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Combined Effect of EGR and NiO Nanopartcles on CI Engine Fuelled with Waste Cooking Oil Biodiesel

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Abstract
In this paper, the effect of exhaust gas recirculation (EGR) and Nickel oxide (NiO) nanoparticles on performance, combustion and emission characteristics of diesel engine fueled with waste cooking oil biodiesel is presented. Waste cooking oil (WCO) biodiesel was derived by transesterification process. Methyl ester was prepared by mixing diesel and biodiesel oils as 20% by volume. NiO nanoparticles was blended with biodiesel at concentration of 100 ppm to enhance the physicochemical fuel characteristics to obtain clean and efficient combustion performance. An experimental setup was incorporated into a diesel engine to investigate the influence of these nano-materials on engine performance, combustion and emissions characteristics using WCO biodiesel-diesel mixture. Enriching methyl ester mixture with 100 ppm NiO (B20+100ppm NiO) increased the break thermal efficiency (BTE), heat release rate (HRR) and peak pressure are increased by 3.24%, 2.87% and 7.44% respectively. Emissions of unburned hydrocarbons (UBHC), carbon monoxide (CO), nitrogen oxides (NOX) and smoke opacity are decreased by 5.2%, 9.3%, 11.42% and 4.6% respectively as compared to B20. With the incorporation of 10% EGR, BTE, HRR and peak pressure decreased by 4.22%, 1% and 0.84% respectively as compared to B20+100ppm NiO. Emissions of UBHC, CO, and smoke opacity are marginally increased by 0.37%, 4.65%, and 0.27% respectively as compared to B20+100ppm NiO at full load. Due to the significant reduction in emissions, improvement in combustion and performance characteristics, EGR-NiO nano additives can be used as an effective formula for diesel engines fueled with biodiesel.
Keywords: Biodiesel; Nanoparticles; Nickel oxide; EGR; Performance; Combustion; Emission.

1. Introduction

Due to remarkable progress in industrial development, transportation sector and modernization in lifestyle have led to substantial increase in fuel demand (petroleum based).Some features of petroleum resources are its limited availability, utility, and potential for depletion [1]. At present, biofuel is stated as “fuel for future” due to being recyclable and environmentally friendly and biodiesel is possessing characteristics almost the same as diesel fuel. Biodiesel resulting from renewable resources is further used by means of fuels in the transportation sector. The production of biofuels is significant for declining exhaust emissions and dependency on fossil fuels [1, 2]. Biofuels are obtained by combining the methyl esters of fatty acids, by responding diverse oils with methanol after removal of glycerol and this process is called as transesterification process [3]. Based on existing feedstocks obtainable for biodiesel making, WCO is under the foremost potential for extensive biodiesel making as it can reduce the fuel prices than other alternative feedstocks. Huge volume of WCO can be composed from hotels, cafeterias, and hostels. Certainly, a single outlet of fast-food center can produce 15 L of WCO per day [4]. The methodology for the usage of biodiesels in the range of 20% as alternative fuel in CI engine is a well-known and recognized technique. With respect to this methodology, some appropriate variation of biofuels by means of suitable nanoparticles could be of benefit. To estimate the impacts of Nickel oxide nanoparticles (NNP) mixed WCO on the performance and combustible products of CI engine, a test was carried out in a single-cylinder diesel engine. The addition of nickel oxide nanoparticles with biodiesel will result in better performance with reduced emission characteristics. CI engines generally used in the field of automobiles. And these engines release harmful emission gases. The emission distresses humans, animals, and plants. The investigational results designated improved BTE and better pollutant controls of CI engine. At present, many researchers are doing research by using the metal-based and oxygenated additives aimed to enhance the CI engine performance and emission parameters. The impact of zinc oxide nanoparticles with a variety of biofuel engine characteristics can be analyzed.

2. Materials and methods

This section describes the biodiesel preparation procedure, properties of tested fuels and Experimental set up.

2.1. Transesterification

Transesterification process consists of 2 steps namely Acid Transesterification and Base Transesterification. In acid transesterification, waste cooking oil (WCO) is heated up to 50^{O}C. Then Methanol is added to preheat WCO. After this reaction the bottom deposit is detached from the reaction (Base Transesterification). The obtained mixture is heated for 45–55 min in the presence of KOH (Potassium Hydroxide) and methanol. Once the reaction is completed, the products are permitted to distinct into two deposits. The bottom deposit, which contained glycerol, is removed. The ester (WCOME) leftovers in the upper deposit. Fig. 1 demonstrates the complete operation of the Transesterification method. The fuel properties of Diesel, WCOME with and without NiO were determined and tested to meet the ASTM standard requirement. All the properties of verified biofuels are tabulated in Table 1.

