ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.2790

INFLUENCE OF BIODIESEL FROM EGYPTIAN USED COOKING OIL ON PERFORMANCE AND EMISSIONS OF SMALL DIESEL ENGINE

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Abstract

Egyptian waste cooking oils have special specifications because it expose to high temperatures during use for long hours. In the present experimental study, the performance and emissions of a four strokes, single cylinder, air-cooled diesel engine fuelled with two different biodiesel from Egyptian used cooking oil (palm and sunflower) are evaluated at different speeds. The measured performance parameters include torque, fuel consumption and exhaust gas temperature. Brake power, brake specific fuel consumption and brake thermal efficiency was calculated using the measured test data The emission parameters include carbon monoxide, particulate matter and the oxides of nitrogen. The tests have been carried out with different blends of B5 to B100 of biodiesel with diesel fuel. The results showed that the cetane number of sunflower biodiesel has dropped significantly as a result of high temperatures and negatively affected the performance and emissions of the diesel engine also the engine performance with the palm biodiesel blend B5 is closed to diesel fuel also, for B5 CO emission decreased from 53 to 70% while NOx emission decreased from 13 to 80% compared to diesel fuel.

Keywords: *Diesel engine, biodiesel, Egyptian used cooking oils, engine performance, emissions*

1. Introduction

The annual consumption of vegetable oil in Egypt is about 2 Million Tons, 90% of this amount is imported from different countries. Vegetable oils used in fast food restaurants and houses in frying fish, onion, potatoes, eggplants, chicken beside falafel (most popular food in Egypt). Consequently, most of these oils are discarded each year into sewage systems. Thus, the cost of treating effluent or polluted water streams was increase. The big problem is that the oil is exposed to high temperature during frying and changes their characteristics as a result of use for long hours (sometimes days). The use of these oils in the production of biodiesel adversely affect the physicochemical properties of biodiesel especially cetane number, low cetane number negatively affected the performance and emissions of the diesel engine. The objective of this study is to evaluate experimentally the performance and emissions of diesel engine using two types of biodiesel from Egyptian used cooking oils i.e. Palm (P) and Sunflower (S) and its blends (from 5% to 100%) with diesel fuel and compare the results with ordinary diesel fuel under different speeds from 1500 to 3500 rpm and constant load.

2. Biodiesel production

Table 1 shows the specification of waste cooking oils, which collected from local market in Cairo. The process variables of transesterification are shown in Tab. 2. The resulted yield was 95% for sunflower oil and 97% for palm oil. Tab. 3 shows the physicochemical properties of produced biodiesel compared to the Egyptian standards of petro-diesel fuel and two international biodiesel standards.

Tab. 1. Specification of waste cooking oils

Oil type	Nature of using	Fried temperature	Fried period per day	Change Period
Waste Palm oil	Fried onion	150-180^{o}C	10-12 hr	Every day
Waste sunflower oil	Fried potatoes	Up to 250^{o}C	15 hr	3 times/week

Tab. 2. Process variables of biodiesel production

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

Tab. 3. Physicochemical properties of produced biodiesel compared to the Egyptian standards of petro-diesel fuel and two international biodiesel standards

Test	Produced biodiesel		Egyptian diesel oil	Biodiesel D-6751	Biodiesel EN14214
	Palm	S. flower			
Density g/cm3 @ 15.56 C	0.898	0.886	0.82-0.87	0.88	0.86-90
Kinematic Viscosity cSt @ 40^{o}C	3.8	4.45	1.6-7	1.9-6	3.5-5
Kinematic Viscosity cSt @ 100^{o}C	< 1	< 1	-----	-----	-----
Flash point (^{o}C)	175	185	> 55	> 130	> 101
Cloud point (^{o}C)	7	12	-----	-3 : 15	-----
Pour point (^{o}C)	4	8	4.5-15	-5 : 10	-4
Cetane number	56	28.4	Min. 55	47 min	51 min
Total acid number (mg KOH/g)	0.2	0.2	Nil	0.50 max	0.5 max
Calorific value (MJ/Kg)	42.37	42.33	Min. 44.3	-----	32.9 min
Sulphated Ash (wt%)	Nil.	Nil.	Max. 0.01	0.02 max	0.02 max
Carbon residue (wt%)	0.01	0.086	Max. 0.1	0.05 max	0.3 max
Iodine number (mg)	46.83	30.95	-----	-----	120 max
Copper strip corrosion 3 hrs@ 50 C	1 A	1A	1 A	No. 3 max.	1 A
Water & sediment (wt %)	Nil.	Nil.	Max. 0.15	0.05 max	Max 500 mg/kg
Total glycerine%	0.34	0.15	-----	0.240 max	0.25 max
Free glycerine%	0.062	0.055	-----	0.020 max	0.020 max

As shown in Tab. 3, the physiochemical for produced biodiesel fuel was within the recommended standards of the Egyptian Diesel fuel and International biodiesel fuel (ASTM D6751 and EN 14214) in most properties. Lowering the cetane number for sunflower biodiesel may be due to high cooking temperature for sunflower oil about 250ºC (as stated in the laboratory report, Appendix 1) where cetane number has dropped significantly, as a result of high temperatures; low cetane number negatively affected the performance and emissions of the diesel engine.

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 appendix 2. Engine torque is measured using a Hydraulic dynamometer TechQuipment TD114. During these experiments, emission concentrations of carbon monoxide (CO), particulate matter (PM) and the oxides of nitrogen (NOx) were measured. CO was measured in percentage of total volume (%), while NOx 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 Smokemeter, Fig. 1 shows the photo of experimental set up. Gas analyser's measurement fields are shown in appendix 3.

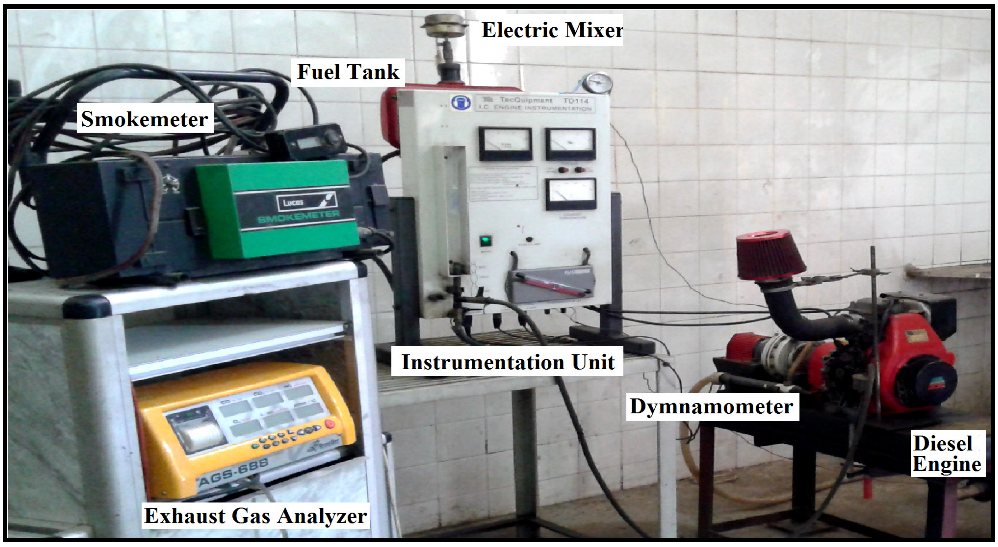


Fig. 1. Photograph of experimental setup

4. Results and discussions

4.1. Engine brake power

Brake power is calculated based on the measured engine torque and speed. Fig. 2-3 illustrated the percent changes in engine power for different palm and sunflower biodiesel blends respectively in comparison with diesel fuel at different speeds. From Fig. 2 increasing the percent of biodiesel in the fuel decrease the power by about 0.45, 2.8, 4.2, 7.6, 11.3, 16.8, 22.2 and 28.8% for PB5, PB10, PB20, PB30, PB40, PB50, PB75 and PB100 respectively (average of all speeds) also, from Fig. 3 the power decreased by about 1.3, 4.2, 7.8, 12.6, 23.3 and 29.6% for SB5, SB10, SB20, SB30, SB40, SB50 and SB75 respectively (average of all speeds). This lower engine Brake Power obtained for biodiesel could be due to the fuel flow problems and agree with such presented by [1-3]. The higher viscosity, higher density, and decreasing combustion efficiency will be due to the lower thermal efficiency and bad fuel injection atomization of biodiesel than diesel fuel. Also as shown in Fig. 4 power losses with palm biodiesel was lower than with sunflower biodiesel.

