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RESEARCH PAPER

Impact of Cobalt Oxide Nanoparticles Dispersed in Water in Diesel Emulsion in Reduction of Diesel Engine Exhaust Pollutants

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ABSTRACT
The present work is aimed at decreasing pollutants emitted by diesel engine exhaust tailpipe and enhancing performance by incorporating cobalt oxide nanoparticles in water emulsified diesel. Water concentration of 5% and 10% is used to prepare various WD emulsion blends, with nano particle dosage levels of 50PPM and 100PPM. High speed homogenizer and ultrasonicator devices are used to disperse water droplets in diesel. Surfactant mixture of span80 and tween20 is used to achieve long term stability of emulsified fuel. The functional groups of emulsified fuel are analysed using FTIR spectroscopy. The characterization of cobalt oxide nanoparticles is carried using scanning electron microscope. Physiochemical properties such as calorific value, density, viscosity of emulsion blends and pure diesel are determined and compared. Experimental results reveal that addition of cobalt oxide nanoparticles in emulsified fuel with increased dosage of 100PPM shows 23%, 33.3%, 25%, and 44.6% reduction in NOX, HC, CO and smoke emission compared to pure diesel. The improvement in BTE and BSFC were observed for all emulsion blends.
Keywords: Performance, Emission, Water Concentration, Smoke, Pure Diesel, Emulsion

INTRODUCTION

Diesel engines are the major prime movers in the current scenario of mobility and stationary power generation. However, these engines are the major contributors to climate change and environmental pollution. Although most of the sectors heavily depend on diesel engines (Tomar et al., 2020). The pollutants of diesel engines not only deteriorate quality of air and water but also affect food chain and human health (Ghannam et al., 2016). The growth of population has led to the increased use of diesel-powered vehicles, simultaneously causing rapid depletion of fossil fuels and also increased cost of petroleum products (Soudagar et Al., 2018; Bhuiya et al., 2014). Inflating fuel price and increasing pollution level are the major concerns at present. For the last few decades, researchers are working on various biodiesels to reduce diesel emission. Using 100% pure simarouba biodiesel in diesel engine requires change in operating parameters such as injection pressure and nozzle geometry. Increasing injection pressure from 205bar to 240bar, adopting six nozzle hole fuel injector with reduced hole diameter from 0.3mm to 0.2mm results in enhanced BTE and reduction in emission except NO_X (Keerthi et al., 2021). Combination of two methyl esters, simarouba and jatropha oil in equal proportion in blend with diesel shows reduced CO, HC and CO_2 emission except NO_X in comparison with diesel (Telgane et al., 2021). In order to mitigate pollution, water emulsified in diesel would be a promising alternative fuel (Anil et al., 2021). Water emulsified diesel appears to be most suitable method to inject water into combustion chamber without engine modification. Occurrence of micro explosion process in the combustion

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chamber results in reducing engine emission. Hot plate method is used to study the impact and occurrence of microexplosion process. Microexplosion process helps in better mixing of fuel and air. Early phase separation of water and diesel affects the microexplosion phenomenon in the combustion chamber (Mura et al., 2012). Forming stable emulsion is the key factor to achieve better performance and emission from the engine. Non-ionic surfactants are widely used to form stable emulsion and also act as corrosion inhibitor and lubricator (Vellaiyan et al., 2016). Increasing the surfactant concentration in the emulsion has a negative impact on microexplosion process (Morozumi et al., 2010). Stability of emulsion by varying water concentration, surfactant percentage, speed of homogenizer and mixing time has been examined by (Ghannam et al., 2009). Maximum stability period of 4 weeks is achieved without phase separation Similar experiments were conducted on stability period and a maximum stability achieved using 10% water concentration, 5% surfactant mixture (Patil et al., 2015). A Stability of 50 days is observed for 5% surfactant concentration with increase in water droplet size from 159nm to 330nm (Preetika et al., 2019).

The blends of WD nano emulsion prepared using high speed mechanical homogenizer (20,000RPM) and mixture of span80 and emrol85 as surfactants. Stability of emulsion depends on ostwald ripening rate and coalescence of water droplets. Further increased water concentration in emulsion results in increased ostwald ripening rate (Al-Sabagh et al., 2011; Uson et al., 2004). Similar experiments on stability of emulsion using different surfactant mixture has been conducted. The maximum stability period of three months with increase in droplet size is observed without macroscopic changes in emulsion prepared by mixture of span80 and tween80 (Porras et al., 2008).Engine emission and performance parameters are influenced by water concentration in emulsion. Adding 2% of water in emulsion improves BSFC whereas 5% water in emulsion reduces engine exhaust gases (Seifi et al., 2019). Power density increases with increase in water concentration and compression ratio. However, it is lower compared to pure diesel (Rai et al., 2019). The effect of surfactant free emulsion on engine emission is compared with emulsified water in diesel fuel and diesel. The result shows reduction in emission for both emulsion free and emulsified fuel compared to diesel (Ithnin et al., 2018). Separate storage tank for direct injection of water into engine cylinder requires modification of engines. The dropdown in stability of water emulsified diesel by the addition of metal based nano additives has been observed and it can be due to interrupted inter surface activity between water and diesel (Hasannuddin et al., 2018).

