Experimental Investigation of Nickel Oxide Nanomaterials with n-Pentane Diesel Blends in Compression Ignition Engine

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Abstract. The non-renewable energy sources are depleting at higher manner because of greater energy demand. Alternative fuel is a replacement for diesel fuel in compressed ignition engines because of its significant environmental benefits. The use of alternative fuel leads to a reduction in Opacity, NO\textsubscript{X}, HC and CO emissions and the increase in fuel consumption and the increase in brake thermal efficiency on diesel engines without any modification. The addition of nanoparticles in alternative fuel increases the thermal efficiency and decreases the NO\textsubscript{X} emission. In this research work, the effect of nano-fuel additives Nickel Oxide (NiO\textsubscript{2}) on the performance and emission characteristics of n-Pentane alternative fuel in a single cylinder, four strokes, water cooled, and compression injection diesel engine is studied. The nano additives are prepared by precipitation method. The results obtained in particle size below 200 nm, the nanoparticles are characterized by using X-Ray Diffraction. The nanoparticles are dispersed with the alternative fuel by using Ultrasonicator and Magnetic stirrer. The results proved that, these additives will be preferred for reducing the particulate matter, carbon monoxide, unburned hydrocarbons and Nitrogen oxides emission. If the additives are added in the alternative fuel at appropriate proportion, it increases the engine combustion and performance characteristics. This nano-additive is used to reduce the fuel consumption and to improve the thermal efficiency during the experiment.

Keywords: n-Pentane, Nickel Oxide Nanomaterials, Opacity, Smoke Meter, Gas Analyzer

1. Introduction

At present, all the countries utilize the fossil fuels to satisfy the energy requirements and increase the energy demand. In many countries, even for the generation of electrical energy, fossil fuel is the key factor and this may leads to rise in the demand on fossil fuels. Due to the continuous growth of the country, there is an energy gap between the supply and demand. It is found that many transportation sector and thermal power plants utilizes huge amount of fossil fuels, which leads to demand on fossil fuels and cause environmental pollution and leads to global warming. Using biodiesel as an alternate fuel in internal combustion engine, performance is near to diesel fuel, but NOx emission is higher and not being controlled. In order to reduce the engine emissions, alternate fuels (chemicals) like pentane, methanol, ethanol, etc. is being replaced and nanomaterials is being added and investigated. By replacing alternate fuels with nanomaterials, can reduce demand on the fossil fuels and the performance of the engine can be improved and emission can be reduced.
2. Literature Review

Many experimental studies are carried by various researchers to investigate the performance of CI engine with an addition of different types of nanoparticle as a fuel blends. During the review results, it is noted that the addition of nanomaterials will enhance the diesel fuel properties like viscosity, flash point and fire point and improves the overall engine performance. The important literatures related to the CI engine performance enhancement with nanoparticles are presented further. Bello et al. [1] examined the application of additives blends with diesel as fuel and the results indicates that there would be increase in thermal efficiency and minimizes the opacity, CO and HC emissions. Selvan et al. [2] analyzed the CI engine performance using diesel as main fuel and also tested the engine performance using diesel blends such as biodiesel and ethanol in addition to cerium oxide as nanoadditive. For neat disel belnds, BSFC is always lower using cerium oxide as additive and it decreases the emission rate. Chen et al. [3] proposed that the gases like hydrogen, propane and natural gas with aid of di-methyl ether has tested as an alternative fuel to diesel and examine the outcome of quantity from di-methyl ether to natural gas for emission analysis. Burnete et al [4] observed that a usage of nano fluid in diesel have reduced the specific consumption rate compared to neat diesel. It was noted that NOx concentration for Nano fluid laden diesel fuel is lways lesser than diesel at type of load condition. Hulwan et al. [5] noted that the decreased emission from the diesel-ethanol with biodiesel blends. In this analysis, the biodiesel is used as a co-solvent diesel-ethanol blend with greater amount of ethanol. Hoseini et al [6] analyzed the usage of graphite oxide as nanomaterial to enhance the performance of the four stroke CI engine. The results of viscosity, flash and fire point is increased with an addition of nanomaterial. It also noted that HC emissions are reduced by using catalytic nanoparticle. Yanfeng et al. [7] studied the application of nanoadditives in CI engine would results in greater brake thermal efficiency and minimized the emission of CO, HC etc. Fangsuwannarak et al. [8] investigated the emission characteristics and engine performance using diesel, palm biodiesel and nanoparticle blended fuel. It is identified that the NiO2 have decreased the fuel consumption rate and improved brake power. Several researchers experimented and investigated the use of different type of chemical as nanoparticle with blending gent and analyzed the various characteristics for different load condition in CI engine from [9]-[22]. Based on literature studies, the Nickel Oxide is preferred as the nanoparticle because of their better thermal performance and as a blending agent the chemical n-Pentane is selected because of their lesser selective even though possessing good physical properties.

