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Research Article

Effect of CNT-Emulsified Fuel on Performance Emission and Combustion Characteristics of Four Stroke Diesel Engine

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Abstract

CNT-emulsified fuel is used in a single cylinder water cooled four stroke diesel engine. CNT: Carbon nano tubes are produced by indigenous flame synthesis method. Water diesel emulsion prepared in the proportion of 83% diesel, 15% water and 2% surfactant is used. Tween 80 and Span 80 are used as surfactants with a HLB balance of 8. CNT in the mass fraction of 50ppm, 100ppm and 150ppm are blended in the water diesel emulsion. CNT are dispersed in the water for 35 minutes with the help of ultrasonicator set at frequency of 40 kHz and ultrasonic power of 120 W. Dispersed CNT are subsequently added in mixture of diesel and surfactant to produce CNT blended water diesel emulsion. A mechanical homogeniser is used to produce emulsion at the speed of 3000 rpm for 25 minutes. The experiment is conducted on a single cylinder diesel engine coupled with eddy current dynamometer and equipped with data acquisition system. Exhaust emissions are measured by AVL Di-gas analyser and AVL smoke opacity meter. Experiment is carried out at a constant speed of 1500 rpm from no load to full load for all fuel specimens. Effect of CNT-emulsified fuel on the characteristics such as rate of pressure rise, net heat release in the cylinder , brake specific fuel consumption ,brake thermal efficiency, and emissions i.e. NOx, CO, HC, CO_2 are analyzed. The results have shown significant improvement in the engine performance, combustions attributes and reduction in emissions using CNT-emulsified fuel.

Keywords: *Diesel engine, Carbon nano tubes, Water-diesel emulsion, Performance, emission.*

1. Introduction

Diesel engines are fuel efficient and better at part load efficiency when compared to petrol engines. But CI diesel engines produce high emissions of NOx, CO, CO_2, HC, smoke and other harmful compounds. As Government is implementing strict emissions norms, the emissions reduction is a major research objective .Techniques such as fuel modification, engine design, exhaust gas treatment etc. have been tried to reduce diesel engines emissions. Emulsification is one of the methods to reduce CI engine emissions without making any modification in the engine design. In water diesel emulsion the presence of water vapor has a beneficial effect on the rate of heat release and reduces the pollutants emission [Cherng-Yuan Lin and Kuo-Hua Wang, 2003; C.Y. Lin and K.H. Wang, 2004; C.Y. Lin and L.W. Chen, 2006; Ghojel J *et al*., 2006; Kadota T and Yamasaki H, 2002; Samec N *et al*., 2002]. Emulsified fuel in internal combustion engines reduces NOx, soot, and particulate emission, [J. M. Ballester *et al*., 1996; R. W. Gunnerman and R. L. Russel ,1997; M. Tsukahara and Y. Yoshimoto, 1992] additionally adding water to diesel fuel reduces the metal temperature, heat flux and the thermal loading of combustion chamber components [M. Y. E. Selim and S. M. S. Elfeky, 2001].

There is trade-off between emissions of nitrogen oxides, particulate matter and hydrocarbons, carbon monoxide with the increase of water content in the emulsion [Lif A and Holmberg K., 2006]. Although there are benefits of emulsion fuels but water diesel emulsion fuel leads to prolongation of ignition delay which subsequently causes high pre-mixed combustion rate, high heat release rate, peak pressure, cold-start problem and rough engine operation [Harbach, J.A. and V. Agosta, 1991; Subramanian, K.A. and A. Ramesh, 2002; M.Y.E. Selim and M.T. Ghannam, 2007; Subramanian K.A and A. Ramesh, 2002; O. Armas *et al*., 2005].

The cetane value of fuel is reduced with the addition of water which causes prolonged ignition delay problem [Kweonha Park *et al*., 2004].Recently some potential additives have been tried to get rid of drawbacks of emulsified fuel. Some work has been reported on applications of various nano–particles for diesel engine. Development in the nano-technology field directs the use of nano-fuel as a potential secondary energy carrier [Wen. D, 2010]. Nano particle blended fuels exhibits different thermo physical

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properties compared to base fuels. High surface area to volume ratio of the nano particles enables a larger contact surface area during rapid oxidation process and helps to release more energy than the best molecular explosives [Rossi C *et al.*, 2007; Sun J and Simon SL, 2007]. Studies have shown the effect of adding nanoparticles to a fluid in enhancing its physical properties such as thermal conductivity and radiative heat transfer [R. Prasher *et al.*, 2006; S. Krishnamurthy *et al.*, 2006; H. Tyagi *et al.*, 2007]. Great concern has been shown on addition of nanoparticles to liquid fuels as nanoparticles having high surface area to volume ratio can increase contact between the fuel and oxidizer. Nanoparticles also affect the timing of chemical reactions, which further decrease ignition delay time [L. T. De Luca *et al.*, 2005; A. Pivkina *et al.*, 2004] Recent some work has been done on adding the potential nanoparticles to shorten the ignition delay. Owing to their enhanced surface area to volume ratio, quick evaporation rate and shorter ignition delay characteristics nano-additives have been considered as fuel-borne catalyst to improve the fuel properties. Report on nano-particle combustion state that adding nano-catalyst to the hydrocarbon fuels (such as diesel) will reduce the ignition delay and soot emissions [H. Tyagi *et al.* 2008; R.A. Yetter *et al.*, 2009]. Adding aqueous aluminium nanofluid to diesel fuel has shown increase in the total combustion heat, while decrease in the smoke and nitrogen oxides in the exhaust emission from diesel engine. In the same way Cerium oxide nanoparticles and ceria nanoparticles have been added to biodiesel witnessing improvement in the brake thermal efficiency and reduction in the ignition delay, heat release rate and the emission level of hydrocarbon and NOx [Kao, M.J *et al.*, 2008; Sajith, V *et al.*, 2010; Selvan, A.M *et al.*, 2009].