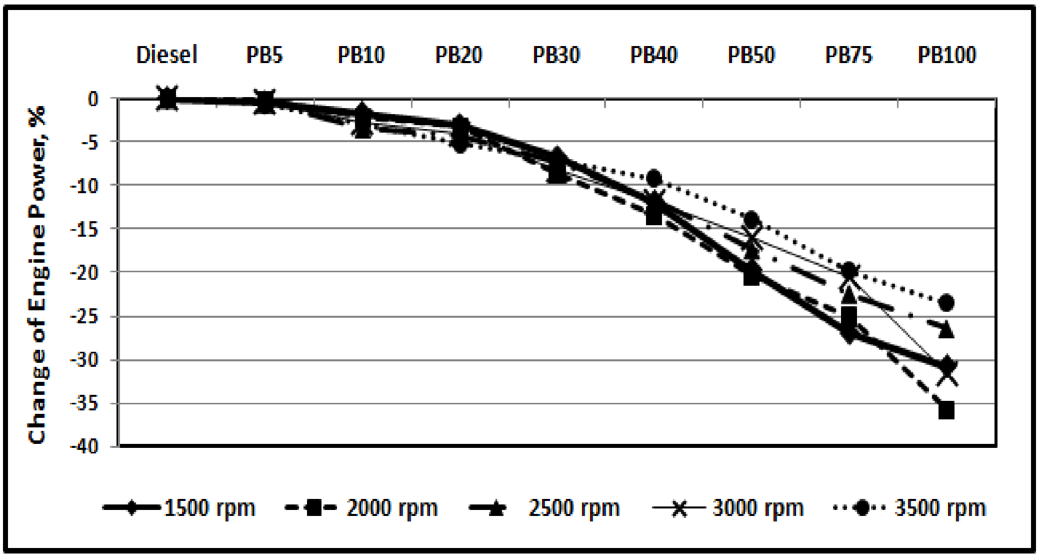


Fig. 2. Changing of engine power (%) for palm biodiesel blends at different speeds

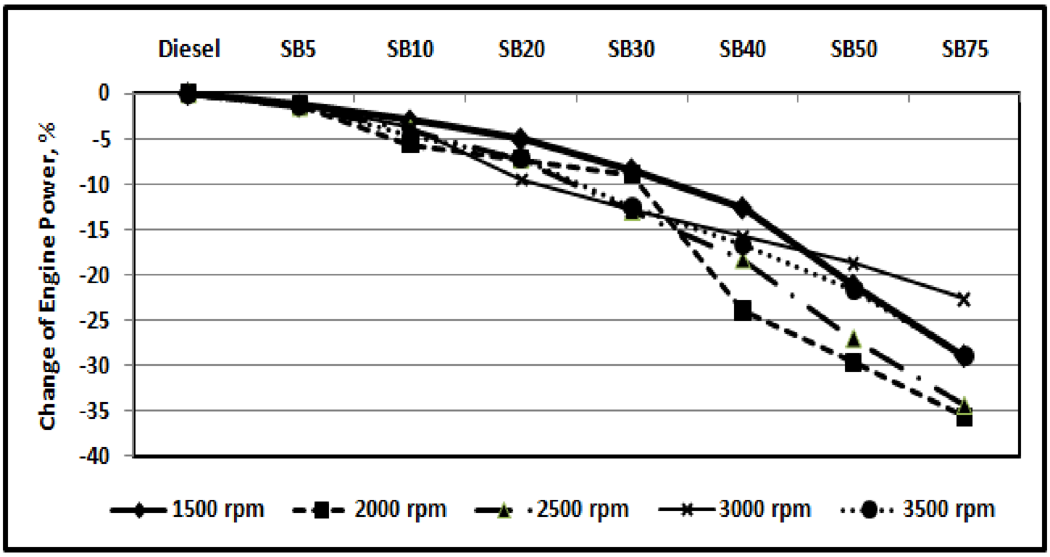


Fig. 3. Changing of engine power (%) for sunflower biodiesel blends at different speeds

4.2. Brake specific fuel consumption (BSFC)

BSFC is defined as the ratio of the fuel consumption rate to the brake power output [4]. Fig. 5-6 illustrated the percent changes in BSFC for different palm and sunflower biodiesel blends respectively in comparison with diesel fuel at different speeds. As shown in Fig. 5 increasing the percent of biodiesel in the fuel increase the BSFC by about 0.99, 4, 8, 15, 23, 36, 51 and 69% for PB5, PB10, PB20, PB30, PB40, PB50, PB75 and PB100 respectively (average of all speeds) also, from Fig. 6 there are increase in the BSFC by about 2.6, 3.5, 12, 22, 34, 50 and 68% for SB5, SB10, SB20, SB30, SB40, SB50 and SB75 respectively (average of all speeds). BSFC increase with the increasing of biodiesel blend, this is due to higher fuel density, higher viscosity and the lowering of heating value of biodiesel than that of diesel fuel. Therefore, if biodiesel blends were increased, the BSFC will increase due to the produced lower brake power caused by the lower energy content of the biodiesel. Low heating value on the fuel means that more fuel would be required to produce the same energy and result in a high BSFC. Increased BSFC in the case of biodiesel agrees with some authors reported [1, 5]. As shown in Fig. 7 BSFC with palm biodiesel was lower than with sunflower biodiesel at all speeds.

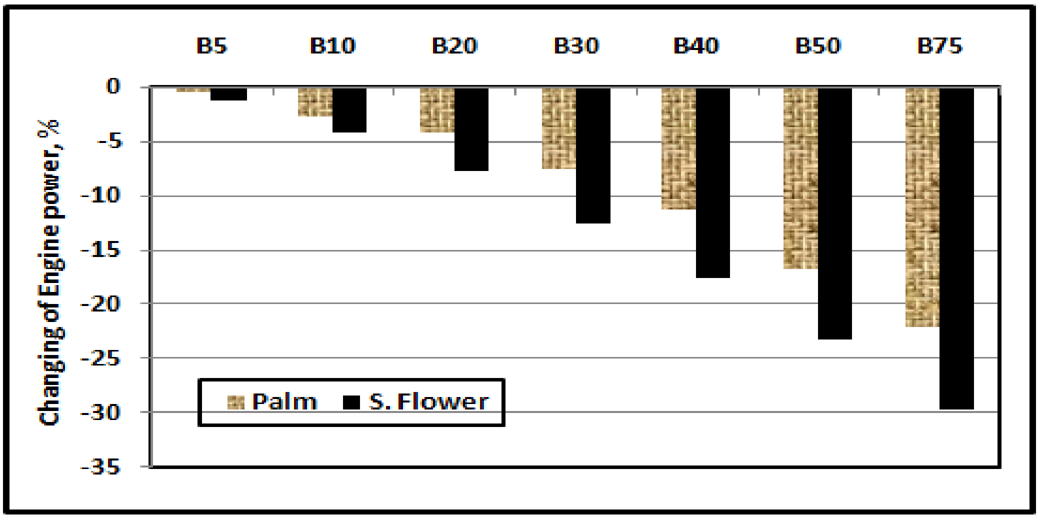


Fig. 4. Average changing of engine power for Palm and sunflower blends at all speeds

