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Influence of Biodiesel from Egyptian used Cooking Oils on Performance and Emissions of Diesel Engine

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Due to diminishing petroleum reserves and the environmental negative effects of exhaust gases from diesel fueled engines, alternative fuels for diesel engines are becoming increasingly important. Egyptian waste cooking oils have special specifications because it is exposed 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 engine performance with the palm biodiesel blend B5 is closed to diesel fuel also, for B5 the reduction percent ranges of CO emission was from 53 to 70% while the reduction percent ranges of NOx emission was from 13 to 80% compared to diesel fuel.

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

1 Introduction

The consumption of vegetable oil in Egypt is about 2 million tons every year, 90% of this amount is imported from different countries. It is used in fast food restaurants, factories manufacturing foods and houses. Consequently, most of these oils are discarded each year into drain or toilet.

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Thus, the cost of treating effluent or polluted water streams was increased; many Egyptian people cannot recognize how to manage this problem instead of getting rid of it in the sewerage networks [1-2]. The big problem is that the (Egyptian) oil is exposed to high temperatures during frying and changes their characteristics as a result of use for long times.
The use of these oils in the production of biodiesel adversely affects the physicochemical properties of biodiesel especially cetane number, low cetane number increasing delay period and negatively influenced on the performance and pollutants emissions of the diesel engine.
Oil sources are non-renewable, so the demand for alternative fuels to preserve the environment and also cheap, as the reduction of dependence on oil fuel is due to limited resources and harmful pollution of humans and the environment [3]. The current fuel: Biodiesel considers an alternative fuel that can be applied as a replacement of diesel in diesel engines either in clean form (B100) or by mixing with conventional diesel fuel. Biodiesel has many advantages such as; it is a renewable energy source, it also has a tendency to reduce the level of pollution which in turn reduces the greenhouse effect [4]. The world's major source of carbon dioxide emissions is the transport sector, which accounts for about 60% of world oil consumption.
Therefore, the scientific community has been interested in research to find new types of renewable energy sources, due to two reasons: the severe shortage of fossil fuel sources and the second greenhouse effect of growth and the use of petroleum fuels. Biodiesel is a potential alternative to diesel oil [5]. Research on environmental pollution and alternative energy resources has been undertaken to seek a solution due to high oil prices and global environmental problems that have become an important topic in recent years. In particular, it is necessary to reduce NOx and particle simultaneously and effectively because the effects of NOx and PM emitted from the diesel engine are harmful to the human element. On the other hand, biodiesel was noted as a low-emission alternative fuel that would reduce harmful emissions in accordance with climate change agreements [6]. The objective of this study is to conduct a pilot assessment of four-stroke, air cooling, and single cylinder diesel engine powered by different biodiesel fuel blending (B0 to B100) of various cooking oils used in Egypt (palm and sunflower) to assess the engine performance and emissions then compare the results with ordinary diesel fuel under different speeds from 1500 to 3500 rpm and constant load

2 Biodiesel Production

The used cooking oils are available in the local Egyptian market in a cheap price. Table (1) showed the properties of used oils. Several methods were used to produce biodiesel; Dilution, micro-emulsification, pyrolysis, and transesterification [7]. The easiest and the most common method can be done by transesterification.
Different parameters are considered during the transesterification process; the molar ratio (alcohol to oil), reaction time and temperature, stirring speed and catalyst type and concentration [8]. The process variables of transesterification are shown in table (2).
The resulted yield was 95% for sunflower oil and 97% for palm oil.

Table 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 ºC	10 – 12 hr	Every day
Waste sunflower oil	Fried potatoes and chips	Up to 250 ºC	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 ºC
Reaction time	120 minute
Stirrer speed	400 rpm

Table 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-	0.88	0.86-90
Viscosity cSt @ 40 ºC	3.8	4.45	1.6-7	1.9-6	3.5-5
Viscosity cSt @ 100 ºC	<l	<l	---	---	---
Flash point (ºC)	175	1785	> 55	> 130	> 101
Cloud point (ºC)	7	12	---	-3:15	---
Pour point (ºC)	4	8	4.5-15	-5:10	-4
Cetane number	56	28.4	Min. 55	47 min	51 min
Total acid number (mg	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 corrosion 3hrs@ 50 ºC	1A	1A	1A	No. 3	1A
Water & sediment (wt %)	Nil.	Nil.	Max. 0.15	0.05 max	Max 500
Total glycerin%	0.34	0.15	---	0.240 ,ax	0.25 max
Free glycerin%	0.062	0.055	---	0.20 x	0.02 max

As shown in table (3), the physiochemical properties of the produced biodiesel were 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 250 ºC (as stated in the laboratory report, Appendix I).

3 Experimental Setup

A single cylinder, air cooled diesel engine TD111 type ('Robin' - Fuji DY23D) was used during the experiments. The technical specifications of the engine are shown in Appendix (II). The engine is equipped with the hydraulic dynamometer TechQuipment TD114 for loading the engine. The engine emissions; carbon monoxide (CO) and the oxides of nitrogen (NOx) were measured using a Brain Bee S.P.A, AGS-688 Gas Analyzer while PM was measured using a Lucas Smoke Meter, the measurement fields of gas analyzer are shown in appendix III.
Figure (1) shows the photograph of the experimental test rig.

4 Results and Discussions

4.1 Engine Brake Power

Brake power is calculated based on the measured engine torque and speed. The changing of engine brake power for different biodiesel blends are presented in figs. (2-3). From the figs it can be noted that the engine power decreasing with the increasing of the percent of biodiesel in the fuel. The detail power reduction can be found in table (4).

