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Impact of Carbon Nanotubes as Additives with Cotton Seed Biodiesel Blended with Diesel in Ci Engine - An Experimental Analysis

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ABSTRACT

In the present global scenario, fossil fuels are facing challenges due to escalating costs, increasing demand and impact on environmental pollution. In internal combustion engines, the emission characteristics and economy of the fuel are controlled by the chemical and physical properties of the fuel. Various additives are being used to act like catalysts with the fuels to improve quality of fuel, to obtain better combustion and to reduce exhaust emissions. At the time of combustion process, fuel instability reactions get accelerated by the catalysts which improve the performance of the engine. In this study, the B10, B15 and B20 fuel blends of cotton seed oil and diesel were mixed with the carbon nanotubes (CNTs) as an additive to analyse the performance and exhaust emissions of a CI engine. The carbon nanotubes were mixed with each fuel blend with the concentration of 50 ppm. All the tests were carried out for different engine loads. Tested characteristics were power, brake thermal efficiency (BTE), specific fuel consumption (SFC), and analysis of exhaust gases like hydrocarbons (HC), CO_2, CO and smoke. The experimental results showed that there was significant reduction of SFC and improved combustion by addition of CNTs. It was also observed that the exhaust emissions, CO, HC and smoke percentage got decreased by the influence of CNTs.

INTRODUCTION

The environmental degradation and atmospheric pollution are the two main factors which cause imminent harm to the existence of the world. There are number of reasons for the pollution, but the pollution caused by the exhaust emissions from automobiles and power generation unit takes major part in degradation of environment and global warming. The primary source of energy for vehicles and power generators are the petroleum fuels which are depleting very rapidly. In country like India, 2/3rd of the total economy was spent to acquire petroleum products despite they being responsible for environmental pollution. But the use of transportation vehicles and power generation cannot be neglected as they both are the foundation for the economic growth of the country (Perumal & Ilangkumaran 2017). Therefore, the search for renewable alternative fuels which are environment friendly has been enforced. Particularly, biofuels are the replacement for the fossil fuels and becoming a renewable source of energy. Hence, the use of biodiesel blend with diesel fuel in engines is a promising option. The reason behind using biodiesel as an alternative fuel is that, it can be used without any modification in engine and the power generated from engine using biodiesel fuels are similar to the engine using diesel fuel (Caliskan 2017). The commercialization of bio fuel and related projects enforces the employment either in direct or indirect manner. These projects are responsible to employ all the categories of people, including skilled and unskilled workers from different departments. The government has already initiated programs for urban, industrial and commercial applications. These programs aimed to evaluate energy from vegetable wastes, agriculture residue, municipal wastes, and industrial wastes (Gaurav et al. 2017).

Biodiesel is nothing but methyl or ethyl ester of fatty acids which is made from both edible and non-edible vegetable oils and animal fats. For the production of biodiesel the main resources are non-edible oils extracted from plant species such as *Calophyllum inophyllum, Pongamia pinnata, Jatropha curcas, Hevea brasiliensis* etc. Biodiesel can be used in its unadulterated form in engine or can be blended with pure diesel fuel in any proportion. Like petroleum diesel, biodiesel has similar properties and works in compression ignition engine with minor or no engine modifications. It can be stored just like pure diesel and does not require any separate storage. The use of biodiesel in compression ignition engines results in reduction of emissions like carbon monoxide, unburned hydrocarbons and particulate matters (Agarwal 2007) Presently, the first-generation biofuels are dominating

Fig. 1: TEM image of carbon nanotubes.

