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Alternative Fuels for Diesel Engines Using Highly Saturated and Highly Unsaturated Vegetable Oils

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THE QUALITY of fatty acid methyl esters of linseed oil; …….a highly unsaturated oil, as a biodiesel fuel, was compared to that prepared using palm oil; a highly saturated vegetable oil. The comparison included the fuel properties such as the calorific value, flash point, carbon residue %, ash %, pour point, cetane index, viscosity, ASTM distillation characteristics and oxidative stability. The performance of a diesel engine running using 50% blend of each with regular diesel has been also assessed at different engine loadings and compared to that using regular diesel fuel. The parameters considered in this assessment were the brake specific fuel consumption, the brake thermal efficiency, and the composition of the combustion exhaust The results have shown that biodiesel produced by trans-esterification of linseed oil have two advantages over that produced by trans-esterification of palm oil being more volatile with higher heating value. However, the flash point of linseed biodiesel was lower than that of palm oil biodiesel which makes it less safe during handling and storage. Moreover, linseed biodiesel was much less stable to oxidation than palm oil biodiesel whereby the induction period measured by Rancimat test was 40.6 hours in case of palm biodiesel compared to 2.8 hours in case of linseed. The effect of biodiesel unsaturation on diesel engine performance in terms of fuel consumption rate and brake thermal efficiency was insignificant.

Keywords: Biodiesel, Unsaturation, Linseed oil, Palm oil, Oxidative stability**.**

No doubt that the world energy needs continue to gradually and exponentially increase by time. This is due to the rapid increase in consumption rate of fuel. The most feasible way to solve this problem is through finding renewable fuels alternative to regular petrol fuels. One example of these alternatives is biofuels such as biodiesel which is advantageous over fossil fuels as being more environmentally friendly [1-4]. It should be emphasized that some other advantages of biodiesel over petrodiesel are its high lubricity and the fact that it is biodegradable. Biodiesel can be used to run most vehicles as a blend with regular diesel. The major feedstock for production of biodiesel is plant oil such as soybean, rapeseed and sunflower oils. Biodiesel is considered to be safer than petrol diesel during handling, transportation, and storage [5,6]

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Biodiesel can be prepared by transesterification of vegetable oils which are triacylglycerol with monohydric alcohols especially short chain ones. The reaction can be catalyzed by alkaline or the acidic catalysts such as sodium hydroxide and sulfuric acid respectively [7-9]. Acidic catalysts are preferred whenever the oil acidity is high as the case with used frying oil. Non-catalyzed transesterification is also possible if the reaction occurs at the supercritical conditions of the used alcohol [10,11].

The fatty acid profile of biodiesel is quite similar to that of the feedstock used. Thus, biodiesel fuels derived from different sources can have significantly varying fatty acid profiles and properties. Most important variations in the structure are the degree of unsaturation of fatty acids as well as their chain lengths [12].

Therefore it is important to understand the effect of the previously mentioned two parameters on the physical and chemical properties of biodiesel such as the calorific value, flash point, carbon residue %, ash%, pour point, cetane index, viscosity, volatility and oxidative stability. This is necessary to be able to select the most suitable feedstock required to optimize the benefits of biodiesel [13-15].

The aim of this study was to explore the influence of the degree of unsaturation of fatty acids as well as the chain length of the feedstock used for the production of biodiesel on its properties as a fuel as well as its stability during storage. The results of this work could be a guide for determining the feedstock or their blends for the production of biodiesel.

Experimental

Materials

Two types of oils have been used in this study being palm oil and linseed oil obtained from the local market in Egypt. The first oil was selected as being rich in saturated fatty acids while the latter was rich in unsaturated fatty acids. Both oils have been analyzed for their fatty acid composition using gas liquid chromatography according to AOCS Official Methods [16]. The fatty acid compositions of the two oils are listed in Table 1.

The two oils were trans-esterified with methanol to yield biodiesel and the products of esterification have been then assessed as fuels for diesel engines according to their fuel properties, their oxidative stability as well as the performance of a diesel engine when run using biodiesel compared to regular diesel.