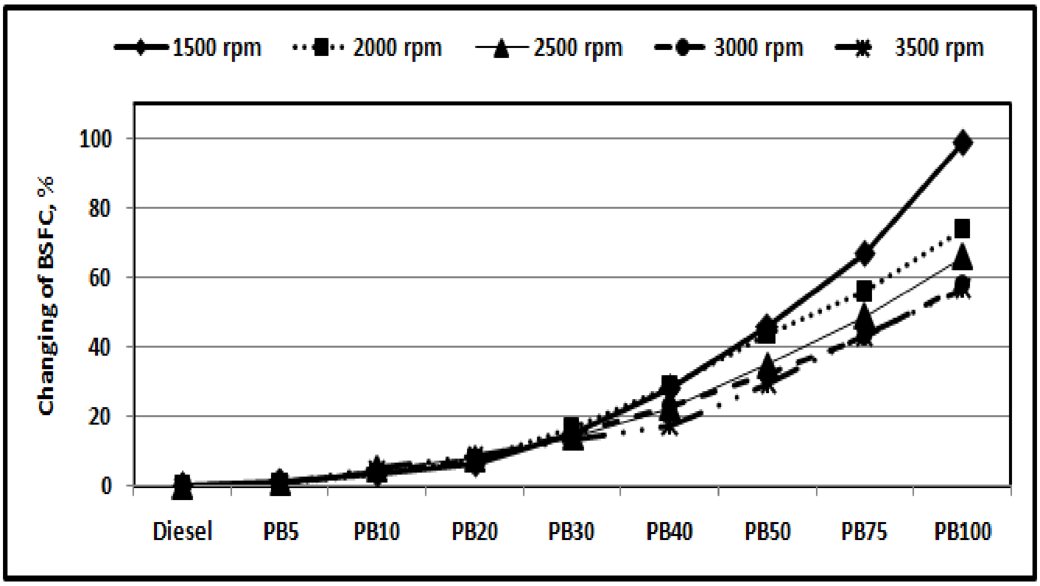


Fig. 5. Changing of BSFC (%) for palm biodiesel blends at different speeds

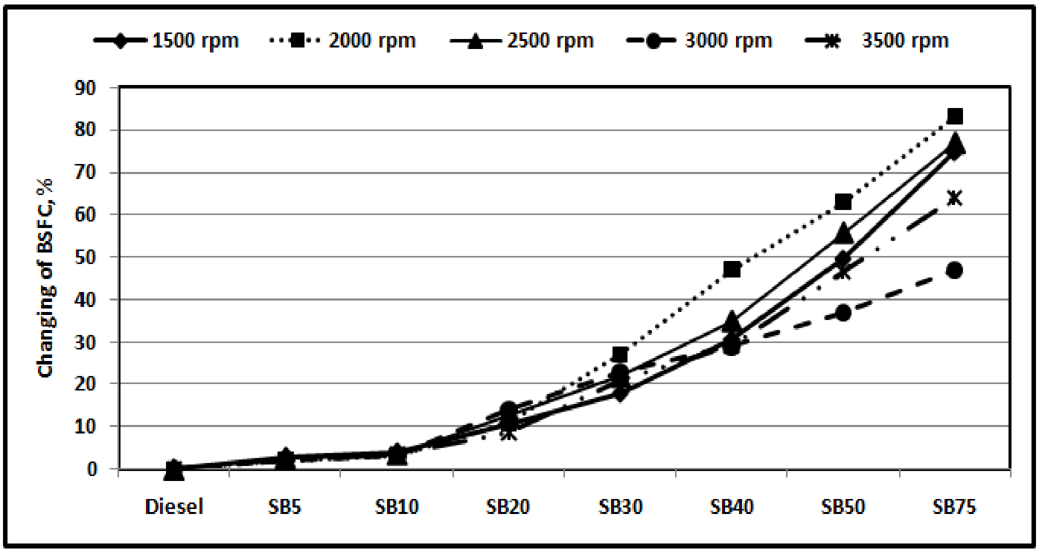


Fig. 6. Changing of BSFC (%) for sunflower biodiesel blends at different speeds

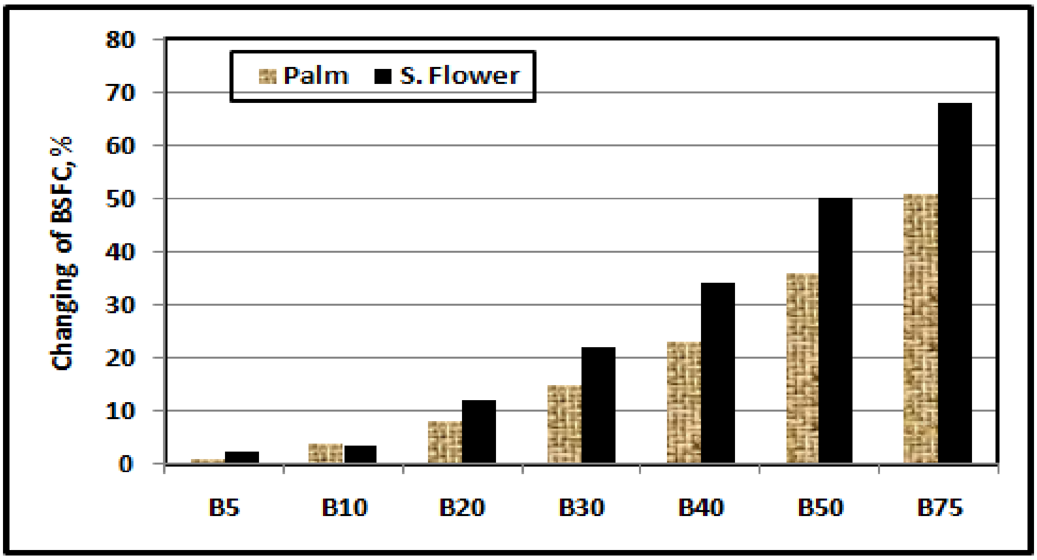


Fig. 7. Average changing of BSFC for Palm and sunflower blends at all speeds

4.3. Brake thermal efficiency (BTE)

It is the ratio of the thermal energy in the fuel to the energy delivered by the engine at the crankshaft [6]. Fig. 8-9 show the percent changes in BTE for different palm and sunflower biodiesel blends respectively in comparison with diesel fuel at different speeds. From Fig. 8 increasing the percent of biodiesel in the fuel decrease the BTE by about 0.7, 4, 6, 11, 19, 25 and 32% for PB5, PB10, PB20, PB30, PB40, PB50, PB75 and PB100 respectively (average at all speeds) also, from Fig. 9 there are decrease in the BTE by about 2, 2.8, 9.7, 16, 23, 31 and 38% for SB5, SB10, SB20, SB30, SB40, SB50 and SB75 respectively (average at all speeds). As shown in Fig. 10, Palm biodiesel is better than sunflower biodiesel in term of BTE (average of all speeds). The reduction of BTE with biodiesel blends was attributed to many reasons like high viscosity, lower calorific value and poor spray characteristics of biodiesel and its blends. Decreased BTE in the case of biodiesel agrees with some authors reported [7-9]; also BTE for B5 is close to diesel fuel at all speeds.