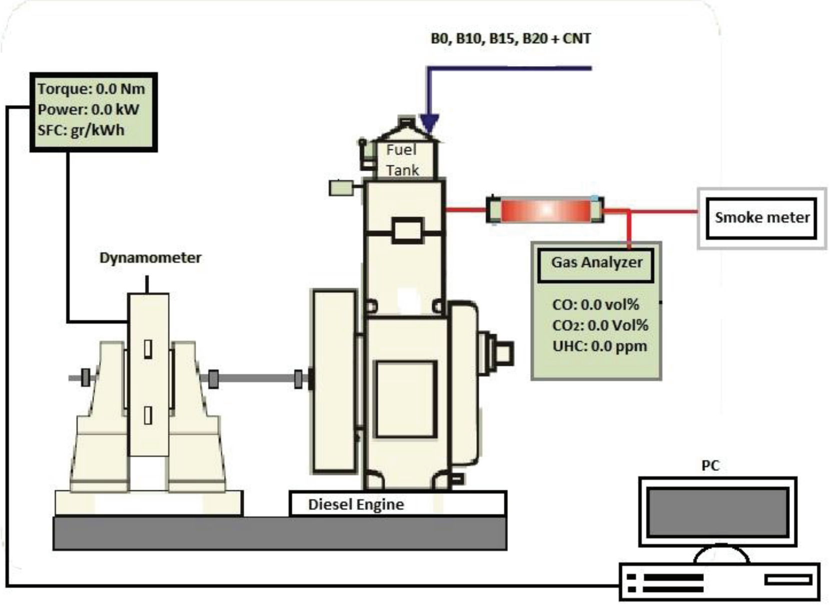

Fig. 2: Measurement setup and devices for the experiments.

the biofuel sector, such as bioethanol and biodiesel. These biofuels can be used as blends with petroleum fuels in low percentage and can be utilized with existing infrastructure. The main advantage of using vegetable oils as alternative to conventional fuels exist in their renewable nature and there is wide availability from different variety of sources. There are also some disadvantages of using these vegetable oils which has incompatibility with petroleum lubricating oils, higher viscosity and problem of foul injector nozzles. To minimize the viscosity as well as problems related to lubrication, trans-esterification method and de-gumming of vegetable oil has been used (Eevera & Pazhanichamy 2013).

MATERIALS AND METHODS

In this research, the cotton seed biodiesel was produced from the cotton seed oil, using trans-esterification process. The carbon nanotubes (CNTs) used with the dose of 50 ppm and then mixed with B10, B15 and B20 fuel blends. Each fuel blends were made of 500 mL sample to be tested in the engine.

Multi-walled carbon nanotubes (MWNTs) were supplied from Platonic Nanotech Private Limited, India with purity more than 97%. The average diameter of the carbon nanotubes varied from 10-15 nm and their length from 2-10 μm.

Carbon nanotubes acts as an useful additives for improving the quality of the fuels (Hosseini et al. 2017). Recently, several researchers have incorporated different additives to improve the fuel properties of the biofuels. Addition of CNTs with the diesel fuel increases the cetane number, burning rate and suppresses the smoke formation in the engine cylinder during combustion process (Basha 2015, Tennent et al. 2002). The carbon nanotubes contain amide group and has property of reacting with many chemicals. The TEM (transmission electron microscopy) image of carbon nanotubes which was used with diesel-biodiesel blended fuel is shown in Fig.1. The CNTs added to all fuel blends were stirred for 15 min to get the homogeneous emulsion fuel.

Experimental Set-up

The experimental system consists of one cylinder, four strokes, VCR (Variable Compression Ratio) diesel engine which was connected to eddy current type dynamometer for loading with its main parameters are given in Table 1.

In order to compute and assess the exhaust gas emissions a mobile AVL DITEST GAS analyser was also used for this experiment. A smoke opacity meter was used to calculate the amount of soot coming out from the exhaust which is attached to exhaust gas duct coming from engine. An onboard computer system is used to perform the common combustion calculations to eliminate the use of tables and complex calculations. Details of the measuring instruments used for testing are given in Table 1.

Experimental Procedure

For the experiment different fuel blends (i.e. diesel base, B10, B15, B20, B10C50, B15C50, B20C50) were prepared. The blending of diesel fuel with biodiesel was made in 500 mL flask which was directly poured in fuel tank. The kinematic viscosity, fire point, flash point, density and calorific value were calculated immediately after the biodiesel preparation. The experiments were performed under variable loads on engine to get different speeds. Various parameters such as torque, specific fuel consumption (SFC), mechanical efficiency, power, volumetric efficiency and brake thermal efficiency were recorded and the data was transferred to the computer which was connected to the engine setup. The analysis done for the performance of engine is for 500 mL quantity of fuel for each fuel blend. To establish the baseline data, first the diesel fuel was used in the engine at varied loading conditions. Similarly, the testing was executed for different biodiesel blends at different load conditions. To attain the steady state conditions and to minimize the residual from previous fuel blends each test was started by a 10 min start-up period.