Water percentage of 10% is the optimum level to get better performance and emissions. Furthermore adding 1-4 dioxane to the emulsion enhances BTE by 7% and reduces HC and smoke by 31.66% and 27.83% respectively in comparison with diesel (Vigneswaran et al., 2018). The incorporation of ZnO nanoparticles in 10% distilled water decreases NOx for compression ratio 18.5 (Vali et al., 2020). Evaluation of Emulsified biodiesel with 10% water results in lower CO, HC and NOx with reduced BSFC than other tested fuels (Vellaiyan et al., 2020). CeO_2 nanoparticles in biodiesel significantly improves BTE and BSFC and reduction in HC and CO for 60PPM dosage of nanoparticles compared to diesel (Perumal et al., 2018; Raju et Al., 2019). Similar results were found when CeO_2 nanoparticles (90PPM) and water (7% wt.) dispersed in biodiesel-diesel fuel. This is attributed to microexplosion of water in the emulsion and catalytic activity of CeO_2 nanoparticles (Gharehghani et al., 2019). The manganese and cobalt oxide nanoparticles incorporated in biodiesel blended diesel fuel to analyse the characteristics of Urea-SCR equipped engine. cobalt oxide nanoparticles blended fuel shows improved BTE and BSFC than manganese oxide nanoparticle blended fuel. Also, lower NOx, CO, HC emissions were observed for cobalt oxide nanoparticle blended fuel (Mehregan et al., 2018).

Variable compression ratio diesel engine characteristics studied by incorporating mixture of cerium oxide and carbon nanotube as additive in diesterol blend in various proportion. Ultrasonication method is used to stabilize the fuel. The results show enhanced BTE and BSFC due to oxygen buffering activity of cerium nanoparticles and accelerated fuel burning rate by carbon nanotubes (Selvan et al., 2014). The addition of 30% hydrotreated vegetable oil to the diesel with ferrocene nanoparticle in old passenger car results in reduction of NO_x (Elżbieta et al., 2020). The present work focuses on preparation of WD emulsion using both Mechanical homogenizer and Ultrasonicator to achieve long term stability. The effect of cobalt oxide nanoparticles on stability of WD emulsion, engine performance and emission with of 50PPM and 100PPM dosage has been investigated. First step, the effect of 5% and 10% water concentration in emulsion has been studied. Second step, the effect of nanoparticle dosage of 50PPM and 100PPM incorporated in 5% and 10% water emulsified diesel is studied.

MATERIALS AND METHODS

The WD emulsion blends are prepared using span80 and tween20 surfactants mixture by varying the distilled water percentage of 5% and 10%. Various authors suggested that water concentration of 10% and surfactant percentage of 0 to 5% is suitable to form stabled water in diesel emulsion (Vellaiyan et al., 2016; Patil et al., 2015; Mondal et al., 2019). Initially, water is emulsified in diesel using mechanical homogenizer (15,000RPM) and constantly processed for 10 minutes. Prepared emulsion is subjected to ultrasonication process to achieve long term stability. Cobalt oxide nanoparticles are added to the WD emulsion with dosage level of 50PPM and 100PPM and constantly stirred. The physicochemical properties are tested for all the prepared WD emulsion blends. The impact of cobalt oxide nanoparticle on diesel engine performance and emissions are analysed based on experimental results.

Water is emulsified in diesel using mechanical homogenizer and ultrasonicator for a time period of 20minutes. Table 1 and Table 2 show technical specifications of mechanical homogenizer and ultrasonicator respectively. Stability period of water in diesel emulsions are noted at the time of separation of water from the diesel in graduated scale test tube. From figure 1, the maximum stability of 16 days is observed for WD5 emulsion at the homogenizer speed of 15,000RPM compared to 5,000 and 10,000RPM. The 6% reduction in stability is observed for WD10 compared to WD5 at 15000RPM homogeniser speed. The various surfactants such as span20, span60, span80, span85, tween20, tween60 and tween80 are used to achieve long term stability of WD emulsion. The maximum stability obtained is 30 days using 10% water, 5% mixture of span80 and tween80 and 20minutes mixing time (Patil et al., 2015). WD emulsion formed using Triton X-100 surfactant is stabled for 4 weeks containing 10% water and 0.2% of triton X-100 (Ghannam et al., 2009). The incorporation of Cobalt oxide nanoparticles in WD5 and WD10 results in dropdown of stability period due to reduced effect of span80 and tween20 mixture. Higher homogenizer speed and mixing time results in fallout of nanoparticles from emulsion phase causing reduced stability (Hasannuddin et al., 2018). The physiochemical properties of WD emulsion blends are tested at AIT, chikamagaluru and is shown in table 3. The FTIR Spectroscopy tests were conducted at Nitte Pharmacy college, Mangaluru and SEM test is conducted at MIT, Udupi. Cobalt oxide nano particles are procured from plotonic nanotech PVT. LTD., Jharkhand. The surfactants are purchased from Lobo chemie PVT. LMT.