This reduction of engine power with increasing the percent of biodiesel blends can be due to the lower heating value of the biodiesel as well as its higher viscosity and density, fuel flow problems and bad fuel injection atomization and combustion efficiency which lead to lower thermal efficiency [9-11]. It can be also noticed that the reduction of engine power with sunflower biodiesel more than the palm biodiesel due to the lower cetane number of sunflower biodiesel which lead to increase the ignition delay and reduce the engine power.

Table (4) summarized the percent changing of engine power for different biodiesel blends (average of all speeds).

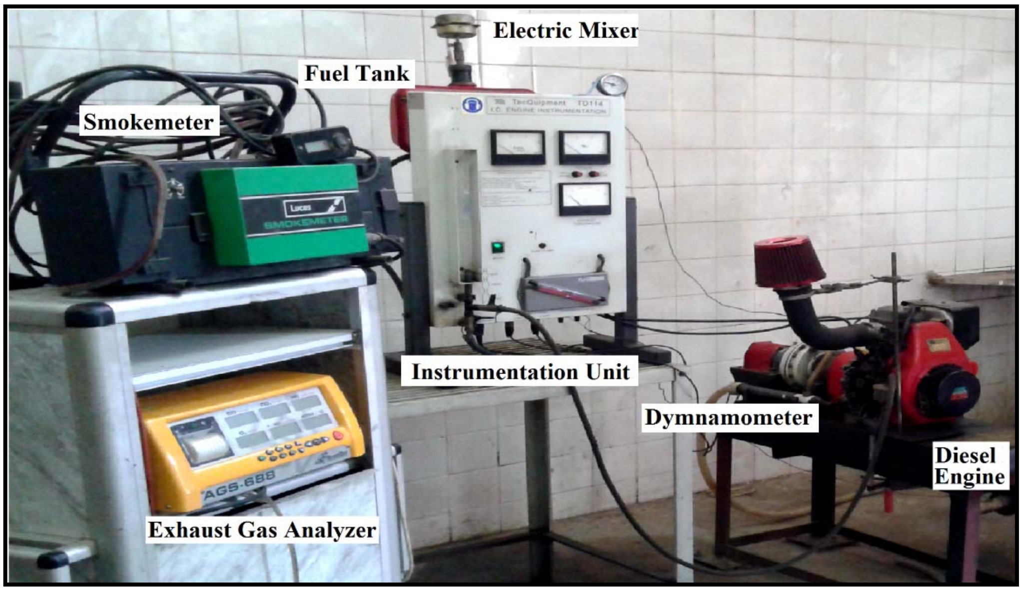

Figure 1 Photograph of experimental setup

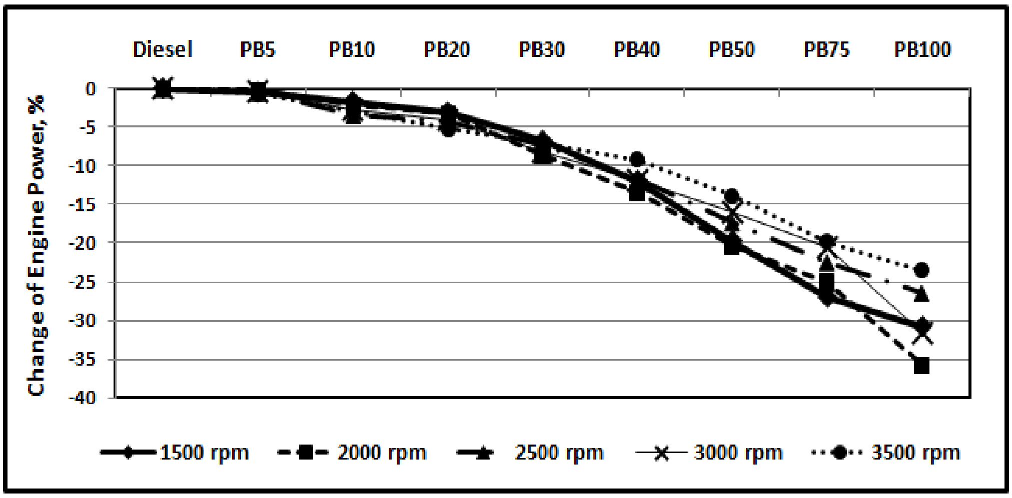

Figure 2 Changing of engine power for palm biodiesel blends at different speeds.

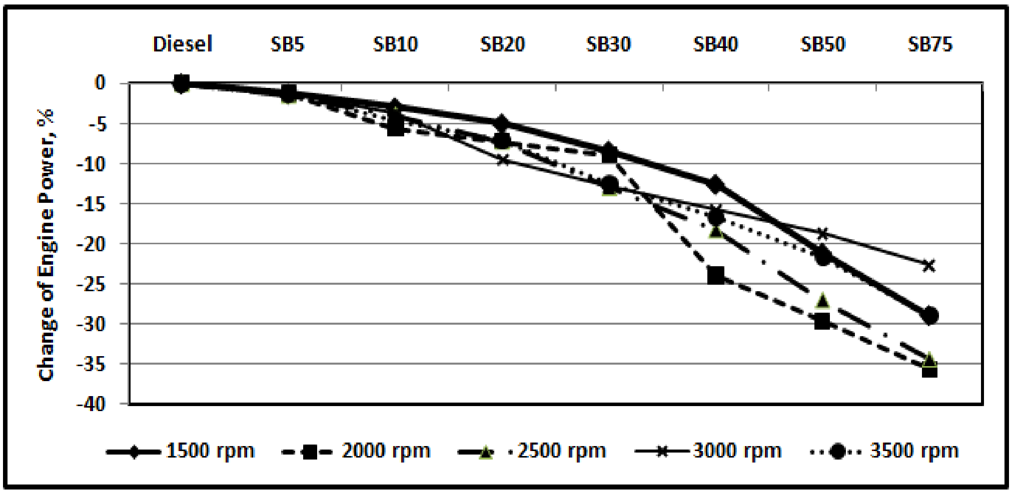

Figure 3 Changing of engine power for sunflower biodiesel blends at different speeds.