RESULTS AND DISCUSSION

Table 2 gives the characteristics, which were measured based on ASTM (American Society for Testing and Materials) standards for the tested fuel blends. By adding carbon nanotubes in fuel blends the viscosity decreases and makes it easier to slip. Because of this the spraying and powdering of fuel inside combustion chamber is more proper. Duraisamy & Gowrishankar (2011) proved that the volatility and viscosity have interdependency with the dose of carbon nanotubes (20-80 ppm).

Engine Torque and Power

Table 3 gives the effect of addition of CNTs with diesel-biodiesel blends on engine torque. It is observed that maximum torque for each fuel blends is at higher loads and as the load decreases there is decrease in torque. By decreasing the engine load from 12 to 0 kg the torque decreases on an average by 4.20%. It can be observed that use of CNTs with diesel-biodiesel blends leads to improve the engine torque at certain loads compared to pure diesel and diesel-biodiesel blends. The output torque increases by raising the concen-

Table 1: Specifications of all equipment and devices used in the experiments.

Engine type	4-stroke VCR diesel engine
Number of cylinders	One
Bore × stroke	87.5 × 110 mm
Swept volume	661 cc
Compression ratio	17.5:1
Rated power	3.5 kW at 1500 rpm
Fuel injection timing	23° BTDC
Dynamometer type	Eddy current, water cooled with loading unit
Emission Analyzer	AVL DITEST GAS 1000, Emission diagnostics of HC, CO, CO_2
Smoke Opacity Meter	Model AVL DiSmoke 480 BT

Table 2: Properties of all the fuel blends.

Properties	Diesel base	B10	B15	B20
Kinematic Viscosity (mm^2/sec)	2.25	2.38	2.56	2.73
Density (kg/m^3)	790	802	810	817
Calorific value (MJ/kg)	43.25	42.89	42.16	41.35
Flash point (ºC)	56	71.60	80.25	88.5

Table 3: Torque at different loads for all the fuel blends.

Load (kg)	B0	B10	B10C50	B15	B15C50	B20	B20C 50
0 kg	0.91	0.97	0.98	0.98	0.98	0.99	0.70
3 kg	5.81	5.84	6.03	5.85	5.73	5.88	5.76
6 kg	11.24	11.29	11.27	11.27	11.28	11.28	11.21
9 kg	16.68	16.71	16.70	16.71	16.87	16.70	16.64
12 kg	21.91	22.14	22.10	22.29	22.10	22.11	22.06

Table 4: Power at different loads for all the fuel blends.

Load (kg)	B0	B10	B10C50	B15	B15C50	B20	B20C 50
0 kg	0.14	0.15	0.15	0.15	0.15	0.15	0.11
3 kg	0.89	0.91	0.91	0.90	0.88	0.90	0.90
6 kg	1.71	1.72	1.72	1.73	1.73	1.71	1.72
9 kg	2.53	2.54	2.54	2.54	2.56	2.52	2.52
12 kg	3.29	3.32	3.32	3.35	3.31	3.30	3.31

tration of CNTs in fuel blends, which improves the complete combustion inside the cylinder.

Table 4 gives the power variation at different loads for all fuel blends. As seen from the table, the power increases sharply as the load is increased. B0, B10 and B20 have lower power output as compared to B10C50, B15, B15C50, B20C50. In general, the brake power increases with the use of CNTs in fuel blends at variable loads. The reason for increased power with CNTs and fuel blends is energy produced inside the cylinder. According to the earlier research, the catalyst reduces the combustion duration and ignition delay, which leads to faster heat release rate and higher peak pressure inside the cylinder (Heydari-Maleney et al. 2017, Ma et al. 2013, Kannan et al. 2011). The addition of nanoparticles modifies the mechanism of ignition for liquid fuels, which accelerates the thermal interchangeability between the surrounding air and fuel droplets (Solero 2012).

