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Effect of CNT as additive with biodiesel on the performance and emission characteristics of a DI diesel engine

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Abstract : Biodiesel as an alternative to diesel fuel prepared from vegetable oils or animal fats has attracted more and more attention because of its renewability and environmental-friendly nature. Further several studies report lesser performance and higher NO_x emissions for biodiesel fuel compared with conventional diesel fuel. In this paper, the experimental investigation on the effect of carbon nanotubes (CNT) additive on performance and emissions in a methyl ester of neem oil fuelled direct injection diesel engine has been investigated and reported. The nano additive is mixed in various proportions (100 to 300 ppm) with methyl ester of neem oil. The performance and emissions was tested in a computerized single cylinder, 4-stroke, stationary, water-cooled diesel engine of 3.5 kW rated power. Results show that the nano additive is effective in increasing the performance and controlling the NO emissions of methyl ester of neem oil fuelled diesel engines.
Keywords: Biodiesel, Carbon Nanotubes, Additive, Performance, Engine emission.

Introduction and test fuels

Biodiesel is one of the substitutes to fossil diesel fuel today in the world. Biodiesel production and demand have been growing fast and will continue to do so[1]. The main global warming pollutant, carbondioxide, problem is not there with biodiesel usage. Biodiesel emits the same amount of CO_2 as the plants absorb in growth and hence no greenhouse effect and global warming[2, 3].

Except NO_x, emissions like unburned hydrocarbon, carbon monoxide, particulate matter, sulphates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons and ozone potential of speciated HC are less. The oxygen content of biodiesel is an important factor in the NO_x formation because it causes to high local temperatures due to excess hydrocarbon oxidation. The increased oxygen levels increase the maximum temperature during the combustion, and increase the thermal NO_x formation. For 100 % biodiesel, NO_x emission increases by 13 % more than that for petrodiesel[4, 5]. NO_x is a major cause of smog, ground level ozone and also a cause of acid rain. As the use of biodiesel has increased tremendously, the rise in NO_x emission can become a significant barrier to market expansion. The development of improved NO_x reduction technologies is therefore critical to the global environment. On the other hand, biodiesel has some disadvantages, such as higher viscosity and pour point, and lower volatility compared with diesel. The performance of biodiesel is low due to its higher viscosity, resulting poor vapourization and atomization.

Nanofluids, solutions containing a stable suspension of nanoparticles (e.g., metals, oxides, carbides, nitrides, or carbon nanotubes) with typical lengths of 1–100 nm, have attracted great interest recently[6,7]. Because of their enhanced thermal conductivity, nanofluids can be used in energy-related systems. A comprehensive review of nanofluids applications in transportation, micromechanics and instrumentation, heating, ventilating and air-conditioning (HVAC) and medical fields is reported[8]. Because of high surface area, nanoscale energetic materials offer high reactivity, shortened ignition delays and fast energy release[9]. Addition of aluminum nanoparticles could substantially decrease the ignition delay time of slurries of n-dodecane is reported[10]. Using a simple hot-plate experiment, found that nano-aluminum significantly enhance the ignition probability of diesel fuel[11]. Results revealed that addition of Al_2O_3 nanoparticles to diesel fuel can improve the combustion features of the spray flame and giving rise to lower CO emission levels[12].

Application of nanoscale energetic metal particle additives in liquid fuel is an interesting concept yet unexplored to its full potential. Such formulated nanofuels offer: shortened ignition delay, decreased burn times and rapid oxidation which leads to complete combustion[13]. Nano additive enhances surface area/ volume ratio and increases catalytic activity[14]. The peak pressure and the maximum rate of pressure rise were also low for the alumina/CNT nanoparticles blend due to shorten ignition delay[15, 16].

These previous studies have revealed some ignition characteristics of fuels with the addition of nanoparticles. However the effect of nanoparticles on performance and emission characteristics of fuels has been rarely investigated. This paper, presents the outcome of investigation on the effect of nano additive on performance and emissions of a neem-derived biodiesel fuelled direct injection diesel engine.