Transesterification of palm and linseed oils

Transesterification of palm and linseed oils was performed using methanol in presence of sulfuric acid as a catalyst at a percentage of three percent of the mixture weight .About six moles of alcohol were used for each mole of oil .The reaction progress was followed during the reaction using thin layer chromatography until completed as described by Megahed [17].

Table 1. Fatty acid composition of palm and linseed oils.

Fatty acids	Palm Oil	Linseed oil
C14:0	1.0	0.0
C16:0	41.2	6.6
C18:0	3.3	3.4
C20:0	0.4	0.0
Σ SFA	45.9	10.0
C18:1	41.9	20.3
Σ MUFA	41.9	20.3
C18:2	11.9	15.3
C18:3	0.3	54.4
Σ PUFA	12.2	69.8
PUFA/SFA	0.006	6.98

Σ SFA = total saturated fatty acids
Σ MUFA= total mono unsaturated fatty acids
Σ PUFA= total poly unsaturated fatty acids

Evaluation of the fuel properties of the trans-esterified products

The trans-esterified products were then evaluated for their fuel properties as compared to regular diesel fuel using ASTM methods. They have been determined in the central analytical lab at the Egyptian Petroleum Research Institute, EPRI, Nasr City, Cairo following the standard methods of analysis, ASTM [18]. These include the calorific value (ASTM D-224), Flash point (ASTM D-93), carbon residue (ASTM D-189), ash% (ASTM D-482) sulfur % (ASTM D-4294), pour point (ASTM D-9), Kinematic viscosity (ASTM D-445) and density (ASTM D-4052).

Oxidative stability of the products obtained by transesterification of palm and linseed oils.

Rancimat 673 (Metrohm Co., Herisou, Switzerland), was used to determine the oxidative stability of the two biodiesels according to Rancimat method as described by Fatemi and Hammond [19]. A stream of air at a flow rate of 20 L/hr was bubbled through the oil at 100 °C. The volatile degradation products were trapped in distilled water in a second vessel, causing an increase in water conductivity. This instrument measures the induction period (IP) whereby the higher the IP value is the more stable the oil to oxidation.

Engine testing using biodiesel

The prepared biodiesel fuel has been evaluated according to the performance of a diesel engine operated using a 50% blend of biodiesel with regular diesel fuel as compared to that using regular diesel fuel (solar). Engine testing has been conducted on a direct injection four strokes, four cylinders diesel engine (capacity1931cm^3). A schematic layout of the experimental set-up used is described in Fig. 1. The instruments and measuring devices used in this set-up include:

1- Hydraulic dynamometer which is essentially a torque measuring device
2- Tachometer and stroboscope which are rpm measuring devices.
3- Thermocouples to measure the temperature of the cooling water, inlet and exit as well as the temperature of the exhaust.
4- Air tank and orifice meter which is used to calculate the air flow rate.
5- Fuel tank as well as a fuel metering system

The experiments were carried at a constant speed of 1250 rpm. Five experimental runs were made using each fuel at different loads being; zero, 15, 40, 65 and 75 Nm. In each run, the following readings were recorded for performance evaluation:

1- Dynamometer reading (load) and engine rpm.
2- Fuel flow rate as well as air flow rate.
3- The cooling water flow rate and temperature rise.
4- Exhaust temperature

On the basis of these readings, the performance parameters of the engine can be estimated which include:
1- Brake specific fuel consumption, BSFC, (gm/Kw.hr),
2- Brake thermal efficiency (%),
3- Indicated specific fuel consumption, ISFC (gm/Kw.hr)
4- Indicated thermal efficiency (%),

