Effect of additives and injection pressure on performance of CI engine

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Abstract- Diesel engine contributes the most in the field of automobile, agriculture, construction and power generation, Due to serious environmental problem and rising cost of diesel, lot of research work is going on to replace conventional source of energy by a renewable source of energy. Diesel engine cannot be replaced because of its efficient performance at higher power and reliability with alternative engines. Diesel engines emissions contribute the most in the environmental problem, which is causing serious health problems for humans. The major emissions are smoke and NOx which need to be controlled in an effective manner. To find out the suitable additives to reduce exhaust emissions an enhance performance of CI engine, this experiment was carried out. For this purpose, detailed experiments were conducted with different sets of diesel–2–methoxy ethyl ether–nitromethane blends. Mixing of 5% MXEE and 2.5% NM with 92.5% diesel on volume basis (D–MXEE5–NM2.5) showed optimum results of emission and performance. Compared to the fuel mixture D-MXEE5-NM2.5 with diesel, an increase in BTE was found to be 4.90% and a decrease in smoke by 25.28%. However NOx increased by 17.94%.

Keywords –CI engine; 2–methoxy ethyl ether; injection pressure; Nitromethane; Performance; Emissions.

1. INTRODUCTION

For economic development of any country, use of energy plays a very important role. Research in energy sector has been very useful for overall growth of developing countries. Energy contributes an extremely essential role in our modern life. It makes our life comfortable and provides the facility for lighting, food preparation and storage, water cooling and heating, education, construction, manufacturing and automobile etc. The world energy consumption is increasing rapidly as shown in the figure 1 [1].

From the above figures it is clear that in 2040 the world consumption of marketing energy is expected to increase from 549 quadrillion BTUs to 815 quadrillion BTUs. The transport sector energy consumption is increasing by 1.4% per year by 2040, where as its consumption is increasing by 25% of world energy.

The figure 2 also shows world energy consumption by energy source in the transport sector by 2040 and it is clear from the figure that liquid petroleum fuel is expected to account for more than 85% of world petroleum consumption in 2040.

Due to increase in environment pollution and depleting diesel storage, development of alternate source of fuel to control diesel engine emissions at the same time to improve its performance has attracted many researchers. Use of additives is one of the best ways to control emission and improve performance [2]. Several additives are easily available at low cost to produce blends of diesel and additives in proportionate quantities for used in diesel engines. Among these additives, oxygenated additives are more famous because more amount of oxygen is present in their molecular structures that help to smooth combustion [3]. It was discovered that to reduce exhaust emissions additives having higher oxygen content can be added up to 10–20%. The mixing of additives in diesel with appropriate quantities will enhance the combustion properties of the above blend, such as: density, cetane number, volatility, viscosity, and boiling point. High oxygen content is also available in nitro paraffin compound, which may help in gating better combustion in diesel engine [4].

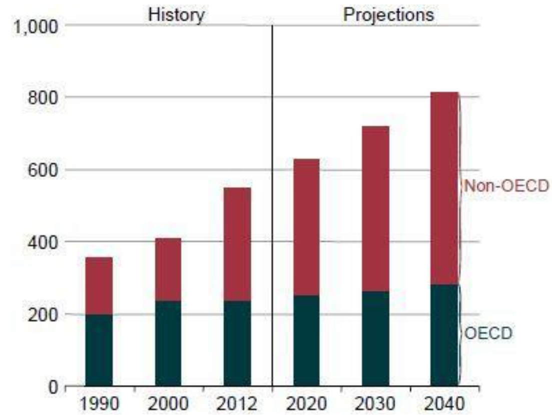

Figure 1: World energy consumption 1990–2040 (quadrillion Btu) [1]

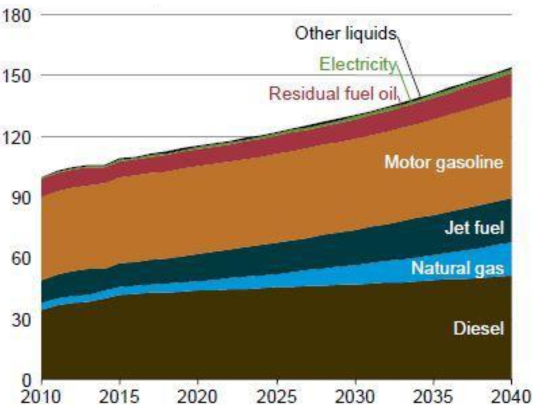

Figure 2: World energy consumption in transportation sector (quadrillion Btu) [1]