Potential of CNT in a base fluid indicates to enhance the surface-area-to-volume ratio and settling time. CNT could act as a potential nano-additive for the fuels to improve the cetane number by enhancing the burning rate, and act as an anti-knock additive to promote clean burning by suppressing the smoke formation[David Moy *et al.*, 2002; Marquis, E. D. S. and Chibante, L.P.F, 2005]. On the applications of CNT, experiments have been conducted in a single cylinder diesel engine using CNT and Alumina nanoparticles as additive with diesel, biodiesel, water–diesel emulsions with lower percentage of water in the emulsion and observed an appreciable increase in the brake thermal efficiency and reduced harmful pollutants compared to that of neat diesel and water diesel emulsions [J. Sadhik Basha and R.B. Anand, 2010, 2011, 2011 and 2014].

The present work determine the effects of CNT as an additive with the water diesel emulsion on the combustion characteristics, emission and the performance of a single cylinder direct injection diesel engine. Hence this investigation is dedicated to provide a solid pathway to use the potential benefits of CNT with the water–diesel emulsion (15% of water content).

2. Experimentations Details

2.1 Carbon nano tubes as an additive in emulsified fuel

In emulsification process water is mixed with fuel in micro scale. Surfactant is added to reduce the surface tension of water and to help in avoiding the contact of water with engine surfaces. Limitations of emulsified fuel have pressed the investigators to find some solutions. CNT have possessed the potential to eliminate the drawback of emulsified fuel.