3. Materials and Methods

3.1. Nickel Oxide

In this experimentation, Nickel oxide (NiO₂) chemical is preferred as nanoparticle. The exact physical properties are obtained by doing the proper characterization and preparation of the nanoparticles. The sizing and stability of the nanoparticle is achieved by Zeta sizer device. XRD analyzer is used to find the structure form and morphology of the nanoparticle. The dispersion characteristics are studied on the alternative fuel besides the addition of nanoparticles to it. Result shows that the nanoparticle size is below 200 nm. From the results, it is observed that the stability of nanoparticle is higher. Also the dispersion studies are done after adding the diesel by Ultrasonicator. The physical characteristics of nickel oxide are shown in Table 1. The sample photograph of this reagent is exposed in Figure 1.

| Physical Properties | Values           |
|---------------------|------------------|
| Chemical formula    | NiO₂             |
| Nickel (%)          | 78.6             |
| Mass of O₂ (%)      | 21.39            |
| Mass of Molar (g/mol) | 74.71           |
| Appearance          | Black crystalline solid |
3.2. Preparation Method

The preparation of the nanoparticle is done by with the process of chemical synthesis route by precipitation method. At high temperature and pressure, the precipitation synthesis reaction is conceded. One gram of Nickel II chloride (NiCl₂) is added with distilled water of 50 ml. amount of a 0.1 molar concentration is utilized. The surface energy and reaction rate is reduced with the help of the surfactant. 0.5 gram is added with distilled water 10 ml at a 0.1 molar concentration of PEG (Poly Ethel Glycol) is worn out as the surfactant when it is mixed with precursor solution. As a reducing agent Sodium hydroxide is selected and used as 0.05 gram with 10 ml of distilled at same concentrations in droplets and made as to the precursor mixture. The reaction mixture of 60 ml is the transferred to the Teflon-lined autoclave. From the sample, the impurities are separated and eliminated by ultra-centrifugal device. The purified sample is stored using what man filter. This auto calve is kept inside the hot air oven for 12 hours and heated at a temperature 100°C. After that, it will move to box furnace is kept for the heating and cooling process for 6 hours duration. From the oven, the autoclave is removed and cool down to room atmosphere. Thus the Nickel oxide nanoparticles are prepared. The XRD results are shown in the Figure 2. Table 2 reveals about the crystallite size of the nickel oxide.

![Figure 1. Nickel Oxide (NiO₂).](image1)

![Figure 2. XRD resultant graph of Nickel Oxide.](image2)

| d-Spacing | Crystallite Size |
|-----------|-----------------|
| 2.39757   | 161.111500      |
| 2.08052   | 164.250700      |
| 1.47350   | 153.255400      |
| 1.25788   | 232.699800      |

3.3. n-Pentance as Blending Agent

C₅H₁₂ is a molecular formula for pentane having five number of carbon atoms. Pentane is subdivided into three categories n-pentane, isopentane (methyl butane) and neopentane (dimethyl propane). It is the substance used as a solvent with an addition of the alternative fuel. Table 3 exposes about the properties of n-pentane blending agent.
### Table 3. Properties of n-Pentane.

