Influence of zinc oxide nano particles on performance, combustion and emission characteristics of butanol-diesel-ethanol blends in DI CI engine

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Abstract

Ethanol is a renewable fuel and can be produced from biomass. Diesohol (ethanol and diesel) blends containing 45% diesel, 45% ethanol with 10% butanol as co solvent can be utilized as fuel in a direct injection compression ignition (DI CI) engine without any modification. 10% butanol was found as an optimum level to control phase separation in diesohol blends. In this work, zinc oxide nano particles were added to D45E45B10 (45%diesel, 45% ethanol and 10% butanol) in three proportions by means of ultra-sonication to arrive at a homogeneous blend. Blends were tested for essential properties as per ASTM standards and tested in a CI engine at various loads for performance. The results were compared with diesel. The results showed significant improvement in the energy content of the blends as a result of the addition of zinc oxide nanoparticles. The catalytic action of zinc oxide nano particles resulted in an increase in brake thermal efficiency and a decrease in the emissions of CO, HC, and smoke. However, there was a slight increase in emissions of NOx at rated power. The in cylinder pressure and the rate of heat release of all the blends were improved by the addition of zinc oxide nano particles.

1. Introduction

It is highly essential to speed up the research on alternate fuels to replace or reduce the dependency on fossil fuels to fuel the internal combustion engines to satisfy the needs of power source for enabling the multifold growth of transportation, agriculture etc., Literature survey shows possibility of the available fossil fuel resources getting used up in the near future. The most suitable alternatives for diesel are biodiesel from various vegetable oils and alcohols from biomass. Utilization of biodiesel in diesel engine has been suggested by most of the researchers who have reported that the higher content of biodiesel diesel-biodiesel blends lead to higher NOx emissions and resulting in scarcity of vegetable sources [1]. Among the alcohols available, ethanol is a suitable alternative for replacing or reducing the dependency on diesel as it is renewable and can be produced from biomass. Fueling diesel engines by ethanol-diesel blends (diesohol) has certain advantages as the octane number and oxygen content can improve burning efficiency resulting from lesser emissions of CO, NOx, HC and particulate matter (PM) [2]. However, ethanol has some limitations for fueling to diesel engines such as lower cetane number, viscosity and flash point. It also suffers phase separation for higher ethanol content in diesohol [3]. The limitation of phase separation can be overcome by the use of various additives and co-solvents [4]. Butanol is one of the cosolvents for the purpose. The major reason for the phase separation in diesohol blends is due to the breakage of the interfacial film caused by the increase in pressure at temperatures lesser than ambient (25°C) [5, 6]. The first author has made a study of phase stability analysis of diesohol with butanol as cosolvent and reported that diesohol of 50% ethanol and 10% butanol were found stable in the range temperature of 5°C to 25°C and above for 20 days without phase separation [7]. The present study is the analyzing effects of zinc oxide nano particles on the performance of diesohol blends in various proportions in a CI engine. The addition of
nano particles has been the subject matter of study by many researchers. Nano particles have been reported having an extremely high ratio of surface to volume resulting in better interaction between the particle surfaces and surrounding liquid to overcome the difference in density [7-11]. Use of nano scale energetic materials as fuel additives for enhancing combustion of traditional fuels is an interesting concept and the high energy density of metals improves the power output of engines thereby reducing the consumption of liquid fuels, consequently less CO2, NOx etc., [12-17]. Zinc oxide nano material was added to the blend of diesel-palm stearin wax, fuelled in diesel engine and reported that there was an increase in the calorific value of the blends. It was also reported that there was an increase in BTE and decrease of BSFC by the addition of zinc oxide nano materials. It was reported that the addition of zinc oxide to diesel-biodiesel-ethanol blends improved the BTE and decreased the emissions significantly [18, 19]. As a summary, it can be drawn from the previous studies that the addition of zinc oxide giving a good impact on the necessary parameters of fuel in a diesel engine.

The objective of this study is to conduct an investigation on the effects of addition of zinc oxide nano particles on the performance characteristics of blends of diesohol in three proportions (100ppm, 200ppm, and 300 ppm) in a DI CI engine and the results were compared with diesel as base fuel.

2. Preparation of blends and property testing

Three blends of diesohol were made by the addition of 100ppm, 200ppm and 300ppm of zinc oxide nano particles and tested for properties as per ASTM standards. Diesel used for this study was procured from the fuel stock of Shell Lubricants of a low sulfur content commercial brand. Ethanol was 99.9% pure and free from water, Butanol of lab grade from the commercial market was used in this study. Zinc Oxide nano was procured from M/s Sigma Aldrich USA, 10-50 nm size of specific surface area 15-25 m²/g and the color of the powder is white.