Brake Thermal Efficiency (BTE)

The brake thermal efficiency for all the fuel blends is given in Table 5. Due to reduction in volumetric efficiency the BTE increases as the load on engine increases. The lowest values of BTE are for B20C50, B0 and B10 fuels and the maximum values of BTE are related to B10C50, B15, B15C50 and B20 fuel blends. Therefore, adding CNTs (50ppm) in fuel blends shows increase in amount of BTE due to better fuel spraying and dropped viscosity for some of the fuel blends.

Specific Fuel Consumption (SFC)

The variations of SFC of all fuel blends for the different loads are shown in Table 6. At different loads the SFC is lower for B15, B15C50, B20 and B10C50, whereas B0, B10, and B20C50 had the higher SFC. The reason for higher SFC is higher viscosity, lower heating value and oxygenated characteristic of biodiesel fuels (Singh et al. 2012, Porteiro et al. 2007). Therefore, addition of CNTs to the diesel-biodiesel fuel blends improves combustion, increases power and decreases the SFC of the engine. It has been observed from Table 6 that as the load is increased there is reduction in SFC. The reason for lower SFC values is the higher BTE of the fuels with CNTs, which is due to existence of oxygen molecules and CNTs.

Table 5: Brake thermal efficiency at different loads for all fuel blends.

Load (kg)	B0	B10	B10C50	B15	B15C50	B20	B20C 50
0 kg	3.50	3.74	3.81	4.42	4.40	3.81	2.69
3 kg	17.01	17.36	17.71	17.25	16.88	17.25	15.45
6 kg	26.72	26.85	26.80	27.10	27.07	26.74	24.67
9 kg	31.08	31.17	31.12	31.27	31.53	31.04	30.93
12 kg	35.43	33.61	33.48	33.93	33.55	33.45	31.61

Table 6: Brake specific fuel consumption at different loads for all fuel blends.

Load (kg)	B0	B10	B10C50	B15	B15C50	B20	B20C 50
0 kg	2.45	2.29	2.25	1.94	1.95	2.25	3.18
3 kg	0.50	0.49	0.48	0.50	0.51	0.50	0.55
6 kg	0.32	0.32	0.32	0.32	0.32	0.32	0.35
9 kg	0.28	0.28	0.28	0.27	0.27	0.28	0.28
12 kg	0.24	0.26	0.26	0.25	0.26	0.26	0.27

Analysis of Emissions

Carbon monoxide (% Vol)

The carbon monoxide emissions which comes from engine exhaust represents the loss of chemical energy which is not fully employed to generate engine power. Fig. 3 shows the percentage of concentration of CO emissions for all the fuel blends at variable loads. It has been noticed that at higher loads the CO emissions are less and at medium loads the CO emissions are highest in all the fuel blends. B10, B10C50, B15C50 had the lower CO content, whereas B0, B15, B20, B20C50 had the higher CO content. The average CO emissions decreased 27.27 % for the fuel blends with CNTs when compared to neat diesel and biodiesel blends. It was observed that there is significant lowering of CO emissions when CNTs, biodiesel and its blends were used as compared to pure diesel. The reason behind lowering of CO emission is existence of more oxygen content in biodiesel than pure diesel fuel, which causes to make complete combustion of the mixture present in combustion chamber and ensures less CO emissions (Taghizadeh-Alisaraei and Rezaei-Asl 2016). Decreased viscosity of the fuel plays significant role in minimizing CO emissions by improving fuel atomization. As the CNTs had larger surface area, it increases the chemical reactivity by which the ignition delay gets consecutively shortened. Due to the effect of shortened ignition delay uniform burning and fuel-air mixing had been improved which promotes complete combustion of fuels in presence of potential CNTs (Javed et al. 2016, Srinivas et al. 2016).