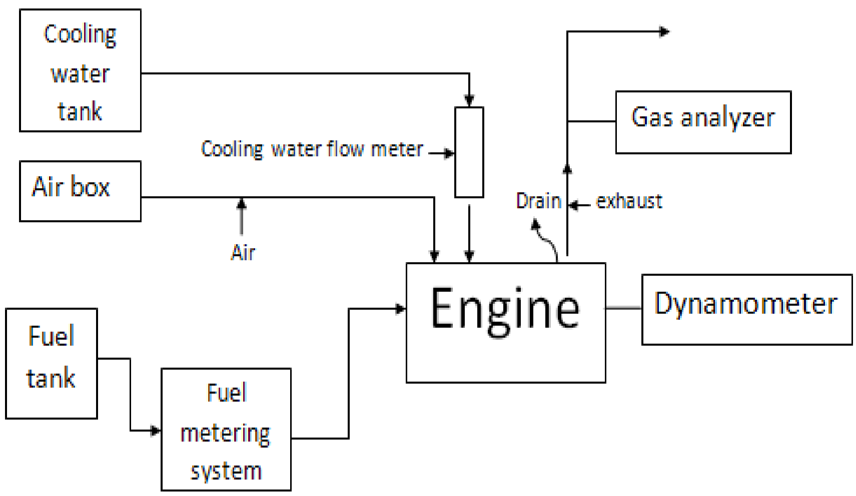

Fig. 1. Experimental setup.

Results

Fuel properties of biodiesel compared to regular diesel

Table 2 lists the properties of biodiesel produced using linseed and palm oils as compared to regular diesel fuel. These include the density, kinematic viscosity, pour point, sulfur%, ash%, carbon residue%, cetane index, flash point , calorific value, distillation characteristics as well as the induction period (hr), of both biodiesels as determined by Rancimat test. It is obvious that biodiesels produced by transesterification of both types of oils are more viscous than regular diesel fuel. It follows that their atomization in the engine would occur less efficiently with expected problems of carbon deposition in the engine due to inefficient combustion. Also, the calorific value of each of the two biodiesel products is less than that of regular diesel being about 88% and 80% of that of regular diesel in case of linseed biodiesel and palm oil biodiesel respectively. This means that the expected output power upon combustion of biodiesel will be lower. However, they are more volatile than regular diesel according to the results of ASTM distillation which makes their combustion easier. Moreover, both biodiesels have the advantage of being completely free of sulfur. Sulfur oxidation during fuel combustion would release corrosive oxides which have an adverse impact on the environment and the engine components as well. In view of that finding, it can be stated that biodiesel is more environment friendly than petrol fuel not only because it reduces carbon dioxide emissions but also because it eliminates the emission of corrosive sulfur oxides.

The results presented in Table 2 show also that biodiesel produced by trans-esterification of highly unsaturated linseed oil have two advantages over that produced by trans-esterification of the highly saturated palm oil being more volatile with higher heating value. However, the flash point of the former (linseed biodiesel) is lower than that of the latter (palm oil biodiesel) which makes it less safe during handling and storage. Moreover, linseed biodiesel is much less stable to oxidation than palm oil biodiesel whereby the induction period measured by Rancimat test was 40.6 hours in case of palm biodiesel compared to 2.8 hours in case of linseed biodiesel. This result is quite expected since the ratio between total poly unsaturated fatty acids and total saturated fatty acids, PUFA/SFA, was 6.98 in the case of linseed oil compared to 0.006 in case of palm oil as in Table 1.

Results of engine testing

The results of the diesel engine running using regular diesel fuel and its 50% blend with palm biodiesel and linseed biodiesel are listed in Tables 3-8. It can be seen that the brake specific fuel consumption, BSFC, has been increased by blending with regular diesel with biodiesel. At a brake power 9.8 Kw, it has been increased from 285 gm/ Kw hr to about 320 gm/ Kw hr. This is a quite expected result since the heating value of biodiesel is lower than that of regular diesel. The estimated brake thermal efficiency was 30% using regular diesel compared to 27% if it was blended with 50% biodiesel. The variations in the composition of the exhaust by blending regular diesel with biodiesel are not noticeable. However

TABLE 2 - Properties of linseed and palm oil biodiesels compared to regular diesel.

