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EFFECTS OF SPECIFIC FUEL CONSUMPTION AND EXHAUST EMISSIONS OF FOUR STROKE DIESEL ENGINE WITH CUO/WATER NANOFLUID AS COOLANT

This article reports the effects of CuO/water based coolant on specific fuel consumption and exhaust emissions of four stroke single cylinder diesel engine. The CuO nanoparticles of 27 nm were used to prepare the nanofluid-based engine coolant. Three different volume concentrations (i.e 0.05%, 0.1%, and 0.2%) of CuO/water nanofluids were prepared by using two-step method. The purpose of this study is to investigate the exhaust emissions (NO_x), exhaust gas temperature and specific fuel consumption under different load conditions with CuO/water nanofluid. After a series of experiments, it was observed that the CuO/water nanofluids, even at low volume concentrations, have a significant influence on exhaust emissions. The experimental results revealed that, at full load condition, the specific fuel consumption was reduced by 8.6%, 15.1% and 21.1% for the addition of 0.05%, 0.1% and 0.2% CuO nanoparticles with water, respectively. Also, the emission tests were concluded that 881 ppm, 853 ppm and 833 ppm of NO_x emissions were observed at high load with 0.05%, 0.1% and 0.2% volume concentrations of CuO/water nanofluids, respectively.

Nomenclature

EGT – Exhaust gas temperature
NO_x – Nitrogen oxides
SFC – Specific fuel consumption (kg/kW hr)
ppm – particulate per million
Φ – Volume concentration
V_{sp} – Volume of solid particles (m^3)
V_w – Volume of water (m^3)
W_{sp} – Weight of solid particles (kg)
W_w – Weight of water (kg)
ρ_{sp} – Density of solid particle (kg/m^3)
ρ_w – Density of water (kg/m^3)

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1. Introduction

Nanofluids are the suspension of nanometer-sized (1-100 nm) particles in conventional heat transfer fluids such as water, Ethylene Glycol, and Propylene Glycol etc. Due to the high dispersion stability, high surface to volume ratio nanofluids possesses high heat transfer characteristics compared to other base fluids. Therefore, the nanofluids will be a promising next generation heat transfer fluids in modern heat exchangers. Choi [1] has developed the first nanoparticle dispersed fluid by adding small quantity (less than 1% by volume) of nanoparticles in base fluid. In recent decades, the researchers have used different metal (Cu, Al, Silver, Nickel etc.), metal oxides (CuO, Al_2O_3, SiO_2, TiO_2 etc.) nanoparticles to prepare the nanofluids in different applications. Examples for metal oxide nanofluids are given below. Behabadi et al. [2] used CuO nanofluids, Naik et al. [3, 4], Michael and Iniyan [5], Bouhalleb and Abbassi [6] and Goudarzi et al. [7] also used CuO nanofluid and obtained better heat transfer rates. Abbassi et al. [8], Hemant Kumar et al. [9], Shojaeizadeh et al. [10] and Esfe et al. [11] studied the thermal properties of Al_2O_3 nanofluids using different experimental methods. In addition, many research works devoted to investigate the thermal properties of different CuO based nanofluids using different experimental methods. Esfe et al. [12] investigated the thermal conductivity of Ethylene Glycol-water based CuO nanofluids and the thermal conductivity of CuO/EG-water nanofluid increases with the increase of Volume concentration. The study of Syam Sundar et al. [13] showed that the thermal conductivity of EG-water based CuO nanofluid is more compared to the Al_2O_3 based nanofluid under same volume concentration and temperature. The mixture of EG-water based nanofluid was studied by Rohit et al. [14], Rashin et al. [15]. Their experimental results showed that the thermal conductivity of nanofluid is the function of volume concentration of nanoparticles and sonication time. Table 1 shows the summary of the literature on CuO nanofluids for heat transfer applications.

The above research articles focus on the thermal properties of CuO based nanofluids. As mentioned above, plenty of research articles has been published on the investigation of thermal properties of CuO based nanofluids. But very few ar-

Table 1.