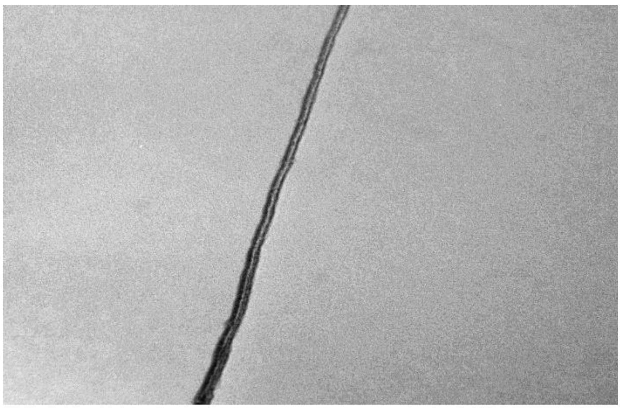

Fig. 1 TEM micrograph of synthesized MWCNT

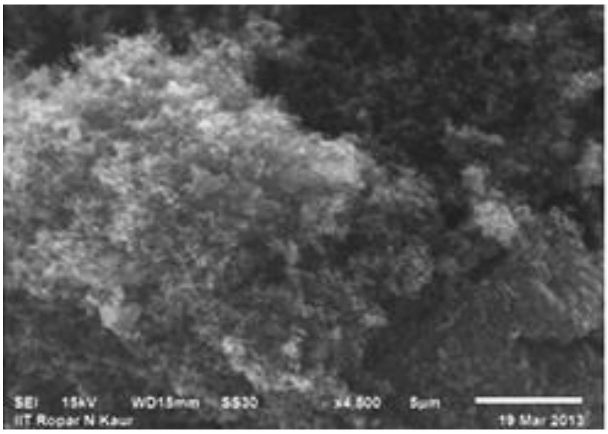

Fig. 2 SEM image of purified MWCNT

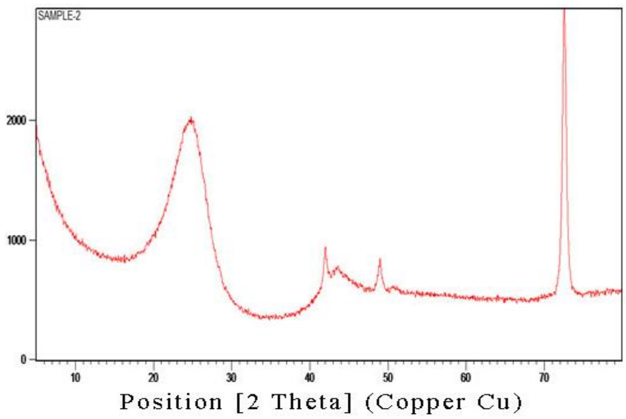

Fig. 3 XRD Spectra Showing peaks of ordered MWCNT

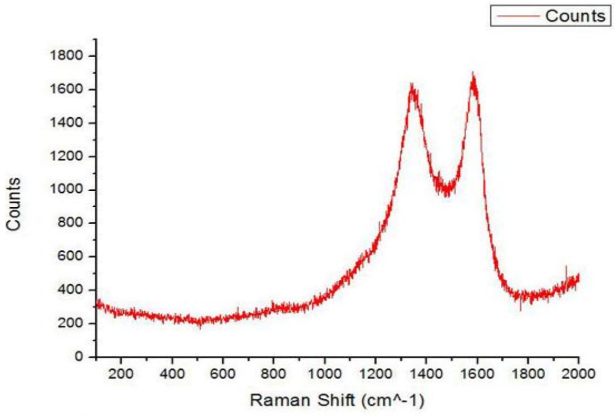

Fig. 4 Raman spectra showing D band and G band peaks of MWCNT

CNT are used in the emulsified fuel to add their benefits. CNT are produced from domestic LPG by an open Flame Synthesis method using oxygen as an oxidizer. Transmission Electron Microscopy, Scanning Electron Microscopy, X Ray Diffraction and Raman Spectroscopy techniques are used to characterize the CNT produced indigenously. Fig. 1, 2, 3 and 4 shows the TEM micrograph, SEM image, the XRPD pattern and the Raman analysis of the synthesized MWCNT [Bharj J. *et al*., 2014].

MWCNT produced in the lab are weighted in the mass fraction of 50ppm, 100ppm and 150ppm. These CNT are blended in the water diesel emulsion to investigate their effect on combustion performance and emission aspect of diesel engine. Mixing of CNT in water diesel emulsion is discussed in section test fuels and methods.

2.2 Experimental apparatus

The test engine in this study is a water-cooled single-cylinder direct injection diesel engine (shown in Fig. 5). It is equipped with data acquisition system to analyse the performance and combustion characteristics using different fuel specimens. Engine specifications are listed in Tab. 1. Exhaust emissions are measured by an AVL Di-gas analyser i.e. carbon monoxide, carbon dioxide, hydrocarbon and oxides of nitrogen. The AVL smoke opacity meter is used to measure the smoke opacity. AVL Di-gas analyser (model AVL Di-gas 4000 light) and smoke opacity meter (model AVL 437) used are shown in Fig. 6 and 7. The experiments are performed at a constant rated speed of 1500 rpm with a fixed compression ratio of 17.5: 1 at constant injection timing of 23^0 before top dead center. Results are obtained by varying the loads. The tests is conducted at 0% 20%, 40%, 60%, 80% and 100% load and repeated three times for all kind of fuel specimens in order to increase the reliability of test results. All the tests are conducted starting with pure diesel, water diesel emulsion and then with CNT blended water diesel emulsions. Each test is conducted by flushing out the previous fuel then putting the new fuel to maintain the accuracy of the results. During the tests, the parameters such as rate of pressure rise and net heat release in the cylinder, brake thermal efficiency and specific fuel consumption are recorded on the computer attached to the engine test rig .

Fig. 5 Single cylinder diesel engine test rig

Fig. 6 AVL Di-gas analyser

Fig. 7 AVL smoke opacity meter

Table 1 Engine specifications

Type	Kirloskar TV1 make single cylinder Four stroke direct injection
Nozzle opening pressure	200 -205 bar
Bore × Stroke	87.5*110 mm
Compression Ratio	17.5 : 1
Cubic capacity	661.5 cc
Rated Power Output	5.2 KW (7HP) at 1500 rpm.
Injection of fuel	23^0 before TDC
Dynamometer	Water cooled ,Eddy current
Data acquisition system	NI USB-6210,16 bit,250 kS/s
Speed scan interval	2000 msec
No of cycles	10

Table 2 Fuel Designation

Sample No.	(Fuel designation)[%Diesel+% of water+% of Surfactant+% of CNT]
1	(PD)[100% Diesel]
2	(D15W2S) [83%Diesel+15%Water+2%Surfactant]
3	(D15W2S50N) [83%Diesel+15%Water+2%Surfactant+50ppmCNT]
4	(D15W2S100N) [83%Diesel+15%Water+2%Surfactant+100ppmCNT]
5	(D15W2S150N) [83%Diesel+15%Water+2%Surfactant+150ppmCNT]

Table 3 Tested fuel Properties and their stability period

Properties of emulsions	Method	Units	PD	D15W2S	D15W2S50N	D15W2S100N	D15W2S150N
Density@20^{o}C (Kg/m3)	ASTM D7042	g/cc	0.83101	0.85317	0.85518	0.85827	0.86161
API Density@15^{o}C (Kg/m3)	ASTM D7042	g/cc	0.83227	0.85674	0.85953	0.86324	0.86631
Kinematic Viscosity@40^{o}C (Cst)	ASTM D7042	Cst	2.72	3.632	4.99	5.05	5.20
Specific gravity@20^{o}C	ASTM D445-12	-	0.83009	0.85470	0.85759	0.85982	0.86027
Flash point (^{o}C)	ASTM D92	^{0}C	58	63	68	70	72.
Fire point (^{o}C)	ASTM D92	^{0}C	71	75	79	83	85
Calorific value	ASTM D240	MJ	42.9	39.2	38.9	39.7	40.9
Cetane index	ASTM D4737	-	47	44	48	49	49.8
Stability Period	-	Days	Stable	7	7	7	7

