PERFORMANCE OF A DIESEL ENGINE USING SUDANESE PEANUT OIL AS A FUEL.

BY

Sabir Mohd. Salih & Hassan Elobaid Hassan.

Mechanical Engineering Department, Colledge of Engineering, Sudan University of Science and Technology (SUST), Khartoum, Sudan.

ABSTRACT

The world has recently faced fossil fuel depletion and environmental degradation that triggers the research for using alternative modes. Bio-fuels appear to be one of the most reliable and recommended ones. Sudan potentiality of producing bio- fuels is highly promising and can be quite feasible since enough fertile land, water and suitable climate are available. In this paper production of sudanese peanut oil methanol ester was attempted and tested in a 4-stroke diesel engine for performance evaluation and compared with fossil fuel. Using transesterification process at volumetric ratio of 40oil: 12methanol: 1 NaOH, a temperature of 60 ^{0}c and stirring for one hour time, produced a bio-diesel of better properties as an acceptable substitute for conventional diesel fuel. Without any need for engine systems modifications, engine performance was improved and exhaust emissions were highly reduced.

الملخص:

يواجه العالم اليوم مشكلتي تناقص مخزون الوقود الحفري واتساع استخدامه والتدهور البيئي من انبعاث غازات احتراقه التي تساهم في تهديد كوكبنا بالاحتباس الحراري، مما ادى الى توجيه البحوث عالميا نحو الوقود الحيوي كافضل بديل لحل هذه المشكلة مستقبلا.

في هذا البحث استخدم زيت الفول السوداني لانتاج الوقود الحيوي الميثانولي بمساعدة هيدروكسيد الصوديوم، وباستخدام نسبة حجمية 40 زيت : 12 ميثانول : 1 هيدروكسيد صوديوم واجراء خلط مستمر لمدة ساعة في درجة حرارة 60 درجة مئوية، تحقق مستوى افضل لخواص وقود الديزل الحيوي مقارنة بخواص وقود الديزل التقليدي. وباختبار هذا الوقود في محركات ديزل بدون اي تعديل كان مستوى الاداء مشابها لأداء الوقود التقليدي وانبعاث غازات العادم منخفضا مما يؤكد تقليل تلوث البيئة. للسودان امكانية كبيرة من اراضي زراعية، ومياه،

وطاقات طبيعية وبشرية مما يمكنه من انتاج هذا الوقود والتنافس به في السوق العالمي محققا استراتيجية اقتصادية واجتماعية مقدرة.

1-INTRODUCTION

Enormous growth of world population, increased technical development, and standard of living in the industrial nations has led to an intricate situation in the field of energy supply and demand. This is presently accompanied with twin crises of fossil fuel depletion and environmental degradation. Recent increases in petroleum prices, uncertainties of petroleum future availability and climate change due to global warming have been a key political and social issue in most developed countries. As stated by Avinash, K. A.(2006)[2] that improving energy security, decreasing vehicle contributions to air pollution and reducing or even eliminating greenhouse gas (GHG) emissions are primary goals compelling governments to identify and commercialize alternatives to the petroleum fuels. Murphy J D & McCarthy K.(2005)[8] explained that the fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis and various bio-fuel energy resources explored. Bio-diesel is chosen from other alternative energies to secure a future substitute for the conventional fuel due to reduced exhaust emissions as recommended by Barnwal, B.K.& Sharma, M.P.(2004)[4]. Bio-diesel is safe to use, non-flamable, non-toxic, reasonable cetane number possess less knocking tendency also unchanged engine performance with reduced maintenance and long engine life due to bio-diesel lubricity eliminate the inherent variability associated with the use of other additives as suggested by Paul,L. and Steve, H.(1998)[14] .

Esters are usually referred to as bio-diesel. The chemical process is called transesterification whereby, glycerin is separated from fat or vegetable oil-methyl esters (the chemical name for bio-diesel) and glycerin (a valuable byproduct usually sold to be used in soaps and other products). **Different methods** are used to produce bio-diesel such as: Blending, Micro-emulsification, Cracking, suggested by Ramadhas,A.S. Jayaraj,S. &Muraleed H.C. (2003)[3]; Ozonization of vegetable oil, recommended by Nestor U (2005)[12]; Use of Hydrogen to enhance the performance of vegetable oil fuelled C.I.E. suggested by M Senthil, A Ramesh. and B Nagalingam (2002)[10]; Transesterification (known as alcoholysis) is the reaction of fat or oil with an alcohol to form esters and glycerin. A catalyst is used to improve the reaction rate and yield recommended by Nwafor,O.M.I.(2004)[13];

Semi-Refined oil (SRO) was achieved by acidified hot water degumming combined with filteration to five microns. SRO is suitable economically as explained by Kelvin P.M., Shane M. W. & Paul B. M.(2005)[9]; Use of supercritical methanol and CO_2 as co-solvent recommended by Hengwen H.N, Weiliang C.& Jingchang Z.(2005)[6] and Use of ultrasonic technology suggested by Preschern, H. and Engeljehringer, K.(2006)[15] which improved mixing and enhanced chemical activity .