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From experimental study it was observed that higher cetane number (CN) of fuel is mainly accountable for higher power output and lower smoke and NOx emissions. It was found that the alcohol mixture in the diesel decreased the CN of the fuel blends, causing poor self-ignition problems. Ethylhexyl nitrate ($C8H17NO3$), cyclohexyl nitrate ($C6H5NO3$) and 2–methoxyethyl ether ($C6H14O3$) were mixed in methanol–biodiesel blends in order to improve CN [5]. In other experimental studies with NE, NM, DGM and metal additives, it has been reported that mixing these additives with ethanol–diesel blends improved performance and reduced emissions. The DGM blended fuel showed best performance, while the NM blended fuel showed best results in smoke reduction. In general, smoke was reduced for all additive–blended fuels while NOx and CO were found to vary according to the nature of additive and operating conditions [6-8].

A study was conducted with diglyme and five other oxygenated additives blended with diesel fuel on a CI engine. It was observed that on addition of these additives the total duration of combustion decreased, but at the same time, combustion improved due to availability of oxygen, particularly during the diffusion combustion phase [9].

An experimental study was conducted with diglyme–diesel blends under 5 different engine loads with different engine speeds of 1800 rpm and 2400 rpm. Diglyme–diesel blends containing 5%, 10.1%, 15.2%, 20.4%, 25.7% and 53% of diglyme (v/v) contain2%, 4%, 6%, 8%, 10% and 20% of oxygen (by mass) respectively. The blending of DGM in diesel resulted in increased BSFC with a maximum increase of 45.1% observed for 53% DGM–diesel blend. BTE was found to be improving slightly for lower blends, but reducing for higher blends. BTE reduced by 3.6% with 53% DGM blend as compared to diesel. By increasing oxygen content in fuel blend, smoke emission reduction was observed. NOx also reduced slightly with DGM blending in diesel [10]. Another investigation showed that reduction of HC is more for additives having less percentage of oxygen. The reduction in PM is generally dependent on the oxygen content in fuel, whereas reduction in CO and HC emissions depends on the molecular composition of the oxygenating additives too. Up to 15% blending of diethelene–glycol–dimethyl–ether (Diglyme) with diesel resulted in 60% reduction in smoke [11].

Nitromethane having 50% (by weight) oxygen content is available and it is responsible to reduce the external requirement of oxygen for completing the combustion. NM has been used with diesel fuel as a oxygeneted additives [12,13].

By adding of NM in diesel, the performance of engine has been found improved and exhaust smoke reduced. The high amount of oxygen available in nitroparaffin compound may be another reason for high BTE. It was found that smoke reduced up to 16.2 % with NM–diesel blend and NOx increased up to 5.1 % with diesel–NM blend [14]. Additives, NE, NM and DGM were mixed into the ethanol–diesel mixture to study exhaust emission characteristics of the CI engine and its performance. It was observed that the use of these additives reduced the smoke in the range of 27–50% respectively.

The emissions of carbon monoxide and CO2 reduced for NM and DGM blends, NOx increased for NM blend, but decreased for DGM blend and HC increased for all additive–blended fuels as compared to ethanol–diesel blend [6,7].

Fuel injection pressure plays a very important role in the performance of the CI engine controlling its exhaust emissions. High fuel injection pressure may responsible for enhancing performance and reducing engine emissions significantly [15,16]. An experiment conducted by Liu et al. [17] on diesel engine using common rail direct injection system with diesel methanol dual fuel showed that BSFC, CO, HC and smoke emissions decreased with the increase of IP. Aalam et al. [18] performed an experiment using mahua methyl ester blend at different IP (22 MPa to 88 MPa). At higher IP, enhanced BTE was observed as compared to lower IP. It was observed that by increasing the IP there was reduction in smoke, HC and CO. This was mainly possible due to better atomization of spray at higher injection pressure. Gumus et al. [19] performed an experiment using biodiesel–diesel blends at various IP (18, 20, 22 and 24 MPa). At higher IP BSFC decreases for different biodiesel-diesel blends (20%, 50% and 100%). Reduction in HC, CO and smoke emissions with increase in IP was also found.