| Properties               | Value   |
|--------------------------|---------|
| Molar mass (g/mol)       | 72.15   |
| Density (g/ml)           | 0.626   |
| Melting point (°C)       | -130.5 to -129.1 |
| Boiling point (°C)       | 35.9 to 36.3 |
| Solubility in water (mg/l)| 40      |
| Vapor pressure (kPa)     | 57.90   |
| Refractive Index         | 1.358   |
| Specific heat capacity (J/Kmol) | 167.19 |

### 4. Experiment Setup

The experimental engine testing setup is shown in the Figure 3. It is the computerized variable compression ratio (VCR) engine. It is four stroke water cooled type from Kirloskar make. The prepared nano materials like nickel oxide and n-pentane at various weight ratios are testing in this setup. During the experimental testing, the smoke outlet is connected to the measuring instruments like five gas analyzer and smoke meter. Five gas analyzer is used to measure amount of gas emissions like CO, CO₂, HC, O₂ and NOₓ. Smoke meter is used to know the density and concentration of the emitted gas during the conduct of experiment. Table 4 gives the specifications of the engine.

![Experimental Setup](image)

**Figure 3.** Experimental Setup.

### Table 4. Engine Specifications.

| Name of the specifications | Operating conditions |
|----------------------------|----------------------|
| No. of cylinders           | single               |
| Rated power                | 3.5 kW @1475 rpm     |
| Bore diameter              | 88 mm                |
| Length                     | 120 mm               |
| Compression ratio          | 17.4 : 1             |
| Dynamometer type           | Eddy current         |
5. Instrumentation

5.1. Five Gas Analyzer
Five gas analyzer is an instrument used for analyzing the amount of species present in the gas sample. It has an ability to measure the content percentage with LED display. It consists of two types hand operated and automatic one. The most commonly used type is hand operated because of simple and ease of operation and instrument photograph is shown in Figure 4.

5.2. Smoke Meter
Smoke meter is used to measure the density of emitted pollution air. It is defined as the coefficient of light absorbed by the exhaust gases by the vehicle during emission and articulated as m⁻¹. The model number of this below instrument is AVL 437C. Smoke density is identified by the light disappearance between source and receiver. The measuring range of opacity is 0 - 100%. Figure 5 shows the smoke meter instrument used during testing.

6. Performance Characteristics of CI Engine

6.1. Brake Thermal Efficiency
Figure 6 reveals the deviations of the brake thermal efficiency for the pure diesel, a chemical with additive with the load. It was observed that during all type of test condition, the brake thermal efficiency increase with increase in brake power value. It also indicates that an addition of the NiO₂ nanoparticles with alternative fuel would increases the efficiency. The NiO₂ is act as a alternative fuel, it helps for successful combustion process compared with pure diesel. It also concludes that, there would be 8% increase in brake thermal efficiency with an addition of NiO₂.

6.2. Brake Specific Fuel Consumption
Figure 7 gives about the characteristics of brake specific fuel consumption with rated power for a diesel without impurities, alternative fuel with NiO₂. At all load conditions, it is lesser when added with alternative fuel compared to pure diesel. Because of catalytic chemical oxidation, nickel oxides with alternative fuel results in 15% diminish. Since the nanoparticles acts O₂ buffer and reduces the fuel consumption rate compared to pure diesel and supports for completing combustion process.

6.3. Indicated Thermal Efficiency
Figure 8 illustrate that B₁₀ is much higher compared to all other blends of the biodiesel blends for indicated thermal efficiency. When comparing with diesel the ITE of B₁₀NiO₂ is almost equal to diesel and this is because of the increase in the heating value with the addition of the alternative fuel. As a result of increase in load, there would be increase in friction and change in viscosity of fuel. It also increases the engine temperature and there could be more fuel consumption.
7. Emission Characteristics of CI Engine

7.1. Unburned Hydrocarbon
Figure 9 gives the digression of the HC emission for various loads. The emission content is reduced by having higher cetane number and also it decreases with increasing load condition. The hydrocarbon emission of pure diesel decreased on the addition of nanoparticles at all load condition. During full load condition, there would be 40% reduction in emission.