Summary of literature on CuO nanofluid

Base fluid	Size (nm)	Enhancement of thermal conductivity (%)	Preparation method	Ref.
DI Water	50	13-25	Two step	[16]
Oleic Acid	1-80	28	Single step	[17]
Base oil	50	6.2	Two step	[18]
EG	29	22.4	Two step	[19, 20]
Water	31	5.5	Two step	[21]
EG	31	9	Two step	[21]

ticles can be found to describe the performance of IC engine with nanofluid-based coolant. Kulkarni et al. [22] explored the application of Al2O3 nanofluids in a diesel electric generator. They prepared three different volume concentrations (2%, 4%, and 6%) of Al2O3 based nanofluid by dispersing in EG-water. Their results showed that the specific heat of nanofluids increases with temperature. Also, they observed that the efficiency of diesel generator decreases with increasing particle volume concentration. Raja et al. [23] performed their experiment in CI engine to study the effect of exhaust emissions and heat transfer enhancement using Al2O3/water nanofluids. They prepared Al2O3 nanoparticle dispersed coolants with four different volume concentrations using two-step method. Based on the test results, the coolant with Al_2O_3 nanoparticles showed the 11%, 18%, 23% and 25% enhancement of heat transfer coefficient at 0.5, 1, 1.5 and 2% volume concentrations, respectively, under no load condition. Also, the experimental results revealed that 12.5% of NO_x emission was reduced at full load and 3-5% at no load, part load conditions. Peyghambarzadeh et al. [24] presented experimental investigations of heat transfer enhancement of Al_2O_3/water –EG nanofluids. Their experimental results showed that about 40% heat transfer enhancement was obtained compared to base fluid.

In this study, CuO/water nanofluids with three different volume concentrations of 0.05, 0.1 and 0.2% were prepared. The prepared nanofluids were used as a coolant for four stroke single cylinder diesel engine. The objective of this research work was to investigate the specific fuel consumption and exhaust emissions of CI engine with CuO/water nanofluid based coolant.

2. Preparation of nanofluid

A two-step method was adopted to prepare the CuO/water nanofluids as engine coolant. CuO nanoparticles (Sigma Aldrich, India) with an average diameter of 27 nm, the density 6.3 gm/cm^3, surface area 29 m^2/gm and the purity > 99% were used in this work. The XRD (X-ray Diffraction) spectra of the CuO nanoparticle are as shown in Fig. 1. The XRD image gives the details of the intensity of reflected ‘X’ – ray and the Bragg angle (θ). The average grain size of the CuO nanoparticle was calculated using the Scherrer formula. The nanofluids of different volume concentrations (Φ = 0.05%, 0.1% and 0.2%) were prepared by dispersing CuO nanoparticles in distilled water. No surfactant was used in this experiment. To achieve stable dispersion and low agglomeration of particles the prepared fluid was ultrasonicated for about 4 hrs. The sonicated fluid was stirred continuously for 1 hr. Equations 1, 2 were used to calculate the amount of CuO nanoparticles required to prepare the CuO/water nanofluid. A photograph of prepared CuO/water nanofluids is shown in Fig. 2.

$$(\Phi) = \frac{V_{sp}}{V_{sp} + V_w} \times 100 \tag{1}$$

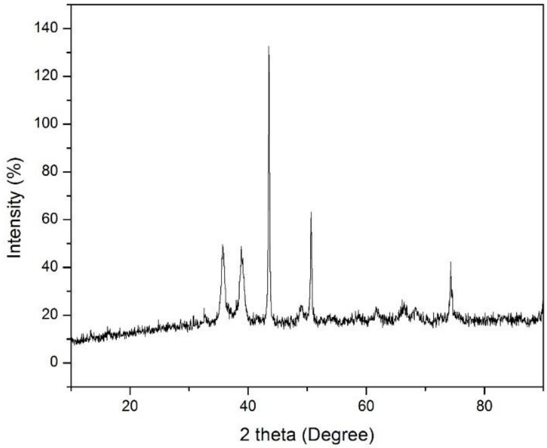

Fig. 1. XRD pattern of CuO nanoparticle

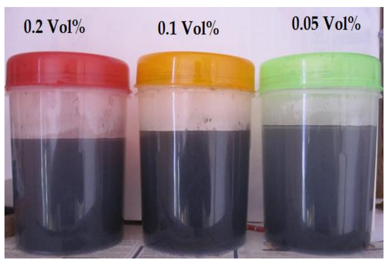

Fig. 2. Photograph of prepared CuO/water nanofluid

$$(\Phi) = \frac{\dfrac{w_{sp}}{\rho_{sp}}}{\dfrac{w_{sp}}{\rho_{sp}} + \dfrac{w_w}{\rho_w}} \times 100 \tag{2}$$