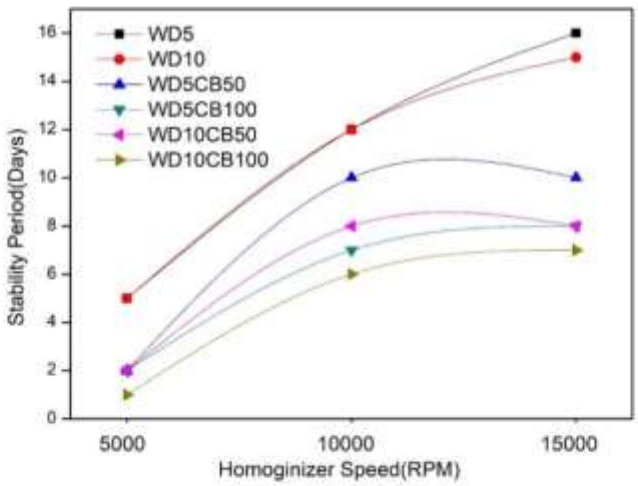


Fig.1: Stability period of water emulsified diesel samples at different homogenizer speed

Table 1: Mechanical homogenizer Specifications.

Make, Model	REMI Elektrotechnik Ltd., RQT-127(D)
Shaft Diameter(mm)	8
Stirling Shaft Length(mm)	240
Stirring Capacity(Litre)	8
Impeller Cross Blades	4
Motor specification	AC/DC, 1/8 HP
Max. stirring Speed(RPM)	15000

Table 2: Specification of Ultrasonicator.

Manufacturer	Labman scientific instruments PVT. LTD.
Frequency	20 – 25KHz
Amplitude output	0 – 100%
Process Capacity	0.5 – 500ml
Probe Diameter	6mm
Probe material	Titanium
Temperature range	0 – 99^{0}C
Power supply	220V/50Hz
Data output	6.5 – 650W
Other features	Auto tuning, automatic fault alarm, LCD Display with time and temperature setting.

Table 3: Properties of WD emulsion fuels and neat Diesel as per ASTM Standards

Emulsion Properties	Density (g/cc)	Viscosity @ 40^o C (mm^2/sec)	Flash point (^{o} C)	Calorific value, (MJ/Kg)
WD5	0.854	4.18	68	42.3
WD10	0.856	4.31	75	41.4
WD5CB50	0.8547	4.27	71	42.46
WD5CB100	0.8549	4.36	70	42.67
WD10CB50	0.8564	4.62	77	41.51
WD10CB100	0.8568	4.43	75	42.18
DIESEL	0.842	2.6	60	43.1