Table 4 Percentage of engine power reduction using different biodiesel blends

	B5	B10	B20	B30	B40	B50	B75	B100
Palm	-0.45	-2.8	-4.2	-7.6	-11	-16.8	-22	-28.8
Sun Flower	-1.3	-4.2	-7.8	-11.7	-17.6	-23.3	-29	---

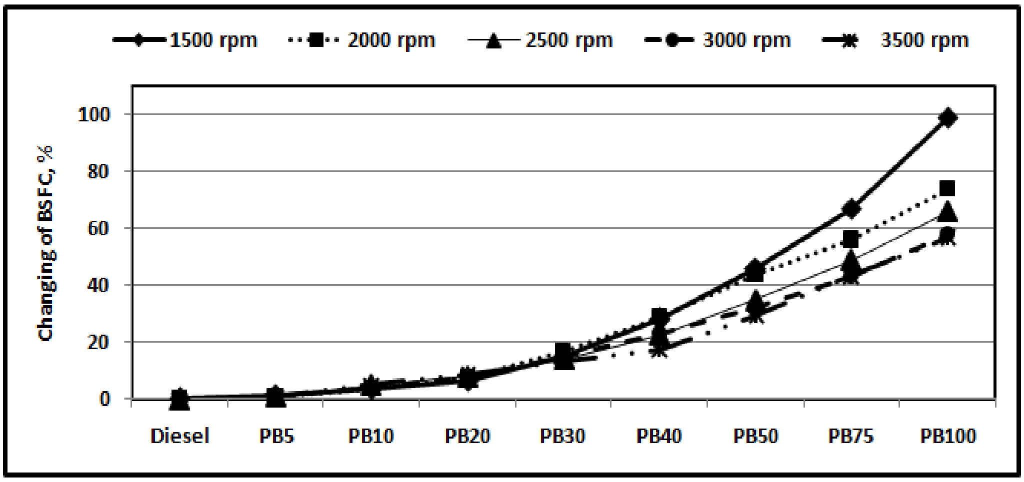

Figure 4 Changing of BSFC for palm biodiesel blends at different speeds

4.2 Brake Specific Fuel Consumption (BSFC)

Engine performance and fuel consumption were strongly controlled by the physical and chemical properties of the fuel used. To assess the engine performance with different fuel blends, a useful performance indicator, namely brake specific fuel consumption (BSFC) was used. BSFC is defined as the ratio of the fuel consumption rate to the brake power output [12]. The changing of BSFC for different biodiesel blends compared to diesel fuel is shown in figs. (4-5) for palm and sunflower respectively. As seen in the figs which summarized in table (5), the BSFC increases with the increase of biodiesel blends in the mixture, this is due to the lower heating value of the biodiesel than the diesel fuel which requires more fuel to produce the same energy. From table (5), the increasing of BSFC with palm blends was lower than with sunflower blends. Increased BSFC in the case of biodiesel agrees with some authors [13]

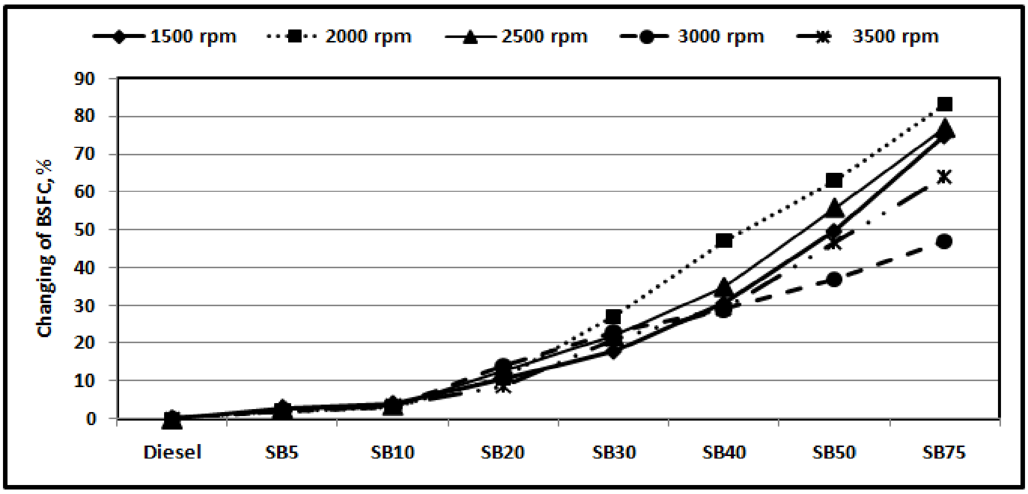

Figure 5 Changing of BSFC for sunflower biodiesel blends at different speeds.