Test Fuels

Neem oil is light to dark brown in colour, bitter in taste and has a strong odour. The neem tree is native to India and Burma[17] and almost the whole tree is usable for various purposes such as medicines, pesticides and organic fertilizer. Neem can be grown on very marginal soils that may be very rocky, shallow, dry, or pan forming. Neem tree get full maturity in just 10 years and gives an average seed yield of around 5.25 tonnes per hectare and has oil content of 45%. As the energy ratio of neem biodiesel is around 1.64, it is considered as one of the best renewable fuels in view of environmental inputs. The biodiesel produced from neem oil is prepared by a method of two-step process. The measured properties of diesel fuel, neem oil, methyl ester of neem oil and CNT additives are given in Table 1.

Table 1 Properties of test fuels and blends

	Density (g/cm^3)	**Net Calorific Value (kJ/kg)**	**Kinematic Viscosity (Cst)**	**Flash Point (℃)**	**Cetane Number**
Standard Method	ASTM D941	ASTM D240	ASTM D613	ASTM D445	ASTM D93
Diesel	0.8359	44500	2-3	75	51
Neem Oil (NO)	0.944	39742	38.2	201	55
Methyl Ester of NO (MENO)	0.890	40678	4.27	180	53
MENO+CNT100	0.889	40920	4.28	181	53
MENO+CNT200	0.889	40921	4.28	181	54
MENO+CNT300	0.888	40926	4.29	182	54
MENO+CNT400	0.888	40929	4.29	182	55

The photographic image of CNT additive is obtained using the Scanning Electronic Microscope (SEM) to study their morphology in Fig 1. The CNT additive is subjected to X-ray Diffraction (XRD) tests and the result on the variations of relative intensity with respect to 2-theta is given in Fig 2. Nano additive is accurately weighed using a high precision electronic weighing balance and added to measured quantity of neem biodiesel. To make 0.010%-m of biodiesel blend 100 mg of additive is added to 1 kg of biodiesel. The performance and emissions from the engines were studied at different biodiesel and biodiesel blends 0.010 %-m (MENO+CNT100), 0.020 %-m (MENO+CNT200), 0.030 %-m (MENO+CNT300), with a mean engine speed of 1500 rpm. An Ultrasonic 20 kHz homogenizers (SONOPULS-HD2070) is used to prepare a homogeneous mixture of additive and fuel.