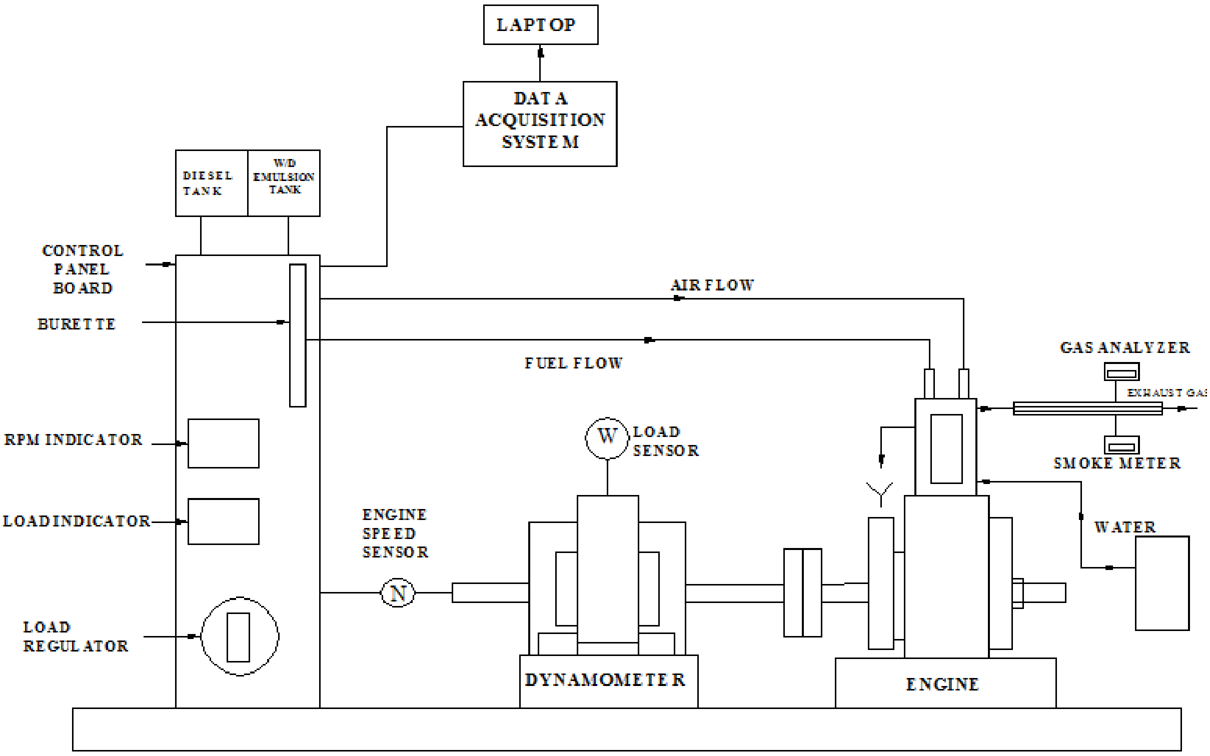


Fig.2: Diesel engine setup

Four stroke, single cylinder, constant speed, computerized VCR diesel engine is connected with water cooled eddy current dynamometer. The diesel engine setup is represented in figure 2. In cylinder pressure, diesel line pressure and crank angle measuring instruments are interfaced with computer to attain P-θ diagrams. The electronic piezo sensors are adopted in engine for measuring the combustion pressure, diesel line pressure at 5,000 PSI range with low noise cable. Setup panel consists of fuel tank, air & fuel flow measuring transmitters and hardware interface. Rotameter is used to measure cooling water flow rate. NI USB 6210 data acquisition device is used to transfer signals from engine to computer. The engine performance and combustion evaluation performed by "ICEnginesoft" software package. The specifications of diesel engine, smoke meter and gas analyzer are shown in table 4. AVL437 Smoke meter is connected to VCR engine to measure the smoke opacity of exhaust tailpipe and the toxic pollutants of diesel engine NO_X, CO, HC, CO_2 and O_2 are measured using AVL DIGAS 444N 5 gas analyzer. The specification of engine parameters is shown in table 5.

Table 4: Specification of Engine, Smoke meter and Gas Analyzer.

Engine	Kirloskar made, Bore(87.5mm), stroke(110mm), power (3.5KW), speed (1500RPM), CR range(12-18). Open ECU.
Smoke meter	AVL 437, operating temperature(5- 50^0C), Power supply(220V,50Hz), measurement length(0.43mm± 0.005mm)
Gas analyzer	AVL 444N, LCD display, voltage(100-300V,50-60Hz), power consumption(max. 10W)

Table 5: Specification of engine components.

Parameters	Measurement range	Resolution	Accuracy
CO	0 – 15% (Vol.)	0.001(%)	±0.01(% vol.)
HC	0 – 20000(PPM Vol.)	1(PPM)	±1 (PPM vol.)
CO_2	0 – 20(% Vol.)	0.1(% Vol.)	±0.1(% vol.)
O_2	0 – 25(% Vol.)	0.01(% Vol.)	±0.15(% vol.)
NO_X	0 – 5000(PPM Vol.)	1 (PPM Vol.)	±1 (PPM)
Engine speed	400 – 6000RPM	1RPM	--
Lambda	0 – 9.999	0.001	--
Smoke	0 – 100% (opacity) 0 – 99.99m^{-1} (absorption)	±1%	0.1% (opacity) 0.01m^{-1} (absorption)
Pressure sensor	--	--	±1%
Speed indicator	--	--	±0.05%

Table 6: Engine uncertainties.

Parameters	Uncertainity Error (%)
BSFC	±0.5
BTE	±0.8
BP	±0.01
Torque	±0.07
Speed	±1.25
CO	±0.01
NOx	±0.2
HC	±0.2
Smoke	±0.5

RESULTS AND DISCUSSION

The WD5 and WD10 result in reduced calorific value of 1.85% and 3.9% than pure diesel. This attributed by high calorific value of diesel. The properties like viscosity, flash point and density increase with increase in water concentration. The incorporation of nanoparticles in emulsion shows marginal variation in fuel properties compared to water emulsified diesel.

The conditions which lead to generation of error in diesel engines are improper calibration, reading, defects in the instruments, environmental conditions and human errors (Kumar et al., 2019). These errors can be found using root mean square method and the calculated errors for various engine parameters are shown in table 6. Total engine uncertainty is evaluated by,

$$\text{Uncertainty}=\sqrt{\begin{matrix}(UE)^2_{BSFC}+(UE)^2_{BTE}+(UE)^2_{BP}+(UE)^2_{Speed}+(UE)^2_{Torque}\\ +(UE)^2_{CO}+(UE)^2_{NOx}+(UE)^2_{HC}+(UE)^2_{Smoke}\end{matrix}} = \pm 1.67\% \quad (1)$$

The FTIR spectroscopy is used to study the functional groups of emulsion fuels and Nano particles blended emulsion fuel. The C-H stretching is observed for WD5, WD10 and WD10CB100 at the peak of 2923.82cm-1,2921cm-1 and 2921.41cm-1 as shown in figure 3. Peaks observed are similar with previous FTIR studies on water in diesel emulsion (Vigneswaran et al., 2018). Characterization of cobalt oxide nanoparticles is studied in SEM at magnification level of 10Kx and 25Kx and is shown in figure 4. The detailed specification of span80 and tween20 surfactants are shown in table 7.