3. Experimental setup

A four stroke, single cylinder, constant speed compression ignition engine was used to investigate the performance and exhaust emissions. The engine was Kirloskar make, water cooled vertical engine. The engine was coupled with eddy current dynamometer to provide an external load. The schematic diagram of the experimental setup is shown in Fig. 3. The engine develops 3.75 kW power output at 1500 rev/min. The specifications of the test engine and different instruments used in this study are given in Table 2 and Table 3, respectively. The digital tachometer and the rotameter were used to measure the engine speed and volume flow rate of fuel and coolant, respectively. The separate coolant tank was used to store

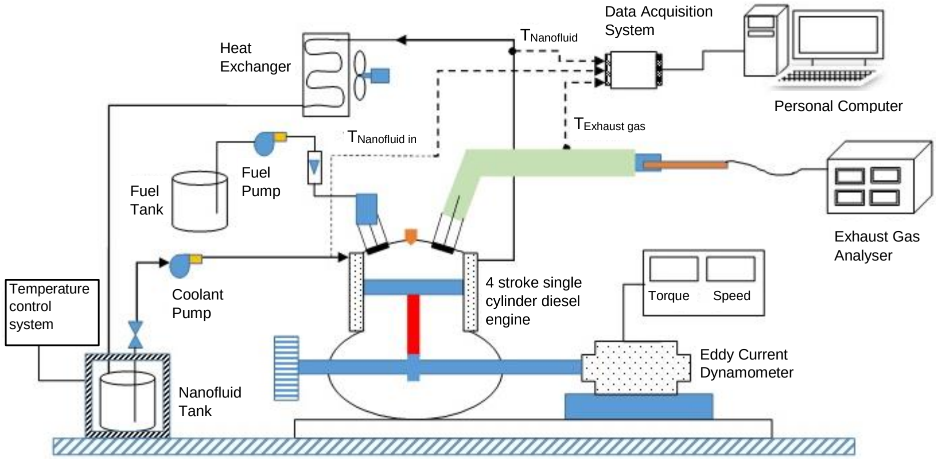

Fig. 3. Schematic diagram of experimental setup

Table 2.

Engine specification

Engine Model	Kirloasker, AVI
Number of cylinder/stroke	1 / 4
Engine type	Water cooled, compression ignition, vertical and direct injection
Rated power	3.75 kW
Brake Horse power	5 BHP
Compression ratio	16.5 :1
Bore / Stroke	80 /110 mm
Rated speed	1500 rpm

Table 3.

Technical specification of instruments

S.No	Measured variable	Instrument	Range	Uncertinity
1	Engine speed	Digital tachometer	10-10000 rpm	±2%
2	Engine torque	Electrical dynamometer	0-100 N-m	±2%
3	NO_x	Exhaust gas analyzer	0-9999 ppm	±2%
4	Temperature	K-type thermocouple	0-5000C	20C
5	Coolant flow rate	Rotameter	0-100LPH	±2%

the CuO/water-based nanofluid coolant. The Arduino based temperature control system was used to maintain the temperature of the nanofluid coolant in the storage tank. The K-type thermocouples were used to measure the coolant temperature and exhaust gas temperature. The AVL gas analyzer was used to measure the NO_x in the exhaust gas. To record the real time data, the Lab VIEW based data acquisition system with a personal computer was used.

4. Testing procedure

The exhaust gas temperature and exhaust emissions such as NO_x, and specific fuel consumption from the engine running with different volume concentrations of CuO/water nanofluid-based coolants were investigated and the results were compared with water coolants. The engine speed was maintained constant at 1500 rev/min. The tests were performed under steady-state conditions. Initially, the engine was running for few minutes with no load condition, afterwards the exhaust gas temperature, specific fuel consumption and concentrations of NO_x were measured for different load conditions. The tests were repeated for three times and the results were averaged.

5. The engine test results and discussions

Experiments were carried out with water and CuO/water nanofluid coolants. The engine was operated with pure diesel at a constant speed of 1500 rev/min. After completing the collection of experimental data, the effects of 0.05%, 0.1%, and 0.2% volume concentrations of CuO/water nanofluid on the engine performance and exhaust emission characteristics were studied and discussed in this section.