In view of these aspects, oxygenated and nitrogenated additives to form ternary blends is proposed. It was decided to select 2–methoxyethyl ether and nitromethane as the experimental additives. Current study thus aims to present an experimental investigation using selective combinations of “2–methoxyethyl ether–nitromethane–diesel” ternary blends to determine performance and emission of diesel engine by optimizing IP.

2. EXPERIMENTAL SETUP

2.1 Blend preparation

Blend preparation was the first task of the experiments. Three blends of diesel, 2–methoxyethyl ether and nitromethane (D–MXEE2.5–NM2.5, D–MXEE5–NM2.5, D–MXEE7.5–NM2.5) were prepared on volume basis. Initially the pure diesel fuel was taken according to the blending ratio in glass container, after that 2–methoxyethyl ether according to blending ratio mixed in pure diesel drop by drop and stirrer it continuously with the help of magnetic stirrer. After mixing of 2–methoxyethyl ether in pure diesel, 2.5% of nitromethane in a fixed quantity was poured in diesel–2–methoxyethyl ether blend similarly. All the above steps were repeated for different fuel blend. Various properties of the diesel, diethyl ether and ethanol have shown in the table 1.

Table 1: Comparison of Properties of diesel, 2–methoxyethyl ether and nitromethane [20-22]

Properties	**Diesel**	**MXEE**	**NM**
Chemical formula	$C_{12}H_{23}$	$C_6H_{14}O$	CH_3NO_2
Calorific value (MJ/kg)	45	24.5	11.4
Density (kg/m^3)	829	950	1138
Viscosity (cSt)	2.45	1.08	0.62
Cetane number	50	125	NA
Latent heat of evaporation (KJ/kg)	250	322	561
Oxygen content (%)	0	36	50
Self ignition temperature (^{o}C)	315	190	420
Flash point (^{o}C)	70	51	38

2.2 Engine set up

4 stroke single cylinder water cooled variable compression ratio direct injection compression ignition engine was used in this testing. A calibrated protector is placed on the injection nozzle, so that nozzle pressure can be change with that protector. Figure 3 shows the pictorial view of engine setup.

There were various sensors attached with engine to measure the temperature at various positions in the engine. The engine is also attached with eddy current dynamometer, computer, smoke analyzer, gas analyzer and control panel. The specifications of all equipments are given in the table 2.

Figure. 3: Pictorial view of engine setup and control panel

Table 2 Equipment specifications and set up

Equipment	**Specification**
Engine	TVI Kriloskar, Constant rpm (1500), single cylinder, four stroke, 3750W, 0.556 litre, 8cm bore, 10.1cm stroke length, 14-21 CR, self/crank start
Dynamometer	Power mug, eddy current type, power rating 3750W, constant rpm (1500), air cooled, load

	sensor S type.
Exhaust Gas analyzer	AVL-DIGAS Modal- 444N NOx gas- Electrochemical, Range 0-5000 PPM , Resolution 1PPM
Fuel rate measurement	Range of fuel rate- 0-10kg/hr, resolution-0.06kg/hr The fuel rate is measured by two capacitive sensors with a glass burred and solenoid valve.
Air intake measurement	An orifice and differential pressure transmitter used for the measurement of air flow (m^3/s). range of air rate – $50m^3/hr$, resolution – $0.1m^3/hr$
Temperature measurement	K Type thermocouple , range 0-700^0C, Resolution -1^0C
Water flow measurement	Transducer- turbine flow type, range- 0- 99.9cc/s, resolution-0.1 cc/s

Test procedure and condition

The experiments were carried out at the constant speed of 1500 rpm. The load had been varied like 0%, 25%, 50%, 75% and 100%. The load calculation had done by the eddy current dynamometer. The experiment was started by ignition switch for this battery was connected with their terminals. All the water connections werebe opened for cooling the engine. Gas analyzer was checked for any leakage. Now moderately varies the load on the engine by adjusting dimmer state on the control panel. The applied load on the engine is measure by strain gauge load cell. After 20-25 minutes performance and emission data had been observed and recorded for different load condition on the engine.