2.3 Test fuels and methods

Four specimens of fuels prepared in this study are shown in Fig. 8, possessing one fuel specimen of 15% water diesel emulsion and three fuel specimens having CNT blended in 15% water diesel emulsions with the mass fraction of 50ppm, 100ppm and 150ppm. The baseline diesel fuel has a cetane index of 47. Mechanical Homogeniser is used to make the emulsion. For preparing emulsion of different compounds having different properties a surfactant or binding substance is needed. The conventional surfactants used in this study are span 80 (sorbitan monooleate) hydrophobic in nature and Tween 80 (polyxyethylene sorbitan monooleate) hydrophilic in nature. The surfactant mixture is prepared by mixing the two surfactants 2% by volume with an HLB balance of 8 to provide a stable water diesel emulsion [Rosen, M.J, 2004; Lin, C.Y. and L.W. Chen, 2008]. It is added into the pure diesel (83% by volume). Now mixture of surfactant and diesel are mixed with mechanical homogeniser at a speed of 3000 rpm for 20-25 minutes.

D15W2S, D15W2S50N, D15W2S100N, D15W2S150N

Fig.8 Specimens of water diesel emulsion and CNT-emulsified fuel by ratio of 50ppm.100ppm, 150ppm of CNT in 15% water diesel emulsion

Simultaneously required percentage of water (15% by volume) is added continuously to make the water diesel emulsion. Thus 15% water diesel emulsion is prepared (D15W2S). The emulsion thus obtained is checked for stability [C.Y. Lin, K.H. Wang, 2004]. The added water is taken as distilled water to achieve fair results. To make the blends of CNT blended water diesel emulsion, CNT are weighed first on Digital weighing machine to a mass fraction of 50ppm, 100ppm and 150ppm. These CNT are dispersed in water with the help of ultrasonicator set at a frequency of 40 kHz, ultrasonic power of 120 W for a period 35 minutes. Those dispersed CNT are added continuously in diesel surfactant mixture and stirred further in mechanical homogeniser for 20-25 minutes. Thus water diesel emulsion blended with CNT in the ratio of ratio of 50ppm, 100ppm and 150ppm are prepared (D15W2S50N, D15W2S100N, and D15W2S150N). Tab. 2 and 3 resp. shows the fuel designations of different fuel specimens along with their stability period.

3. Results and Discussions

The combustion, performance and emission aspects of the pure diesel, D15W2S, D15W2S50N, D15W2S100N, and D15W2S150N are investigated to explore the role of CNT in the emulsified fuel. In the combustion aspect, pressure rise in the cylinder and net heat release are analyzed and reported. The performance parameters such as brake specific fuel consumptions, brake thermal efficiency and emission characteristics such as oxides of nitrogen, carbon dioxide ,carbon monoxide, hydrocarbon and smoke opacity are analyzed and discussed.

3.1 Combustion analysis

To analyse the combustion attributes of CNT blended water diesel emulsion, rate of pressure rise and net heat release are plotted against the crank angle.