Carbon dioxide

Fig. 4 shows the carbon dioxide emissions at different loads for various fuel blends. After comparing CO and CO_2 emissions, it has been noted that the molecular component and balance for a given fuel have opposite behaviours. Therefore, the carbon present in exhaust gas has potential to become CO_2 or CO. As the load on the engine was increased then the CO_2 content got increased. B15, B20, B10C50, B15C50 had the higher CO_2 content while B0, B10, B20C50 had the lower CO_2 content.

As a rule, the most cost effective and efficient use of fuel takes place when the CO_2 content in the exhaust is maximized. This happens only when there is sufficient O_2 present in the supplied air to react with carbon present in the fuel. Therefore, as the amount of air gets increased in the combustion chamber the concentration of CO molecules gets decreased. Due to this, the additional atoms of oxygen present in the air reacts with this CO molecules and form CO_2. The maximum amount of CO_2 depends upon the category of fuel used (TSI 2004).

Hydrocarbons emissions

The unburned hydrocarbon present in the exhaust is the consequence of incomplete combustion of fuel. The variations of HC emissions are shown in Fig. 5 for all the fuel blends at variable loads. The minimum and maximum HC emissions are observed at lower and higher loads respectively. The larger reduction of HC emissions is for the B20C50, B20, B15C50 and B15 fuel blends. This is because of higher oxygen content present in the biodiesel which makes possible to obtain more complete combustion inside the combustion chamber (Sahoo et al. 2007). The HC emissions are found to be noticeably reduced due to addition of CNTs to the fuel blends. The reason behind this is significant fuel distribution

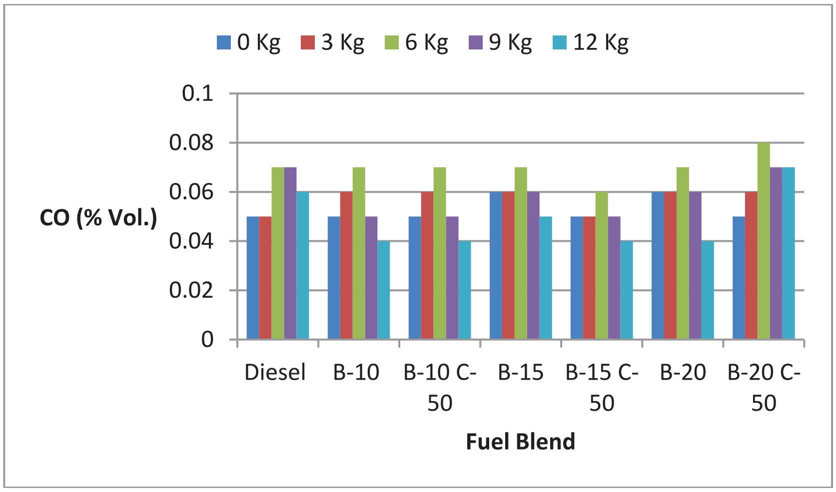

Fig. 3: CO for different fuel blends at different loads.

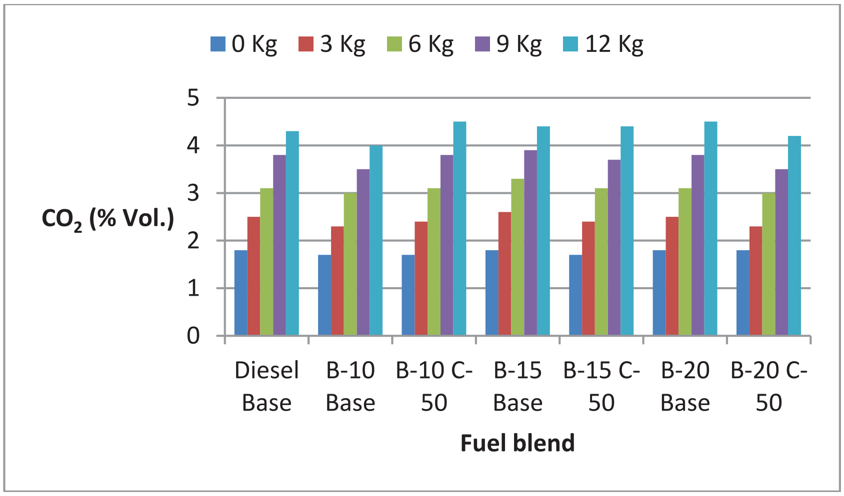

Fig. 4: CO_2 for different fuel blends at different loads.

and intensive atomization with the existence of CNTs in combustion chamber which causes CO and HC oxidation during the combustion (Sadhik Basha & Anand 2014).