3. RESULT AND DISCUSSION

A detailed experimental study of the CI engine has been done with different exhaust emission and performance analysis of CI engines for various fuel blends (D-MXEE-NM) and pure diesel. Experiments were conducted with all sets of fuels, pure diesel and blends (D-MXEE2.5-NM2.5, D-MXEE5-NM2.5, D-MXEE7.5-NM2.5) with standard engine parameters (CR–17.5, IP–200 bar and IT–23° before TDC).

The BTE of the engine represents the part of heat that is directly converted to shaft power output. The relationship between BTE (%) and BP (kW) is shown in figure 4.

As per the above curve the BTE (%) is highest for D-MXEE5-NM2.5 (40.2%) at the peak load and the efficiency decreases as the additives quantity is increased. The above result confirms the heating value of diesel being the highest.The mixture fuels release smaller heat because of lower heating value, which in turn reduces BTE of engine [24].

As per the figure 5 the quantity of smoke is least for blend D–MXEE5–NM2.5 as the additives have low boiling point, lower ignition temperature and higher oxygen content as compare to diesel.

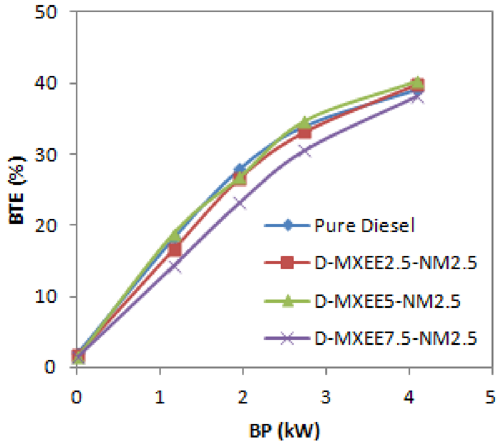

Figure 4: BTE v/s BP curve for diesel and different blends

The higher ignition delay that gives more time for air-fuel mixing and good volatility characteristic of MXEE and NM (due to low boiling temperature 162 °C and 100°C) as compare to pure diesel (high boiling temperature 180–360°C), responsible to improving combustion quality. The high oxygen content of MXEE and NM (36 and 52.4) is also responsible to provide sufficient oxygen in fuel rich region that helps in smoke reduction [25,26]. A minimum value of 72 HSU% smoke emission value was observed with blend D-MXEE5-NM2.5 in peak load conditions between all D-MXEE-NM mixtures and pure diesel.

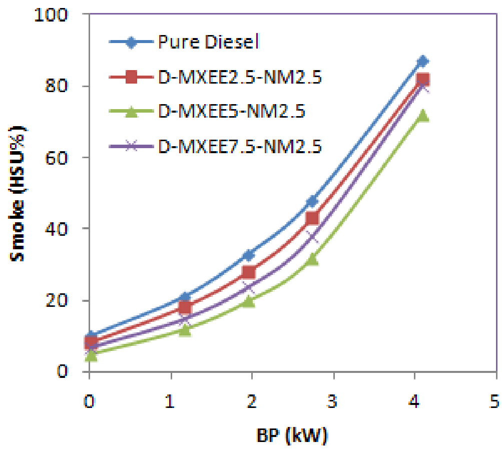

Figure 5: Smoke v/s BP curve for diesel and different blends

As per the figure 6 the quantity of NOx is the least for the blend D–MXEE2.5–NM2.5, as compared to pure diesel. Reason being additive have high cetane number and high oxygen content makes a early combustion. A minimum value of 190 ppm NOx emission value was observed with blend D-MXEE2.5-NM2.5 in peak load conditions between all D-MXEE-NM mixtures and pure diesel. Highest NOx content has been obtained with D–MXEE7.5–NM2.5.