Development of bio-fuel industry would strengthen the domestic, agricultural economy of agricultural based countries like Sudan. It seems more logical to use unemployed labours and unused land recourses for the production of renewable raw materials in general and bio-diesel in particular, in addition to emission reduction of CO, CO_2, SO_2 and NO_x.

This study concentrates on assessing the viability of using alternative fuels in internal combustion engines seeking opportunities in the Sudan for the use of environmentally friendly bio-diesel as a fuel for diesel engines. This will be done through experimental investigations on engines performance, using an optimized better bio-diesel constituents and by analyzing results in Sudan context. Sudan peanut oil selection for bio-diesel is suitable since its production and properties are promising as shown in tables 6[12] and 7[13] (appendix 1). Sudan government declared a strategy towards encouraging bio-agriculture in the country (2008)[7]. Improvement can be achieved by developing agriculture and industry since enough land, water and suitable climate are available.

In this research blends of peanut vegetable oil and conventional diesel fuel were made and tested for properties. Bio-diesel samples were produced using transesterification method simply processing peanut oil, methanol and NaOH with optimization to obtain better properties by using volumetric ratio 40oil : 12meth. : 1 NaOH at a temperature of 60 ^{o}c and stirring for one hour time producing sample "E_4" which has been used for engines tests. The diesel engines used for these tests were of single and multi cylinder type and the research outputs will show the effects of using this sample of fuel on the engines performance and emissions compared with the conventional diesel fuel.

2-EXPERIMENTAL SET UP

2.1. Bio-diesel production and properties tests

(equipments figs. 1 to 10 are listed in appendix 2)

2.1.1 First batch of samples

2.1.1.1 Preparation

(Peanut oil methanol ester Preparation using Transesterification method)

Equipments and material : - Methanol - Isopropyl Alcohol 99% IPA - Pea nut vegetable oil -PH paper for acidity test (9 to 10)to find the amount of NaOH solution suitable for the vegetable oil - Measuring glasses - Gloves and skin protecting cover as recommended by Nestor U.Soriano (2005)[12] . A water bath using a heating furnace and two metallic vessels, one for hot water and the other smaller for the oil to be heated , a stirrer, hydrometer and a thermometer. Transesterification method was used as presented in fig.11 follows.

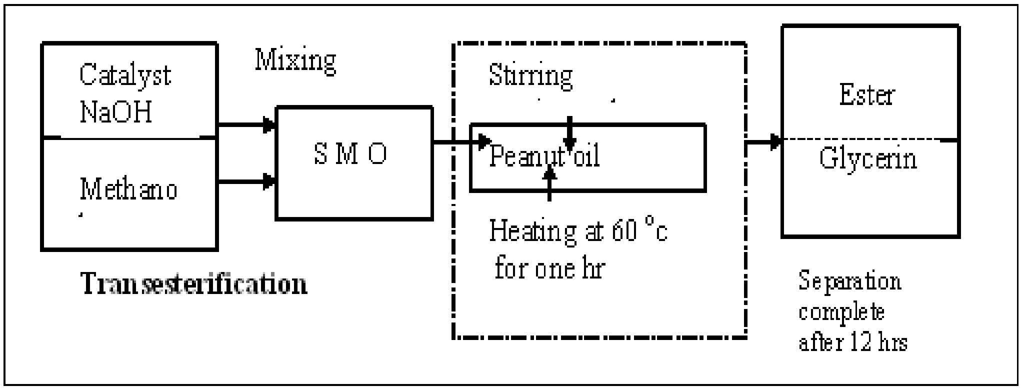

Fig.11: Flow diagram of peanut ester production process

Two types of liquids of different densities and colours are shown in fig.13. Separation can be done easily and ratio of ester to glycerine was found about 90%. Relative density of the ester has to be tested , using the hydrometer , to check if it is on the range of 0.85–0.90 , the ester is valid as bio-diesel. Bio-diesel (Ester denoted by sample"E") will be tested for fuel properties as on the following. Then preparing different samples by blending with diesel fuel and properties tested as follows :

Samples prepared for tests:(mix by volume) shown in fig.12.

Sample " S_1 " : 100% pea nut oil & 0.0% diesel fuel.

Sample " S_2 " : 75% S_1 & 25% diesel fuel .

