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COMBINED EFFECT OF SUPERCHARGING AND INJECTION PRESSURE ON EMISSION CHARACTERISTICS OF A DIESEL ENGINE FUELED WITH PALM BIODIESEL - DIESEL BLEND

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Abstract — *In recent years alternative fuels based on biomass are gaining more popularity as they have less emission profile. In this investigation experimental work is carried out to estimate the emission characteristics of a single cylinder four stroke diesel engine running on Palm biodiesel blended with diesel. Engine tests have been carried out at constant speed of 1500 rpm and compression ratio 18 using palm biodiesel and diesel with blends of D0, D50 and D100, where palm biodiesel is denoted by D0 and diesel is denoted by D100, at different loading conditions. This study also targets at finding the effects of supercharging and fuel injection pressure (IP) jointly on engine emissions of carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), unburned hydrocarbons (HC) and oxides of nitrogen (NOx) with above fuels. The results of experimental investigation with biodiesel blends with diesel are compared with that of diesel. The results indicated that the HC and NOx emissions are less for D0. NOx emission was found 30.17% lower for biodiesel (D0) in comparison to diesel. It is found that with increase in injection pressure and with supercharging condition palm biodiesel D0 have considerable lesser emissions of HC, O_2, NOx as compared to D100. D100 has lowest CO emissions at all loading conditions than D0 for both normal and supercharging condition. Significant improvement in CO_2 emissions has been observed for D100 in supercharging condition.*

Keywords- *Blend, Diesel, Injection Pressure (IP), Palm biodiesel, Emission characteristics, Supercharging*

I. INTRODUCTION

Diesel engines are extensively used as power source for road transport sector. They are dominating power source as they offer high thermal efficiency, robustness and lower emissions [8]. In recent years bio diesel has come out as accepted alternative to diesel as its utilization does not require significant changes in engine. Biodiesel is petroleum-based fuel derived from vegetable oils, animal fats and waste cooking oil including triglycerides [2]. Bio diesel is getting attention from world countries due to its environmental friendly characteristics. Different research works have proved that performance of biodiesel is almost like diesel engines [1, 4-5, 7, 10]. In comparison to older mechanical fuel injection systems with advanced fuel injection systems, fuel injection pressures have risen to considerable amount. Supercharging especially with bio diesel is also helpful to improve performance of an engine [15]. It is therefore very important to investigate the effects of fuel injection pressure and supercharging on comparative performance, emissions and combustion characteristics of biodiesel and diesel for effective utilization of biodiesel in modern CI engines. This work focuses on finding the effects of engine parameters viz. inlet air pressure and injection pressure on diesel engine emission characteristics like carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), unburned hydrocarbons (HC) and oxides of nitrogen (NOx) when it runs with bio diesel. Two different conditions (normal and supercharging) are analyzed for comparing the results of C.I. Engine fueled by (a) 100% diesel (D100) (b) Blend of diesel & biodiesel (D50) and (c) 100% biodiesel (D0).

II. REVIEW OF LITERATURE

Many researchers around the world have successfully carried out large number of experiments with biodiesel as a replacement fuel in diesel engines. R. El - Araby et al. (2017) [3] studied characteristics of palm oil biodiesel – diesel fuel blend. They investigate the key properties (density, kinematic viscosity and flash point) of palm oil, palm oil methyl ester in a blend with diesel fuel. It has been found that the properties of palm oil - palm oil biodiesel blends have no significant difference in fuel properties of the blends up to 30% volume of oil/ biodiesel of palm. Neeraj Goreya et al. (2017) [4] studied characterization of palm oil as biodiesel. Investigators studied the standardization and optimization of biodiesel production from palm oil using transesterification in order to design process parameter for production. The exhaust emission characteristics of palm biodiesel blends Bl0, B50 and B100 were compared with diesel. The fuel properties of biodiesel after transesterification were found to be comparable to diesel and were conforming to the latest biodiesel standards. Flash and fire point were higher compared to diesel and cloud point and pour point was also observed low. Moreover biodiesel gave less power, less thermal efficiency, more BSFC, less CO and HC emission and higher NOx emission compared to that of diesel.

