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Improving the Performance Characteristics and Emission Reduction of Small Diesel Engine Operated with Biodiesel Fuel

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ABSTRACT:

This research aims to enhance the performance characteristics of diesel engine fuelled with biodiesel produced from waste cooking oils. The effects of fuel injection pressure (IP) on the performance characteristics of diesel engine and emission pollutants are investigated through experimental works using one cylinder diesel engine, direct injection using conventional petroleum diesel and two biodiesel blends (B5) from waste oil i.e. palm and sunflower oil. Five different IPs 100, 110, 130 and 140 kg/cm^2, were used besides the original IP of 120 kg/cm^2. Performance characteristics of diesel engine such as brake power, brake specific fuel consumption and exhaust emission such as CO, CO_2, HC, NO_x and PM have been measured while the engine speed is ranged from 1500 to 3500rpm and constant load (65%). The results showed a significant enhancement of the performance of diesel engine fuelled with biodiesel at an IP of 130 kg/cm^2.

KEYWORDS:

Biodiesel fuel; Pressure of fuel injection; Engine performance; Emission characteristics

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1. Introduction

Internal combustion engine especially diesel engine is used in both stationary and movable applications, especially where high torque is needed. It is considered to be one of the efficient and reliable power trains among the existing technologies [1]. Diesel engines have significance amongst internal combustion engines because of fairly superior fuel economy, lesser emissions of HC and CO compared to spark ignition engines. However, PM and NO_x emissions are high. For this diesel engine, fuel injection system has used to achieve higher pressure of injection [2]. So, it is intended to decrease the exhaust pollutants by rising efficiency of diesel engines [3, 4]. Fuel injection parameters of the engine have a significant role in diesel engine performance to get optimal combustion. The performance characteristics and pollutions of diesel engine is related to several parameters. The significant parameters which affect the performance and pollution of diesel engine are fuel injection pressure (IP), fuel nozzle holes and its size [5].

While the pressure of fuel injection is low, fuel particulates diameters will increase and delay the period of ignition during the combustion. This condition leads to dreadful combustion in the engine and causes the raise in NO_x and CO emissions. When the fuel IP is increased, the diameters of fuel particle will be decreased. The blending of fuel and air becomes better during period of ignition delay that causes low particulates and CO emission. The ignition delay period becomes shorter when the pressure of fuel injection is too high. So, possibilities of uniform mixing reduces and the combustion effectiveness drops down. Therefore, particulates are created in engine exhaust [6, 7]. The fuel diffusion space becomes bigger and the blend formation of the fuel and air was enhanced when the time of combustion became lower as the fuel IP will be higher [8]. The influences of high IP benefits are [9]:

- Enhanced fuel atomization giving finer fuel droplets.
- The fuel-air mixing will be improved due to the rapidly evaporation of smaller droplets of fuel.
- The time of fuel injection will be decreased.
- Injection timing may be retarded at shorter injection duration.
- Ignition delay period will be decreased when fuel was injected near to TDC in hotter air, resulting in emission decrease.
- Higher fuel diffusion and improved air utilization.

The world's quickly decreasing petroleum supplies; their increasing cost and the fast rising of vehicle pollutions from conventional petroleum fuels have derived to a concentrated search for alternative fuels to replace diesel fuel [10]. Biodiesel is most common biofuel for diesel engine. It is formed from vegetable oils or fats by transesterification and is a liquid comparable in composition to conventional diesel. Biodiesel fuel has heat energy value of about 12% less than fossil diesel fuel. The molecular weight density, viscosity and flash point of the fuel are higher, than conventional diesel fuel [11]. In recent years, a lot of experimental tests were carried out on fuel IP to improve the engine external characteristics and to decrease the engine exhaust emissions [12]. According to increase of the fuel cetane number (CN), the ignition delay period is decreased and causes the engine to operate steadily. On the other hand, a CN higher than the normal value causes the formation of extreme particulates and decreases the engine performance [13]. When the CN is low, it may be not easy to start the engine, and it will cause it to operate the engine knocking. The dissimilarity of ignition delay period by fuel cetane number is illustrated in Fig. 1. When the CN is improved, the delay period of ignition will be shorter, and depending on it, the maximum pressure is raised [14].