Table 5 Percentage of increasing the BSFC using different biodiesel blends compared to diesel fuel

	B5	B10	B20	B30	B40	B50	B75	B100
Palm	0.9	4	8	15	23	36	51	69
Sun Flower	2.6	3.5	12	22	34	50	68	---

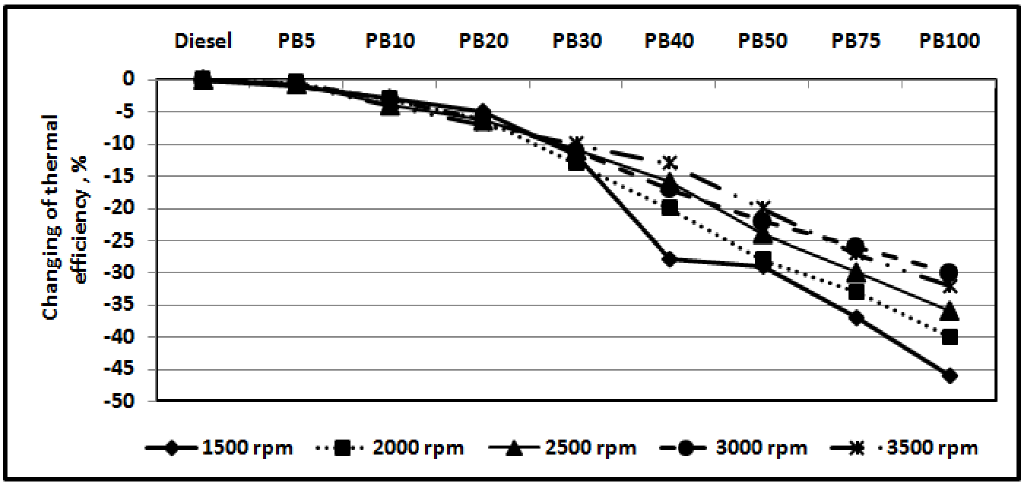

Figure 6 Changing of BTE for palm biodiesel blends at different speeds.

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. It greatly depends on the manner in which the energy is converted as the efficiency is normalized respect to the fuel heating value [14]. Figs. (6-7) show the changing of BTE for different blends of palm and sunflower biodiesel at different speeds when compared with diesel fuel. As shown in the figs., all biodiesel blends reduce the BTE at all speeds, also increase the percent of blends leads to decrease the BTE. The reduction of BTE with biodiesel blendes was attributed to many factors like high viscosity, lower calorific value and poor spray characteristics of biodiesel and it's blends. The reduction of BTE with sunflower blends was higher than with palm blends as shown in table (6) also BTE for B5 is close to diesel fuel at all speeds. Decreased BTE in the case of biodiesel agrees with some authors reported [15-17].

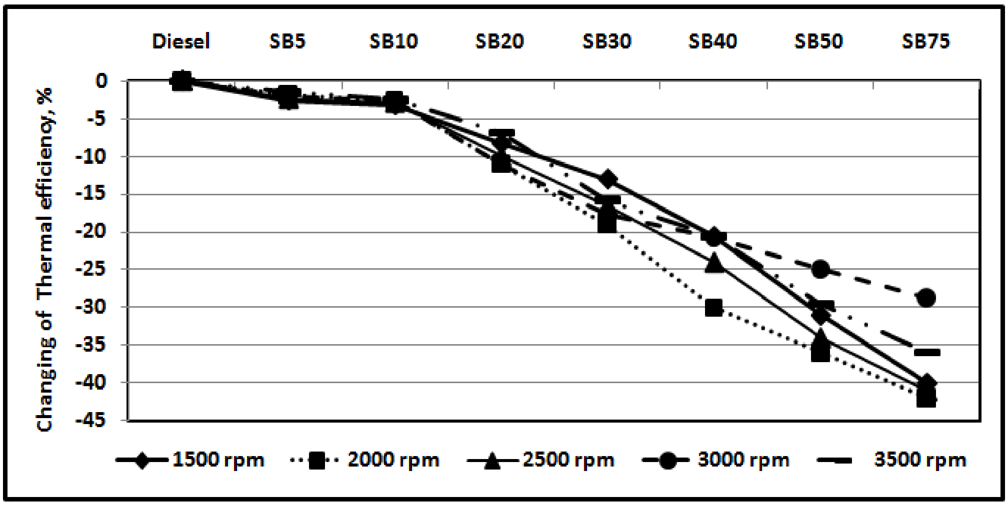

Figure 7 Changing of BTE for sunflower biodiesel blends at different speeds.

Table 6 Average decreasing of BTE using different biodiesel blends compared to diesel fuel

	B5	B10	B20	B30	B40	B50	B75	B100
Palm	-0.7	-4	-6	-11	-19	-25	-31	-36
Sun Flower	-2	-2.8	-9.7	-16	-23	-31	-38	---