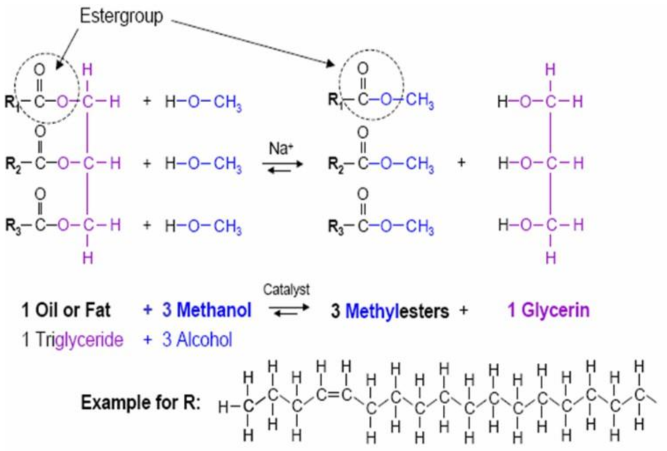

Figure 1: Transesterification process.

Figure 2: Engine setup.

2.2. Error analysis and uncertainty

The experimental results will certainly have error and uncertainties, which can rise from the incorrect calibration of instruments due to excessive handling and mishandling, surrounding conditions, experimental test conditions and planning, surveillance and reading. The errors which are gotten become a hindrance to obtain accurate results. Thus to nullify these errors, tools and methods from mathematics and statistics are used. Generally, the method used is repetition of the taking data from the experimentation (at least 3 times) and finding the mean in order to minimize the error that may occur. Measurements of uncertainties were calculated and results are shown in Table 3. The uncertainty of the experiment was 1.8445%.

Table 1. Properties of fuels.

Properties	ASTM	Diesel	WCO	WCOME	B20	B20+100PPM NiO
Kinematic viscosity (40ºC,Cst)	19.6	3.05	43	5.83	4.01	4.05
Density (Kg/m^3)	870-900	828	914	874	826	828
Heat value (MJ/Kg)	-	42.6	29	37.2	39.2	41.2
Flash point (ºC)	>130	60	307	150	98	105
Cetane number	40-55	40	53	51.48	51	52.5

Table 2: Nanoparticle Properties.

Parameters	Nickel oxide(Nio)
Manufacturer	Nano Research Lab
Chemical Name	Nickel Oxide
Form Color	Powder Gray
Particle Size	25–50 nm
Specific Surface Area	75 m^2/g
Molecular Weight	74.69 g/mole

Table 3: Error analysis and uncertainty.

Measurements	Accuracy	Uncertainty
Speed	±3 RPM	± 0.3%
BSFC	±3 kg/KWh	± 0.35%
Power (KW)	±0.3KW	± 0.40%
CO	±0.02%	± 1.0%
NOx	±7 ppm	± 0.7%
In cylinder pressure	±0.1 bar	± 0.2%
Temperature	±1ºC	± 0.1%
Torque	± 0.1Nm	± 1%

Table 4: The specification of engine.

Parameters	Specifications
Engine	Four Stroke Single Cylinder
Make	Kirloskar
Number of cylinder	One
Speed	1500 rev/min
Bore	85 mm
Stroke length	110 mm
Compression ratio	17.5:1
Starting	Cranking
Working length	four Stroke
Method of cooling	Water cooled
Method of ignition	Compression ignition
Dynamometer	Eddy current

3. Exhaust gas recirculation

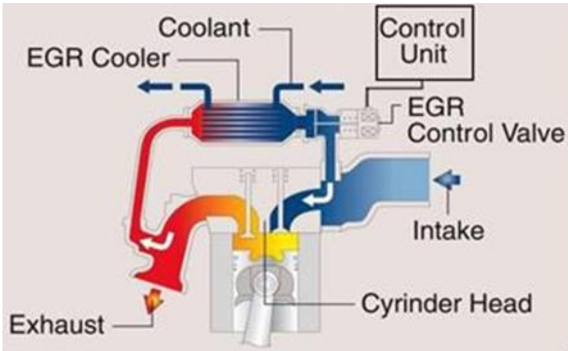

Figure 3: Exhaust gas recirculation.