From the above study, it is concluded that the best results are obtain from the blend D–MXEE5–NM2.5 at peak load and IP–200. Now, further studies have been carried out with different injection pressure for best blend.

3.1 Optimum IP selection for best blend (D–MXEE5–NM2.5)

After the selection of best blend, the experiments were carried out for various injection pressure (i.e., 180 bar, 190 bar, 200 bar, 210 bar and 220 bar). Using best blend (D–MXEE5–NM2.5), various engine performance and exhaust emissions results of engine was obtained at different injection pressure.

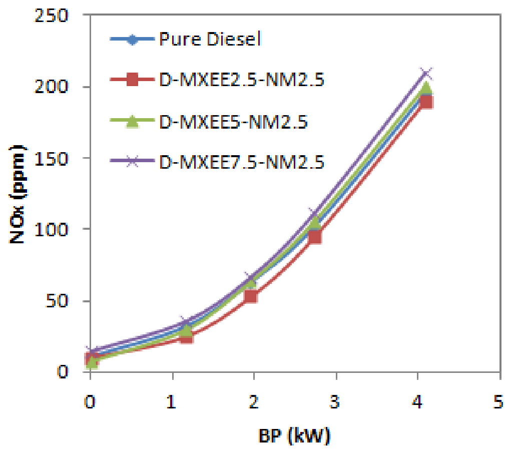

Figure 6: NOx v/s BP curve for diesel and different blends

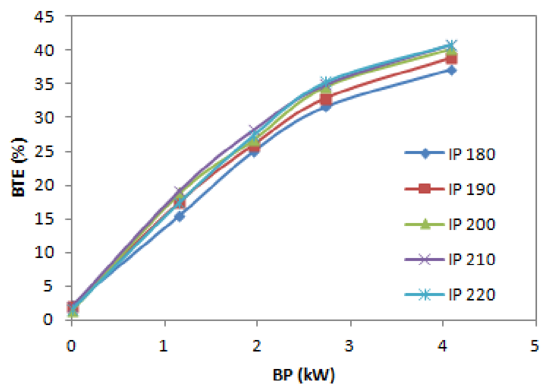

Figure 7: BTE v/s BP curve for D–MXEE5–NM2.5 at different IP

From the above it is observe that at IP 220 bar, highest BTE value (40.932%) is achieved at peak load. Higher the IP will lead to better penetration of fuel in the intake charge leading to homogeneous mixture and better combustion.

From the fig. 8, it is observe that at IP 220 bar, lowest smoke is achieved at peak load. This is due better combustion of fuel during power stroke. The minimum value of 65 HSU% smoke emissions was observed at IP 220 bar with selected blend among all injection pressure at peak load condition.

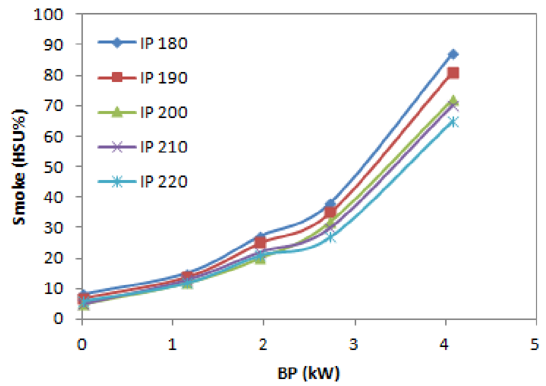

Figure 8: Smoke v/s BP curve for D–MXEE5–NM2.5 at different IP

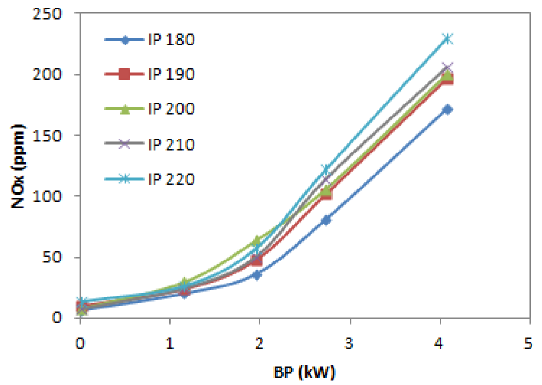

Figure 9: NOx v/s BP curve for D–MXEE5–NM2.5 at different IP

From the above figure 9, it is observed that highest NOx is obtained at IP 220 bar and lowest at IP 180 bar. This due to complete combustion of fuel, which may be responsible for higher temperature. The minimum value 172 ppm of NOx emission was observed at lowest IP 180 bar among all IP with selected blend at peak load condition [27].