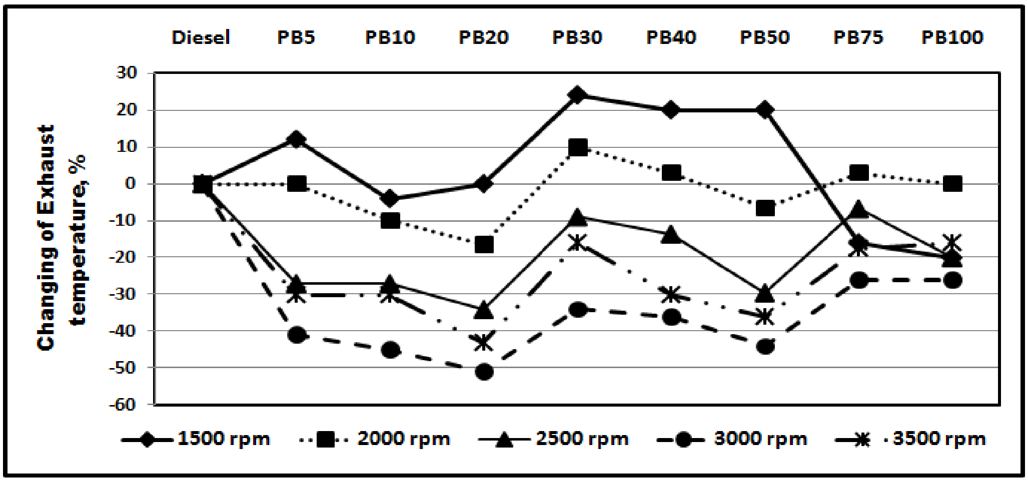

Figure 8 Changing of exhaust temperature for palm blends at different speeds.

4.4 Exhaust Gas Temperature (EGT)

The exhaust gas temperature indicates how efficiently the heat energy of the fuel is been used. The heat loss in the exhaust pipe or an increase in the exhaust temperature reduces the conversion of heat energy of the fuel to work [18]. Figs. (8-9) show the percent change of EGT for different biodiesel blendes 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. 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.
Table (7) summarized the average change in EGT for different blends of palm and sunflower compared to diesel fuel. 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 [19-20].

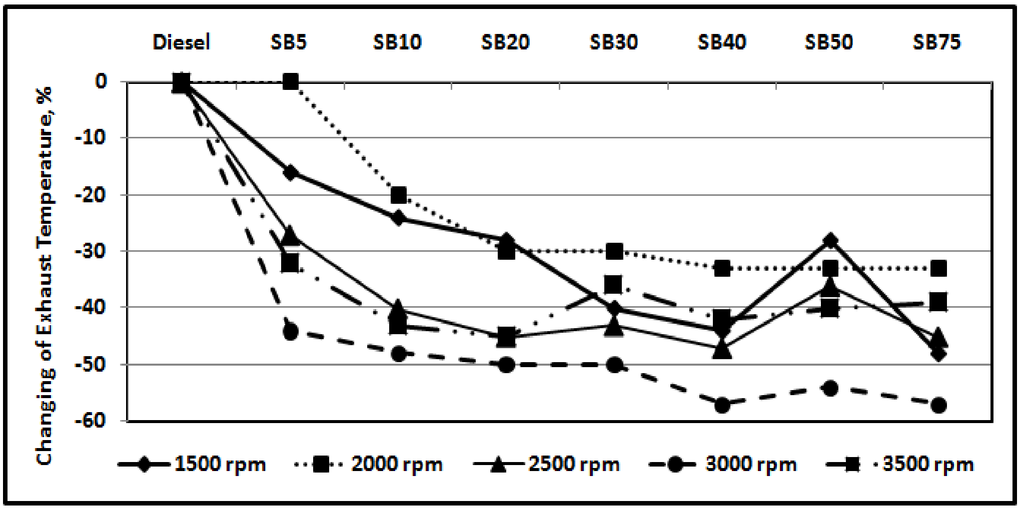

Figure 9 Changing in exhaust temperature for sunflower blends at different speeds.

Table 7 Average decreasing of EGT using different biodiesel blends compared to diesel fuel

	B5	B10	B20	B30	B40	B50	B75	B100
Palm	-17	-23	-28	-5	-11	-19	-13	-16
Sun Flower	-23	-35	-39	-39	-44	-38	-44	---

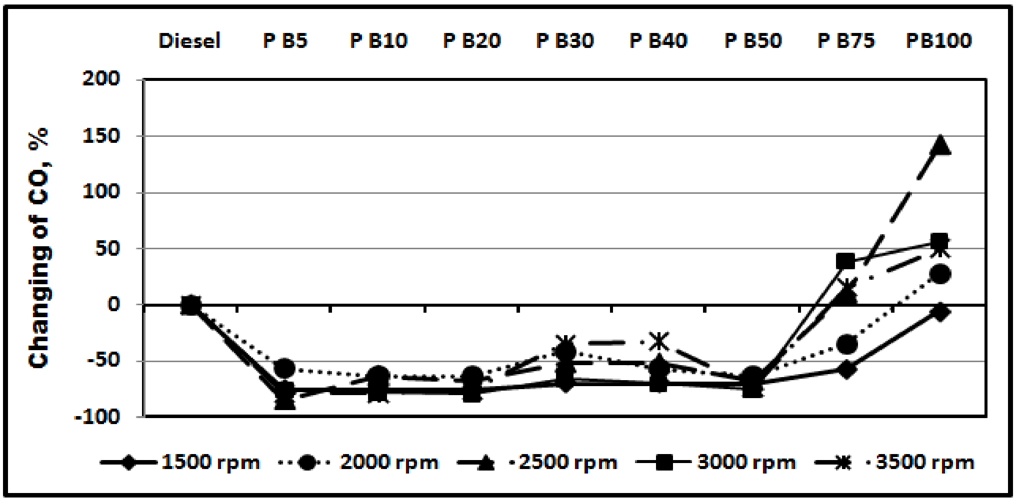

Figure 10 changing of CO emission for different palm blends at different engine speeds

4.5 Carbon Monoxide (CO)

The carbon monoxide (CO) emissions signify that the combustion which is taking place inside the cylinder is not completed and the basic two reasons are either the oxygen is lesser than theoretical or time available for combustion is lesser [9]. Figs (10-11) illustrate the change of CO emission for different blends of palm and sunflower biodiesel respectively at different engine speeds. As shown in the figs with biodiesel blends from B5 to B50 the oxygen present in the biodiesel support for complete combustion and lead to decrease the CO emission at all speeds except at 3500 rpm for sunflower biodiesel also, higher cetane number helps for lowering ignition delay and complete combustion. Increasing the percentage of biodiesel blends more than 50% lead to increasing the CO emission due to high viscosity and density for biodiesel when compared to diesel fuel. Table (8) summarized the average changing of CO emission for palm and sunflower blends compared to diesel fuel. The reduction in CO emission agrees with some authors [21].