2.1 Preparation of Blends

To start with specified proportions of zinc oxide nano particles were added to diesel by means of ultrasonicator. These blends were added to the mixture of diesel 45% ethanol of 45% and butanol of 10%. Blends were stirred well to arrive at a clear blend. Prepared blends were kept undisturbed to ensure that the nano particles were not settled at the bottom of the container.

![Figure 1 Blends after Ultra-sonication](image1.png)

![Figure 2. Schematic Experimental Set up](image2.png)
It is seen from Figure 1 that there was no settlement of zinc oxide nano particles and no phase separation. Ultrasound waves are allowed to propagate through the liquid which induces the alternate different pressure cycles like low pressure and high pressure [11]. This results in a mechanical stress in the individual particles of the liquid and separates them one another. Ultrasonic disruptors were included in the ultrasonicator which disperses the particles uniformly and mix properly and form a clear blend. This step is very important and the ultra-sonication was conducted in a cycle time of 60min. and repeated for several times to achieve the proper dispersion. This process was shielded by ice bath to maintain the temperature constant equivalent to ambient (25°C) and this prevents the rise of temperature resulted from repeated ultra-sonication (10 times of one minute in each setting). The specification of ultrasonicator used is Model 3.5L100/DTC, Power 220-240 V AC, 50-60Hz PZT, Sandwich type Bonded Transducer and 40 KHz frequency was used. The prepared blends were kept undisturbed at ambient temperature (35°C) for 7days. The prepared blends were tested for basic properties such as flash point, kinematic viscosity, density, calorific value and cetane number as per ASTM standard. The properties were presented in Table 1. Figure 1 depicts the homogenous blend after 7days having no separation and the blends are noted for representation.

2.2 Experimental set up

Compression Ignition engine (CI) of 5hp capacity of Kirloskar make duly connected with eddy current dynamometer of water cooled was used for testing the fuel blends. Pressure of the cylinder was monitored by the piezoelectric transducer and crank angle encoder of Kistler make. Pressure readings of 100 consecutive cycles were recorded and the mean value was taken for analysis for every crank angle. The captured signals were interfaced to a data acquisition device and fed into a computer for smoothening of combustion characteristics. The specific fuel consumption was captured by digital flow meter. To measure the emissions from the engine AVL Di gas exhaust gas analyzer was used. Each test was conducted for five consecutive times and the average of the five was taken for analysis. This reduces the uncertainty error to a minimum. The schematic test set up [21] is as presented in Figure 2. Uncertainty analysis was performed for the identification of errors of measurement during the experiment and for ensuring repeatability of the test. Combined uncertainty analysis of performance test was done from which total uncertainty was arrived. The uncertainty value varies from 0.05% to 0.15% and is presented in Table 2. To get the realistic uncertainty limits for the computed result, the principle of root-mean Square was used. [20].

3. Results and Discussions

Prepared blends were tested in CI engine at five load conditions and the characteristics were presented as:

3.1 Combustion Parameters

Monitoring the combustion parameters and analyzing is the best method to understand about the behavior of the fuel blends in the engine. In this paper, variation of heat release rate (HRR) and variation of pressure with respect to crank angle at all the load conditions are observed. As a representation, variation of HRR versus crank angle and variation of in cylinder pressure are presented in the following sections.

3.1.1 Heat Release Rate (HRR)

Measuring the rate of heat release (HRR) is one of the combustion parameter to know about the in cylinder combustion. Rate of heat release versus crank angle at rated power condition is presented in figure 3. It is observed that HRR of the fuel blends containing zinc oxide nano particles are significantly higher than D45E45B10. Also, blends containing higher than 100ppm of zinc oxide...
produces higher HRR compared to diesel and the blend D45E45B10ZNO100 produces lesser HRR than diesel at all loads. The reason for lesser HRR from D45E45B10ZNO100 is that the effect of nano particles produced by 100 ppm is not sufficient to overcome the dominance created by heat of vaporization of ethanol and butanol in the blend.