Sample " S_3 " : 50% S_1& 50% diesel fuel.
Sample."S_4" : 0.0% S_1 & 100% diesel fuel.
Sample "S_5" :first sample of bio-diesel E".
Sample " S_6 " : 75% S_5& 25% S_4 .
Sample " S_7 " : 50% S_5& 50% S_4 .
Sample " S_8 " : 25% S_5& 75% S_4 .

Fig.12. Blends samples .

2.1.1.2 Properties tables: are shown in appendix 1.

Table 1. shows the blends samples (fig.12) properties.

2.1. 2 Second batch of samples

2.1.2.1 Preparation: It was prepared similarly as in the first batch but using a new made processor, and changing ratios (also temperature and time) to obtain different samples of better performance, as shown in fig.13 below and table 2. is shown in appendix1.

Notice : SMO for sodium methoxide, Oil for pea nut vegetable oil, Meth. for methanol, A for fossil fuel, E for ester produced as bio-diesel, S_5 for first batch sample, E_4 for second batch sample.

Separation between ester (bio-diesel) in the upper part of the glass and glycerin in the lower part is seen of different colours(fig.13).

Fig. 13 Bio-diesel samples.

2.1.2.2 Properties tables: are shown in appendix 1.

Table 3. shows the properties of the bio-diesel samples (fig.13) . E_4 was selected as the best optimized sample to be used for the engine test in section 2.2 .

2.1.2.3 Standardization tables: are shown in appendix 1.

Table 4. shows bio-diesel fuel standard.

Table 5. shows diesel fuel standard.

2.1.3 Tables of Sudan bio-diesel potential: are shown in appendix 1.

Table 6[12]. shows Sudan vegetable oil productivity and properties.

Table 7[13]. shows Sudan pea nut seeds production.

2.1.4 Graphical presentation of properties results: *Fuel samples properties*

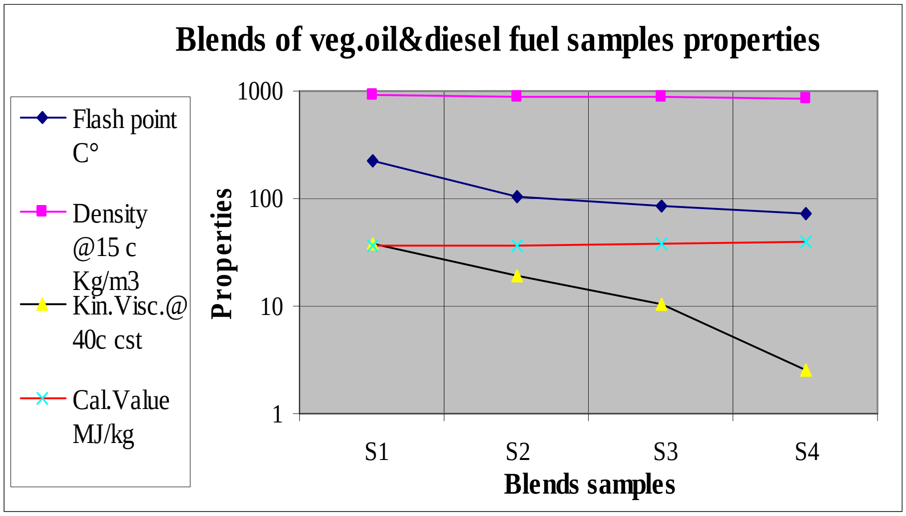

Fig.14 Properties against blends of vegetable oil and diesel fuel samples.

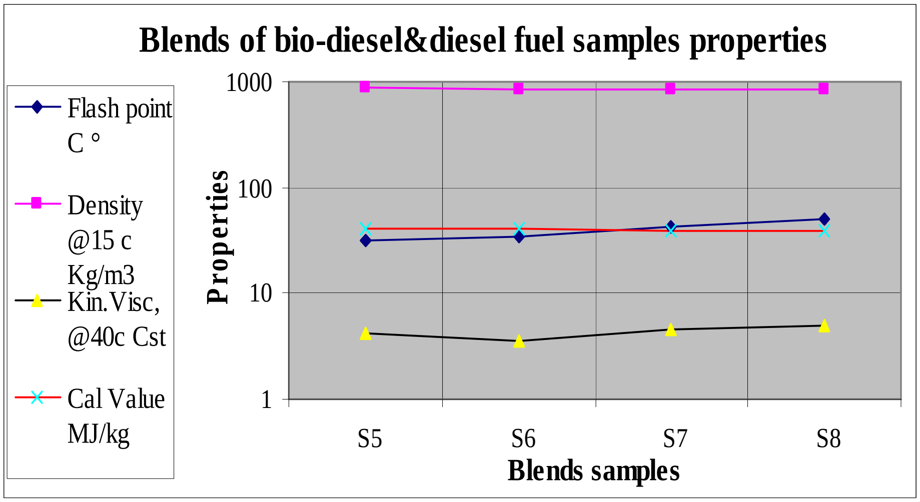

Fig.15 Properties against blends of bio-diesel and diesel fuel samples.

