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Aluminum oxide and copper oxide nanodiesel fuel properties and usage in a compression ignition engine

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HIGHLIGHTS

- The synthesis and physicochemical properties of nanodiesel including CuO and Al_2O_3 nanoparticles were investigated.
- The combustion performance of nanodiesel in a diesel engine was also investigated.
- Nano particle addition were improved the flash point temperature and cetane index of diesel.
- The addition of Al_2O_3 and CuO decreases BSFC but also reduces NO_x emissions.

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ABSTRACT

This study deals with an experimental work that aims to examine the effects of nanoparticles added to diesel fuels. Nanodiesel fuels were prepared by adding aluminum oxide and copper oxide nanoparticles. These nanoparticles were blended with diesel fuel in varying mass fractions by the means of a mechanical homogenizer and an ultrasonicator. Physicochemical properties of nanodiesels were measured and compared with neat diesel fuel. Their stability characteristics were analyzed under static conditions. The effects of the additive nanoparticles on the engine performance and emissions were also investigated. The results showed that the stability of nanodiesel can be increased by regulating pH and using dispersant. The storage and combustion characteristics were also improved by adding nanoparticles. The engine test results indicated that the nanodiesel in terms of engine performance efficiency and environmentally friendly emissions could be recognized as the potential candidates in diesel engines.

1. Introduction

Depletion of fossil fuels, increasing fuels prices and environmental considerations have encouraged engineers and scientists to develop alternative fuels and improve the efficiencies of energy systems. Nanofluids are a new class of solid-liquid composite materials consisting of nano-sized solid particles dispersed in any base fluid [1]. In the similar way, the nanoparticles can be added to diesel fuels as base fuel. This type of new fuel is called as nanodiesel (modified diesel).

Many studies concerning nanodiesel have been published especially in the past 10 years [2]. Metallic based and oxygen containing compounds, such as aluminum oxide (Al_2O_3), titanium oxide (TiO_2) and copper oxide (CuO), which act as a combustion catalyst for hydrocarbon fuels. Therefore, nanodiesel has a potential to improve the combustion efficiency and to reduce the air pollutants [2–15]. Recent advances in nano science and nano technology enables production of nano-sized particles that are less than 100 nm. The nanodiesel fuels including nanoparticles have an important advantage according to micron sized particles; because there is no chance for fuel injector and filter clogging. Kuo et al. [3] addressed that there are multiple advantages of adding nanoparticles to propellants and solid fuels such as shortened ignition delay, increase in energy density, and high burn rates. At such dimensions, the surface area to volume ratio of the particle increased considerably and hence allowed more fuel to be in contact with the oxidizer to produce potential output. DeLuca et al. [4] studied that nanoparticle presence in the liquid fuels enhances the surface-area-to-volume ratio and thus allows more fuel to react with the oxidizer. Sabourin et al. [5] studied the burning rates of nanofluids, consisting of nitro methane and nano scale big surface area metal oxides of silicon dioxide (SiO_2) and Al_2O_3. They found that the burning rates were increased with nanoparticle surface area and with nanoparticle concentration. Tyagi et al. [6] investigated the addition of aluminum (Al) and Al_2O_3 nanoparticles on