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M.S. Gad et al. (2017) [6] studied the performance and emissions characteristics of C.I. engine fueled with palm oil/palm oil methyl ester blended with diesel fuel. They found that thermal efficiency of palm biodiesel and oil blends with diesel fuel was lower compared to diesel fuel and sfc were found to be higher. Higher exhaust gas temperatures are recorded for biodiesel and oil blends compared to diesel fuel for the entire engine load. Exhaust gas temperature values for diesel, B20, B100 and PO20 are 302, 312, 371 and 322 ^{0}C, respectively at full load. Air- fuel ratios for diesel-palm biodiesel blends (B20, B100) and palm oil blend (PO20) were lower than diesel fuel. Exhaust emissions of CO and HC were reduced relative to conventional diesel fuel. NO_X emissions increased relative to conventional diesel. The NOx emission for diesel, B20, B100 and PO20 are 174, 190, 285 and 301 ppm respectively, at full load operation. The results proved that performance and exhaust emissions of a diesel engine using palm oil methyl ester blends up to 20% with diesel fuel are reasonable. M.H. Mosarof et al. (2015) [7] studied on implementation of palm biodiesel based on economic aspects, performance, emission, and wear characteristics. According to their study performance and exhaust emissions using palm oil fuel and its blends with conventional diesel fuel in stationary diesel engines are comparable to those of conventional diesel fuel. Moreover, palm oil fuel is environment-friendly and exhaust emission is much cleaner with reduced black smoke, CO, HC, and absence of SO_2 excluding NO_X. Wear analysis also showed that palm oil does not seriously affect engine and bearing components, does not degrade lubricating oil, and produce comparable amounts of carbon deposits. Palm oil and its blends improve the anti-wear characteristics of the engine components. Compared with pure conventional diesel fuel, palm oil and its emulsion with ordinary diesel fuel show slightly higher specific fuel consumption. The high fuel consumption of palm oil fuel and its blends can counteract the lower heating values such that the engines consume an equal amount of energy. The ignition delays for palm oil fuel are shorter than those for diesel fuel. Generally, economic prospects for this fuel are not yet promising because of factors such as production cost and fuel economy.

Luka Lešnik et al. (2013) [10] studied the influence of biodiesel fuel on injection characteristics, diesel engine performance, and emission formation. The influence of pure biodiesel usage on injection, fuel spray, and engine characteristics was investigated experimentally and numerically for a bus MAN diesel engine with mechanically controlled M injection system. They found that higher mean injection pressure results in longer spray penetration lengths of biodiesel. All numerical and experimental results indicate that the maximum reductions of engine power and torque are most exposed at higher engine speeds. Oxygen content in biodiesel contributes to better oxidation processes within the combustion chamber. This reduces CO emission and promotes higher NOx emission. At the bottom line, it looks like the tested biodiesel could be used as replacement for mineral diesel in heavy duty diesel engines that are similar to the tested engine. Donepudi Jagadish et al. (2011) [17] studied the effect of supercharging on performance and emission characteristics of CI engine with diesel ethanol ester blends. They concluded with no supercharging E20B (blend of 20% ethanol, 10% ester, 70% diesel by volume) and E30B (blend of 30% ethanol, 10% ester, 60% diesel by volume) showed a reduction in values of brake specific fuel consumption in comparison to diesel at higher loads, and the same with E10B (blend of 10% ethanol, 5% ester, 85% diesel by volume) at lower loads. Brake specific fuel consumption values are further decreased with supercharging for all the blends. Brake thermal efficiency is high with E20B and E30B when compared with diesel and with super charging E10B showed much improvement, E20B and E30B showed a noticeable improvement. NOx values are lowered with ethanol, ester and diesel blends when compared with pure diesel operation and with supercharging NOx formation is little increased. Unburned HC and CO emissions seem to increase as the ethanol percent increases in the blend, but with supercharging these emissions are little lowered. R. Samsukumar et al. (2015) [18] investigated performance and emission analysis on C.I Engine with palm oil biodiesel blends at different fuel injection pressures. The experiments were done at injection pressure 210 bar (without engine modification), 190 bar and 230 bar (with engine modification). It was found that for using pure biodiesel engine modification is required. Blend B20 gives best result for run on engine without any modifications.