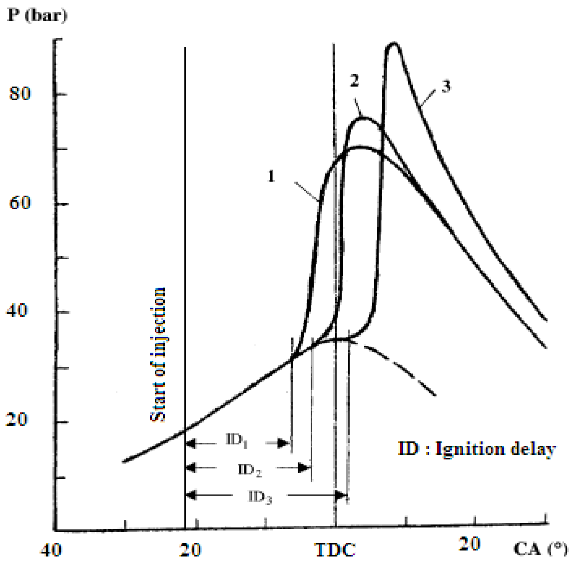

Fig. 1: The variation of ignition delay and the pressure by CN, (1): cetane no. CN = 52, (2): CN - 42, (3): CN = 29 [15]

The objective of this study is to evaluate experimentally the performance and emission characteristics of diesel engine using petroleum diesel and two different type of biodiesel blends B5 (95% diesel fuel + 5% biodiesel from waste palm and sunflower cooking oil). The IPs were 100, 110, 130 and 140 kg/cm^2 in addition to original IP 120 kg/cm^2 and the engine speed was changed from 1500 to 3500rpm and constant load.

2. Production method of biodiesel

To make biodiesel, two types of waste cooking oil (WCO) were collected from two different restaurants in Cairo as shown in Table 1. The generation of biodiesel from waste palm and sunflower oil is utilizing by transesterification process. Transesterification process must be done in the presence of a catalyst. The selection of catalyst depends upon the free fatty acid (FFA) value of waste oil, it is lesser than 2 [16]. The process variables are shown in Table 2. Table 3 shows the properties of produced biodiesel compared to the Egyptian standards of petro-diesel fuel. The low CN of resulted biodiesel from sunflower oil may be due to high cooking temperature for sunflower oil (about 250°C).

Table 1: Specification of waste cooking oils

Oil type	Nature of using	Fried temperature	Fried period/day	Change Period
Waste Palm oil (82 l)	Fried onion	150 - 180°C	10 - 12 hr	Every day
Waste sunflower oil (105 l)	Fried potatoes and chips	Up to 250°C	15 hr	3 times / week

Table 2: Process variables of biodiesel production

Methanol	20% w/w of oil
Catalyst	KoH (1 % w/w of oil)
Reaction temperature	65°C
Reaction time	120 minute
Stirrer speed	400rpm
Separation time	24 hr

Table 3: Biodiesel and conventional diesel fuel specifications

Test	B5 Palm	B5 S. flower	Egyptian diesel
Density g/cm^3 @ 15.56°C	0.898	0.886	0.842
Kinematic viscosity cSt @ 40°C	3.8	4.45	3.34
CN	56	28.5	Min. 55
Calorific value (MJ/Kg)	42.37	42.33	45.44

3. Experimental setup

The experiments were conducted on a single cylinder, direct injection, air cooled, four stroke diesel engine model Robin - Fuji DY23D. The important engine specifications are given in Table 1. Engine torque is measured using a hydraulic dynamometer tech equipment TD114 as shown in Fig. 2.