Smoke

Fig. 6 shows the trend of smoke opacity at different loads for different fuel blends. The percentage of smoke opacity for pure diesel was higher while for the fuel blends with CNTs were drastically lesser. The reason for reduction of smoke for the fuel blends is probably due to intensive atomization, better fuel-air mixing and enhanced air spray momentum (Subramanian & Ramesh 2002, Armas et al. 2005, Rao & Anand 2016)50 and 100 ppm. In case of B20 and B20C50 the smoke opacity is minimum than that of other fuel blends. This is due to higher oxygen content present in the biodiesel which facilitates the complete combustion. Because of heterogeneous nature of the diesel combustion there is variation of fuel-air ratios inside the cylinder of diesel engine, which affects the smoke formation. The smoke formation primarily takes place at higher pressure and temperature in the fuel rich zone of the engine cylinder. As the fuel used in diesel engine is partially oxygenated the major smoke formation can be reduced (Puhan et al. 2005).

Optimal Fuel

In all the fuel blends, addition of CNTs proved to be a better additive which increased the amount of torque. It can be observed that larger power and BTE belongs to B15C50,

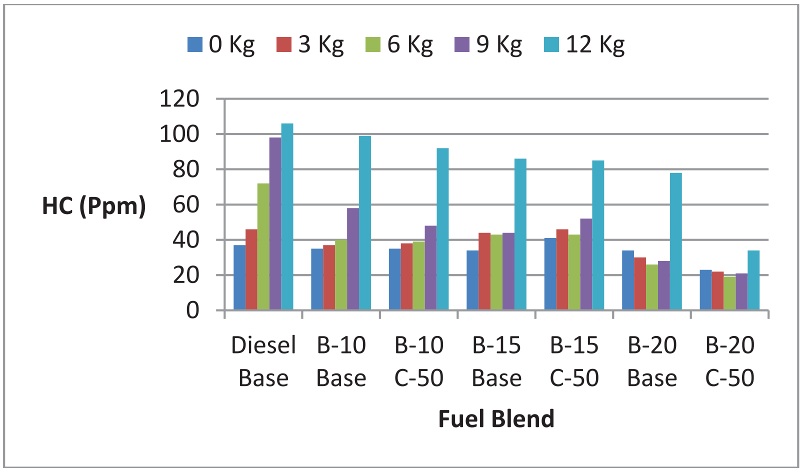

Fig. 5: HC for different fuel blends at different loads.

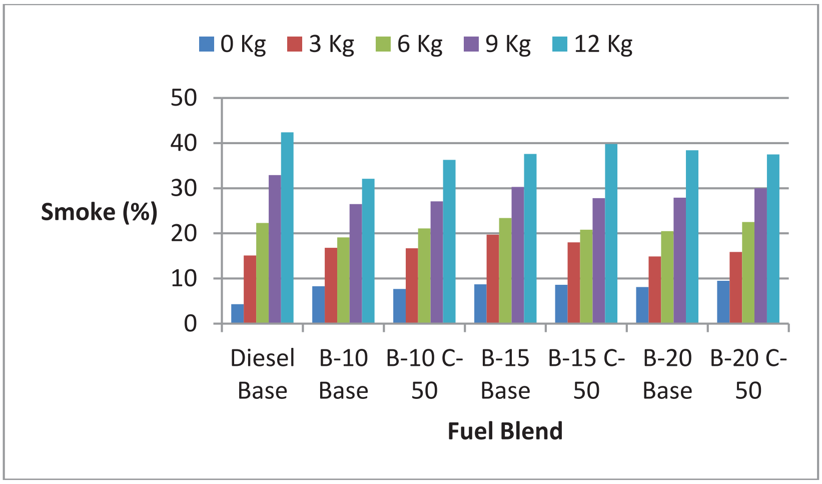

Fig. 6: Variation of smoke opacity for different fuel blends at different loads.