5.1. Effects on specific fuel consumption

Fig. 4 shows the relation between the specific fuel consumption and load using 0.05%, 0.1% and 0.2% volume concentrations of CuO/water nanofluid. From the graph, it was observed that the specific fuel consumption was almost similar

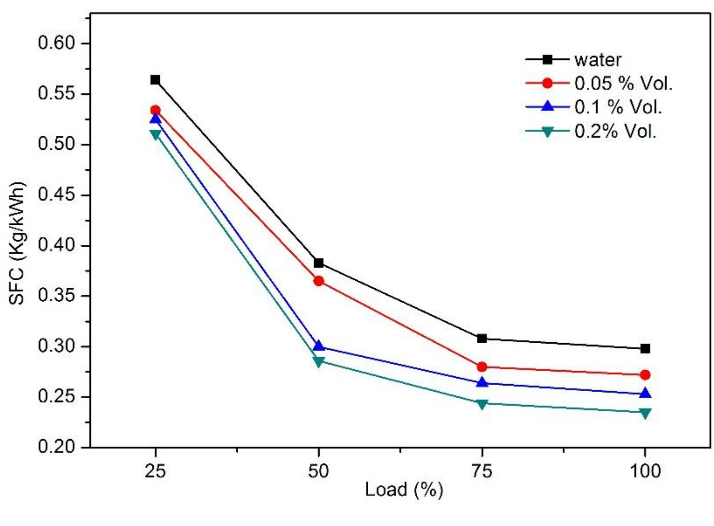

Fig. 4. Effects of CuO/water nanofluid on the specific fuel consumption at different engine loads and different volume concentrations

to that of water at low (1kW) and medium loads (1.97kW and 2.8 kW). At high load (3.5kW), the specific fuel consumption was reduced by 8.6% for the addition of 0.05%, 15.1% for the addition of 0.1% and 21.1% for the addition of 0.2% CuO nanoparticles with water. At low load conditions, residual gas temperatures and engine wall temperatures are low. The CuO/water nanofluids possess high heat transfer characteristics compared to base fluids. Due to the high heat transfer characteristics of nanofluids, the engine wall temperature and the in-cylinder temperature was further reduced. The enhancement of heat transfer characteristics of CuO/water nanofluids as claimed by previous research works [25, 26]. From the literature reviews, the heat transfer coefficient of CuO/water nanofluids is the function of % volume concentrations and flow rates. As a result of this specific fuel consumption, the values of CuO/water nanofluids become closer to pure water at low load conditions. Also, it was noted that the lowest fuel consumption was observed in 0.2% volume concentration of nanofluid.

5.2. Effects of exhaust gas temperature

The variations of exhaust gas temperature with respect to different loads while using 0.05%, 0.1%, and 0.2% volume concentrations of CuO/water nanofluid are shown in Fig. 5. It was observed from the graph that the exhaust gas temperature was increased with the increase in load for all the concentrations of nanofluid. When the engine was running at high loads, the wall temperature and exhaust gas temperature were increased. Therefore, the quantity of fuel supplied and the amount of heat released from the engine are significantly increased, which in turns increases exhaust gas temperature. It can be concluded from Fig. 5 that the

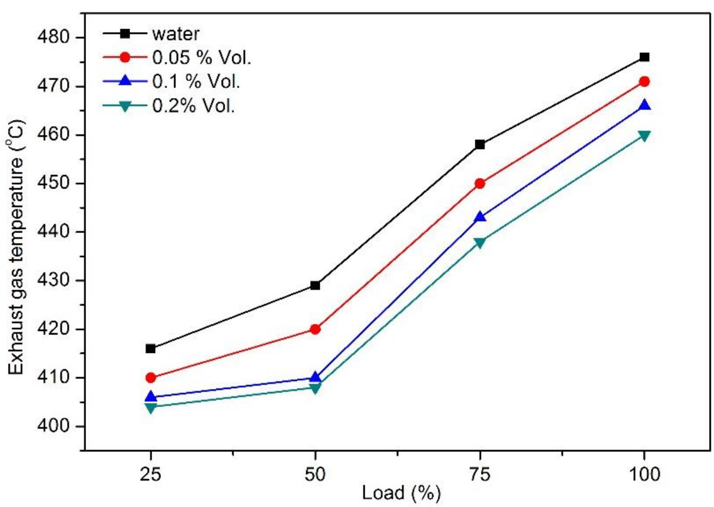

Fig. 5. Effects of CuO/water nanofluid on the exhaust gas temperature at different engine loads and different volume concentrations

EGT varied from 460°C to 480°C for CuO/water nanofluid at full load condition. Also, it was noted that the reduction of EGT was more at CuO/water nanofluids with higher volume concentrations. The possible reason for this reduction is that, at high volume concentrations, the movement of CuO nanoparticles in water is more compared to low volume concentrations. The thermal conductivity and heat transfer coefficient of nanofluids depend on the Brownian motion of nanoparticles and the average size of nanoparticles [27]. This might have led to lower exhaust gas temperature at 0.2%.

