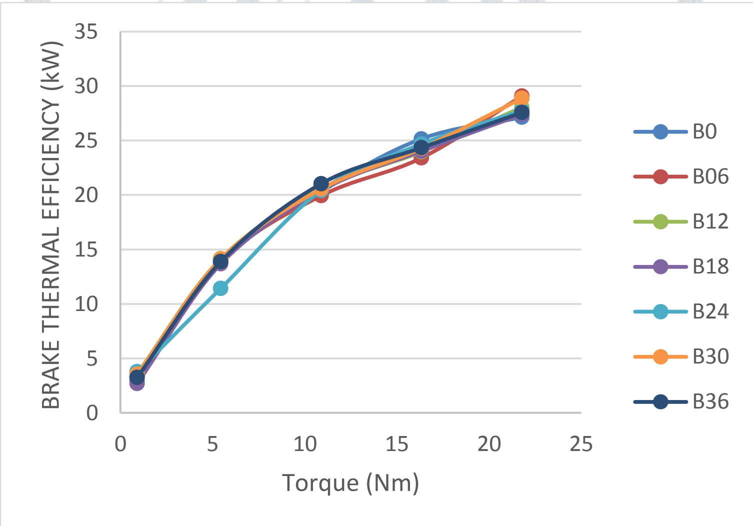

Fig. 14: Results of Brake thermal efficiency for current research with cotton seed oil with CeO2 nanoparticles

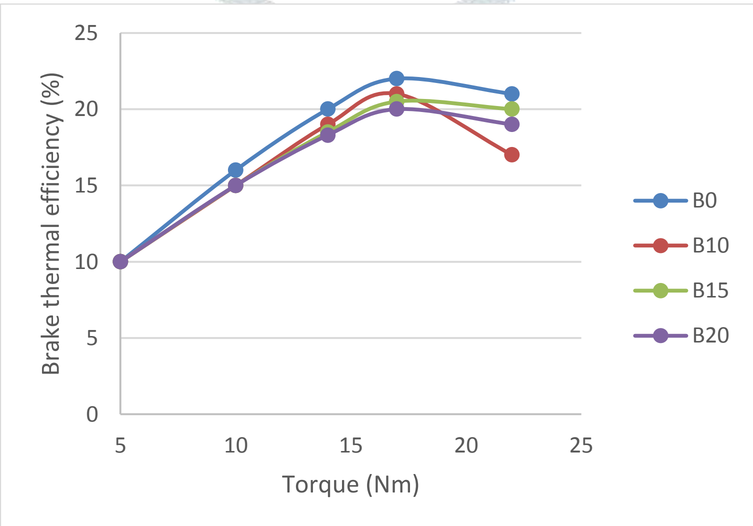

Fig. 15: Results of Brake thermal efficiency for cotton seed biodiesel

Brake specific fuel consumption

The results of brake specific fuel consumption is validated in fig.16 and fig. 17. The variation of bsfc is similar with increasing load. The fuel consumed at 12 kg load in current research is 0.4 kg/kW-hr while the same for the other reference research data is 0.41 kg/kWhr. This reduced fuel consumption if due to nanoparticle use.

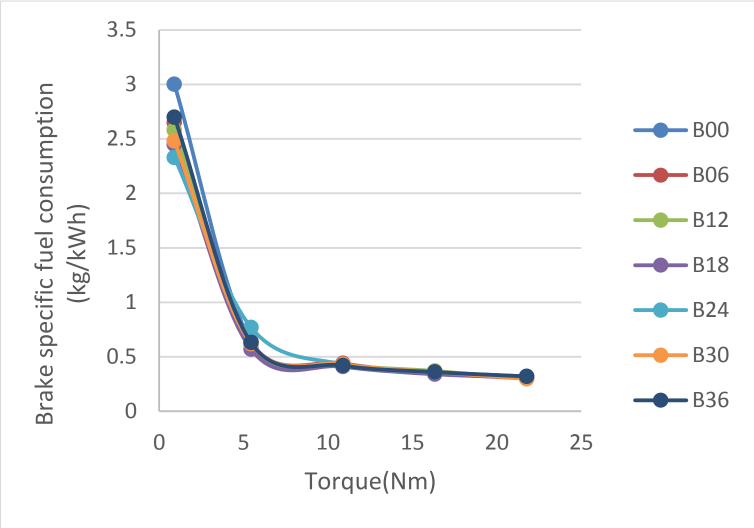

Fig. 16: Results of Brake specific fuel consumption for current research with cotton seed biodiesel with CeO2 nanoparticles

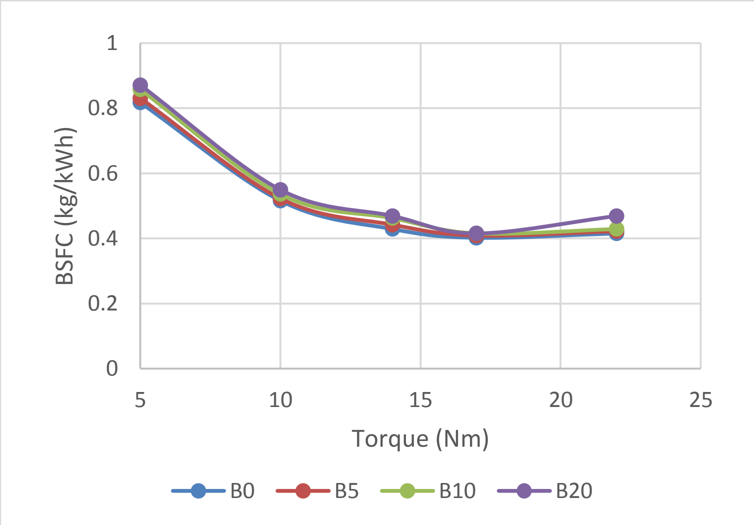

Fig. 17: Results of Brake thermal efficiency for research with cotton seed biodiesel

V CONCLUSION

The engine test was carried out with cottonseed oil biodiesel with cerium oxide nanoparticles in 35 ppm concentration. The test was carried out with compression ratio 16 & 18. After the experimentation and analysis, it can be concluded that-

1. Catton seed biodiesel can be used along with cerium oxide nanoparticles in single cylinder VCR engine without any change in the setup.
2. B30 has given the maximum brake thermal efficiency among all blends with a value of 28.86% at CR-18. Also, other blends have the brake thermal efficiency comparable with that of neat diesel fuel.
3. The exhaust gas temperature was observed with B30 with a value of 3890C.
4. All emissions, except NOx were reduced considerably with the addition of cottonseed biodiesel and nanoparticles. At CR-18, HC and CO emissions were reduced by 38% and 44% respectively.
5. NOx emissions were increased compared with diesel fuel. The maximum increase was 10.6% for B36 as compared with neat diesel, but, from available references, this increase is less as compared with the same in case of diesel-cottonseed biodiesel without cerium oxide nanoparticles.
6. B30 can be considered as the optimum blend among all with 28.86% efficiency at full load. It gives less emissions than diesel. It has higher cylinder pressure than other blends. In future, it can be considered as a good option as an alternative fuel.

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