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the ignition properties of diesel fuel. They found significant improvements in radiative and heat/mass transfer properties of diesel fuel by adding nanoparticles. They also observed that the hot plate ignition probability of the diesel fuel increases significantly by the addition of the nanoparticles. Kao et al. [7] tested Al nanoparticles blended diesel in a single cylinder naturally aspirated diesel engine. They found a significant improvement in the brake specific fuel consumption (BSFC) at engine speeds less than 1800 rpm. The authors concluded that adding a particular quantity of Al nanofluid to diesel also reduces harmful pollutants such as smoke and NO_x. Yetter et al. [8] have critically reviewed the reports on the application of nanoparticles in the combustion system. They concluded that the nano energetic particles have numerous characteristics that make them attractive for use in fuels and energetic materials. Gan and Qiao [9] investigated the combustion characteristics of n-decane and ethanol droplets with the addition of nano and micron sized aluminum Al particles by varying its size, dispersant concentration and type of base fluid. Their results showed that the added nanoparticles could significantly improve the power output of the engine due to higher energy density of metals. They also found a reduction in the emissions of CO_2 and NO_x. Basha and Anand [10] investigated the performance of a diesel engine fuelled with Jatropha biodiesel, Jatropha biodiesel emulsion fuel and Al_2O_3 nanoparticle blended Jatropha biodiesel emulsion fuels. Their results indicated that the addition of aluminum oxide nanoparticles can improve the performance and combustion of biodiesel, while producing fewer emissions. Basha and Anand [11] investigated experimentally the effects of water-diesel emulsion fuel and aluminum oxide nanoparticles blended water-diesel emulsion on the performance, emission and the combustion characteristics of a single cylinder, naturally aspirated four strokes air-cooled direct injection diesel engine. Their results revealed that a significant improvement in the engine performance and the reduction in harmful pollutants. Selvaganapthy et al. [12] investigated the effects of zinc oxide (ZnO) nanoparticles on the performance of single cylinder four strokes vertical water cooled diesel engine. They found that the thermal efficiency increased due to the presence of nanoparticles. ZnO nanoparticle created a negative effect of producing more NO_x than that of neat diesel. The stability or agglomeration of nanoparticles in the base fluid is an important issue to the scientists concern. Sajeevan and Sajith [13] carried out experimental investigations to study the effect of cerium oxide (CeO_2) as nanoadditive in diesel, on the physicochemical properties of diesel as well as the engine performance and emissions. They found that the brake thermal efficiency increased, the HC and NO_x emissions reduced by the addition of CeO_2 nanoparticles in diesel. Lenin et al. [14] reported the effect of nanofuel additives magnesium oxide (MnO) and CuO on the performance and emission characteristics of DI diesel engine. They concluded that the additives caused a marginal increase in performance and significant decrease in levels of pollutants emission. Mehta et al. [15] experimentally investigated the burning characteristics, engine performance and emission parameters of a single-cylinder Compression Ignition (CI) engine using nanofuels. Their results showed that diesel fuels blended with nanoparticles of aluminum, iron and boron particles increases the evaporation rates with early ignition compared to diesel. The engine performance parameter study revealed a noticeable reduction in specific fuel consumption with Al in comparison to diesel for generating equivalent brake power. The authors also observed that the carbon monoxide and hydrocarbons emission decrease with the use of Al and iron (Fe) nanoparticles. Balamurugan and Sajith [16] carried out the stability study of zirconium–cerium oxide (Zr-CeO_2) nanoparticles suspended in diesel. Oleic acid was used as a dispersant in their study. They determined the optimum concentration of dispersant as 0.6% by volume in diesel. Ozgur et al. [17] investigated the effects of addition of oxygen containing nanoparticle additives to biodiesel on fuel properties and effects on diesel engine performance and exhaust emissions. They were used two different nanoparticle additives, namely magnesium oxide (MgO) and SiO_2 to biodiesel at the addition dosage of 25 and 50 ppm. Their results showed that engine emission values NOx and CO were decreased and engine performance values slightly increased with the addition of nanoparticle. Ozgur et al. [18] also investigated the effects of addition of oxygen containing nanoparticles on NOx emissions of diesel fuelled test engine. Nine different nanoparticles namely Al_2O_3, MgO, TiO_2, ZnO, SiO_2, iron oxide (Fe_2O_3), nickel oxide (NiO), nickel iron oxide ($NiFe_2O_4$) and nickel zinc iron oxide ($Zn0.5Ni0.5Fe_2O_4$) were added to diesel fuel at the dosages of 25, 50 and 100 ppm. As a result, optimum additive and addition dosages were determined. Their results showed that NOx emissions were decreased with the addition of nanoparticles.

Literature survey showed that nanodiesels have a potential for use as fuels in the internal combustion engines due to enhanced properties. Recently, there have been a limited number of studies on the synthesis, experimental analysis of the physicochemical properties, engine performance and the emission characteristics of nanodiesels. The main aim of this study is to investigate the synthesis and physicochemical properties of nanodiesel including CuO and Al_2O_3 nanoparticles and the combustion performance in a diesel engine. The roles of pH values, surfactants types and concentration on the stability of the nanodiesel were discussed. The physicochemical properties of the neat and nanodiesel were measured using ATM standard test methods. The effects of the additive CuO and Al_2O_3 nanoparticles on the individual fuel properties, the engine performance, and emissions were studied. Comparisons of the performance of the base fuel (neat diesel) with and without the additives were also presented.

2. Experimental study

The experimental investigations have been carried out in three stages. In the first stage, the influence of pH level and the addition of dispersants on stability of nanodiesel were investigated. Then, various physicochemical properties of neat and nanodiesels including the CuO and Al_2O_3 nanoparticles were measured and compared with those of the neat diesel. The properties studied were the flash and fire point, density, viscosity, sulfur content, cold filter plug point (CFFP), distillation of each sample and the auto ignition temperature (AIT). Standard ASTM test procedures were used in the experiments. Finally, performance tests were conducted on the diesel engine using the nanodiesel fuel samples and compared with those of the neat diesel, to determine the effects on the engine performance and the emissions.

2.1. Nanodiesel preparation

Nanoparticles have generally higher surface energy due to their larger surface area. Hence they tend to agglomerate to form a micro sized particle and start to sediment. Stability of the suspensions is a crucial issue for both scientific research and practical applications. CuO (size ranged from 30 to 50 nm), Al_2O_3 (from 27 to 43 nm) nanoparticles and diesel fuel were used to produce nanodiesel fuels. The nanoparticles were supplied from Nanostructured and Amorphous Materials, Inc. and were used as-received. Sonics VCX 750 model ultrasonic processor was used to stir nanoparticles with neat diesel in order to obtain nanodiesels. The preparation of nanodiesel begins by direct mixing of the diesel fuel as base fluid with the nanoparticles and ultrasonicated for 1 h at 40 Hz. The dispersion stability of the prepared nanodiesels was studied by controlling the sedimentation of particles. In order to