B20C50, B15 and B10C50 fuel blends respectively. Similarly, the torque trend follows the power table and has matching results. B15, B15C50, B20 and B10C50 have the minimum SFC.

According to the emissions results, B10C50, B15C50 had the lower CO content. B20C50, B20, B15C50 and B15 fuel blends have the lowest HC emissions. The smoke opacity is lesser for all the fuel blends with CNTs than the pure diesel. Based on these results, the optimal fuel can be selected as B15C50 fuel blend. Therefore, B15C50 is considered as the best fuel in terms of performance and emissions parameters. The greatest variations occurred for all the parameters are for higher loads.

Cost Analysis

The cost of the CNTs used in the present experiments is about 384 US$ per kg in India and the dose of 50 ppm are respectively 0.05 g per 500 mL for B10, B15 and B20 fuel blends. The specific cost for 50 ppm CNT is 0.0192 US$ for per 500 mL of B10, B15 and B20 fuel blends. In addition, the diesel fuel cost in India is about 0.92 US$. Adding CNTs with the dose of 50 ppm to B10, B15 and B20 fuel blends, the fuel price increases by 2%. In country like India the higher price of diesel fuel enforces the use of additives as it results in reduction of SFC. Hence, the use of CNTs with diesel fuel is much more economical and affordable in India. However, other advantage such as reduction in exhaust emissions can also be contemplated.

CONCLUSIONS

In this study, the B10, B15 and B20 fuel blends included with carbon nanotubes (CNTs) were used to analyse the exhaust emissions and performance characteristics of a single cylinder CI engine. The CNTs were mixed with the dosage of 50 ppm to all the fuel blends. The experiments were conducted by varying the loads on the engine. The results indicated that the performance characteristics such as power, torque, BTE, SFC of B15C50 fuel blend is optimum as compared to other fuel blends and pure diesel. The exhaust emissions of B15C50 fuel blend like CO, HC and smoke opacity were found minimum as compared to pure diesel and other fuel blends. The existence and translocation of CNTs in the fuel molecules improved the fuel atomization and decreased the viscosity. Overall, it has been found that the CNT used with fuel blends has potential advantage to improve the performance and to reduce the exhaust emissions from the diesel engine.

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NOMENCLATURE

B0	Pure Diesel	nm	nanometer
B10	90% Diesel + 10% Biodiesel	µm	micrometer
B15	85% Diesel + 15% Biodiesel	ppm	part per million
B20	80% Diesel + 20% Biodiesel	CI	Compression ignition
B10C50	B10 + 50 ppm CNTs	HC	Hydro carbons
B15C50	B10 + 50 ppm CNTs	CO	Carbon monoxide
B20C50	B10 + 50 ppm CNTs	CO_2	Carbon dioxide
BTE	Brake thermal efficiency (%)	rpm	Revolutions per minute
CNTs	Carbon Nanotubes	SFC	Specific fuel consumption
kW	kilo Watt	Nm	Newton meter

REFERENCES

Agarwal, Avinash Kumar. 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science, 33(3): 233-71.

Armas, O., Ballesteros, R., Martos, F.J. and Agudelo, J.R. 2005. Characterization of light duty diesel engine pollutant emissions using water-emulsified fuel. Fuel, 84: 1011-18.

Basha, J.S., 2015. Applications of functionalized carbon-based nanomaterials. In: Chemical Functionalization of Carbon Nanomaterials, CRC Press, pp. 598-613.

Caliskan, Hakan 2017. Environmental and enviroeconomic researches on diesel engines with diesel and biodiesel fuels. Journal of Cleaner Production, 154: 125-29.

Duraisamy, Ganesh and Gowrishankar, G. 2011. Effect of nano-fuel additive on emission reduction in a biodiesel fuelled CI engine. In 2011 International Conference on Electrical and Control Engineering, IEEE, pp. 3453-3459.