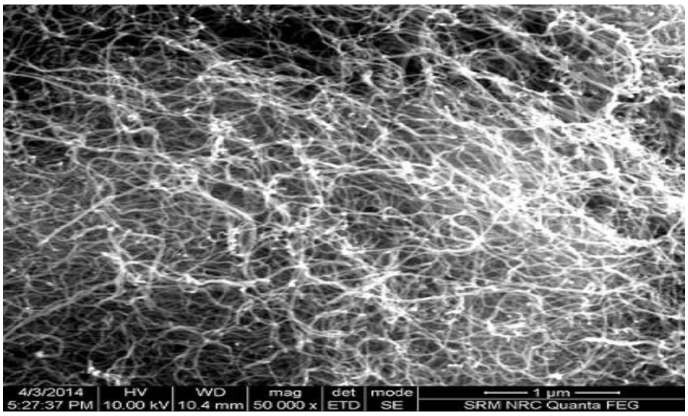

Fig.1 SEM image of CNT nano additive

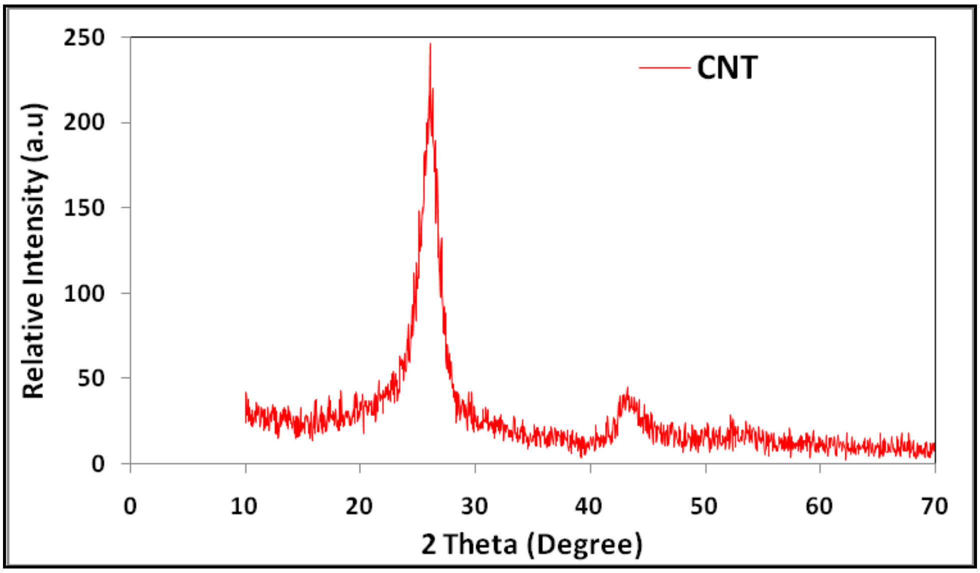

Fig. 2 Variation of Relative Intensity with 2 Theta

Experimental Setup

Emissions and performance experiments are carried out in a single cylinder, stationary, vertical, water-cooled, naturally aspirated direct injection diesel engine of 3.5 kW rated power coupled with an eddy current dynamometer, Fig. 3 & 3a. An eddy current dynamometer coupled to the engine is used as a loading device. The fuel flow rate, speed, load, exhaust gas temperature and gas flow rate are displayed on a personal computer. Exhaust emissions are measured with a AVL DiGas 444 gas (Fig 3b) analyzer and with a smoke meter.

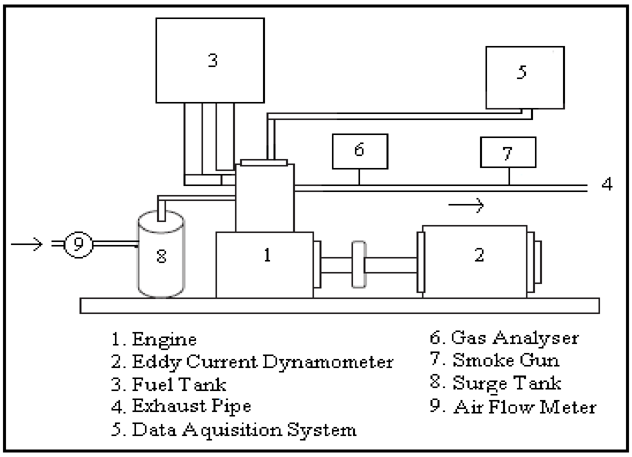

Fig. 3 Layout of engine test rig and data acquisition system

Fig.3a TV1 Kirloskar Engine

Fig.3b AVL Gas Analyser

Experiments are carried out after thorough inspection of the engine and calibration of measuring instruments. The same test procedure and practice are followed for all the test fuel mixtures.

Results and Discussion

The effects of nano additives on performance and emissions with methyl ester of neem oil are investigated in this experimental study. The performance and emission measurements are taken repeatedly for 5 times. The analysis is done for the average of the readings.