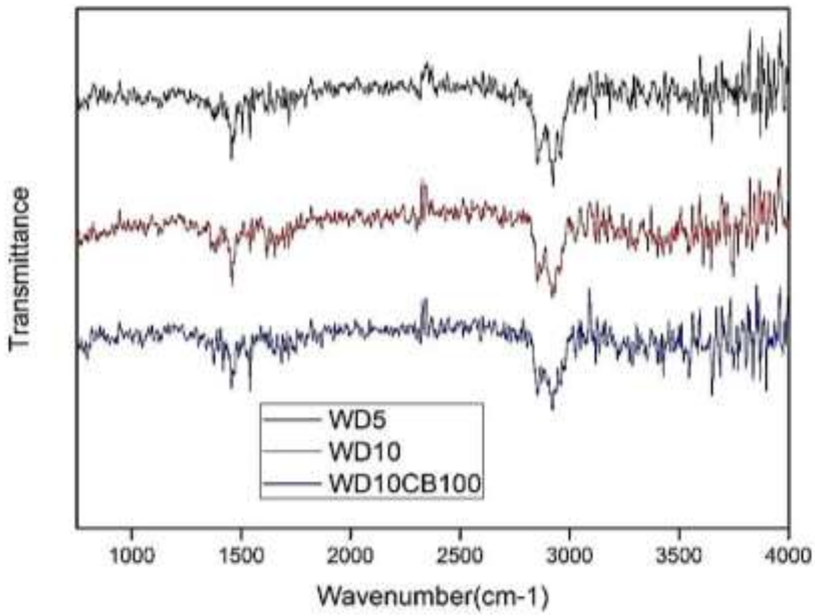


Fig.3: FTIR Spectroscopy comparison for water emulsified fuels

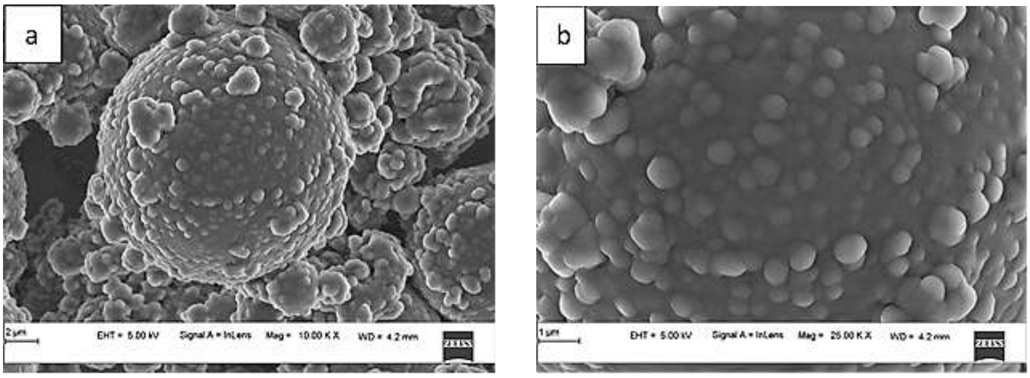
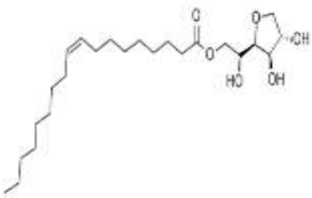
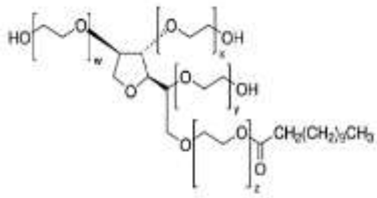


Fig.4: SEM images of Cobalt oxide Nanoparticles at magnification, a. 10Kx, b. 50Kx

Table 7: Specifications of surfactants (Lobo Chemie PVT. LTD.)

Description	Span80	Tween20
Chemical formula	**$C_{24}H_{44}O_6$**	**$C_{58}H_{114}O_{26}$**
Molecular stracture		
Density (g/cm^3)	1	1.1
Appearance	Brownish yellow, Viscous liquid	Golden yellow, Clear liquid
Hydroxyl No.	206.02	97.31

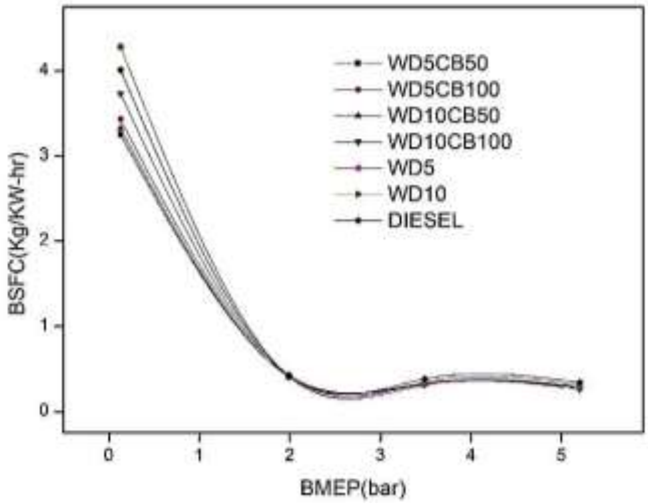


Fig.5: Variation of BSFC with BMEP

The comparison of impact of nanoparticle dosage level of 50PPM and 100PPM on BSFC at different BMEP is shown in Figure 5. Injection of water emulsified diesel up to 10% of water results in reduced BSFC with increase in BMEP. Micro explosion behaviour of water emulsified diesel provides better atomisation to achieve complete combustion hence reduced BSFC. Further incorporation of nanoparticles causes lesser fuel consumption with increase in BMEP due to higher heating value of base fuel (Mehregan et al., 2018). The increased water concentration in diesel about 5 to 10% shows improved BSFC of 6.45% and 14.7% compared to WD5 and pure diesel. The nanoparticle incorporation to the WD emulsion provides enhanced heating value of WD emulsion fuel and rapid disintegration of emulsified fuel droplets in the combustion chamber results in better BSFC.