However, the blend D45E45B10ZNO200 and D45E45B10ZNO300 produces higher HRR than diesel at rated power. The increase in HRR produced by the fuel blends is due to the enhanced combustion occurred in the in cylinder. The combustion is improved by the catalytic action of zinc oxide nano particles and its positive effects on the physical properties of the fuel blend. The presence of zinc oxide nano particles allow more amount of fuel to react which in turn leads to longer and more complete combustion compared to that of diesel. It is also observed that the increase of amount of zinc oxide nano particles increases the percentage of increase of HRR compared to D45E45B10. The percentages of increase of HRR of the fuel blends were 7.1%, 17.3% and 23.5% for the blends D45E45B10ZNO100, D45E45B10ZNO200 and D45E45B10ZNO300 at rated power respectively compared to D45E45B10. Also, HRR of D45E45B10ZNO200 and D45E45B10ZNO300 are 1.1% and 6.2% higher than diesel. This is due to the increased calorific value of the blends by the addition of zinc oxide nano particles. It can be seen that there was a shift towards top dead centre with the addition of zinc oxide nano particles, which is due to increase in cetane number of the fuel blends compared to D45E45B10 and the angle of shift was found proportional to the increase of zinc oxide nano particles in the blends. This is due to reason that there was an increase in the cetane number of the fuel blends with the addition of zinc oxide nano particles.

3.1.2 Pressure Crank Angle Diagram

This is another parameter that can be monitored to understand the in cylinder combustion. Pressure data versus crank angle of the fuel blends at rated power is presented in Figure.4. It is seen that the pressure of the fuel blends was found higher at all the loads compared to diesel except D45E45B10ZNO100. This is due to the better complete combustion of the fuel blends in comparison to that of diesel. This is due to the enhanced combustion by the presence of zinc oxide nano particles in the fuel blend compared to that D45E45B10. The percentages of increase of pressure of the fuel blends were 5.3% and 18.3% for the blends D45E45B10ZNO200 and D45E45B10ZNO300 at rated
power respectively compared to diesel. However, D45E45B10ZNO100 produce lesser pressure than diesel and higher pressure than D45E45B10. This is due to the reason that the addition of 100ppm of zinc oxide is not sufficient to overcome the dominance created by heat of vaporization of D45E45B10, which leads to a cooling effect and reduces the in cylinder temperature. It is observed that the maximum pressures of all the fuel blends with nano zinc oxide were higher than D45E45B10 and increase along with increase in load. Peak pressures of the blends were 52.5bar, 68.5bar and 76.7 bar against 66bar for diesel at rated power. There was an increase in peak pressure with increase in zinc oxide nano material in the fuel blends in comparison to D45E45B10 and diesel for the blends except D45E45B10ZNO100.

3.2 Performance parameter

Brake thermal efficiency (BTE) is a better indicator of performance parameters any fuel blends in a CI engine. Figure. 5 presents the variation of BTE versus brake power of the fuel blends. All the fuel blends were found producing higher BTE after 40% of load.

This was due to the higher latent heat of vaporization of the blends dominated at lower loads lesser than 40% and leads to lesser BTE compared to diesel. However, after 40% load the average temperature of the in cylinder is higher and the catalytic action of the presence of zinc oxide nano particles enhanced better complete combustion, which results in higher-surface-area –to- volume ratio leading to higher BTE. The percentage of increase of BTE are 7.9% and 10.8% for the blends D45E45B10ZN200 and D45E45B10ZN350 respectively compared to diesel at rated power condition. However, D45E45B10ZNO100 produces lesser BTE compared to diesel and higher BTE compared to D45E45B10.
3.3 Emission Characteristics

Emissions from the test engine have been captured by five gas analyzer, which is capable of measuring the oxides of nitrogen (NOx), smoke opacity, hydrocarbon (HC) and carbon monoxide (CO) from the fuel blends and presented in comparison with diesel.

3.3.1 Emissions of Oxides of Nitrogen (NOx)

An increase of NOx emissions from a fuel indicates better complete combustion happened in the combustion chamber. From Figure 6 it is seen that there was lesser NOx emissions produced by the fuel blends compared to diesel. However, the NOx emissions are increasing with the increase in the amount of zinc oxide nano particles in the blend. This is due to the increase in calorific value and cetane number by the addition of zinc oxide nano particles to D45E45B10. Also, the NOx emissions of D45E45B10ZNO750 are 8.2% higher than diesel and 38.3% higher than D45E45B10. The percentage of increases of NOx emissions of fuel blends D45E45B10ZNO100, D45E45B10ZNO200 and D45E45B10ZNO300 are 19.1%, 26.3% and 38.3% higher than D45E45B10 at rated power.