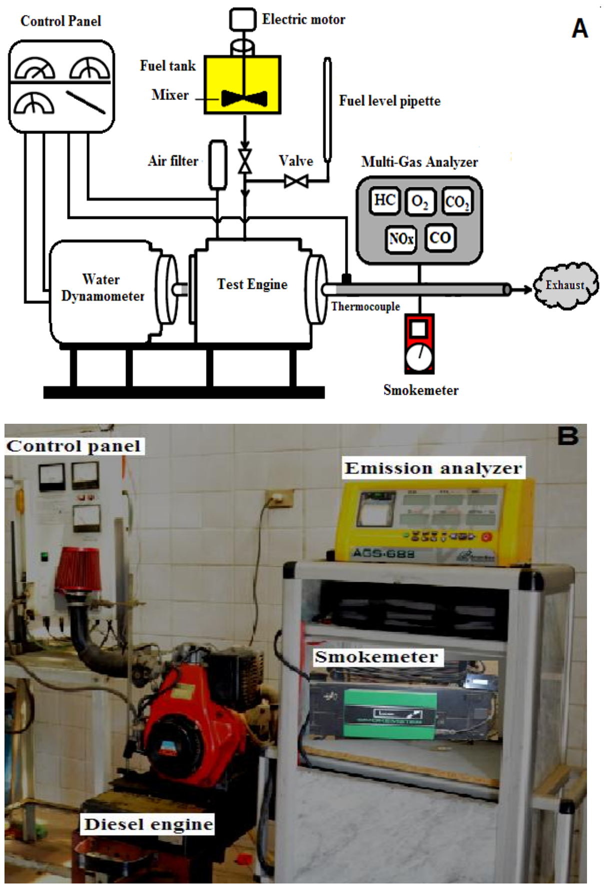

Fig. 2: Engine test bed schematic (Top) & photograph (Bottom)

Table 1: Specification of the test diesel engine

Model	Robin - Fuji DY23D.
Engine displacement	230 cm^3
Bore / stoke	70/60 mm
Compression ratio	21
Nominal output power	3.5 kW @ 3600 rev/min.
Maximum torque	10.5 Nm @ 2200 rev/min.
Standard fuel IP	120 kg/cm^2

During these experiments, emission concentrations of carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), particulate matter (PM) and the oxides of nitrogen (NO_x) were measured. CO_2 and CO were measured in percentage of total volume (%), while, HC, NO_x and PM were measured in parts per million (ppm). The emissions were measured using a Brain Bee S.P.A, AGS-688 gas analyser, while PM was measured using smoke meter. Table 2 shows the measurement fields of gas analyser. Fig. 3 shows the fuel injector while measuring the IP

Table 2: Gas analyser's measurement fields

Constituent	Symbol	Scale	Unit	Resolution
Carbon monoxide	CO	0-9.99	% vol.	0.01
Carbon dioxide	CO_2	0-19.9	% vol.	0.1
Total hydrocarbon	HC	0- 9999	ppm	1
Oxygen	O_2	0-25	% vol.	0.01
Oxides of nitrogen	NO_x	0-5000	ppm	10

Fig. 3: Fuel injector while measuring IP

4. Results and discussion

4.1. Engine brake power (BP)

Fig. 4 shows the variation of BP for diesel fuel at different IPs, different engine speed at certain load. The BP increases with an increase of engine speed at all IPs. Increasing the fuel IP lead to increase of the BP. At low speed (1500rpm) increasing the IP from 120 to 130 and 140 kg/cm^2 increases the BP from 0.3 and 2.3% respectively. Decreasing the IP from 120 to 110 and 100 kg/cm^2 decreases the BP from 19 to 26% respectively. Maximum increasing of BP was 29% at 3000rpm when IP was increased from 120 to 130 kg/cm^2. Fig. 5 shows the variation of BP for different fuels at IP 130 kg/cm^2, different speed and constant load. The use of palm biodiesel as a fuel for engine enhances the BP5 better than SB5 at fuel IP 130 kg/cm^2.