The most effective way of reducing NOx emissions is to hold combustion chamber temperatures down. Although practical, this is a very unfortunate method in that it also reduces the thermal efficiency of the engine. We have been taught since infancy in our first thermodynamics course that for maximum engine thermal efficiency, Qin should be at the highest temperature possible. Probably the simplest practical method of reducing maximum flame temperature is to dilute the air-fuel mixture with a non-reacting parasite gas. This gas absorbs energy during combustion without contributing any energy input. The net result is a lower flame temperature. Any no reacting gas would work as a diluent. Those gases with larger specific heats would absorb the most energy per unit mass and would therefore require the least amount; thus less C02 (carbon dioxide) would be required than argon for the same maximum temperature. However, neither C02 nor argon is readily available for use in an engine. Air is available as a diluent but is not totally no reacting. Adding air changes, the AF and combustion characteristics. The one no reacting gas that is available to use in an engine is exhaust gas, and this is used in all modern automobile and other medium-size and large engines.

4. Result and discussions

Exhaustive experimentation has been made with varied load and the readings have been tabulated and plotted in graphs.

4.1. Engine performance

4.1.1. Brake thermal efficiency

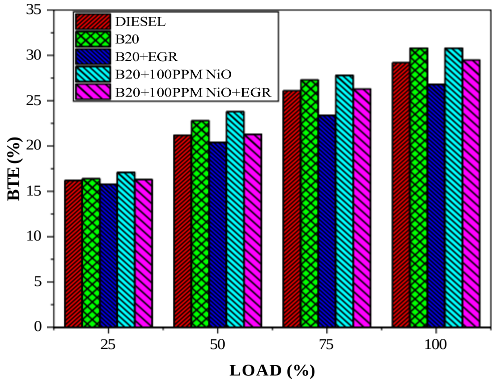

Fig 4: Variation of BTE with load.

Fig. 4 shows the variation of BTE with Load. Brake thermal efficiency increases for Nano additive biodiesel than the diesel. Addition of Nano particle improves the combustion activity and more useful work is obtained from the fuel, due to improvement in surface area to volume ratio increases the power attribute by enhancing the heat transfer rate inside the engine cylinder. Addition of Nano particle minimizes the ignition delay period and provides better atomization of fuel from the fuel injector's cause's rapid evaporation indeed increases the thermal efficiency. . At higher loading condition, BTE of B20+ NiO increased by 8.2% and BTE of B20+ NiO +EGR increased by 4.22% compared to B20.

4.1.2. Break specific fuel consumption (BSFC)

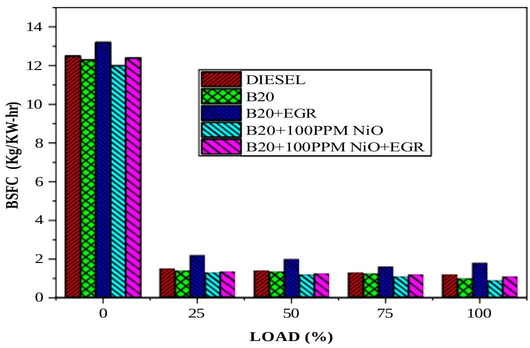

Fig 5: Variation of BSFC with load.

Fig. 5 shows the variation of BSFC with Load. BSFC decreases as the loading increases. Addition of nano particles to biodiesel improves the quality of the fuel. Due to lesser size and homogenous mixing of nano particles with biodiesel prevents the clogging of the fuel and increases the atomization property. Nano particle have higher reactive surface area causes increases in the catalytic property, which improves the combustion with minimum fuel consumption. Oxide will enhances the secondary atomization causing increases in combustion uniformly. At higher loading condition, BSFC of B20+ NiO decreased by 10% and BSFC of B20+ NiO +EGR decreased by 7% compared to B20.

4.2. Combustion parameters

4.2.1. HRR (heat release rate)

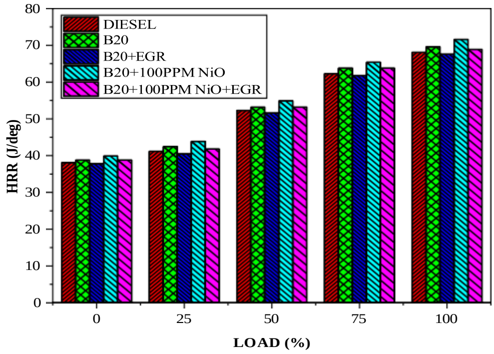

Fig 6: Variation of HRR with load.