Performance characteristics

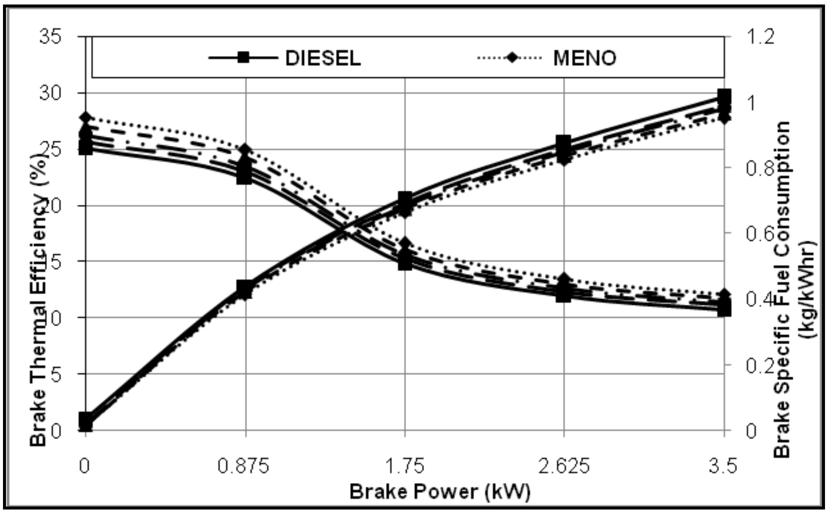

Fig.4 Variation of BTE and BSFC with brake power

Fig 4, shows the variation of brake thermal efficiency and brake specific fuel consumption with brake power for diesel, neat biodiesel and biodiesel-nano additive blends. The brake thermal efficiency is lower for MENO at all loads when compared with diesel fuel due to its high viscosity and poor mixture formation. For MENO+CNT100, MENO+CNT200 and MENO+CNT300 blends brake thermal efficiency increases by 2.12 %, 4.17 % and 3.43 % respectively compared to neat biodiesel at full load condition. The increase in additive proportion with MENO increases brake thermal efficiency till MENO+CNT200 and then it decreases compared to neat for MENO for all loads. This may be due to the positive effects of nanoparticles on physical properties of fuel and also by the decrease of the ignition delay time which leads to better combustion from additive addition. It is observed that the brake specific fuel consumption for neat biodiesel is more than diesel fuel. This may be due to higher viscosity and lower calorific value of biodiesel. The addition of nano additive decreases the brake specific fuel consumption for all biodiesel blends compared to neat biodiesel. This reduction in BSFC may be due to the positive effects of nanoparticles on physical properties of fuel and also decrease of the ignition delay time which leads to more complete combustion[14].