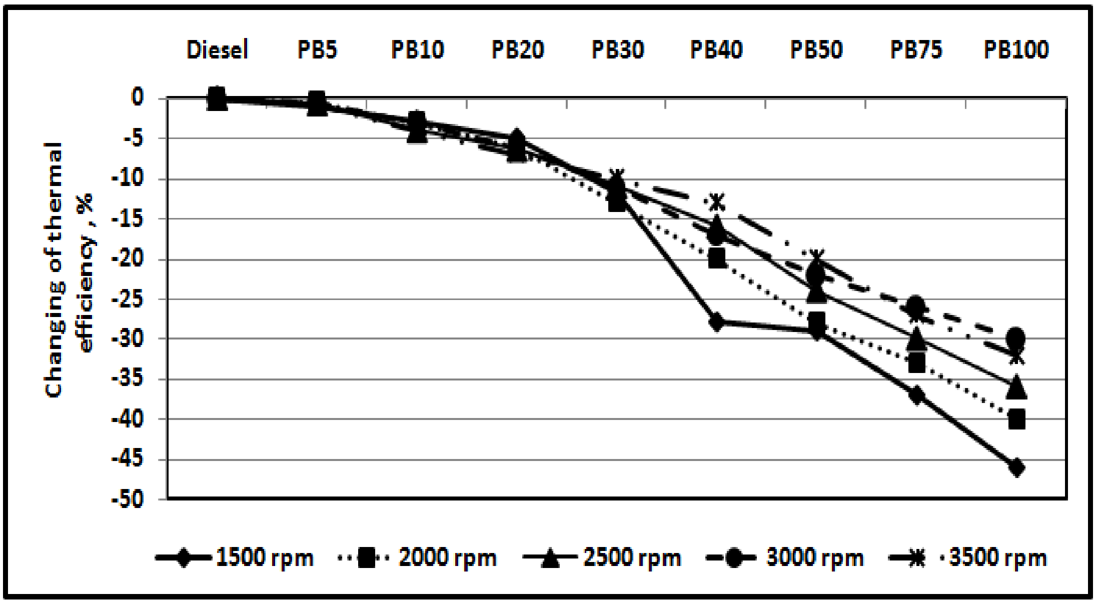


Fig. 8. Changing of BTE (%) for palm biodiesel blends at different speeds

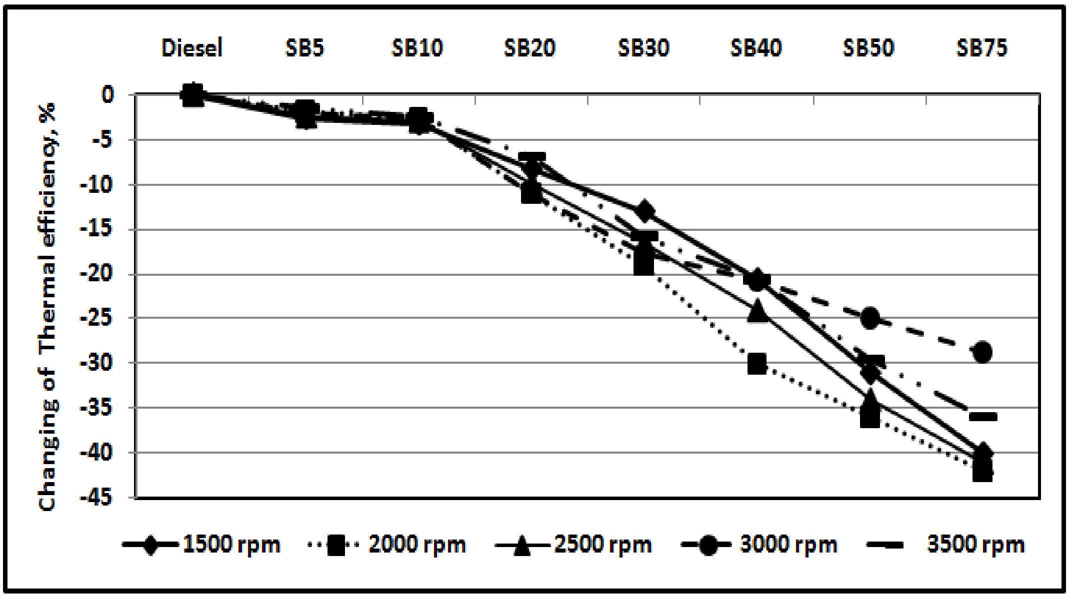


Fig. 9. Changing of BTE (%) for sunflower biodiesel blends at different speeds

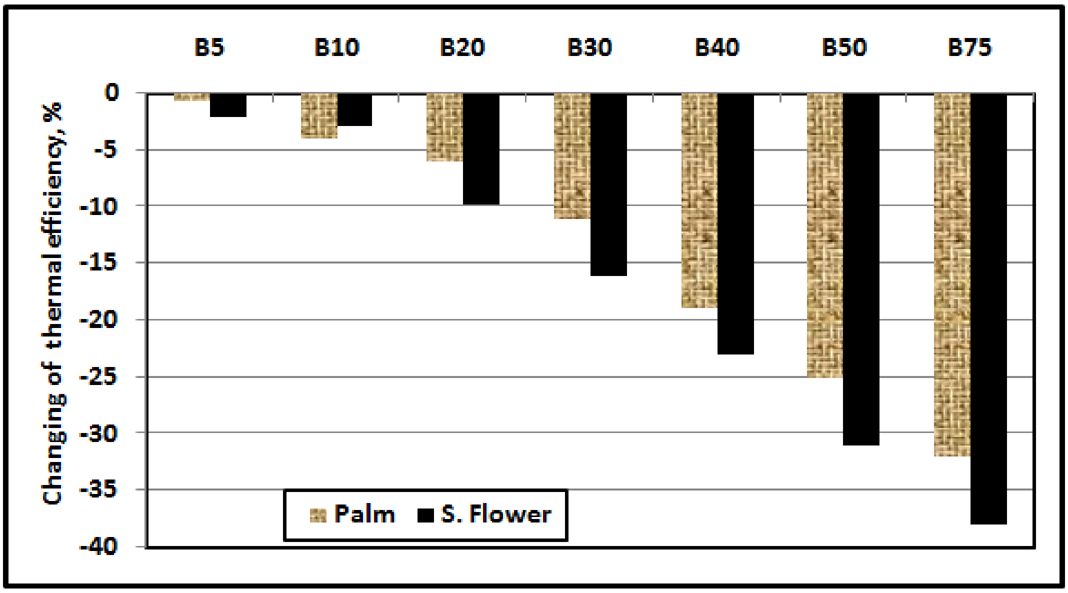


Fig. 10. Average changing of thermal efficiency for palm and sunflower at all speeds

4.4. Exhaust gas temperature (EGT)

The EGT indicates how efficiently the heat energy of the fuel is been used [10]. Fig. 11 and 12 show the percent changing of EGT for different biodiesel blends of palm and sunflower respectively. The biodiesel blends had lower EGT than diesel fuel. The lower heating value of the biodiesel blends caused less burning gas temperatures inside the combustion chamber. In fact, many researchers have also reported that the EGT is lower with the engine fuelled with biodiesel-blended fuel compared to the baseline diesel [11, 12]. The general causes behind this phenomenon are mainly due to the lower calorific value and the existence of chemically bound oxygen of biodiesel blends, which reduces the total energy, released and improves the combustion, respectively. The comparison between palm and sunflower biodiesel is illustrated in Fig. 13. From the figure, the lowering in EGT for palm biodiesel is lower than sunflower biodiesel.