5.3. Effects of NO_x emissions

The formation of NO_x depends on the combustion temperature, air–fuel ratio and reaction time [28]. At high temperature, nitrogen reacts quickly with oxygen. Fig. 6 shows the effects of CuO/water nanofluid coolant on NO_x emissions at four different load conditions. Generally, NO_x emissions increased with engine load for water and all concentrations of nanofluids. According to Fig. 6, at low and medium load conditions, the NO_x emissions were almost similar to that of water. NO_x emissions at low loads for CuO/water nanofluids with 0.05%, 0.1% and 0.2% volume concentrations were 430 ppm, 413 ppm and 401 ppm, respectively. At high load, 881 ppm, 853 ppm and 833 ppm of NO_x emissions were observed while using CuO/water nanofluids with 0.05%, 0.1%, and 0.2% volume concentrations, respectively. The decrease in NO_x emissions was due to the use of CuO/water nanofluid with 0.2% volume concentration. So it is clear evident that the value of NO_x emissions are the functions of % volume concentrations of nanofluids.

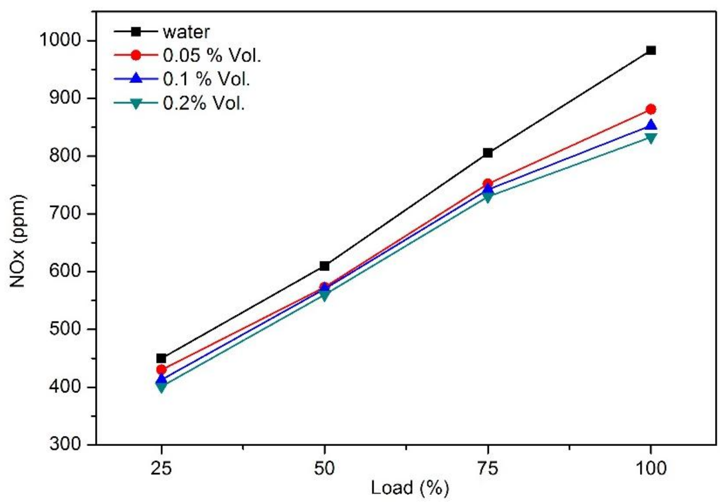

Fig. 6. Effects of CuO/water nanofluid on the nitrogen oxides emission at different engine loads and different volume concentrations

6. Summary and conclusion

An experimental investigation was carried out with four stroke single cylinder water cooled diesel engine to figure out the effects of CuO nanoparticle dispersed coolants on specific fuel consumption, exhaust gas temperature, and exhaust emissions. The most important outcomes of this study are summarized as follows:

1. The addition of different volume concentrations of CuO nanoparticles with commercial engine coolant increases the heat transfer coefficient. Because of its special properties, CuO nanoparticle dispersed engine coolant is suitable for diesel engine without any modifications on the engine system.
2. Specific fuel consumption – at high loads, the specific fuel consumption was reduced about 8.6%, 15.1% and 21.1% for the addition of 0.05%, 0.1% and 0.2% volume concentrations of CuO nanoparticles with water.
3. Exhaust gas temperature – the experimental results revealed that the exhaust gas temperature was increased with the increase of engine load for all % volume concentrations of nanofluids. The exhaust gas temperature varied from 460°C to 4800 C for CuO/water nanofluid at 100% of engine load.
4. NO_x emissions – NO_x emissions decreased with an increase in % volume concentrations of CuO/water nanofluids.at low load conditions, the NO_x emissions were almost similar than those of water. For all load conditions, the value of NO_x emissions are the functions of % volume concentrations of nanofluid.

From this study, it can be concluded that the fuel consumption and NO_x emissions were reduced marginally at high load conditions and high % volume concentrations. From this results, this study strongly recommends to use CuO/water nanofluid as a coolant in four stroke diesel engine without any modifications to the engine system.

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