Lowest BSFC for WD10CB100 is noticed about 0.26kg/KW-hr compared to WD5(0.31 kg/KW-hr), WD10(0.29kg/KW-hr), WD5CB50(0.29kg/KW-hr), WD5CB100(0.29kg/KW-hr), WD10CB50(0.28kg/KW-hr) and neat diesel(0.34kg/KW-hr). This is attributed to reduced ignition delay period and higher heating value of WD10CB100 blend. Further enhanced turbulence created by the microexplosion process and high combustion temperature at 5.2bar BMEP increases combustion rate hence lower BSFC.

Figure 6 represents variation of BTE with BMEP for different WD emulsion fuels and neat diesel. The experimental results show enhanced BTE with addition of nanoparticles to the WD blends. The enhanced dosage level of nanoparticles up to 100PPM shortens delay period from start of injection to the beginning of air fuel burning of the emulsified fuel results in complete combustion. Hence higher BTE. This could also be attributed to improved heating value by the addition of nanoparticles enhances heat release rate, secondary atomisation of WD fuel and reduced evaporation time of fuels (Vigneswaran et al., 2018). The nanoparticles catalytic activity has led to higher combustion temperatures, which results in more effectual evaporation of the water molecules. Thus, higher BTE for nanoparticles added WD emulsion (Hosseinzadeh et al., 2019).

The increased BTE of 12.5%, 4.3 %, 3.5 %, 3.3 %, 2.6 % and 14.97% is noticed for WD 10 CB100 compared to WD5, WD10, WD5CB50, WD5CB100, WD10CB50 and pure diesel respectively at higher BMEP of 5.2 bar. The high combustion temperature at higher BMEP results in rapid evaporation of water causing secondary atomisation of WD emulsion. Further, nanoparticles present in emulsion enhance turbulence and heat release rate; this combined effect of emulsion and nanoparticles makes higher BTE.

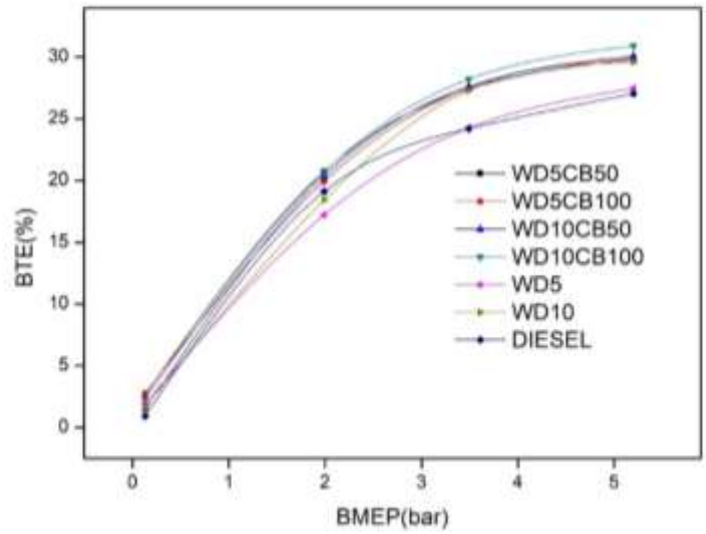


Fig.6: Variation of BTE with BMEP

Variation of CO emission with BMEP for various dosage level of Cobalt oxide nanoparticles as presented in figure 7. The presence of oxygen in the water in diesel emulsion helps in enhancing combustion of air fuel mixture, hence for 5% and 10% water concentration in diesel results in 8.3% and 16.6% decrease in CO emission compared to diesel. Further, incorporation of Cobalt oxide nanoparticles reduces CO emission because of decreased ignition time period and improved secondary atomization caused by micro explosion process. The CO emission reduced by 12.5%, 16.6%, 20.8% and 25% respectively for WD5CB50, WD5CB100, WD10CB50 and WD10CB100 compared to pure diesel. Enhanced dosage level from 50PPM to 100PPM reduces ignition delay and enhances heat release rate causes complete fuel air mixture burning results in lesser CO emission. Similar results of lower CO emission were observed for CeO_2 nanoparticles incorporated water biodiesel-diesel fuel in diesel engine (Gharehghani et al., 2019).