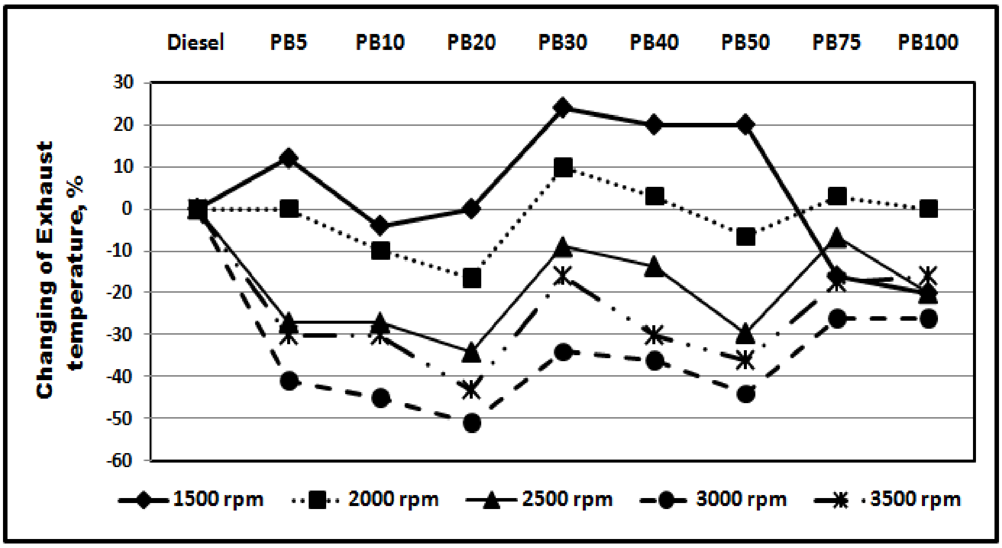


Fig. 11. Changing of exhaust temperature (%) for palm biodiesel blends at different speeds

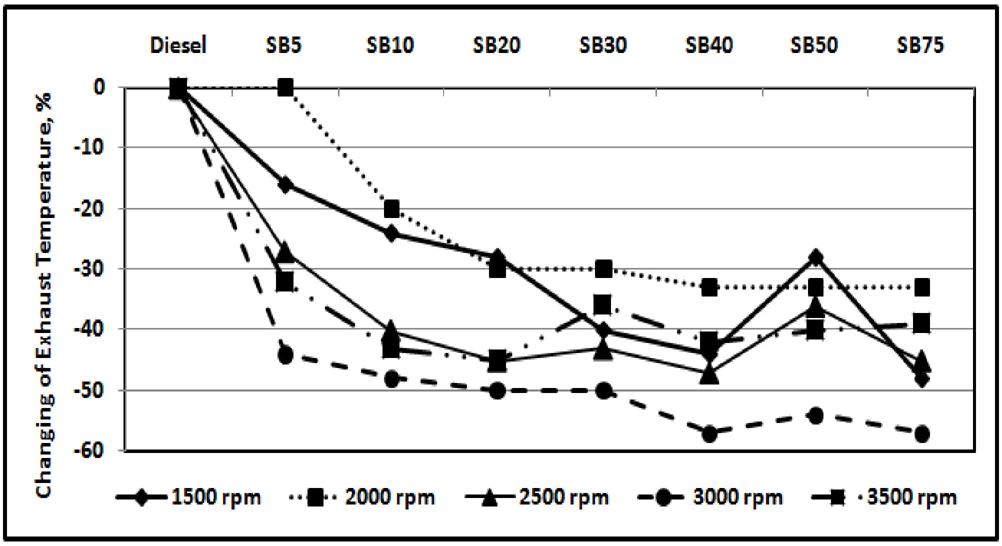


Fig. 12. Changing in exhaust temperature. (%) for sunflower biodiesel blends at different speeds

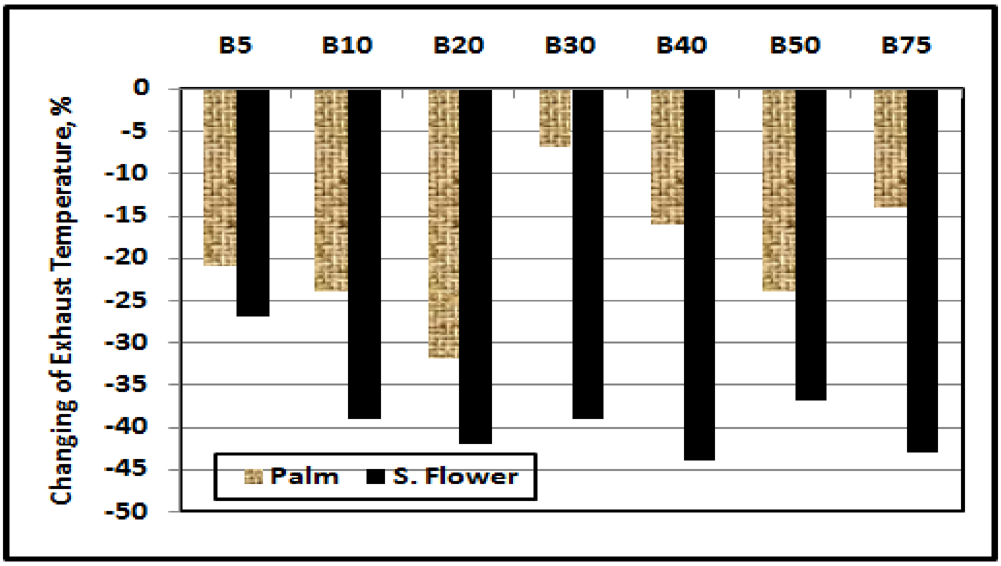


Fig. 13. Average changing of exhaust temperature for palm and sunflower at all speeds

4.5. Carbon monoxide (CO)

The carbon monoxide (CO) emissions signify that the combustion inside the cylinder is not complete [13]. Fig. 14 and 15 illustrate the percentage changing of CO emission for different blends of PB and SB with engine speeds. As shown in Fig. 5, 6 at lower concentration of biodiesel blends (B5, B10, B20, B30, B40), the oxygen present in the biodiesel support for complete combustion and lead to decreased CO emission. Also higher cetane number helps for lowering ignition delay and complete combustion. However, at high concentration of biodiesel blends (B75 and B100 for palm), the CO emission increased due to high viscosity and density for biodiesel compare to diesel fuel. Fig. 16 shows the comparison of average changing of CO emission between Palm and Sunflower blends. As shown in Fig. 7 PB5 gave the maximum reduction in CO by about 70% while PB100 gave the maximum increased in CO emission by about 53% also SB5 and SB10 gave the maximum reduction in CO emission by about 50% at while SB100 gave the maximum increased in CO emission by about 13%. Decreased CO emission agrees with some authors reported [13-17].