3.3.2 Smoke Emissions

Details of the smoke emissions of the fuel blends are presented in Figure 7. A decrease in smoke emissions for all the fuel blends at all loads is observed. This is due to the higher surface-area-to-volume ratio of the nano materials and higher cetane number resulting in better and complete combustion. Higher oxygen content in the blend enhances better complete combustion and results in significant decrease in smoke emissions.

![Figure 7 Variations of Smoke Emissions versus Brake Power](image)

![Figure 8 Variation of CO versus brake power](image)

![Figure 9 Variation of HC versus Brake Power](image)

The percentages of reduction of smoke emissions of the fuel blends are 15.6% and 26.8%, for the blends D45E45B10ZNO200 and D45E45B10ZNO300 compared to diesel. However, blend D45E45B10ZNO100 produce slightly higher smoke emissions compared to diesel and 28.8% lesser than D45E45B10. This is due to the higher reactivity of the blend containing zinc oxide nano particles. Also, the presence of zinc oxide suppresses the cooling effect of the presence of ethanol in the blend.
3.3.3 Emissions of Carbon Monoxide (CO)

Emissions of CO from a CI engine are an indication of incomplete combustion of any fuel utilized in engine. CO emissions of the fuel blends vs. brake power are presented in Figure 8. A reduction in CO emissions with the increase of load for the fuel blends compared to diesel was observed. This is due to the higher average temperature of the combustion chamber occurred due to the presence of zinc oxide nano material in the fuel blends. Decrease of CO emissions was seen with an increase in load and nano material content in the blend. Higher average temperature of the combustion chamber enhanced the oxygen in the blend to react with the hydrocarbon resulted in less CO emissions at higher loads compared to lower loads. However, at loads lesser than 40% the CO emissions were found higher and this was due to the higher latent heat of vaporization of the blends dominated and the average temperature of the in cylinder was lesser. For the blend D45E45B10ZN750 CO emissions were found lesser than diesel at all loads as the blend contains higher amount of zinc oxide nano particles which enhanced complete combustion due to the catalytic action. However, the blend D45E45B10ZNO250 produces higher CO emissions up to 60% of load condition and after 60% of load the CO emissions are lesser than diesel. This is due to the dominance of heat of vaporization of the blend containing higher volume of ethanol at lower loads.

3.3.4 Emissions of Hydrocarbons

An emission of HC from an engine is also an indication of incomplete combustion. From Figure 9 it is seen that HC emissions of the fuel blends were found higher than diesel except for D45E45B10ZN300. However for this blend alone after the load of 25% and above there was a decrease in HC emissions as the increase of average temperature of combustion chamber and the rapid reaction of oxygen present in the blend was comparatively more than at lower loads. It is observed that there was decrease in HC emissions of all the fuel blends with increase of load for all the fuel blends due to the same reason stated. The percentages of reduction in HC emissions of the fuel blends are 7.8%, 27.5%, 29.5% and 48.5% for the blend D45E45B1ZNO300 at 40%, 60%, 80% and 100% load respectively.

4. CONCLUSION

An experimental investigation on the performance, combustion and emission characteristics of butanol-diesohol blends by the addition of zinc oxide nano material was conducted and the following conclusions were drawn:

- HRR and in cylinder pressure of the fuel blends containing zinc oxide nano materials (more than 100 ppm) was found higher than diesel. Maximum HRR of 69.77J/CA was produced by D45E45B10ZNO300 and was 6.5% higher than diesel at rated power.
- Maximum cylinder pressure of 76.2bar was produced by D45E45B10ZNO300 at rated power and was 16.2% higher than diesel.
- BTE of the blends containing nano zinc oxide higher than 100 ppm was found higher than diesel. Maximum BTE was offered by D45E45B1ZNO300 and was 6.2% higher than diesel at rated power.
- In general, the emissions produced by the fuel blends were found lesser than diesel. NOx emissions of D45E45B10ZNO300 were found slightly lesser than diesel. This was due to the higher heat of vaporization of the fuel blends compared to diesel.
- Significant reduction of HC and CO emissions were produced by the fuel blends compared to diesel. Minimum CO and HC emissions were from D45E45B10ZNO300 at rate power and were 9.1% and 22.1% lesser than diesel.

As a summary, addition of zinc oxide nano material into D45E45B10 enhanced the combustion and improved the performance significantly and the emissions produced by the blends were also
found lesser than diesel. This results in reduction of 55% utilization of diesel a fossil fuel for fuelling diesel engine. Also, the addition of zinc oxide will not lead to any heal hazards as the exhaust will not cause any sensitivity to human and the material safety data sheet is attached as supplementary data.

5. REFERENCES

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