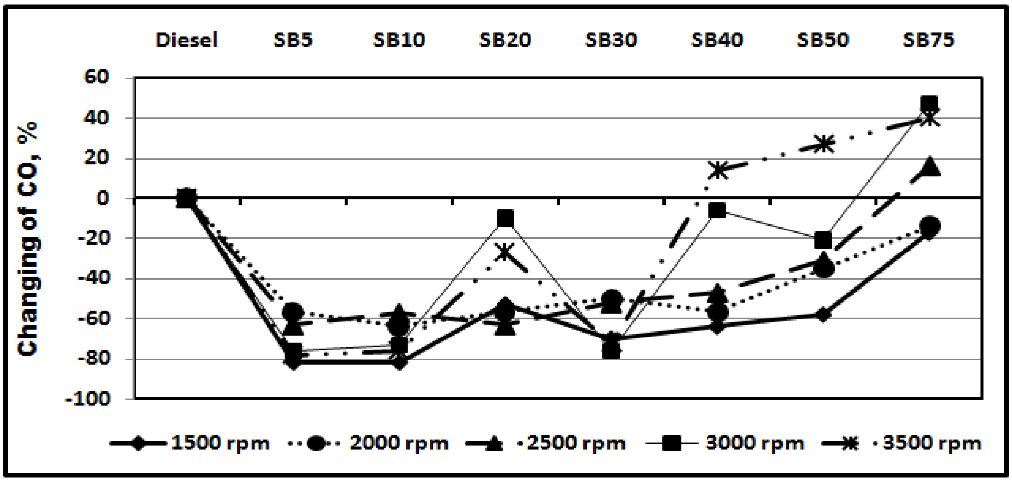

Figure 11 changing of CO emission for different sunflower blends at different engine speeds

Table 8 Average changing of CO emission using different biodiesel blends compared to diesel fuel

	B5	B10	B20	B30	B40	B50	B75	B100
Palm	-75	-72	-73	-53	-57	-70	-6	+54
Sun Flower	-71	-70	-42	-64	-32	-23	+14	---

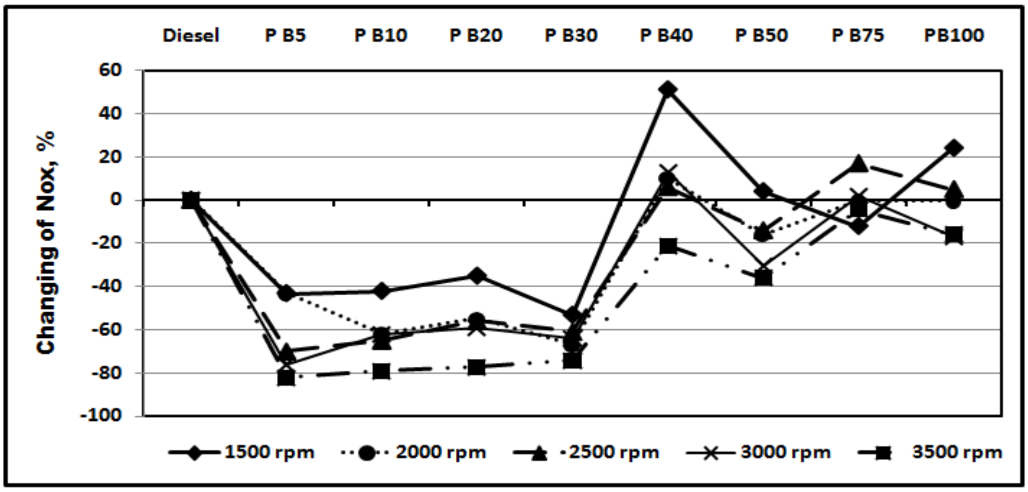

Figure 12 changing of NOx emission for palm biodiesel blends at different speeds.

4-6 Nitrogen Oxides (NOx)

Nitrogen oxides are produced by the reaction between nitrogen and oxygen at high temperature and pressure generated in the engines during combustion of fuel [22]. In general, biodiesels cause the faster propagation of pressure waves and more rapid pressure rise, which may indicates the necessity of retarding injection timing several crank degrees.

The earlier combustion can result higher combustion temperature and higher NOx emission has been occurred [23]. Figs (12-13) illustrate the percent change of NOx emission for palm and sunflower biodiesel blends at different speeds. As shown in the figs, palm blends from PB5 to PB30 gave lower NOx emission than diesel fuel at all speeds. Table (19) presents the average change of NOx emission for palm and sunflower blends. From the table it can note that palm biodiesel blends is better than sunflower blends, this is may be due to the lowering of cetane number for sunflower biodiesel which affect the ignition delay and combustion temperature as reported by some authors [24].