Eevera, T. and Pazhanichamy, K. 2013. Cotton seed oil: a feasible oil source for biodiesel production. Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 35(12): 1118-28.

Gaurav, N., Sivasankari, S., Kiran, G.S., Ninawe, A. and Selvin, J. 2017. Utilization of bioresources for sustainable biofuels: A review. Renewable and Sustainable Energy Reviews, 73: 205-14.

Heydari-Maleney, K., Taghizadeh-Alisaraei, A., Ghobadian, B. and Abbaszadeh-Mayvan, A. 2017. Analyzing and evaluation of carbon nanotubes additives to diesohol-B2 fuels on performance and emission of diesel engines. Fuel, 196: 110-23.

Hosseini, S.H., Taghizadeh-Alisaraei, A., Ghobadian, B. and Abbaszadeh-Mayvan, A. 2017. Performance and emission characteristics of a ci engine fuelled with carbon nanotubes and diesel-biodiesel blends. Renewable Energy, 111: 201-13.

Javed, S., Murthy, Y.S., Baig, R.U. and Rao, T.N. 2016. Vibration analysis of a diesel engine using biodiesel fuel blended with nano particles by dual fueling of hydrogen. Journal of Natural Gas Science and Engineering, 33: 217-30.

Kannan, G. R., Karvembu, R. and Anand, R. 2011. Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel. Applied Energy, 88(11): 3694-3703.

Ma, Y., Zhu, M. and Zhang, D. 2013. The effect of a homogeneous combustion catalyst on exhaust emissions from a single cylinder diesel engine. Applied Energy, 102: 556-62.

Perumal, V. and Ilangkumaran, M. 2017. Experimental analysis of engine performance, combustion and emission using pongamia biodiesel as fuel in CI engine. Energy, 129: 228-36.

Porteiro, J., Granada, E. and Mora, J. C. 2007. Performance and exhaust emissions in the use of biodiesel in outboard diesel engines. Fuel, 86: 1765-71.

Puhan, S., Vedaraman, N., Ram, B.V., Sankarnarayanan, G. and Jeychandran, K., 2005. Mahua oil (Madhuca Indica seed oil) methyl ester as biodiesel-preparation and emission characterstics. Biomass and Bioenergy, 28(1): 87-93.

Rao, M. Srinivasa and Anand, R.B. 2016. Performance and emission characteristics improvement studies on a biodiesel fuelled DICI engine using water and AlO(OH) nanoparticles. Applied Thermal Engineering, 98: 636-45.

Sadhik Basha, J. and Anand, R.B. 2014. Performance, emission and combustion characteristics of a diesel engine using carbon nanotubes blended jatropha methyl ester emulsions. Alexandria Engineering Journal, 53(2): 259-73.

Sahoo, P. K., Das, L. M., Babu, M.K.G. and Naik, S. N. 2007. Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI Engine. Fuel, 86(3): 448-54.

Singh, Bhupendra, Naveen Kumar and Haeng Muk, 2012. A study on the performance and emission of a diesel engine fueled with jatropha biodiesel oil and its blends. Energy, 37(1): 616-22.

Solero, Giulio 2012. Experimental analysis of the influence of inert nano-additives upon combustion of diesel sprays. Nanoscience and Nanotechnology, 2(4): 129-33.

Srinivas, Dilip, Puneesh Puri and Vigor Yang 2016. A general theory of ignition and combustion of nano- and micron-sized aluminum particles. Combustion and Flame, 169: 94-109.

Subramanian, K. A. and Ramesh, A. 2002. Use of diethyl ether along with water-diesel emulsion in a di diesel engine. In: SAE Technical Paper, SAE International.

Taghizadeh-Alisaraei, Ahmad and Abbas Rezaei-Asl. 2016. The effect of added ethanol to diesel fuel on performance, vibration, combustion and knocking of a CI engine. Fuel, 185: 718-33.

Tennent, Howard, Kennett Square and References Cited 2002. (12) United States Patent (10) Patent No.: 2(0): 4-7.

TSI 2004. Combustion analysis basics: An overview of measurements, methods and calculations used in combustion analysis. TSI Incorporated, 2004