In this study effect of supercharging and injection pressure on engine performance have been investigated for palm bio diesel, pure diesel and their blend to explore prospects of Palm biodiesel/blends for its utilization in CI engines.

III. PALM OIL

The performance and emission characteristics of biodiesel fueled engine depend purely upon the thermo physical properties of the biodiesel [1]. Basically the biodiesels are derived from vegetable oils via a popular process, transesterification in the presence of a catalyst and alcohol as a reactant [5]. The purpose of the transesterification process is to lower the viscosity of the oil. Table 3.1 shows properties of diesel and palm biodiesel.

Table 3.1 Comparison of properties Palm biodiesel vs Diesel

Sr. no.	Properties	Palm Bio Diesel	Diesel
1	Density@15°c kg/m^3	879	833
2	Kinematic viscosity at 40° C (cSt)	4.57	3.06
3	Calorific Value (KJ/Kg)	40560	44800
4	Flash point (°C)	136	67
5	Fire point (°C)	153	138
6	Cetane number	62	52

IV. EXPERIMENATL SET UP

The engine set up consists of single cylinder four stroke, water cooled computerised research engine in which loading has been provided by eddy current dynamometer. Set up is provided with all necessary instruments for combustion pressure, diesel line pressure and crank-angle measurements. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. It has stand - alone panel box consisting of air box, two fuel flow measurements, process indicator and hardware interface. Lab view based Engine Performance Analysis software package “Engine soft” is provided for on line performance evaluation.

Fig 4.1 Front view of experimental setup

Fig 4.2 Side view of experimental setup

In this experiment, single cylinder water cooled diesel engine coupled with eddy current dynamometer is used. The set up is fully computerized and provided with all types of sensors to note readings. A gas analyzer is used for analysis of the pollutants within the exhaust gas. This gas analyzer is connected to the engine exhaust pipe. This instrument is employed to measure the necessary pollutants i.e. carbon monoxide gas (CO), NOx, unburnt Hydrocarbons (HC) etc. The specifications / working range of this gas analyzer is shown in Table 4.2. Inlet air pressure & injection pressure are taken for the optimization for same compression ratio at different load. Atmospheric air as inlet air is supplied to engine in normal condition and in supercharging condition continuous flow of air with the use of air compressor is supplied to engine. Performance tests were carried out using pure diesel, blended diesel & bio-diesel fuel for different load and different injection pressure in both conditions. Tests were conducted with compression ratio 18 and rated speed 1500 rpm at different injection pressures (Low – 140 bar, Medium – 180 bar, High – 220 bar) with different loading for all fuels.

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Table 4.1 Technical specifications of engine

Engine manufacturer	Apex Innovations (Research Engine test set up)
Software	Engine soft Engine performance analysis software
Engine type	Single cylinder four stroke multi fuel research engine
No. of cylinder	1
Type of cooling	Water cooled
Cubic Capacity	0.661 litres
Rated Power	3.5 kW @ 1500 rpm
Cylinder diameter	87.5 mm
Orifice diameter	20 mm
Stroke length	110 mm
Connecting rod length	234 mm
Dynamometer	Type: eddy current, water cooled, with loading unit

Table 4.2 Exhaust gas analyzer specifications

Constituent	Specified Range	Accuracy Vol.	Accuracy %	Resolution
CO	0-10% ±	0.06 ±	3%	0.01%
HC	0-20000 PPM	± 12 PPM	± 55%	1 PPM
CO_2	0-20%	± 0.4%	± 4.0%	0.1%
O_2	0-21%	± 0.1%	± 3%	0.01%
NO_X	0-5000 PPM	25 PPM	± 5%	1 PPM

Where,
CO = Carbon monoxide % volume measured.
CO_2 = Carbon dioxide % volume measured.
HC = Hydrocarbon ppm measured
O_2 = Oxygen % volume measure

V. RESULTS AND DISCUSSIONS

An alternative fuel used in engines is always evaluated on the basis of both engine performances and its environmental impacts. As such, various parameters related to the emissions of diesel engine have been analyzed in this section. The relationship between different variables is shown in figures and discussed in following sections. The investigation was done with three fuels, namely pure Diesel (D100), pure palm biodiesel (D0) and blended palm biodiesel (D50). In present work effects of fuel injection pressure (IP) and supercharging on carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), unburned hydrocarbons (HC) and oxides of nitrogen (NOx) emissions were investigated at different load for all fuels.