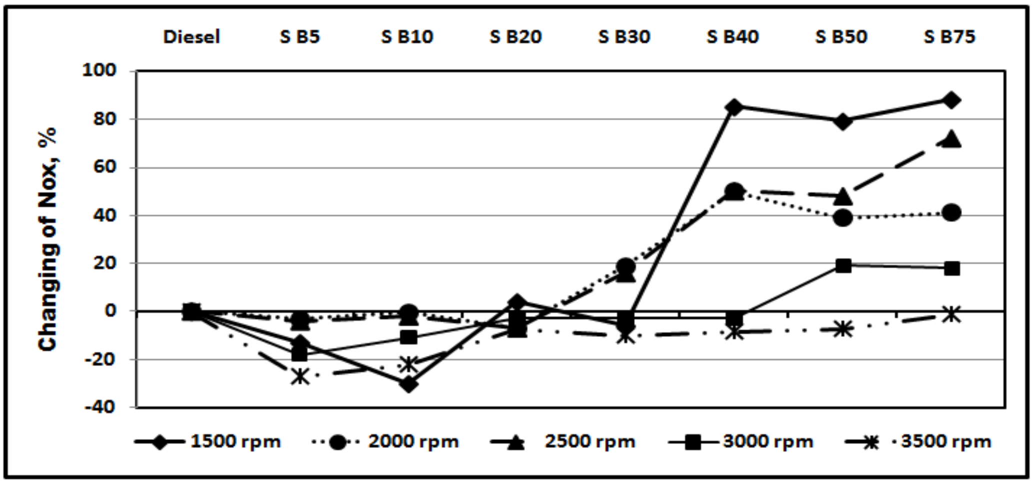

Figure 13 Changing of NOx emission for sunflower biodiesel blends at different speeds.

Table 9 Average changing of NOx emission for different biodiesel blends compared to diesel fuel

	B5	B10	B20	B30	B40	B50	B75	B100
Palm	-63	-62	-56	-63	+11.8	-18	+0.5	-0.9
Sun Flower	-13	-13	-4	+3.2	+35	+36	+44	---

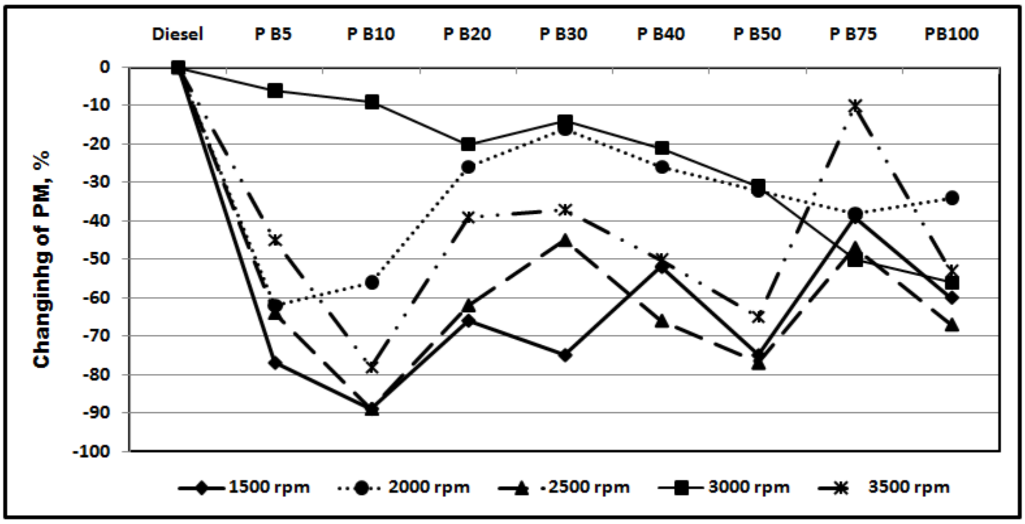

Figure 14 changing of PM emission for different blends of palm biodiesel at different speeds.

4-7 Particulate matter (PM)

Particulate matter (PM) is a generic term used for a type of airborne pollution which consists of varying mixtures, complexity and sizes of particles [25]. Figs (14-15) show the changing of PM emission for different blends of palm and sunflower at different engine speeds. As shown in the figs all biodiesel blends decreasing the PM emission at all speeds compared to diesel fuel. Decreasing of PM emission for biodiesel is may be due to the high oxygen content of biodiesel which leads to complete combustion and it agrees with some authors reported [26-27].
Table 10 summarized the average changing of PM emission for different blends of palm and sunflower, from the table the reduction of PM emission with palm biodiesel blends is higher than with sunflower blends.

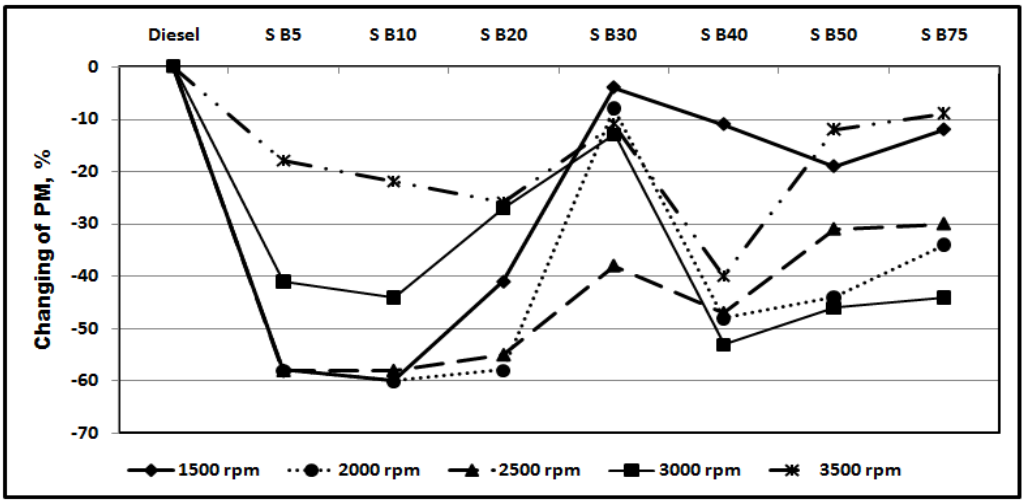

Figure 15 changing of PM emission for different blends of sunflower at different speeds.