Experiment	Method	Regular diesel	Biodiesel of linseed oil	Biodiesel of palm oil
Density, @ 15.56 °C Specific Gravity API gravity @ 60 °F	ASTMD-1298	0.8543 0.8551 33.97	0.8811 0.8896 28.94	0.8700 0.8709 30.98
Kinematic viscosity, cSt, @ 40°C	ASTM D-445	2.64	5.94	3.73
Pour point, °C	ASTM D-97	3	-9	-3
Total Sulphur, wt %	ASTM D-4294	0.68	Nil	Nil
Ash content, wt%	ASTM D-482	0.006	0.001	Nil
Carbon residue, wt%	ASTM D-189	0.016	Nil	Nil
Cetane index	ASTM D-976	47	31.5	34
Flash point, °C	ASTM D-93	88	69	103
Gross Calorific value cal/g Net Calorific value cal/g	ASTM D-224	11357 10741	9936 9340	8968 8364
Induction period, hr at 100°C	Rancimat test	-	2.8	40.6
Distillation Initial boiling point, °C 10 ml 20 ml 30 ml 40 ml 50 ml 60 ml 70 ml 80 ml 90 ml Recovery, ml Residue, ml Loss %	ASTM D-86	 170 205 235 264 275 278 300 310 315 322 91 8 1	 90 190 210 225 240 245 245 245 245 260 91 7 2	 90 190 220 225 230 240 260 270 280 300 91 7 2

such blending effects an increase of the temperature of the exhaust of about 10 °C which can be attributed to the increase in the rate of fuel consumption by biodiesel blending.

TABLE 3. Results of Diesel engine running using regular diesel fuel.

Brake power (KW)	0	1.9	5.2	8.5	9.8
Indicated power (KW)	5.8	7.8	11.1	14.3	15.6
Mechanical efficiency (%)	0	25.1	47.1	59.2	62.6
BSFC (gm/Kw.hr)	--	642.8	352.7	291.8	285.6
ISFC (gm/Kw.hr)	184.5	161.2	166.4	172.7	178.8
BMEP (Kpa)	0	97.6	260.3	422.9	488.0
IMEP (Kpa)	291.4	389.0	551.7	714.3	779.4
Brake thermal efficiency (%)	0	13.3	24.3	29.3	30.0
Indicated thermal efficiency (%)	46.4	53.1	51.5	49.6	47.9
A/F ratio	54.9	47.0	32.1	23.9	21.1
Volumetric efficiency (%)	72.0	72.0	72.0	72.0	72.0

TABLE 4. Exhaust temperature and composition of Diesel engine running using regular diesel fuel.

Brake power (KW)		0	1.9	5.2	8.5	9.8
Exhaust Temp (^OC)		113.9	143.1	206.2	267	307.2
Emissions	O_2 (%)	16.8	15.6	13.4	10.7	9.4
	CO (ppm)	1606	1318	1256	1445	1489
	CO_2 (%)	0	3.4	4.3	5.8	7.7
	SO_2 (ppm)	348	167	142	140	170
	NO_x (ppm)	89	512	540	794	714

TABLE 5. Results of Diesel engine running using 50%blend of palm biodiesel with regular diesel fuel.

Brake power (KW)	0	1.9	5.2	8.5	9.8
Indicated power (KW)	4.3	6.3	9.6	12.8	14.1
Mechanical efficiency (%)	0	30.9	54.4	66.0	69.1
BSFC (gm/Kw.hr)	--	754.2	368.7	358.5	317.0
ISFC (gm/Kw.hr)	258.1	233.5	200.8	236.7	219.3
BMEP (Kpa)	0	97.6	260.2	422.9	488.0
IMEP (Kpa)	217.5	315.1	477.8	640.5	705.5
Brake thermal efficiency (%)	0	11.3	23.2	23.9	27.0
Indicated thermal efficiency (%)	33.2	36.7	42.7	36.2	39.1
A/F ratio	55.1	42.1	32.2	20.3	19.9
Volumetric efficiency (%)	74.6	74.6	74.6	74.6	74.6

TABLE 6. Exhaust temperature and composition of Diesel engine running using 50%blend of palm biodiesel with regular diesel fuel.

Brake power (KW)		0	1.9	5.2	8.5	9.8
Exhaust Temp (^OC)		113.2	143.5	201.9	278	320.1
Emissions	O_2 (%)	17.2	16.1	14.2	11.6	10.2
	CO (ppm)	1585	1232	1692	1904	1887
	CO_2 (%)	5.6	2.9	0	7.2	7.8
	SO_2 (ppm)	340	222	196	159	134
	NO_x (ppm)	57	161	454	693	666

TABLE 7. Results of Diesel engine running using 50%blend of linseed biodiesel with regular diesel fuel.