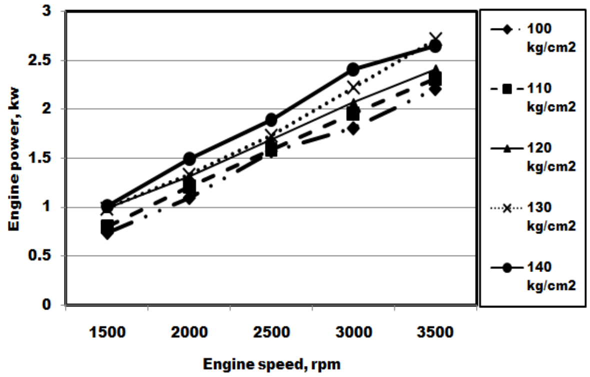

Fig. 4: Variation of BP for diesel fuel at different IPs, different speed and 65% load

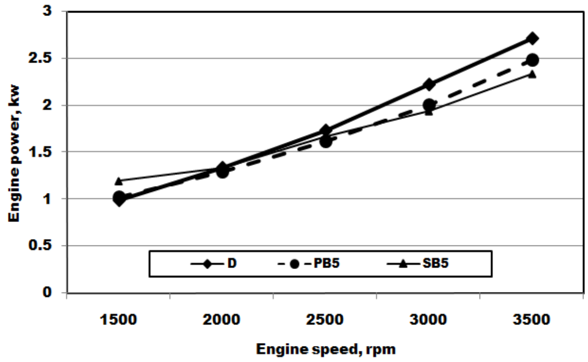

Fig. 5: Variation of engine brake power for different fuels at 130 kg/cm^2 and 65% load

4.2. Fuel consumption (FC)

The effect of different IPs on the engine FC at different speeds and constant load is shown in Fig. 6. Increasing the engine speed leads to increase of the FC for all fuels. At 1500rpm, for an increase of the IP from 120 to 130 and up to 140 kg /cm^2, the FC decreased by about 8 and 13% respectively. Decreasing the IP from 120 to 110 and up to 100 kg/cm^2, the FC increased by about 2.3 and 19% respectively. Maximum reduction in FC was 26 and 24% when IP was increased from 120 to 130 and 140 kg/cm^2 respectively. The variation of FC for constant engine speed at IP 130 kg/cm^2 for three types of fuels is shown in Fig. 7. The average of FC for palm and sunflower biodiesel is 6.3 and 19 % more than the conventional diesel fuel.

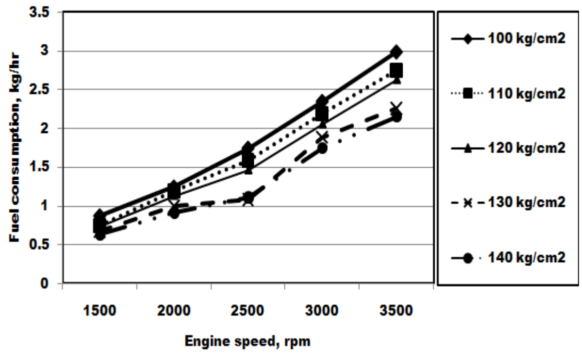

Fig. 6: Variation of fuel consumption for diesel fuel at different IPs and 65% load

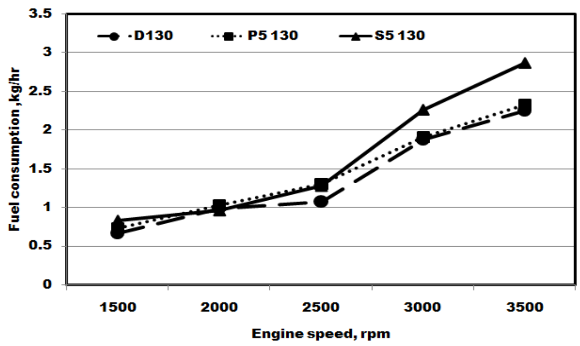

Fig. 7: Variation of FC for different fuels at IP 130 kg/cm^2 and constant load

4.3. Specific fuel consumption (SFC)

SFC is an ideal and important parameter for comparing the engine performance of the fuels having different density, viscosity and calorific values. SFC is defined as the FC rate divided by its corresponding engine power output. Fig. 8 shows the variation of SFC with respect to engine speed at different IP and constant load for diesel fuel. The increase of IP from 120 to 130 and 140 kg/cm^2 leads to decrease of the BSFC by about 7 and 26%. Decreasing the IP from 120 to 110 and 100 kg/cm^2 leads to an increase of BSFC by 15 and 33% respectively.