A. Carbon Monoxide emission

Carbon monoxide formation is mainly an indication of extent of incompleteness of combustion of fuel [9, 17]. The percentage variation of CO emission for the blends of diesel with different injection pressure and load is shown in figure 5.1. It is observed that CO emissions are decreased with increase in engine load for all fuels. At low load CO emission is more for biodiesel (D0) but with increase in load it reduces or gives same values as diesel. At low loads, high values of CO emission for blends are due to the high viscosity of bio diesel and low in-cylinder temperature. At high loads, reduced CO formation for the blends is mainly due to the effective oxidation of CO due to the high in-cylinder temperature in combination with the presence of oxygen molecule in biodiesel. CO emission increases slightly with increase in injection pressure. With supercharging the amounts of CO emission appears to be slightly reduced due to reduced ignition delay period, a rise in temperature of combustion.

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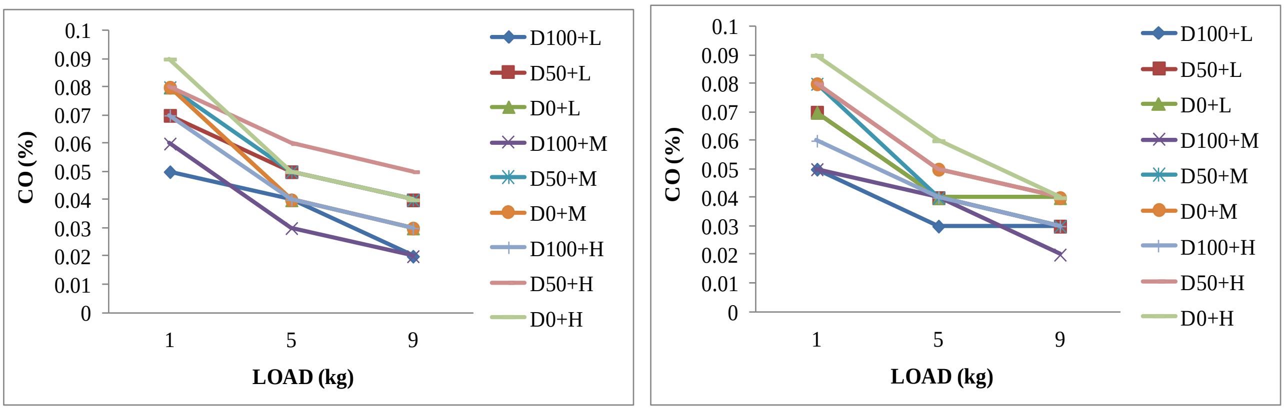
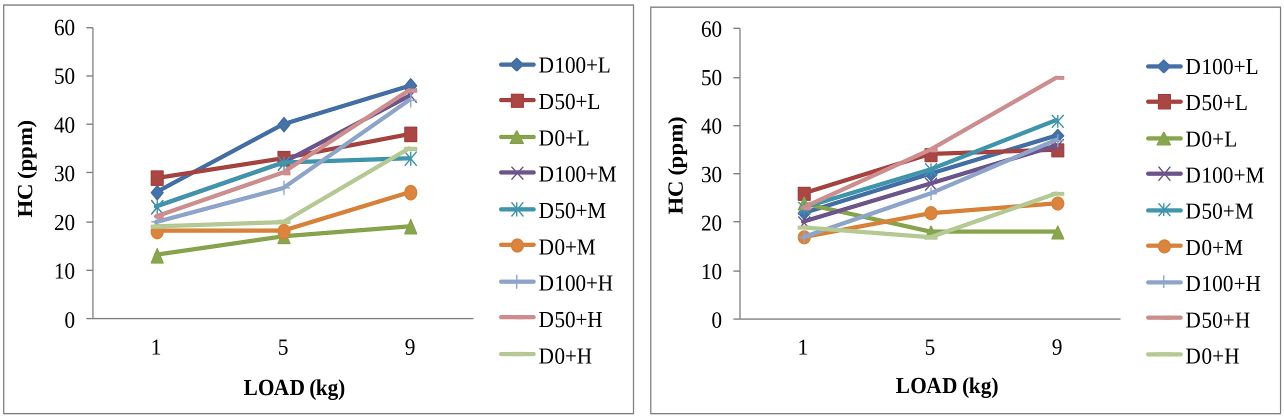