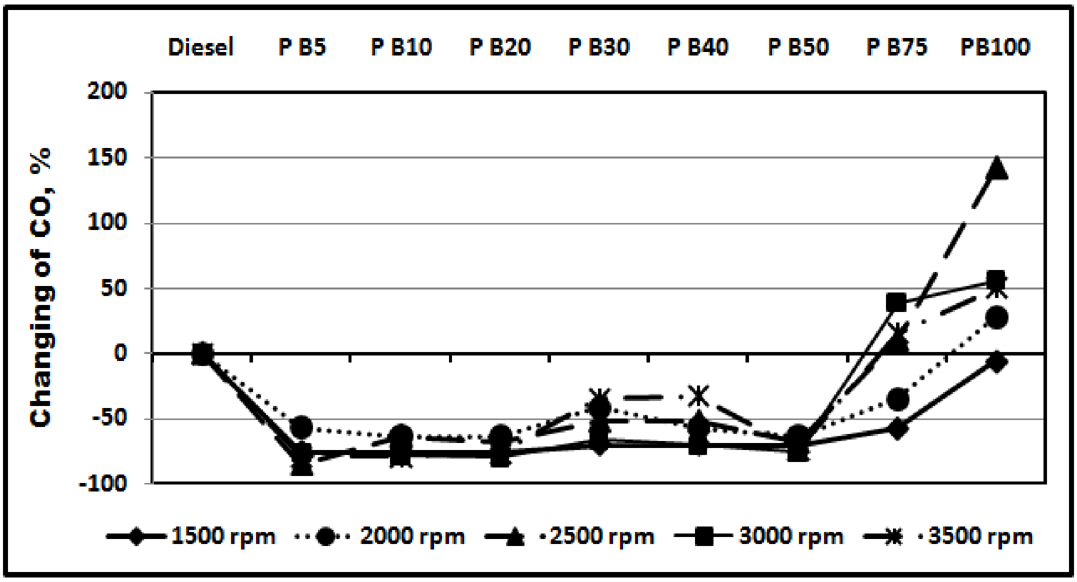


Fig. 14. Percent changing of CO Emission for different palm biodiesel blends at different engine speeds

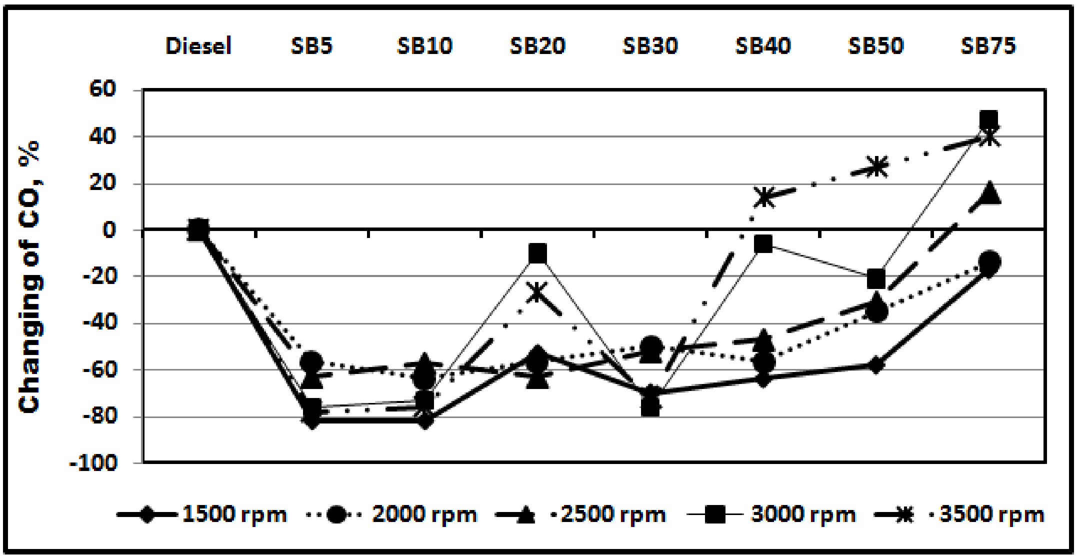


Fig. 15. Percent changing of CO Emission for different sunflower biodiesel blends at different engine speeds

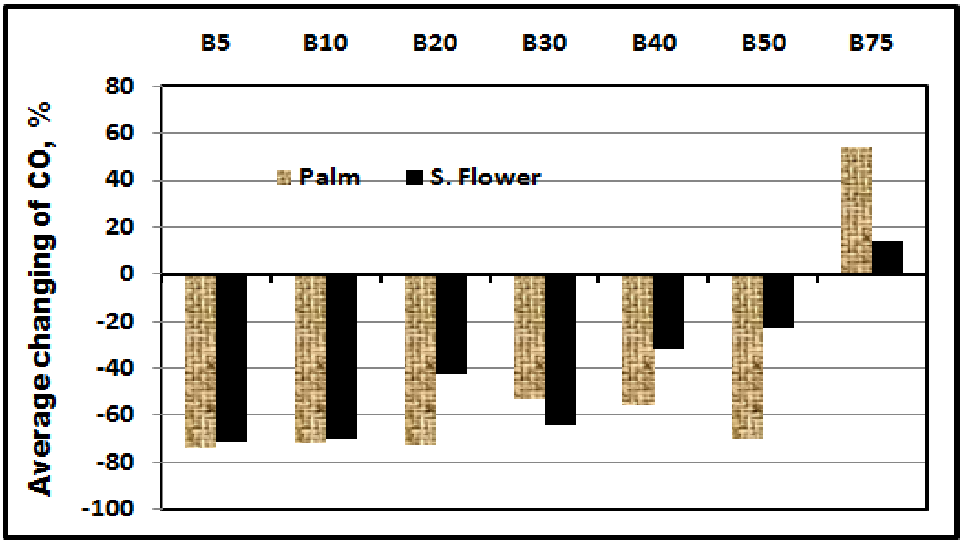


Fig. 16. Average changing of CO emission for Palm and Sunflower blends at all speeds

4.6 Nitrogen oxides (NOx)

NOx are produced by the reaction between oxygen and nitrogen at high temperature and pressure generated inside the cylinder during combustion [18]. The earlier combustion can cause higher combustion temperature and higher NOx emission has been happened [19]. NOx are hazardous airborne toxins because of their deleterious health and environmental effects [20]. Fig. 17 and 18 illustrate the percent changing of NOx emission for palm and sunflower biodiesel blends at different speeds.

As shown in the figures, blends from PB5 to PB30 gave lower NOx emission than diesel fuel at all speeds. PB5 gave the maximum reduction in NOx emission by about 82% at 3500 rpm while PB40 gave the maximum increased in NOx emission by about 51% at 1500 rpm. For sunflower blends B5 and B10 gave lower emission than diesel at all speeds but increasing the blends lead to increase the NOx emission as shown in Fig. 12. SB5 and SB10 gave the maximum decreased in NOx emission by about 13%, 30% at 1500 rpm and 27%, 22% at 3500 rpm. Maximum increased in NOx emission for SB75 by about 88% at 1500 rpm. Fig. 19 shows the comparison of average changing of NOx emission between Palm and Sunflower blends, from the figure we can note that palm biodiesel blends is better than sunflower blends. Decreased NOx emission agrees with some authors reported [21].