Table 10 Average changing of PM emission for different biodiesel blends compared to diesel fuel

	B5	B10	B20	B30	B40	B50	B75	B100
Palm	-51	-64	-43	-37	-43	-56	-37	-54
Sun Flower	-47	-49	-41	-15	-40	-30	-26	---

5 Conclusions

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

- It required a media campaign to inform Egyptian people how to deal with the waste cooking oil, rather than disposal in sewage systems
- Use of waste cooking oil in production of biodiesel will reduce the cost of treating effluent or polluted water streams
- High frying temperature of cooking oil leads to reduce the cetane number of produced biodiesel.
- Engine power of diesel fuel is higher than biodiesel blends because diesel fuel has higher calorific value and more power than biodiesel, also the viscosity and density of biodiesel is higher than diesel fuel.
- The fuel consumption is increased with increase in the percentage of biodiesel blends due to lower calorific value.
- Thermal efficiency for biodiesel blends is lower than diesel fuel. This may be due to poor atomization and higher viscosity of biodiesel blends when compared with diesel fuel. Higher fuel consumption and lower heating value of biodiesel were some of the reasons for decreasing of thermal efficiencies of biodiesel blends in comparison with diesel fuel.
- The oxygen present in the biodiesel (palm and sunflower) support for complete combustion and lead to decrease CO emission when compared with diesel fuel
- Blends from B5 to B30 for both fuels gave lower NOx emission than diesel fuel at all speeds; the reduction in NOx with palm blends is lower than with sunflower blends.

- All blends of biodiesel (palm and sunflower) give PM emission less than diesel fuel at all speeds
- Engine performance with palm biodiesel is better than with sunflower biodiesel due to changing in properties.
- 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

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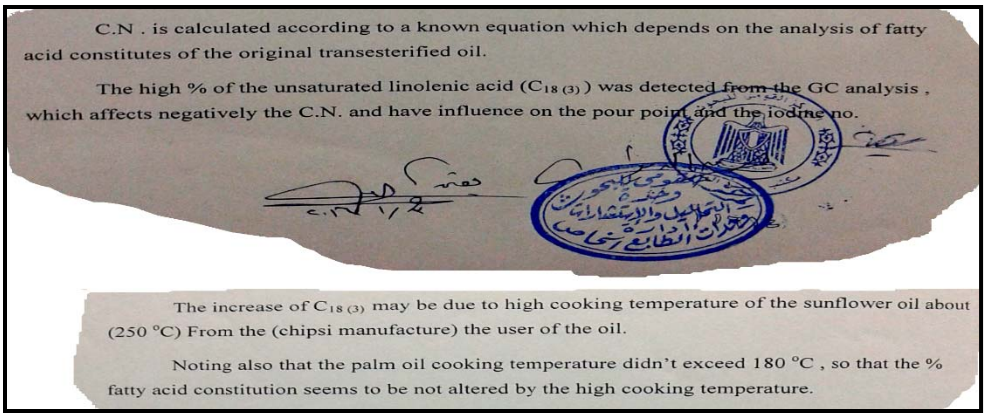
Appendix 1, Laboratory's notes



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,, 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 analyzer'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

چکیده

با توجه به کاهش منابع نفت و اثرات منفی زیست محیطی گازهای سوخته شده از موتورهای دیزل، بر اهمیت سوختهای جایگزین برای موتورهای دیزل افزوده شده است. روغنهای پخت و پز مصرف شده بدلیل اینکه در ساعتهای طولانی تحت تاثیر حرارت قرار گرفته‌اند ویژگی های خاصی دارند. در این مطالعه تجربی بازدهی و انتشار گازها در یک موتور دیزل تک سیلندر چهار زمانه که توسط هوا خنک می‌شود با دو نوع روغن پخت و پز مصری (پالم و آفتابگردان) در سرعتهای مختلف مورد بررسی قرار گرفته است.

پارامترهای مورد بررسی در بازدهی موتور عبارتند از گشتاور، مصرف سوخت و درجه حرارت گاز خروجی. توان توقف، مصرف ویژه سوخت توقف و راندمان حرارتی توقف به کمک داده‌های بدست آمده از آزمایش تعیین شده‌اند. پارامترهای گازهای منتشر شده شامل مونوکسید کربن، مواد معلق و اکسیدهای نیتروژن می‌شوند. آزمایشات با سوخت دیزل با مخلوطهای بایودیزل B5 تا B100 انجام گرفته است. نتایج نشان می دهد که راندمان موتور با مخلوط بایودیزل پالم B5 به نتایج سوخت دیزل نزدیک است. برای B5، میزان کاهش CO در مقایسه با سوخت دیزل از 53 به 70٪ است حال انکه میزان کاهش NOx از 13 به 80٪ است.