(a) *(b)*

Fig 5.1 Variation of CO emission with engine load for all injection pressure and palm bio diesel blend (a) Normal mode (b) Supercharging mode

B. Hydrocarbon emission

The variation of HC emission in parts per million for the blends of diesel with different injection pressure and load is shown in figure 5.2.



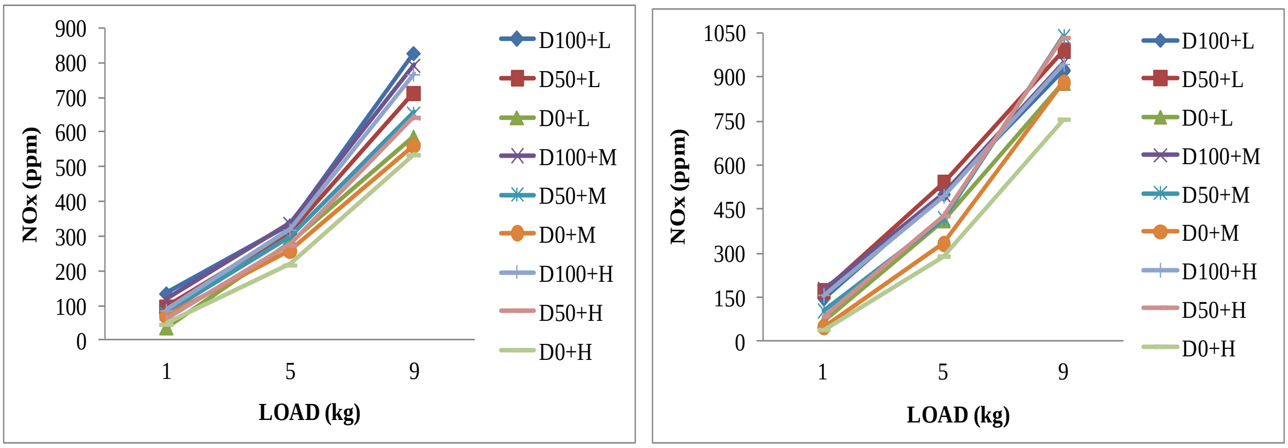
(a) *(b)*

Fig 5.2 Variation of HC emission with engine load for all injection pressure and palm bio diesel blend (a) Normal mode (b) Supercharging mode

HC emission increased with increase in load on the engine for both conditions. This is due to the availability of less oxygen for the reaction when more fuel is injected into the engine cylinder at higher load [19]. Unburned hydrocarbon emissions are remarkable for bio diesel (D0) at all loading conditions because of density, increased gas temperature and cetane number. Higher temperature of burnt gases in biodiesel fuel helps in preventing condensation of higher hydrocarbon reducing unburnt HC. The higher cetane number of biodiesel results decrease in HC emission due to shorter ignition delay. HC emissions are lower by almost 50% for biodiesel as compared to diesel in normal condition. For blend D50 the values are slightly on higher side due to non homogeneity of the mixtures due to low viscosity and density at some regions of combustion chamber. Hydrocarbon emissions tend to decrease with increase in injection pressure. The un-burnt HC emissions are higher for low injection pressure (140 bar) for almost all loads signifies that at lower injection pressures, atomization is poor and large droplets are formed leading to more unvaporised hydrocarbons in the exhaust [14]. With supercharging the unburned HC emissions decreased because of the reduction in the delay period of combustion and improved homogeneity of the mixtures.