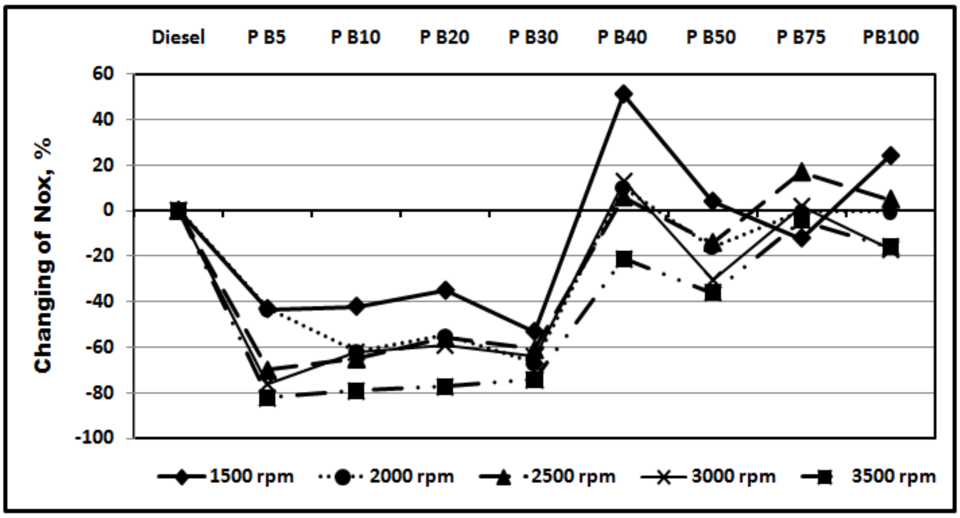


Fig. 17. Percent changing of NOx Emission for palm biodiesel blends at different speeds and constant load

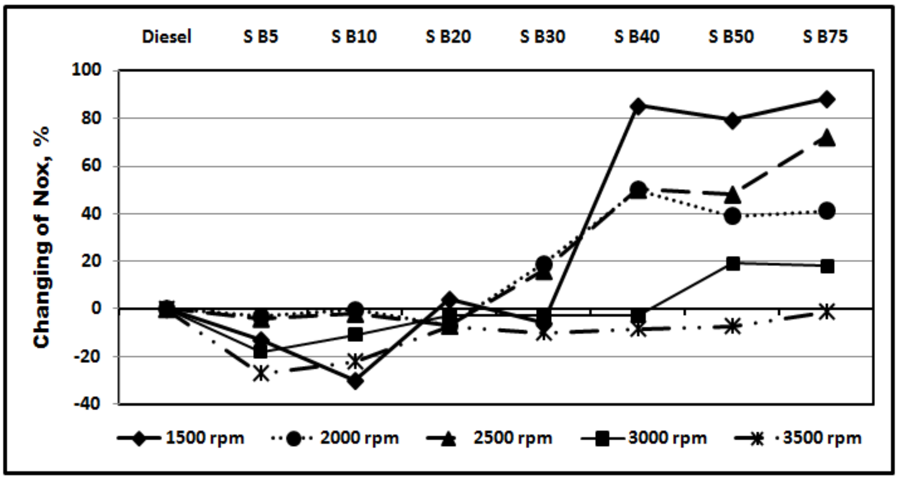


Fig. 18. Changing of NOx Emission (%) for sunflower biodiesel blends at different speeds

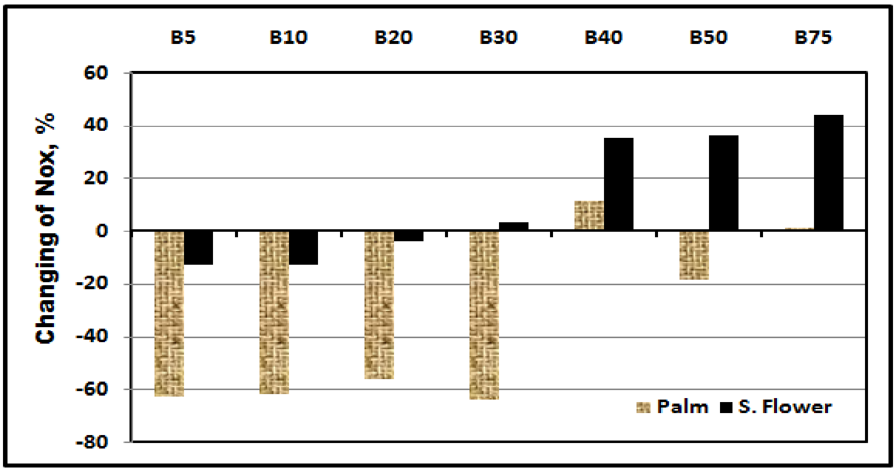


Fig. 19. Average changing of NOx emission between Palm and Sunflower blends at all speeds

4.7 Particulate matter (PM)

Particulate matter (PM) is a type of airborne pollution, which consists of varying mixtures, complexity and sizes of particles [20]. Percent changing of PM emissions for PB and SB blends respectively are shown in Fig. 20 and 21. PM emission increased with increase of speed, also all

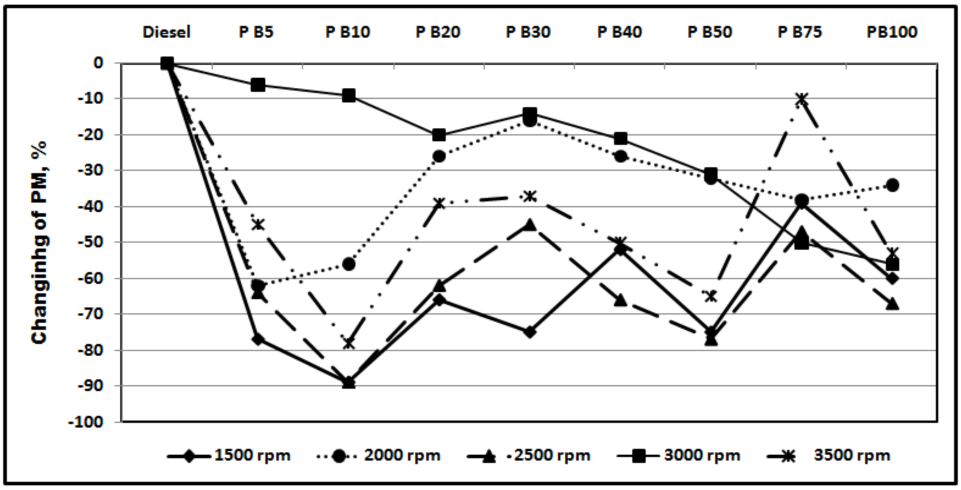


Fig. 20. Percent changing of PM emission for different blends of palm biodiesel at different speeds

blends of PB and SB gave PM emission less than diesel fuel at all speeds. PB10 gave the maximum reduction in PM emission by about 89% at 1500 and 2500 rpm. In addition, the maximum reduction for sunflower was for SB10 by about 60% and 58% at 1500 rpm and 2500 rpm respectively. Fig. 22 shows the comparison of average changing of PM emission between PB and SB, all PB blends are better than SB blends in PM reduction. Decreased PM emission in the case of bio-diesel agrees with some authors reported [22, 23],

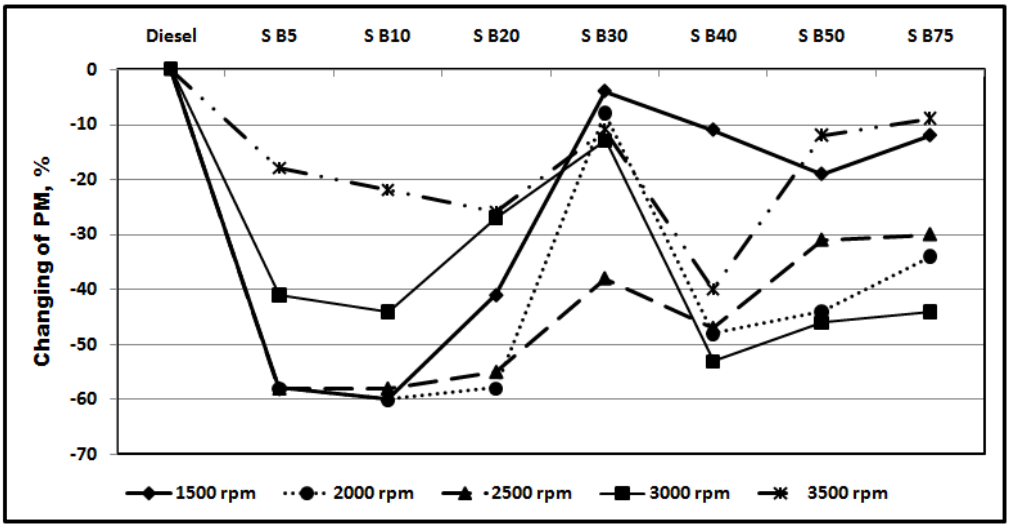


Fig. 21. Percent changing of PM emission for different blends of sunflower biodiesel at different speeds