7.2. Oxides of Nitrogen
The emission characteristic for the NO\textsubscript{X} gas is exposed in the Figure 10. By minimizing the heat loss between piston and cylinder arrangement, the reduction in NiO\textsubscript{2} emission is achievable. At full load, the Nickel Oxide blended alternative fuel shows there would be decreased NO\textsubscript{X} emission because of the occurrence of fuel-bound oxygen endorse improved combustion and it is almost close to the pure diesel NO\textsubscript{X} emission.

7.3. Carbon Monoxide
Figure 11 exposes the influence of the nanoparticles with alternative fuel on carbon monoxide emissions. The rate of degree of fuel air mixing and uniform burning would results in shorter ignition delay with complete combustion and hence reduces the emission content marginally. By the addition of nanoparticle, there is a 10% decline in CO emission at initial load. Comparing all the additives, by adding of pure diesel would results in drop in emission.

7.4. Carbon Dioxide
The emission characteristics for the CO\textsubscript{2} gas for diesel with various proportions of blends with diesel for knowing CO\textsubscript{2} emission for diesel are represented in Figure 12. It is renowned that with a raise in
the concentration of all alternative fuel, CO₂ increases for a richer mixture of the blend. At full load condition, the increasing emission shows the successful combustion process irrespective of other properties, the increased CO₂ emission into the environment will be taken care by the Natural cycle by the trees and plants.

7.5. Exhaust Gas Temperature
Figure 13 gives the emission characteristics for exhaust gas temperature for varying load condition. From the results, it is noted that B₁₅NiO₂ blend is closer to the temperature of diesel exhaust gas. The higher the exhaust gas gives more heat loss. The comparison between the alternative fuel blends and exhaust gas temperature at the full loads condition are studied. Due to lesser kinematic viscosity, reduces the exhaust gas temperature of the blend. Because the fuel will be easily atomized by injector for quick combustion in the cylinder and heat loss is reduced, increasing thermal efficiency when diesel and a B₁₅ lean blend of alternative fuel are used as fuel.

7.6. Opacity
From Figure 14, it is noted that the opacity increases slightly with increase in load for diesel in addition to other fuels. The opacity is always poorer for all other alternative fuels except pure diesel. Because of the increasing mixture ratio would results in increase in load and decrease in the cylinder temperature by reason of the greater latent heat of vaporization of the blend. This result in increase in opacity is lowest at low load and at medium load condition and highest at full load condition.
8. Conclusion

The performance and emission characteristics of CI engine integrating NiO₂ as nanoparticle and n-Pentane as blends were analyzed. From the results obtained, it is concluded that:

- n-Pentane blends properties like kinematic viscosity and calorific value are similar to diesel. The thermal efficiency of the n-Pentane alternative fuel blends is almost similar to diesel. n-Pentane with nickel oxide alternative fuel blends shows that improve in brake thermal efficiency and reduction in fuel consumption rate. The indicated thermal efficiency of B₁₅NiO₂ is almost similar to pure diesel due to increase in the heating value.

- n-Pentane with Nickel Oxide alternative fuel blends shows 40% drop in HC emission. In case of NOₓ, n-pentane with Nickel Oxide alternative fuel blend reveals that slowly decrease at all loads compared to diesel. n-pentane with Nickel Oxide alternative fuel blends shows 10% reduction at peak load condition in CO emission.

- The exhaust temperatures of B₁₅NiO₂ blends are almost equal to the diesel. The smoke density is low for all other alternative blends except diesel.

- There would be a significant boost in brake thermal efficiency by decreasing NOₓ for B₁₅NiO₂ blend. It is renowned that the proper mixing of n-Pentane with nickel oxide alternative fuel with diesel to be advanced and it has a lot of promise for the future research.

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Acknowledgments

The authors acknowledge that the experimental testing carried with the help of Mr. V. Krishnan, Research and Development Centre, M/s. Simpson and Company Ltd., Chennai.