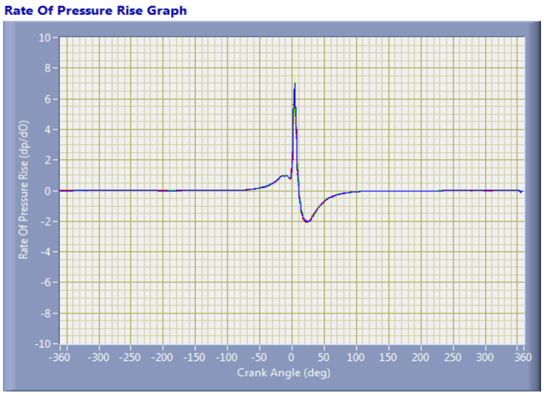

Fig. 9 Rate of pressure rise graph for D15W2S

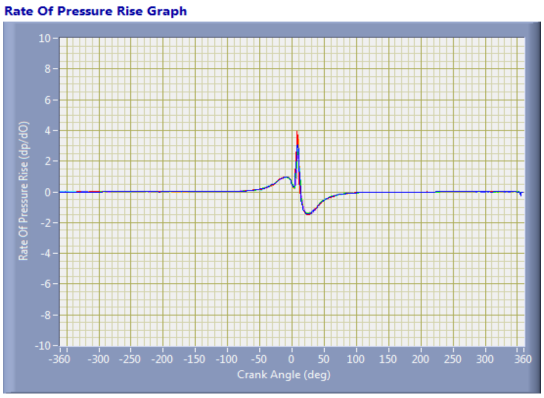

Fig. 10 Rate of pressure rise graph for D15W2S50N

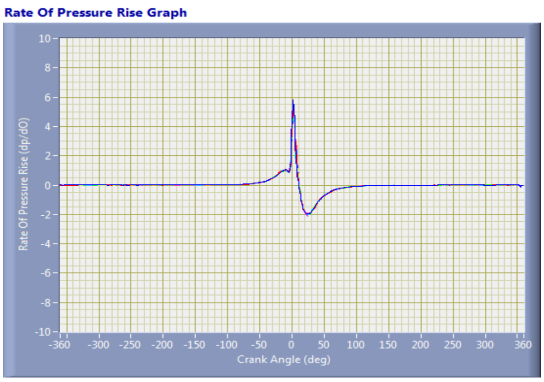

Fig. 11 Rate of pressure rise graph for pure diesel

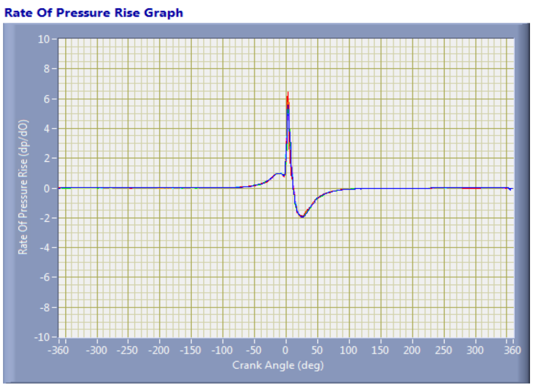

Fig. 12 Rate of pressure rise graph for D15W2S100N

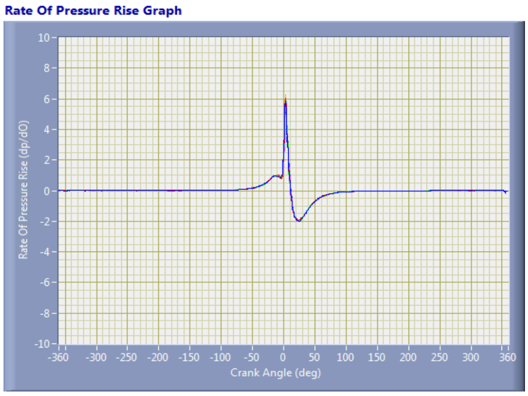

Fig. 13 Rate of pressure rise graph for D15W2S150

Variation of rate of pressure rise in the cylinder for pure diesel, D15W2S, D15W2S50N, D15W2S100N and D15W2S150N are shown in Fig. 9,10,11,12 and 13. Rate of pressure rise observed in the cylinder for D15W2S is high compared to pure diesel. It is reduced with D15W2S50N, D15W2S100N and D15W2S150N fuel specimen respectively. It is also observed that net heat release for the D15W2S is high compared to pure diesel; it is due to the enhanced premixed combustion resulted by longer ignition delay [Subramanian, K.A. and A. Ramesh, 2002]. The observed net heat release for D15W2S was 80 J/deg. However it was 55, 70, 65 and 60 J/deg. for D15W2S50N, D15W2S100N and D15W2S150N and pure diesel (as shown in Fig. 14,15,16,17 and 18).

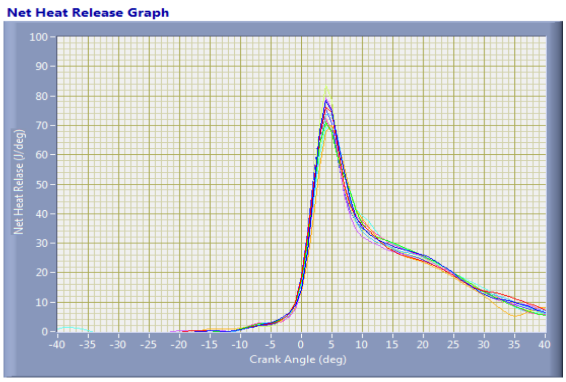

Fig. 14 Net heat release graph for D15W2S

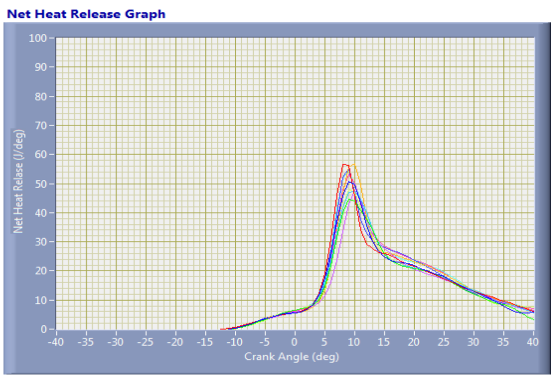

Fig. 15 Net heat release graph for D15W2S50N

The noise level observed is unusual in the case of D15W2S. It may be the reason of prolonged ignition delay. By adding CNT it is reduced significantly. The D15W2S50N specimen has shown better result. It is attributed to the short ignition delay character of CNT. It is also added that CNT emulsified fuel with CNT ratio of 50ppm and 100ppm gives more satisfactory results.