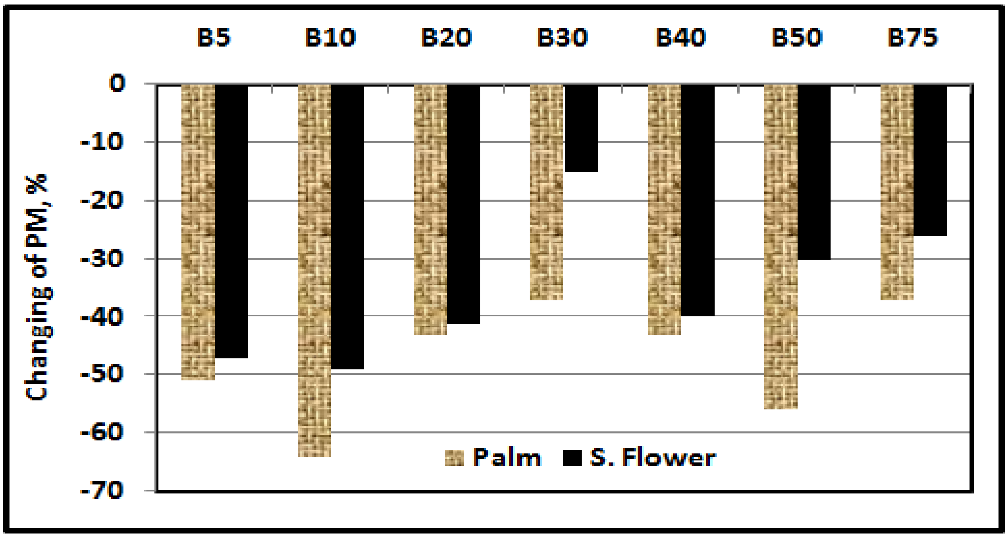


Fig. 22. Average changing of PM emission between Palm and Sunflower blends at all speeds

5. Conclusions

The single cylinder diesel engine was worked successfully using biodiesel blends from waste palm and sunflower oils with diesel fuel. The following conclusions are obtained on the base of experimental results.

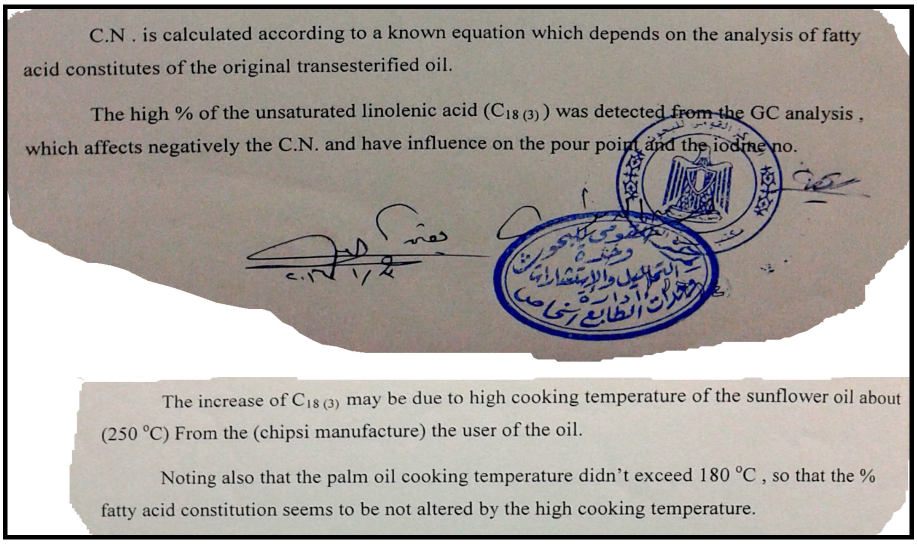
1. High frying temperature of cooking oil lead to reduce the cetane number of produced biodiesel.
2. Engine power with diesel fuel was higher than with biodiesel blends because diesel fuel has higher calorific value and more power than biodiesel, also biodiesel blends have higher viscosity and density than diesel fuel.
3. The fuel consumption increasing with increase the percentage of biodiesel blends due to lower calorific value.

4. Thermal efficiency for biodiesel blends was lower than diesel fuel. This may be due to poor atomization and higher viscosity of biodiesel blends compared to diesel fuel. Higher fuel consumption and lower heating value of biodiesel were some of the reasons for decrease of thermal efficiencies of biodiesel blends compared to diesel fuel.
5. The oxygen present in the biodiesel (Palm and Sunflower) support for complete combustion and lead to decreased CO emission compared to diesel fuel. For PB75, PB100, SB40, SB50 and SB75 the CO emission increased 15, 42, 14, 27 and 40% respectively this may be due to higher viscosity and the poor spray characteristic for bio-diesel, which lead to poor mixing and poor combustion.
6. Blends from B5 to B30 for both fuels gave lower NOx emission than diesel fuel at all speeds; the reduction in NOx with PB is lower than with SB.
7. All blends of biodiesel (palm and sunflower) gave PM emission less than diesel fuel at all speeds
8. Engine performance with palm biodiesel is better than with sunflower biodiesel due to changing in properties.
9. The PB5 is closed to that of the diesel fuel in all performance parameters and it can be recommended as an alternative fuel for diesel engines with no engine modifications.

Acknowledgment

The authors are grateful to Dr. M. S Hamed, National Organization for Drug Control and Research (NODCAR), for her assistance during the production of biodiesel.

Appendix 1. Laboratory's notes


C.N . is calculated according to a known equation which depends on the analysis of fatty acid constitutes of the original transesterified oil.

The high % of the unsaturated linolenic acid ($C_{18\,(3)}$) was detected from the GC analysis , which affects negatively the C.N. and have influence on the pour point and the iodine no.

The increase of $C_{18\,(3)}$ may be due to high cooking temperature of the sunflower oil about (250 °C) From the (chipsi manufacture) the user of the oil.

Noting also that the palm oil cooking temperature didn't exceed 180 °C , so that the % fatty acid constitution seems to be not altered by the high cooking temperature.

Appendix 2. Specification of the test diesel engine

Model	'Robin' – Fuji DY23D.
Type	DI, Air cooled, 4 cycle, overhead valve, single vertical cylinder
Piston displacement	230 cm^3
Bore/Stoke	70 x 60 mm
Compression ratio	21
Nominal output	3.5 kW at 3600 rev/min.
Maximum torque	10.5 Nm at 2200 rev/min.
Injection pressure	120 kg/cm^2

Appendix 3. Gas analyser's measurement fields

Constituent	Symbol	Scale	Unit	Resolution
Carbon monoxide	CO	0-9.99	% vol	0.01
Oxides of nitrogen	NO_x	0-5000	ppm vol	10

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