Fig. 6 Portray the association of HRR (J/Deg) with Load (%). Experiment reveals that as the addition of Nano products to diesel and biodiesel fuel increases the HRR. Adding Nano particles to biodiesel increases the catalytic activity in the biodiesel fuel thus encouraging the full combustion causes increases in HRR. At higher loading condition, HRR of B20+ NiO increased by 2.87% and HRR of B20+ NiO +EGR increased by 1.1% compared to B20.

4.2.2. Peak pressure

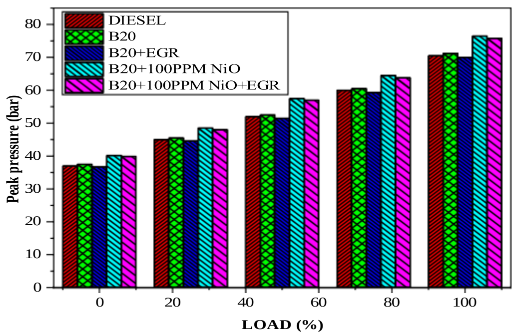

Fig 7: Variation of peak pressure with load.

Fig. 7 depict the relation between Peak pressure (bar) and Load (%), Due to improved combustion efficiency, the ignition delay time decreases for the Nano fluid biodiesel blends compared to diesel fuel and Nano particles also provide sufficient area to volume for the catalytic operation of the fuel leads to increased combustion, thereby Nano fluid biodiesel exhibits higher peak pressure compares to diesel fuel. At higher loading condition, Peak pressure of B20+ NiO increased by 7.44% and Peak pressure of B20+ NiO +EGR increased by 0.84% compared to B20.

4.3. Emissions parameters

4.3.1. Unburned hydrocarbons (UBHC)

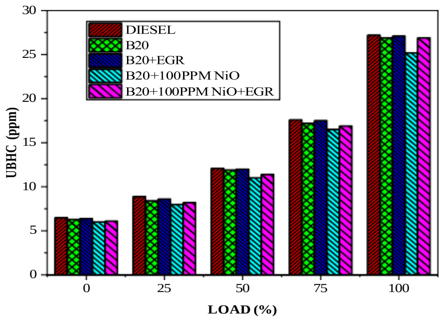

Fig 8: Variation of UBHC with load.

Fig. 8 shows the variation of HC with Load. HC decreases as the load increases were observed. When load increases availability of oxygen gradually decreasing due to fuel injection is more. But for the biodiesel contains oxygen molecules in fatty acid chain hence HC formation for the biodiesel is decreases due to more combustion than diesel will be observed. As the addition of the nano particles to biodiesel blends increases the atomization of fuel and decreases the viscosity of the fuel leads to improvement in the vaporization of particles. Furthermore improved mixing quality of air fuel increases combustion phenomena resulting n reduction in HC formation. Presences of oxygen in the chain increase the combustion rate with lesser combustion duration. Another reason as the addition of nano particles decreases the temperature of carbon combustion and enhances the catalytic activity of oxygen. At higher loading condition, UBHC emission of B20+ NiO decreased by 5.37% and UBHC emission of B20+ NiO +EGR decreased by 0.37% compared to B20.

4.3.2. Carbon monoxide (CO)

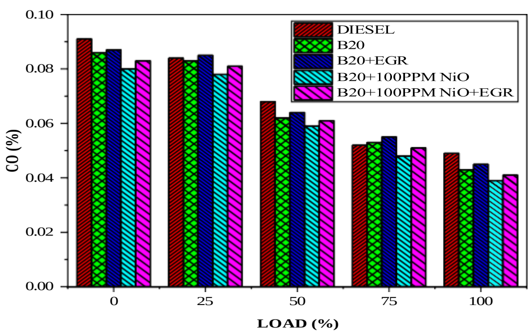

Fig 9: Variation of CO emission with load.

Fig. 9 shows the variation of CO with respect to engine load. A reduction in CO emission significantly due to presence of more oxygen atoms present in the biodiesel blends than the diesel. The oxygen atoms boots up the combustion activity. Nano particles improve the air fuel mixture quality due to higher area to volume ratio which leads burning rate for the complete combustion. Decrease in the viscosity of the biodiesel improves the atomization this plays a vital role in the reduction of CO emission. Nano particles decreases the homogeneity of the biodiesel composition there by increases the breakup rate during injection of fuel from the fuel injector At higher loading condition, CO emission of B20+ NiO decreased by 9.3% and CO emission of B20+ NiO +EGR decreased by 4.65% compared to B20.