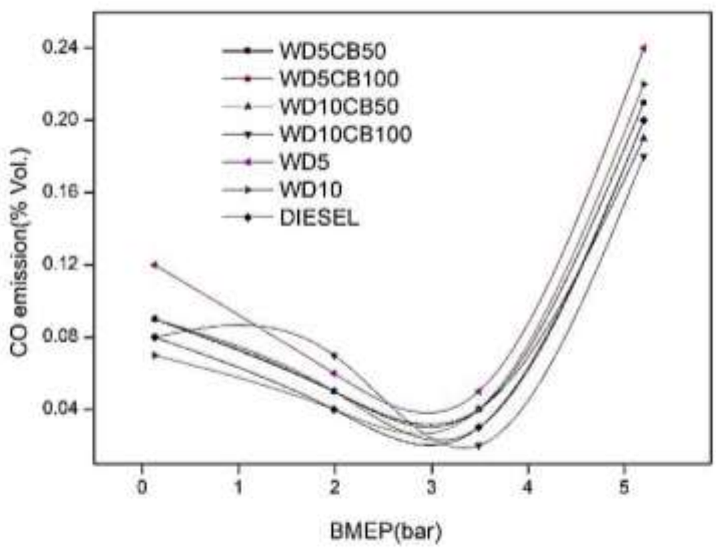


Fig.7: Variation of CO emission against BMEP

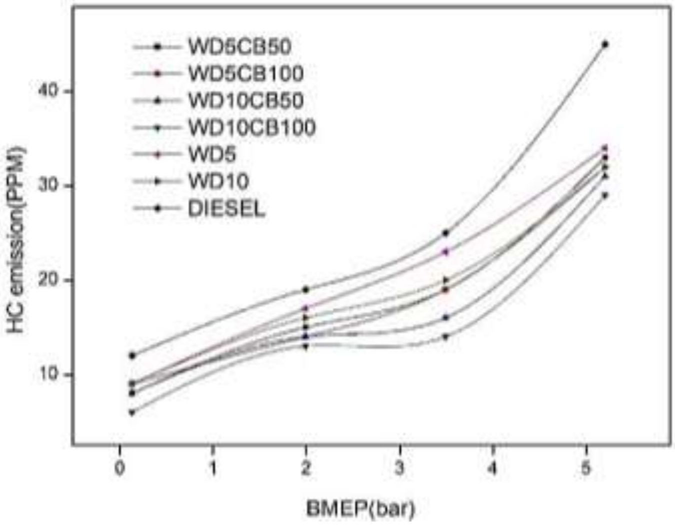


Fig.8: Variation of HC emission against BMEP

HC emission increases with increase in BMEP for all WD emulsion fuels as presented in figure 8. Addition of metal based Cobalt oxide nanoparticles in WD emulsion reduces its emission compared to WD emulsion and pure diesel. The oxidation activity of Cobalt oxide nanoparticles increases combustion rate by shortening delay period and uniform mixture of water droplets and diesel owing to complete combustion therefore lesser HC emission. The lowest HC emission of 29PPM is observed at 5.2 bar BMEP for WD10CB100. High dosage level of nanoparticles reduces ignition delay and enhances combustion rate thus lesser HC emission. The decreased HC emission of 24.4%, 28.8 %, 26.6 %, 28.8 %, 31.1 % and 33.3% were observed for WD5, WD10, WD5CB50, WD5 CB100, WD10CB50, WD10 CB100 respectively than pure diesel. The increase in the combustion temperature by the addition of cobalt oxide nanoparticles at higher dosage level is compensated by heat sink effect caused because of increase in water concentration.

Many researchers experimentally shown that injection of water in diesel emulsion decreases NOx significantly due to heat absorption by water droplets cause reduction in cylinder gas temperature (Hasannuddin et al., 2018; Dinesha et al., 2019). The variation of NOx emission for emulsified fuels and pure diesel with respect to BMEP as shown in figure 9.

Presence of 10% of water in the emulsion shows 7.5% reduction in NOx compared to 5% water. Hence increase in water concentration in emulsion reduces NOx emission, but above 10% water concentration may lead to reduced combustion efficiency due to non-homogeneous dispersion of water droplets in emulsion. Further addition of 50PPM and 100PPM nanoparticle in WD5 emulsion increases NOx by 2.3% and 0.35% compared to WD5. This may be due to reduced water concentration suppresses microexplosion process and increased cylinder gas temperature caused by enhanced burning rate of fuel mixture by cobalt oxide nanoparticles. This problem of increase in NOx can be overcome by enhancing water concentration. The results reveal WD10CB50 3.5% and 1.9% reduction in NOx compared to WD5CB50 and WD5CB100. The increase in nano particle dosage to 100PPM shows reduction in NOx by 1% compared to WD10CB50. This is attributed to heat sink effect of emulsion and homogeneous dispersion of nanoparticles in emulsion. The maximum reduction of 23% for the emulsion WD10CB100 is noted compared to pure diesel. The results obtained are in good agreement with a previous study (Basha et al., 2011).

Variation in smoke emission against BMEP for various emulsion fuels and pure diesel as shown in Figure 10. Smoke is the root cause of incomplete combustion. The addition of water emulsified diesel emits lower smoke compared to diesel. It is clear that, the smoke reduced by 43% for WD10 emulsion compared to diesel and further incorporation of cobalt oxide nanoparticles in the WD10 emulsion reduces smoke emission by 44.6% for 100PPM dosage level. The dropdown of smoke emission is due to microexplosion process and reduced combustion temperature and also oxidation activity of cobalt oxide nano particles improves combustion of water emulsified diesel.