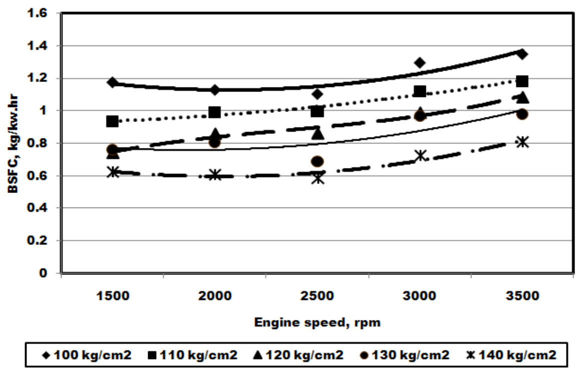

Fig. 8: Variation of BSFC with engine speed for diesel fuel at different IPs and 65% load

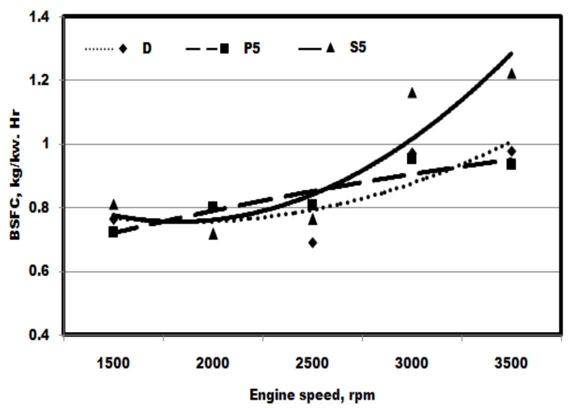

Fig. 9: Variation of BSFC with engine speed for different fuels at IPs 130 kg/cm^2 and 65% load

The variation of BSFC with respect to the engine speed for different fuels at IPs 130 kg/cm^2 and 65% load is illustrated in Fig. 9. For PB5 there is 5% decrease in SFC at engine speed 1500rpm. At engine speed 2500rpm there is 17% increase in SFC comparison to diesel fuel. For SB5, the SFC was increased by 6% at engine speed 1500rpm while the max increase in SFC was 25% at engine speed 3500rpm. The average increase in BSFC is 0.3 and 11% for PB5 and SB5 respectively.

4.4. Brake thermal efficiency (η_{th})

The η_{th} is calculated using BP, FC and fuel calorific value (CV). Fig. 10 shows the variation of η_{th} for various test fuels. The oxygen contents of the biodiesels improved their fuel burning characteristics. The fuel with a higher CN exhibits a superior compression ignition quality in diesel engines and thus evidences better combustion characteristics. The value of η_{th} at 130 kg/cm^2 obtained for biodiesel of sunflower has slightly better than other tested fuels.

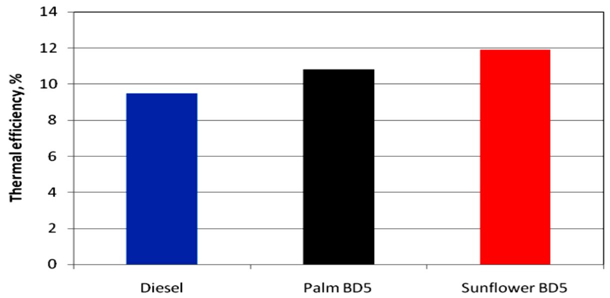

Fig. 10: Thermal efficiency of engine for different types of fuel

4.5. Exhaust emission

4.5.1. Carbon dioxide (CO_2)

Fig. 11 illustrates the emission of CO_2 of diesel engine for variant pressures of fuel injection. It is clear that the increase of engine load increases the CO_2 for all IPs. The CO_2 emission relatively increases when the pressures of fuel injection increase. Fig. 12 shows the effect of different IPs on CO_2 emission for diesel and biodiesel B5 under operating conditions of engine such as constant speed and constant load. The increase of fuel IPs decreases the CO_2 for all fuel types. The CO_2 emission decreases for the fuel type of PB5 more than the SB5 and pure diesel.