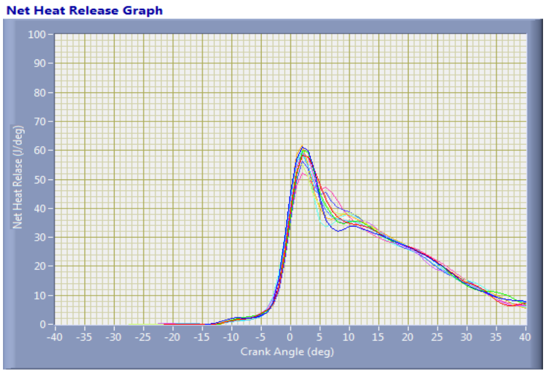

Fig. 16 Net heat release graph for Pure Diesel

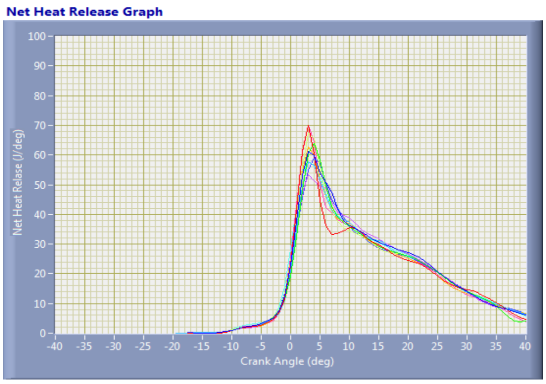

Fig. 17 Net heat release graph for D15W2S100N

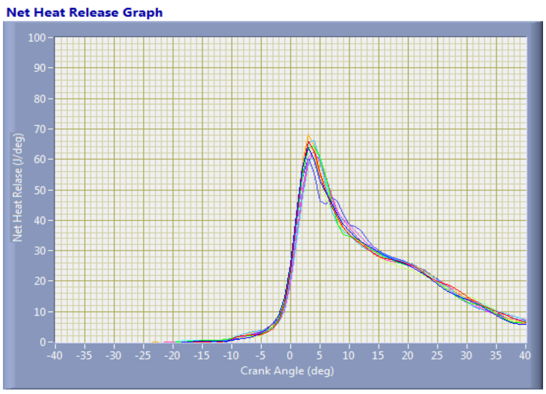

Fig. 18 Net heat release graph for D15W2S150N

3.2 Performance and emission analysis

3.2.1 Variation of Specific fuel consumption with load

Fig. 19 shows the variation of brake specific fuel consumption (bsfc) of pure diesel, water diesel emulsions and CNT blended water diesel emulsions. It shows that bsfc decreases as engine load increases, this is due to fact that more water works as fuel as more water takes space of diesel in burning process. The reduction in bsfc with water emulsified diesel could be attributed to formation of a finer spray due to rapid evaporation in the water. The trend of decline in bsfc for CNT blended water diesel emulsion is more.

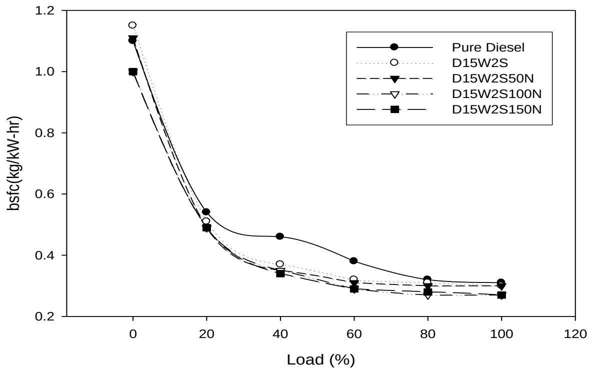

Fig. 19 Variation of Brake specific fuel consumption with load at different fuel specimens

This is due to the high evaporation rate of CNT possessing catalytic potential. Delay period is reduced with the addition of CNT in emulsion which reduces the excesses fuel burning in the premixed phase [Sadhik Basha, R.B. Anand, 2014, Nadeem M. *et al*., 2006]. Brake specific fuel consumption observed at full load is 0.27 kg/kW-hr for D15W2S150N and D15W2S100N whereas it is 0.30, 0.30 and 0.31 for the D15W2S50N, D15W2S and pure diesel.

3.2.2 Variation of brake thermal efficiency with load

Fig. 20 shows the variation of the brake thermal efficiency with load for pure diesel, water diesel emulsion and CNT blended water diesel emulsions.

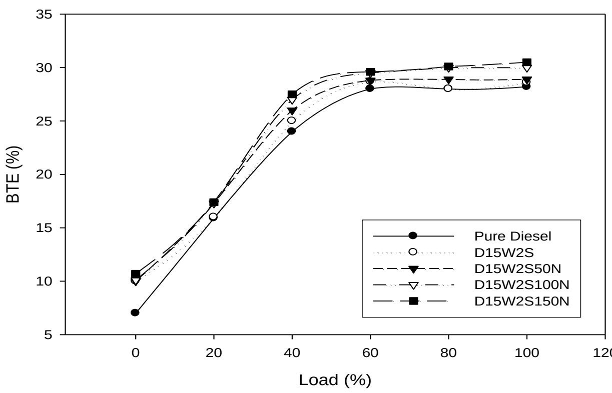

Fig. 20 Variation of Brake Thermal Efficiency with load at different fuel specimens

The maximum brake thermal efficiency of 30.5 % is achieved when 150ppm CNT blended water diesel emulsion is used, and this is due to the fact that CNT have high surface area to volume ratio and participate more effectively in the combustion. This could be attributed to reactive surfaces of CNT having higher chemical reactivity which act as potential catalyst in the combustion process [J. Sadhik Basha, R.B. Anand, 2011, 2014]. Boiling point of water is less than the diesel, so it evaporates first and CNT having higher ratio in the emulsions produce higher thermal efficiency due to micro explosion and secondary atomization of fuel. Brake thermal efficiency observed for D15W2S100N, D15W2S50N, D15W2S and pure diesel is 30, 28.9, 28.6 and 28.2 respectively.