From the above it can be concluded the comparatively better results are obtained (among all IP) with D–MXEE5–NM5 at IP 220 bar.

4. CONCLUSION

In the current work, a CI engine was operated at different IP with ternary fuel blends (diesel–2–methoxyethyl ether–nitromethane) and its performance and emission characteristic were recorded.

At first stage, engine was operated at standard engine parameters using pure diesel and variable ternary blends (D-MXEE2.5-NM2.5, D-MXEE5-NM2.5, D-MXEE7.5-NM2.5), and result were also recorded. Then these results compared with the pure diesel to get the best blend. In second stage best selected blend was tested at different IP for its optimization. Based on the various experimental results, the following conclusions can be drawn:

- D–MXEE5–NM2.5 blend was found the most excellent fuel blend at standard engine parameters (IP 200 bar, IT 23° CA btdc, and CR 17.5) due to its high CN, high oxygen content available in the blend. BTE was increased by 3.02 % and smoke was decreased by 17.24% as compared to pure diesel at peak load. However slightly increment in NOx emission 2.56 %.
- After analyzing the above results, it was observed that at higher IP 220 bar better results were achieved using D-MXEE5-NM2.5 blend, due to the higher IP which lead to better penetration of fuel in the intake charge leading to homogeneous mixture and better combustion. It also resulted that BTE enhancement 1.82 % and 9.72 % decrement in smoke as compared to standard IP (200 bar) at peak load condition. But at the same time due to higher combustion temperature NOx content (15 %) in emission increases.

REFERENCES

[1] Coyle ED, Simmons RA (2014) Understanding the global energy crisis. Purdue University Press e-books.

[2] Kumar C, Rana KB, Tripathi B (2019) Effect of diesel–methanol–nitromethane blends combustion on VCR stationary CI engine performance and exhaust emissions. Environmental science and pollution research, vol. 26 (7), pp. 6517–6531.

[3] Nayyar A, Sharma D, Soni SL, Mathur A (2017) Characterization of n-butanol diesel blends on a small size variable compression ratio diesel engine: Modeling and experimental investigation. Energy Convers Manag. vol. 150, pp.242–258.

[4] Kumar C, Rana KB, Tripathi B, Nayyar A (2018) A comparative study of oxygenated additives for diesel in compression ignition engine. Int. J. Renewable Energy Technology, vol. 9, pp.16-27.

[5] Li R, Wang Z, Ni P, Zhao Y, Li M, Li L (2014) Effects of cetane number improvers on the performance of diesel engine fuelled with methanol/biodiesel blend. Fuel, vol. 128, pp. 180–187.

[6] Pirouzfar V, Zarringhalam A, Mirza B (2012) Physicochemical Properties and Combustion Performance of Gas Oii-Fuei Additives. J Energy Resour Technol, vol. 134, no. 4, pp. 1–7.

[7] Ommi M, Nekofar K (2009) Emission and Properties Characteristics Using Additive – Ethanol–Diesel fuel blends on a diesel. J Eng Ann Fac Eng Hunedoara, vol. 7, no. 2, pp. 35–42.

[8] Fayyazbakhsh A, Pirouzfar V (2016) Investigating the influence of additives-fuel on diesel engine performance and emissions: Analytical modeling and experimental validation. Fuel, vol. 171, pp. 167–177.

[9] Ren Y, Huang Z, Miao H, Di Y, Jiang D, Zeng K, Liu B, Wang X (2008) Combustion and emissions of a DI diesel engine fuelled with diesel-oxygenate blends. Fuel, vol. 87, no. 12, pp. 2691–2697.