4.5.2. Carbon monoxide (CO)

Fig. 13 shows the influence of different pressures of fuel injection on CO emission for diesel and biodiesel PB5 and SB5 under operating conditions; constant speed, constant load. CO emission from diesel engine mainly depends on the chemical and physical characteristics of the used fuel. The biodiesel fuel has oxygen content of 11% which gives a chance for enhancement of the combustion. The amount of CO emission increases at partial loads and again greater increase at 65% load condition for PB5 and SB5. This is normal in all combustion engines, since the air-fuel ratio decreases with an increase in load. The CO emission increases when the oxygen content in mixture becomes greater.

4.5.3. Nitrogen oxides (NOx)

Fig. 14 presents the variations in NOx emission with different IP for three fuels at constant speed, constant load. The NOx emissions increased when the conditions in the combustion chamber are under high temperature and high pressure. The use of the palm biodiesel has shown a decrease in the NOx emission. Biodiesel blend fuel has faster ignition ability; increase the temperature of combustion chamber and pressure, which would finally stimulate the NOx formation.

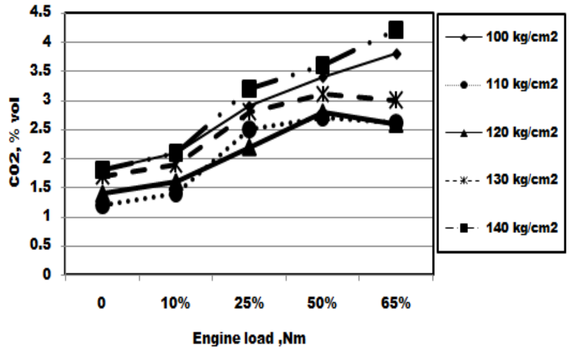

Fig. 11: CO_2 emission results at 2000rpm

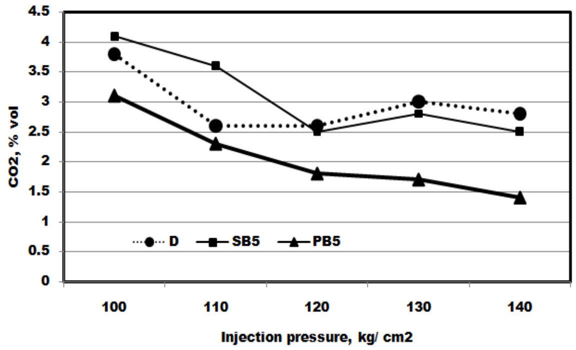

Fig. 12: CO_2 emission results

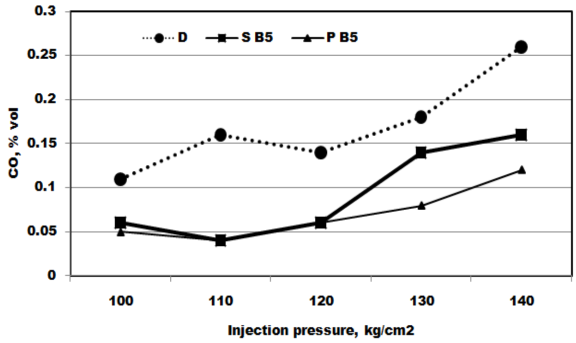

Fig. 13: CO emission results for 65% load and 2000rpm

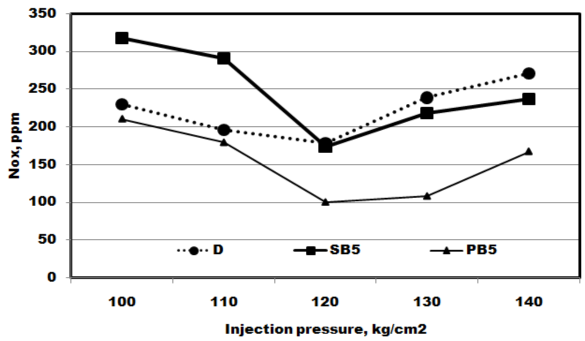

Fig. 14: NOx emission results

4.5.4. Particulates matter (PM)

Fig. 15 shows the variations in PM emission with different IP for three fuels at constant speed, constant load. The formation of particulates is mainly caused by the cracking of high polymer hydrocarbon in high temperature and shortage of oxygen content in the concentrated mixture area of the combustion chamber. The PM emissions decreased with increasing biodiesel blend ratio and increased with increasing engine speed. PM is produced by unburned carbon particles when using a densely blended fuel. It is cleared that the particulates emissions depend on the level of combustion diffusion related to both the distribution of fuel vapour separated from the fuel drops and the flame diffusion in an intense fuel region.