3.2.3 Variation of NOx with load

The variation of NOx with engine load using different fuel specimens is shown in Fig. 21. It is clear that as the water in diesel is added, the exhaust temperature decreases as the heat is absorbed by the additional water, which subsequently decrease the NOx as it is the product of reaction of nitrogen with oxygen at higher temperature [Bharj J *et al.*, 2014]. The latent heat of water will cool the charge due to the evaporation of water, and the cylinder average temperature following injection and before ignition becomes lower due to the water. It is further observed that the NOx emission in case of CNT blended water diesel emulsion is lower than ordinary emulsion, this is attributed to short ignition delay period which results in lower premixed combustion fraction .The cylinder peak pressure is lower in case of CNT blended water diesel emulsions[J. Sadhik Basha, R.B. Anand, 2011]. NOx concentration increased at higher load due to the conversion of nitrogen to NO at high gas temperature by combining with O_2 to form NOx [C.Y. Lin, L.W. Chen, 2006]. It is observed that NOx produced at full load by D15W2S150N, D15W2S100N, D15W2S50N, D15W2S and pure diesel is 245ppm, 250ppm, 305ppm, 370ppm and 428ppm respectively.

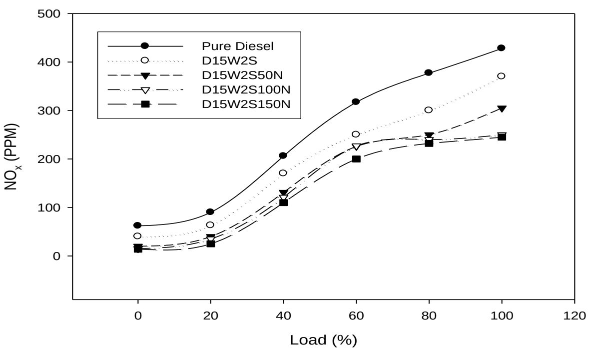

Fig. 21 Variation of NOx with load at different fuel specimens

3.2.4 Variation of Carbon dioxide with load

Carbon dioxide reflects complete combustion of the fuel. Combustion of CNT blended emulsified fuel shows increasing trend with the increased volume of CNT volume. It gives justification for complete combustion of fuel in case of CNT blended emulsions and ordinary emulsion compared to pure diesel. Fig. 23 illustrates the complete trend of variation of Carbon dioxide for different fuel specimens at different loads.

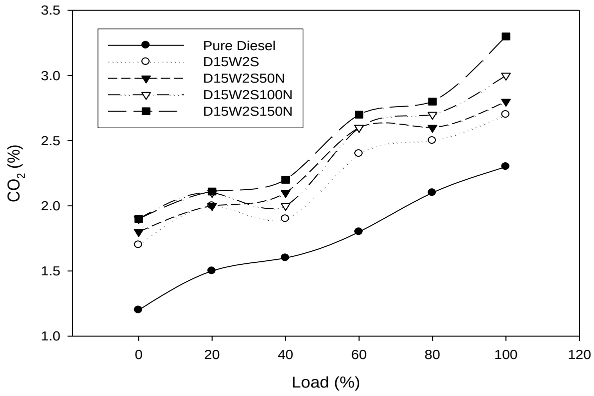

Fig. 23 Variation of Carbon dioxides with load at different fuel specimens

3.2.5 Variation of Carbon monoxide with load

Carbon monoxide is a result of incomplete combustion. It has been observed that emission of CO decreases with increase in volume of CNT in the emulsion. This happens because water helps in micro explosion of fuel and more oxygen supplied by the added water react with CNT witnessing higher surface to volume ratio. CNT blended emulsion produced uniform combustion due to CNT surfaces swallowing all the oxygen in the cylinder. It is also observed that when the load is increased CO concentration increases for all the fuel specimens. CO produced by D15W2S150N D15W2S100N and D15W2S50N is significantly lower compared to D15W2S and pure diesel as shown in the Fig. 24.

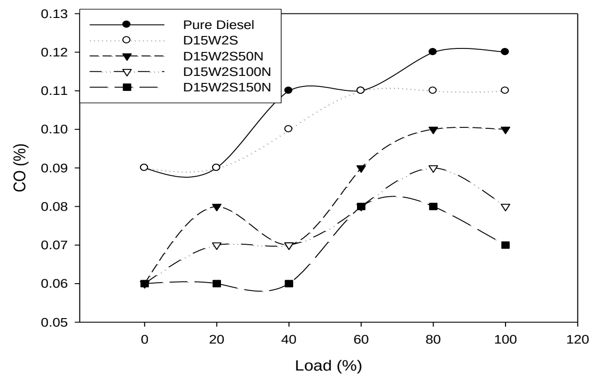

Fig. 24 Variation of Carbon monoxides with load at different fuel specimens

3.2.6 Variation of HC with load

HC is formed when fuel goes to the exhaust without doing the work or not getting proper oxygen for burning. Mostly HC is produced due to incomplete combustion [Subramanian, K.A. and A. Ramesh, 2002].

Potential catalytic property of CNT having high surface area to volume ratio assist in improved combustion as water added to the fuel supplies extra oxygen for proper combustion of fuel. Fig. 25 has shown the variation of HC with load. It shows a decreasing trend of HC comparable to emulsion and pure diesel while increasing CNT concentration in the emulsion.