Emission characteristics

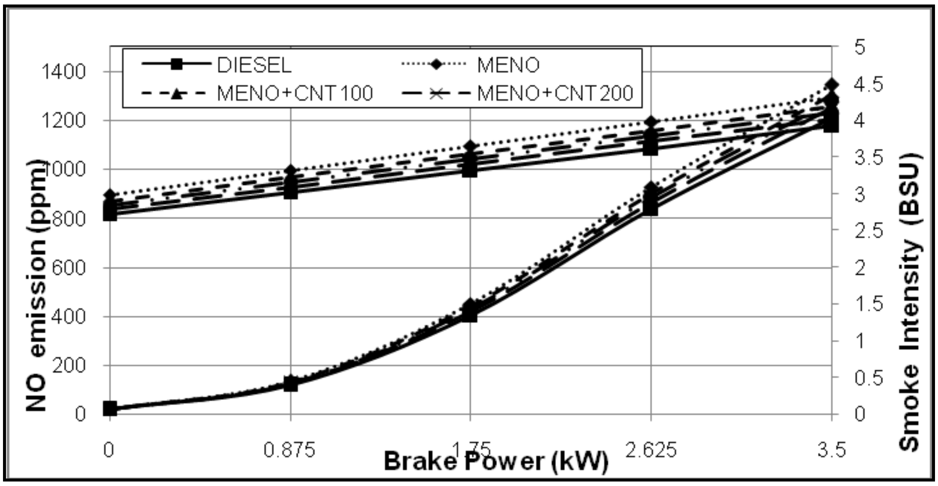

Fig.5 Variation of NO and Smoke Intensity with brake power

Fig 5, shows the variation of NO emission and smoke intensity with brake power for diesel, neat biodiesel and biodiesel-additive blends. The results show that NO emission increases with the increase of engine load due to more fuel combustion temperature. Addition of additive decreases NO emission compared to neat biodiesel. The NO emission decreases till MENO+CNT200 blend and then it increases. For MENO+CNT100, MENO+CNT200 and MENO+CNT300 mixtures NO emission reduces by 2.88 %, 7.25 % and 4.67 % respectively compared to neat biodiesel at full load condition. The peak pressure and the maximum rate of pressure rise were low for the CNT nanoparticles blend due to shortening ignition delay. Thus reduces the NO emissions with the addition of additives. The results show that smoke intensity increases for all fuels with the increase of engine load. Neat MENO gives more smoke than diesel as the higher viscosity of oil leads to poor mixture formation. Addition of additive decreases the smoke intensity at all load conditions. For MENO+CNT100, MENO+CNT200 and MENO+CNT300 mixtures smoke intensity decreases by 3.19 %, 8.38 % and 5.74 % respectively compared to neat biodiesel at full load condition. This may be due to better combustion resulting from better air fuel mixing[14].

HC emissions contribute to the formation of smog and may include photochemically reactive species as well as carcinogens. Additive addition has been shown to decrease in HC emissions. Fig 6, indicates the variation of hydrocarbon and CO emission with brake power for diesel, neat biodiesel and biodiesel-additive blends. The HC emission decreases till MENO+CNT200 and the further addition of nano additives increases the hydrocarbon emission as the fuel is contaminated by the nano additives. For MENO+CNT100, MENO+CNT200 and MENO+CNT300 mixtures HC emission decreases by 3.67 %, 10.39 % and 8.15 % respectively compared to neat biodiesel at full load condition. The higher density and viscosity of neat MENO cause poor mixture formation, which results in high partial burning during combustion process. So CO emissions for neat MENO are more than diesel at all loads. The addition of additive decreases CO emissions. For MENO+CNT100, MENO+CNT200 and MENO+CNT300 mixtures CO emission decreases by 856 %, 16.16 % and 11.77 % respectively compared to neat biodiesel at full load condition. CO emission reduction may be due to short ignition delay and the improved ignition characteristics of CNT nanoparticles leading to higher catalytic activity due to their higher surface to volume ratio and enhancing fuel air mixing in the combustion chamber.

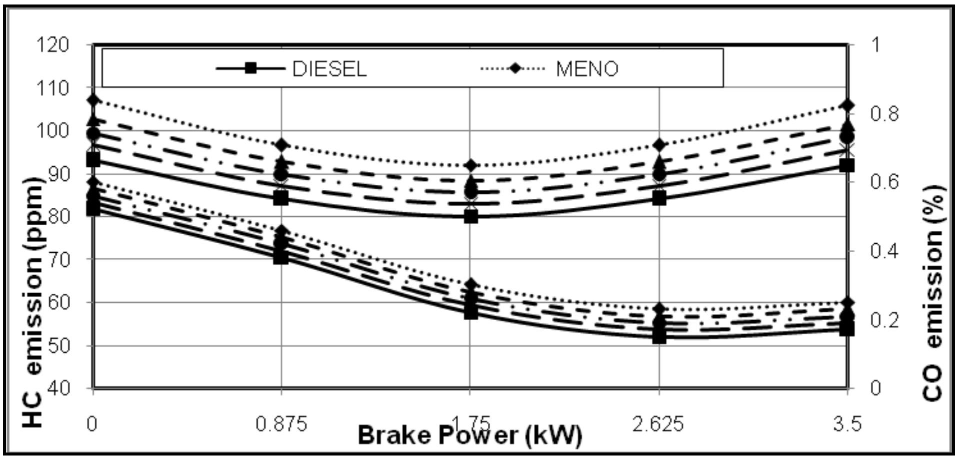

Fig.6 Variation of HC and CO with brake power

Conclusions

The effects of CNT nano additive addition on performance and emission with methyl ester of neem oil fuelled DI diesel engine at different loads has been studied and the main conclusions are:

1. The brake thermal efficiency increases by 4.17 % and NO emissions reduces by 7.25 % for MENO+CNT200 blend compared to neat biodiesel.
2. The NO, HC, CO and smoke emissions were reduces by adding nano additive to the neat biodiesel.
3. The performance parameter like brake thermal efficiency increases and brake specific fuel consumption decreases by adding nano additive.

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