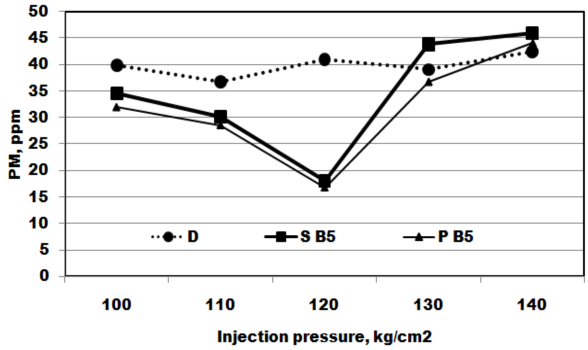

Fig. 15: PM emission results

4.5.5. Hydrocarbons (HC)

Fig. 16 illustrates the influence of different IPs on HC emission for diesel and biodiesel PB5 and SB5 at constant speed, constant load. The occurrence of oxygen in the content of fuel was considered to encourage a complete combustion. It directs to decrease of the unburned HC emissions. This reduction points to optimum combustion of the fuel. HC emissions were found decreasing for biodiesel blends as compared to diesel. This is due to the sufficient availability of oxygen content at higher temperatures resulting in complete combustion. HC emissions decreases with an increase in fuel IP. This is because of better atomization and higher temperature of gases at higher IPs resulting in an increase in the combustion efficiency.

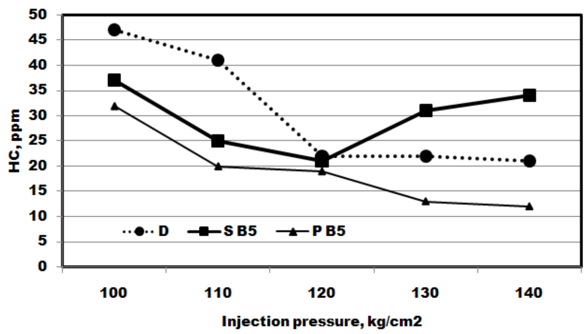

Fig. 16: HC emission results

5. Conclusion

The engine test bed was built and equipped with the needed instrumentations to carry-out the laboratory experiments on single cylinder diesel engine, which is operated with biodiesel fuel produced from waste cooking oils. The fuel IP played a significant role on the decrease of the engine FC at all operating points. At different engine speeds, with the decrease in the fuel IP from 120 to 100kg/cm^2 increases the FC up to 19% while increasing the fuel IP from 120 to 140 kg/cm^2 lead to decrease in the engine FC by 13%. The average of increasing in engine BP is about 11% due to increase in IP from 120 to 140kg/cm^2 while the average of BP decreasing is about 12% due to decrease in IP from 120 to 100 kg/cm^2.

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REFERENCES:

[1] R. Zhang and S. Kook. 2012. Effect of fuel injection pressure on size and structure of in-cylinder soot particles sampled from an automotive-size optical diesel engine, *Proc. 18th Australasian Fluid Mechanics Conf.*, Launceston, Australia.