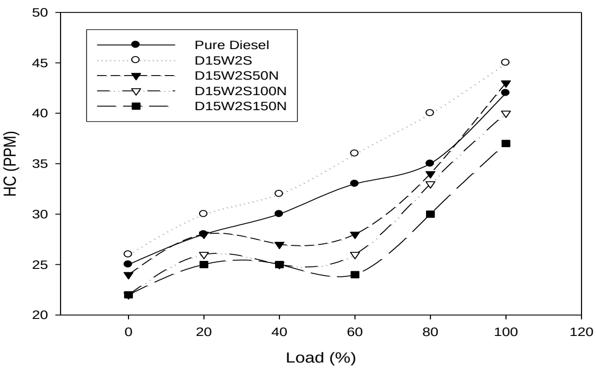

Fig. 25 Variation of HC with load at different fuel specimens

It is further observed that HC increased, with water diesel emulsion due to reduction in gas temperature and incomplete combustion. The magnitude of HC observed at full load by D15W2S150N, D15W2S100N, D15W2S50N, D15W2S and pure diesel is 37ppm, 40ppm, 43ppm, 45ppm and 42ppm respectively.

3.2.7 Variation of Smoke with load

Smoke is the result of incomplete combustion. Tiny unburned particles mostly carbon soot collected in the exhaust produce smoke. As combustion is improved in the CNT blended water diesel emulsion, smoke is reduced significantly [C.Y. Lin, K.H. Wang, 2004; Subramanian, K.A. and A. Ramesh, 2002].

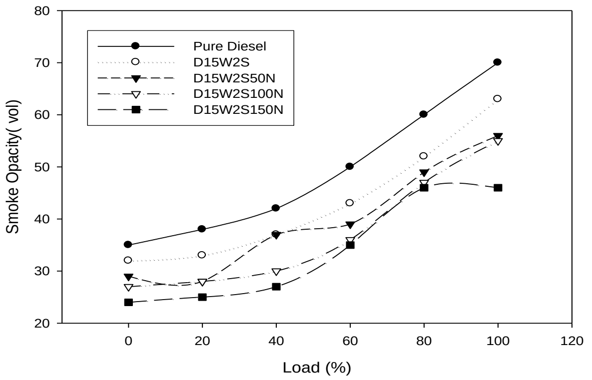

Fig. 26 Variation of smoke with load at different fuel specimens

Addition of CNT in the water diesel emulsion in corporate shorter ignition delay, high evaporation rate and enhanced ignition qualities which further help in reducing the smoke opacity. Increase in the oxygen content meeting with the fuel enhanced the combustion rate and produce less smoke in case of CNT blended fuel compared to others. The smoke opacity for D15W2S150N is 46% whereas it is 55, 56, 63 and 70 % for D15W2S100N, D15W2S50N, D15W2S and pure diesel respectively as shown in Fig. 26.

Conclusions

On the basis of the experimental results investigated on single cylinder direct injection diesel engine using pure diesel, emulsified fuel and emulsified fuel with different ratios of CNT the following conclusions are drawn:

1) The engine noise was unusual while running on D15W2S blend. But it becomes consistent while using D15W2S50N, D15W2S100N and D15W2S100N blends. There was no abnormality in using CNT blended emulsions.

2) Rate of pressure rise in the cylinder for D15W2S is high compared to pure diesel. It is reduced with D15W2S50N, D15W2S100N and D15W2S150N fuel specimen respectively It is also observed that net heat release for the D15W2S is high compared to pure diesel; it is due to the enhanced premixed combustion resulted by longer ignition.

3) The brake specific fuel consumption was observed to decrease with water diesel emulsion. But with the addition of CNT it reduces more with marginal difference. Result shows that specific fuel consumption at full load is 0.27 kg/kW-hr for D15W2S150N and D15W2S100N.

4) The brake thermal efficiency of CNT-emulsified fuel increases with increase in CNT concentration in the emulsion at all the loads. The brake thermal effiency at full load observed for D152S150N was 30.5 and for D15W2S100N, D15W2S50N, D15W2S and Pure Diesel it was 30, 28.9, 28.6 and 28.2 respectively.

5) The NOx emission is reduced significantly with the use of CNT-emulsified fuel. This trend goes on increasing with increase in amount of CNT in the emulsion. NOx emission observed at full load during the investigation was found to be 221ppm for D15W2S150N and for D15W2S150N, D15W2S50N, D15W2S and Pure Diesel it is 224ppm, 255ppm, and 302ppm.

6) Hydrocarbon emissions shows decreasing trend with CNT as compared to diesel. Lowest HC produced by D152S150N is 37ppm however it is highest of 45ppm when using water diesel emulsion. When the load increases HC emissions are higher for water diesel emulsion.

7) Carbon monoxide emissions decrease with increase in CNT concentration in the fuel. However carbon dioxide shows increasing trend with emulsified fuel and CNT blended water diesel emulsion due to uniform combustion.

The test results revealed that water diesel emulsion (15 % water) can be used as a fuel in diesel engine with no engine modification. Addition of CNT to the emulsion helps in reducing the emission significantly and enhancing the performance and combustion characteristics.

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