4.3.3. Nitrogen oxides (NO_X)

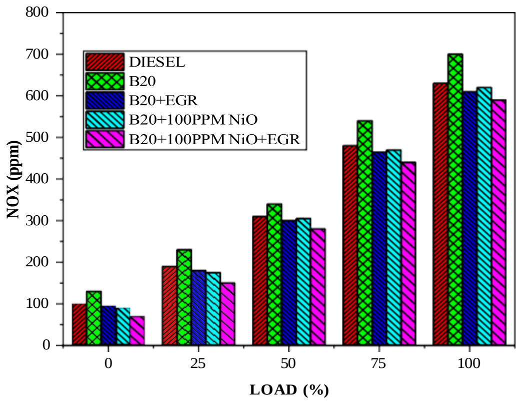

Fig 10: Variation of NO_X emission with load.

Fig. 10 shows the NOx and load relation. NOx emission will be higher for the biodiesel for all loading condition than the diesel fuel. NOx shows higher emission with increase loading condition due to higher adiabatic flame and cylinder temperature. Ignition delay, higher combustion temperature and higher availability of oxygen conditions favor the formation on NOx with higher rate. Due to presence of oxygen, content in the biodiesel shows higher NOx. As the dosing of metal based nanoparticle to biodiesel causes complete combustion. In this condition, peak pressure and HRR will be maximum but due to shorter ignition delay of nanoparticles decreases the cylinder combustion temperature and leads to less NOx formation will be achieved due to thermal breakdown of the hydrocarbons. At higher loading condition, NOx emission of B20+ NiO decreased by 11.42% and NO_x emission of B20+ NiO +EGR decreased by 15.71% compared to B20.

4.3.4. Smoke opacity

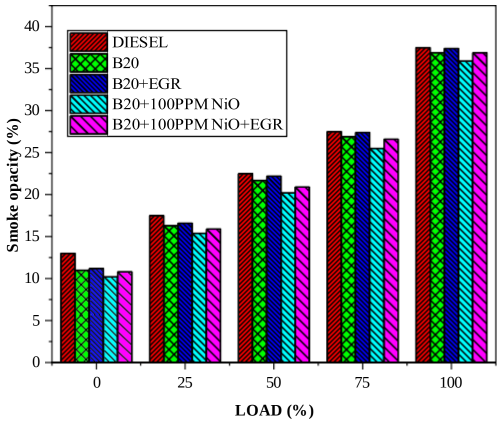

Fig.11: Variation of smoke opacity with load.

This is due to the advanced surface area -to - volume ratio of NiO and greater cetane number causing complete combustion. Higher oxygen content in the blend enhances combustion and results in lowering of smoke emissions. Also due to improved Sulphur and oxygen content of the nanoparticle, blended fuel there is reduction of Smoke opacity. At higher loading condition, Smoke opacity of B20+ NiO decreased by 4.6% and Smoke opacity of B20+ NiO +EGR decreased by 0.27% compared to B20.

5. Conclusions

The following are the conclusions drawn from the experimental results.

With respect to B20+100ppm NiO,

- BTE increased by 3.24% and 8.9% compared B20 and diesel respectively.
- BSFC decreased by 10% and 25% compared B20 and diesel respectively.
- HRR increased by 2.87% and 5.13% compared B20 and diesel respectively.
- Peak pressure increased by 7.44% and 8.51% compared B20 and diesel respectively.
- UBHC decreased by 5.2% and 7.35% compared B20 and diesel respectively.
- CO decreased by 9.3% and 20.4% compared B20 and diesel respectively.
- NO_X decreased by 15.38% and 19.04% compared B20 and diesel respectively.
- Smoke opacity decreased by 4.6% and 6.13% compared B20 and diesel respectively.

With respect to B20+100ppm NiO +EGR,

- BTE increased by 1.29% and 5.84% compared B20 and diesel respectively.

- BSFC decreased by 14.1% and 15.6% compared B20 and diesel respectively.
- HRR increased by 0.51% and 1.93% compared B20 and diesel respectively.
- Peak pressure increased by 1.22% and 1.93% compared B20 and diesel respectively.
- UBHC decreased by 1.06% and 2.17% compared B20 and diesel respectively.
- CO decreased by 6.32% and 12.28% compared B20 and diesel respectively.
- NO_X decreased by 13.18% and 10.31% compared B20 and diesel respectively.
- Smoke opacity decreased by 3.14% and 4.13% compared B20 and diesel respectively.

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