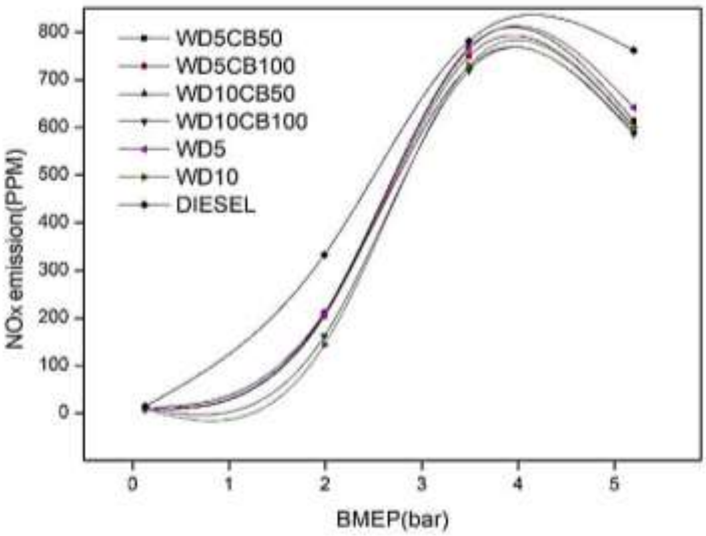


Fig.9: Variation of NOx emission against BMEP.

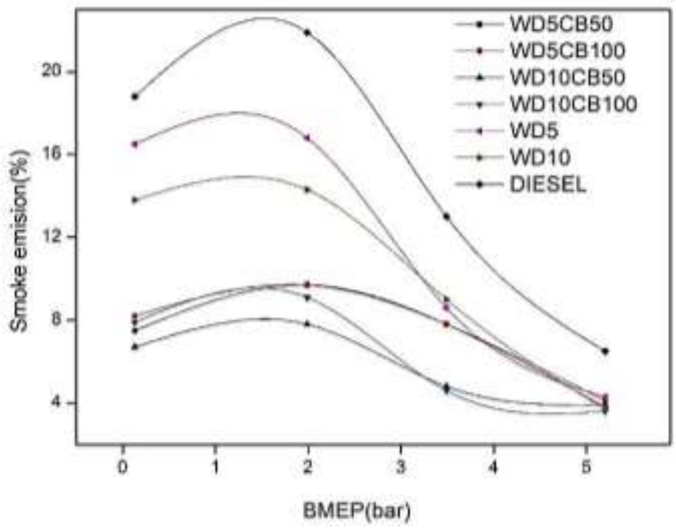


Fig.10: Variation of Smoke emission against BMEP.

CONCLUSION

Experiments have been conducted to examine the impact of Water emulsified fuel samples with incorporation of cobalt oxide nanoparticles on BTE, BSFC, NOx, CO, HC, and smoke emissions. The following results are obtained in comparison with pure diesel.

- The 100PPM dosage of cobalt oxide nano particles in WD10 enhances BTE by 14.97% compared to Diesel.

- CO emission reduced to 20.8% and 25% for emulsions WD10CB50 and WD10CB100. Whereas 31.1% and 33.3% reduction in HC emission is noticed for WD10CB50 and WD10CB100 respectively compared to Diesel.
- NOx emission decreases by 23% for WD10CB100 emulsion compered to neat diesel. Further enhancing dosage level from 50PPM to 100PPM of nanoparticles to the WD10 emulsion reduces NOx compared to all other tested fuels.
- Smoke emission reduced by 43% and 44.6% for WD10CB100 compared to neat diesel. Hence incorporating nanoparticle dosage of 100PPM to the 10% water emulsified diesel shows lower exhaust gas emissions with improvement in brake specific fuel consumption and thermal efficiency.
- Further studies are required to study the effect of cobalt oxide nanoparticles on engine components, environment and human health.

ABBREVIATIONS

WD	Water in Diesel
BMEP	Brake mean effective pressure
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
CO	Carbon monoxide
HC	Hydrocarbon
NO_x	Oxides of Nitrogen
ANP	Aluminum oxide nano particles
CNP	Cerium oxide nano particles
FTIR	Fourier Transform infrared spectroscopy
SEM	Scanning electron microscope
P-θ	Pressure - crank angle

SYMBOLS

WD10	10%Water+1% Surfactant+89%Diesel
WD10CB50	10%Water+1% Surfactant+89%Diesel+ 50PPM Cobalt oxide nanoparticles
WD10CB100	10%Water+1% Surfactant+89%Diesel+ 100PPM Cobalt oxide nanoparticles
WD10CB50	10%Water+1% Surfactant+89%Diesel+ 50PPM Cobalt oxide nanoparticles
WD10CB100	10%Water+1% Surfactant+89%Diesel+ 100PPM Cobalt oxide nanoparticles

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

GRANT SUPPORT DETAILS

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