C. Oxides of Nitrogen emission

NO_X formation is mainly dependent on the in-cylinder temperature, oxygen concentration with bio fuel and fuel air residence time. At higher temperature nitrogen dissociates into nitrous oxide. NO_X is most harmful gaseous emission from engines. The NO_X values as parts per million for different fuels and injection pressure are plotted as function of load (Figure 5.3). As load is increased NO_X emissions are increased significantly because of increase in amount of fuel burnt and increase in cylinder temperature at higher loads. At high load, the NO_X emission was found to be 830 ppm, 795 ppm and 769 ppm for diesel (D100) in normal condition while 920 ppm, 948 ppm and 942 ppm in supercharging conditions, with increasing injection pressure from 140 bar to 220 bar. NO_X emission was found 30.17% lower for biodiesel (D0) in comparison to diesel (for 9 kg load with 220 bar IP) which may be due to lower temperature of combustion inside engine cylinder. Less NO_X emissions are obtained with increase in injection pressure. The possible reasons could be lower localized gas temperature in cylinder, poor atomization at higher pressure and oxidation rate. It can be seen that with supercharging there is a slight increase in formation of NO_X due to rise in temperature of combustion.

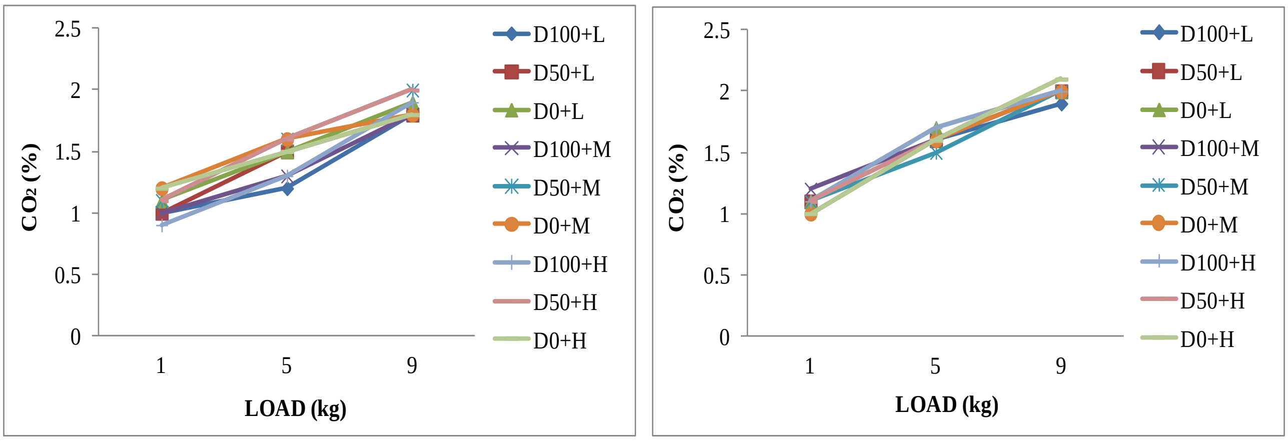


(a) *(b)*

Fig 5.3 Variation of HC emission with engine load for all injection pressure and palm bio diesel blend (a) Normal mode (b) Supercharging mode

D. Carbon Dioxide emission

CO_2 emission in diesel engine indicates how efficiently the fuel is burnt inside the combustion chamber. CO_2 produced by biomass based fuels would cause no effect on environment, because the emitted CO_2 would be absorbed by plants during photosynthesis which causes net zero carbon emission. The variation of Carbon dioxide (CO_2) emission with different load of the engine for all fuels of the engine for normal & supercharging condition at different injection pressure is shown in figure 5.4. Carbon dioxide emission increased with increase in load on the engine for both conditions of the engine for all fuels. CO2 emissions of diesel fuel are lower than biodiesel. CO2 emissions are directly proportional to the percentage of palm in the fuel blend. Since palm biodiesel is an oxygenated fuel, it improves the combustion efficiency and hence increases the concentration of CO2 in the exhaust. CO_2 emissions increase with injection pressure indicating better combustion at higher injection pressures. It can be seen that with supercharging there is a slight increase in CO_2 due to rise in temperature of combustion.