Brake power (KW)	0	1.9	5.2	8.5	9.8
Indicated power (KW)	5.5	7.5	10.7	14.0	15.3
Mechanical efficiency (%)	0	26.1	48.5	60.4	63.8
BSFC (gm/Kw.hr)	--	726.1	397.4	323.1	313.6
ISFC (gm/Kw.hr)	200.7	189.5	192.7	195.4	200.2
BMEP (Kpa)	0	97.6	260.3	422.9	488.0
IMEP (Kpa)	276.3	373.9	536.6	699.3	764.3
Brake thermal efficiency (%)	0	11.8	21.5	26.5	27.3
Indicated thermal efficiency (%)	42.7	45.2	44.4	43.8	42.7
A/F ratio	55.7	43.6	29.9	22.6	20.2
Volumetric efficiency (%)	74.6	74.6	74.6	74.6	74.6

TABLE 8. Exhaust temperature and composition of Diesel engine running using 50%blend of linseed biodiesel with regular diesel fuel.

Brake power (KW)		0	1.9	5.2	8.5	9.8
Exhaust Temp (^{O}C)		111.8	142.6	198	274.5	313.4
Emissions	O_2 (%)	17.2	16	13.9	11.3	10.1
	CO (ppm)	1953	1492	1146	1178	1228
	CO_2 (%)-calculated	0	2.9	3.9	6.7	7.4
	SO_2 (ppm)	484	315	141	146	166
	NO_x (ppm)	33	133	418	753	781

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وقود حيوي بديل لوقود الديزل التقليدي باستخدام الزيوت النباتية المشبعة وعديدة عدم التشبع

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فى هذه الدراسة تم مقارنة جودة وخصائص استرات الأحماض الدهنية، كوقود حيوي للديزل، من زيت بذور الكتان كمثال للزيوت عديد عدم التشبع، وأيضا زيت النخيل كمثال للزيوت النباتية المشبعة. تضمنت الدراسة مقارنة خصائص الوقود: مثل القيمة الحرارية، نقطة الوميض، وبقايا الكربون٪، نسبة الرماد، نقطة الانسكاب، ومؤشر سيتان، اللزوجة، وخصائص التقطير طبقا لمعايير الـ ASTM وكذلك تم دراسة الثبات التأكسدي. وقد تم تقييم الأداء عند أحمال مختلفة لمحرك الديزل باستخدام مزيج 50:50 من كل منهم مع الديزل العادى مقارنة مع وقود الديزل التقليدى منفردا.

والمعايير التى تم تقييمها فى هذه الدراسة تشمل معدل استهلاك الوقود، والكفاءة الحرارية ، وتكوين عادم الاحتراق وقد أظهرت النتائج أن وقود الديزل الحيوي من زيت بذر الكتان يتميز عن ذلك المحضر من زيت النخيل من حيث أنه أكثر تطايرا مع ارتفاع قيمتة الحرارية. ولكن من ناحية أخرى، كانت نقطة الاشتعال لوقود الديزل الحيوي للكتان أقل من تلك الخاصة بزيت النخيل مما يجعل الوقود الناتج من زيت الكتان أقل آمانا أثناء التداول والتخزين. بالإضافة إلى ما سبق فإن وقود الديزل الحيوي للكتان أعطى استقرارا أقل للأكسدة من وقود الديزل الحيوي الناتج من زيت النخيل حيث كانت فترة الثبات التى تم قياسها بجهاز الرانسيمات 40.6 ساعة في حالة وقود الديزل الحيوي لوقود زيت النخيل مقابل 2.8 ساعة في حالة الوقود المجهزمن زيت الكتان.

وقد أظهرت نتائج الدراسة أن تشبع الأحماض الدهنية لوقود الديزل الحيوي من عدمه لا يؤثر تأثيرا ملحوظا على أداء محرك الديزل من حيث معدل استهلاك الوقود والكفاءة الحراريه.