[10] Di Y, Cheung CS, Huang Z (2010) Experimental investigation of particulate emissions from a diesel engine fueled with ultralow-sulfur diesel fuel blended with diglyme. Atmos Environ, vol. 44, no. 1, pp. 55–63.

[11] Baskar P, Nanthagopal K, Elango T (2011) The effect of two oxygenates on diesel engine emissions. ARPN J Eng Appl Sci, vol. 6, no. 3, pp. 55–60.

[12] Raine RR, Thorwarth H (2004) Performance and combustion characteristics of a glow-ignition two-stroke engine. SAE Tech Pap 2004-01-1407.

[13] Ambekar A, Bhangale R, Chatterjee R, Kulkarni C, Kumar S, Chowdhury A (2015) Glow-plug-assisted combustion of nitromethane sprays in a constant volume chamber. Appl Therm Eng, vol. 76, pp. 462–474.

[14] Moghaddam MS, Moghaddam AZ (2014) Chemical engineering research and design performance and exhaust emission characteristics of a CI engine fueled with diesel-nitrogenated additives. Chemical Engineering Research and Design, vol. 92(4), pp. 720–726.

[15] Sastry GRK, Deb M, Panda JK (2015) Effect of Fuel Injection Pressure, Isobutanol and Ethanol Addition on Performance of Diesel-biodiesel Fuelled D.I. Diesel Engine. Phys Procedia, vol. 66, pp. 81–84.

[16] Jindal S, Nandwana BP, Rathore NS, Vashistha V (2010) Experimental investigation of the effect of compression ratio and injection pressure in a direct injection diesel engine running on Jatropha methyl ester. Appl Therm Eng, vol. 30, pp. 442–448.

[17] Liu J, Yao A, Yao C (2015) Effects of diesel injection pressure on the performance and emissions of a HD common-rail diesel engine fueled with diesel/methanol dual fuel. Fuel, vol. 140, pp. 192–200.

[18] Aalam CS, Saravanan CG, Anand BP (2016) Impact of high fuel injection pressure on the characteristics of CRDI diesel engine powered by mahua methyl ester blend. Appl Therm Eng, vol. 106, pp. 702–711.

[19] Gumus M, Sayin C, Canakci M (2012) The impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fueled with biodiesel-diesel fuel blends. Fuel, vol. 95, pp. 486–494.

[20] Kumar C, Rana KB, Tripathi B, Nayyar A (2018) Properties and effects of organic additives on performance and emission characteristics of diesel engine: a comprehensive review. Environmental science and pollution research, vol. 25 (23), pp. 22475–22498.

[21] Sayin C (2010) Engine performance and exhaust gas emissions of methanol and ethanol-diesel blends. Fuel, vol. 89, no. 11, pp. 3410–3415.

[22] Sayin C, Ozsezen AN, Canakci M (2010) The influence of operating parameters on the performance and emissions of a DI diesel engine using methanol-blended-diesel fuel. Fuel, vol. 89, no. 7, pp. 1407–1414.

[23] Can O, Celikten I, Usta N (2004) Effects of ethanol addition on performance and emissions of a turbocharged indirect injection diesel engine running at different injection pressures. Energy Convers Manag, vol. 45, no. 15–16, pp. 2429–2440.

[24] Gyanendra S (1999) An analytical approach to farm mechanization in India-agricultural machinery development and promotion. Journal of Rural Development, vol. 7, No. 2, pp. 297-319.

[25] Giakoumis EG, Rakopoulos CD, Dimaratos AM, Rakopoulos DC (2013) Exhaust emissions with ethanol or n-butanol diesel fuel blends during transient operation : A review. Renew Sustain Energy Rev., vol.17, pp.170–90.

[26] Banapurmath NR, Khandal SV, RanganathaSwamy L, Chandrashekar TK (2015) Alcohol (ethanol and diethyl ethyl ether)–diesel blended fuels for diesel engine applications–a feasible solution. Advances in automobile engineering, vol. 4 (1), pp. 117.
[27] Quadri SAP, Masood M, Ravi Kumar P (2015) Effect of pilot fuel injection operating pressure in hydrogen blended compression ignition engine: An experimental analysis. Fuel, vol. 157, pp. 279–284.