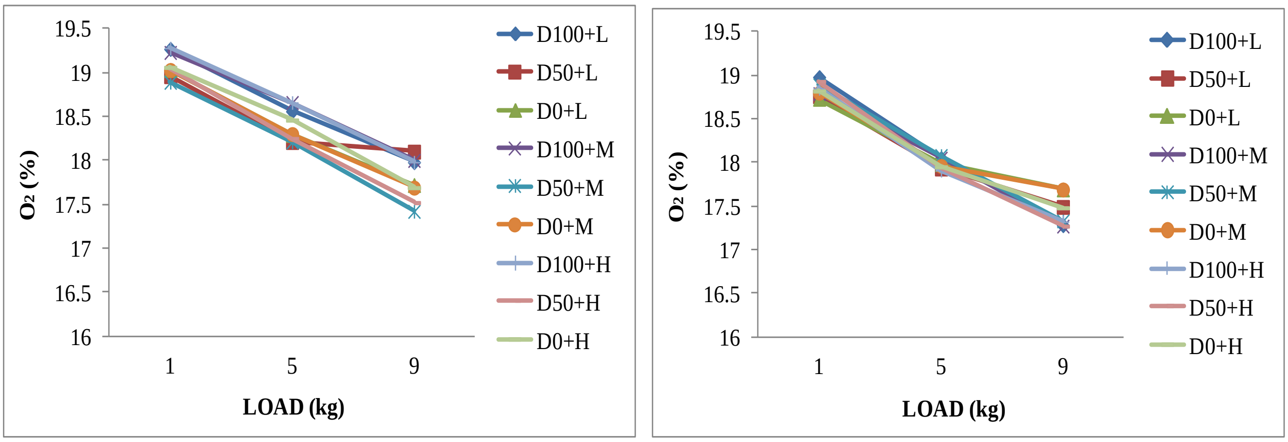


(a) *(b)*

Fig 5.4 Variation of CO_2 emission with engine load for all injection pressure and palm bio diesel blend (a) Normal mode (b) Supercharging mode

E. Oxygen emission

Variations of oxygen (O_2) emission with different load of the engine for all fuels for normal & supercharging condition at different injection pressure is shown in figure 5.5. It is clear that oxygen present in the exhaust gas is decreased as the load increases. There is slight improvement with injection pressure due to improved combustion. There is not significant difference observed between normal and supercharging condition for O_2 emissions.



(a) *(b)*

Fig 5.5 Variation of O_2 emission with engine load for all injection pressure and palm bio diesel blend (a) Normal mode (b) Supercharging mode

VI. CONCLUSION

Emission characteristics of diesel engine running with diesel and palm bio diesel for variation of injection pressure and air inlet condition were investigated at constant speed. Trials with three values of injection pressures (Low – 140 bar, Medium – 180 bar, High – 220 bar) and three fuels (pure Diesel (D100), Palm biodiesel (D0) and Blended Palm biodiesel-diesel (D50)) with variation in inlet condition of air have been analyzed. The results may be summarized as follows:

- CO and O_2 emissions reduced with increase in load while HC, CO_2, NO_X increased for all fuels in both conditions.
- At low load CO and CO_2 emission is found more for biodiesel (D0) compare to diesel whereas HC, O_2 and NO_X values are found less.
- CO, CO_2 emission increases slightly with increase in injection pressure but HC and NO_X emissions decreased.
- CO, CO_2 and NO_X emission increases slightly with supercharging while HC emissions reduced.
- With supercharging condition palm biodiesel D0 have considerable lesser Emission of HC and NO_X as compared to blend D50.
- D50 palm blend have lowest O_2 emission at all loading condition than D0 and D100 fuel in normal condition.
- D0 blend have lowest CO emission among all fuel at all loads for both condition.
- HC emission of diesel engine is very low with the use of D0 fuel for all variations of load and injection pressure. HC emissions are lower by almost 50% for D0 as compared to diesel in normal condition.
- NO_X emissions for D0 palm biodiesel have lowest values at all varying loads of engine in normal condition. NO_x emission was found 30.17% lower for biodiesel (D0) in comparison to D100 (for 9 kg load with 220 bar IP). With the supercharging effect NOx emission is increased but values remained less compare to D50 and D100 fuel.

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