[2] K. Nanthagopal, B. Ashok and R. Raj. 2016. Influence of fuel injection pressures on Calophyllum inophyllum methyl ester fuelled direct injection diesel engine, *Energy Conversion & Mgmt.*, 116, 165-173. https://doi.org/10.1016/j.enconman.2016.03.002.

[3] M. Mourad, F. Mohamed, K. Mahmoud and A. Nouh. 2014. Influence of biodiesel fuel on performance characteristics of hybrid electric vehicle according to urban driving cycle, *Proc. Int. Ren. Energy Congress*, Tunisia. https://doi.org/10.1109/IREC.2014.6826997.

[4] R. Bakar and A. Ismail. 2008. Fuel injection pressure effect on performance of direct injection diesel engines based on experiment, *American J. Applied Sci.*, 5(3), 197-202. https://doi.org/10.3844/ajassp.2008.197.202.

[5] R. Sharma, R. Singh and K. Vishwakarma. 2013. Experimental study of the effect of fuel injector nozzle holes on direct injection diesel engine, *IOSR J. Mech. & Civil Engg.*, 7(4), 67-74. https://doi.org/10.9790/1684-0746774.

[6] K. Kannan and M. Udaya kumar. 2010. Experimental study of the effect of fuel injection pressure on diesel engine performance and emission, *ARPN J. Engg. and Applied Sci.*, 5(5), 42-45.

[7] M. Kumar, S. Drakshayani and K. Reddy. 2012. Effect of fuel injection pressure on performance of single cylinder diesel engine at different intake manifold inclinations, *Int. J. Engg. and Innovative Tech.*, 2(4), 20-28.

[8] H. Pali, N. Kumar and Y. Alhassan. 2015. Performance and emission characteristics of an agricultural diesel engine fueled with blends of Sal methyl esters and diesel, *Energy Conversion & Mgmt.*, 90, 146-153. https://doi.org/10.1016/j.enconman.2014.10.064.

[9] P. Srinath, A. Sharief, S. Kumar, C. Ramachandra and B. Sreeprakash. 2014. Study of fuel injection pressure and injection timing effect on a diesel engine performance and emission, *Int. J. Res. in Sci. & Tech.*, 4(3), 71-80.

[10] C. Reddy, E. Reddy and K. Reddy. 2012. Effect of fuel injection pressures on the performance and emission characteristics of d. i. diesel engine with biodiesel blends cotton seed oil methyl ester, *Int. J. Research and Reviews in Applied Sci.*, 13(1), 139-149.

[11] S. Vedharaj, R. Vallinayagam, W. Yang, Chou, K. Chua and P. Lee. 2015. Performance emission and economic analysis of preheated CNSL biodiesel as an alternate fuel for a diesel engine, *Int. J. Green Energy*, 12, 359-367. https://doi.org/10.1080/15435075.2013.841162.

[12] A. Demirbas. 2008. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections, *Energy Conversion & Mgmt.*, 49, 2106-2116. https://doi.org/10.1016/j.enconman.2008.02.020.

[13] H. Serin and N. Akar. 2014. The performance and emissions of a diesel engine fueled with tea seed (camellia sinensis) oil biodiesel-diesel fuel blends, *Int. J. Green Energy*, 11, 292-301. https://doi.org/10.1080/15435075.2013.773434.

[14] S. Ganesan and A. Elango. 2014. Influence of injection pressure on emission characteristics of DI diesel engine with blends of biodiesel, *Indian J. Applied Research*, 4(10).

[15] C. Sayin, M. Gumus and M. Canakci. 2013. Influence of injector hole number on the performance and emissions of a DI diesel engine fueled with biodiesel-diesel fuel blends, *Applied Thermal Engg.*, 61(2), 121-128. https://doi.org/10.1016/j.applthermaleng.2013.07.038.

[16] A. Ibrahim. 2016. Performance and combustion characteristics of a diesel engine fuelled by butanol-biodiesel-diesel blends, *Applied Thermal Engg.*, 103, 651-659. https://doi.org/10.1016/j.applthermaleng.2016.04.144.