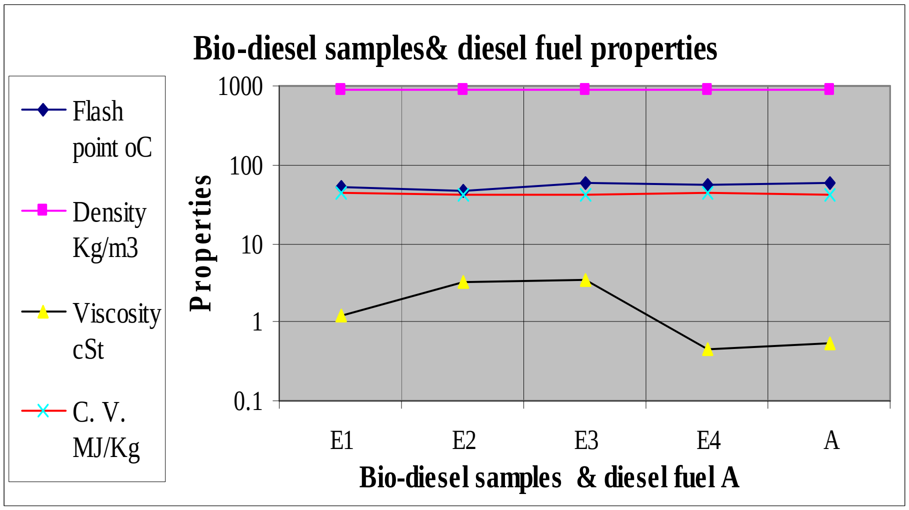

Fig.16 Properties against bio-diesel and diesel fuel samples(no blending).

2.2. Engines test set-up : *(Engines performance and emission tests)*

(Mech. Eng. Dept., Thermal Laboratory, SUST).

The experimental program was carried out using the engines shown in the following schematic diagrams figs. (17 and 18).

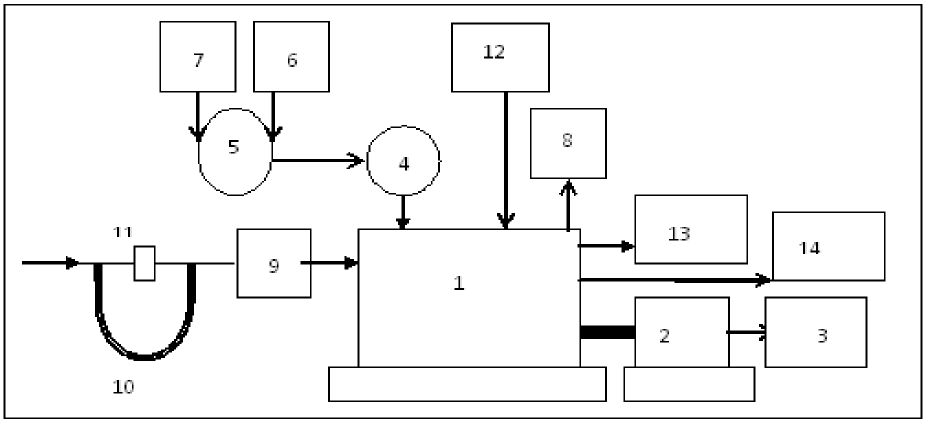

Fig.17 Schematic layout of the test system(single cyl. 4-stroke diesel engine) .

1 –Engine(Ruston). 2 –Dynamometer (mass loading). 3 – Torque display unit. 4 –Fuel flow meter. 5 –Control valve for fuel selection. 6 –Diesel fuel tank. 7 – Bio-diesel fuel tank. 9 –Air box. 10- Air flow pressure difference manometer. 8 –Indicated cylinder pressure by Planometer plots as p-v diagrams.11- Orifice plate. 13 - Exhaust gases digital analyzer(Eline 6000 –Serial 106036)is shown in figs.9&10 in appendix2. 12- Engine cooling tower.14-Speedo-meter.

Engine specifications : Fig.17

Makers: Ruston and Hornsby ltd, England.Type: Iy, class H.R. single cylinder, 4 stroke horizontal diesel engine. Rated output: 7.457 kw , Speed: 475 r.p.m, Compression ratio: 18 : 1, Bore: 14.2875 cm, Stroke: 26.67 cm , Starting: manually, Flywheel diameter: 108.458 cm.

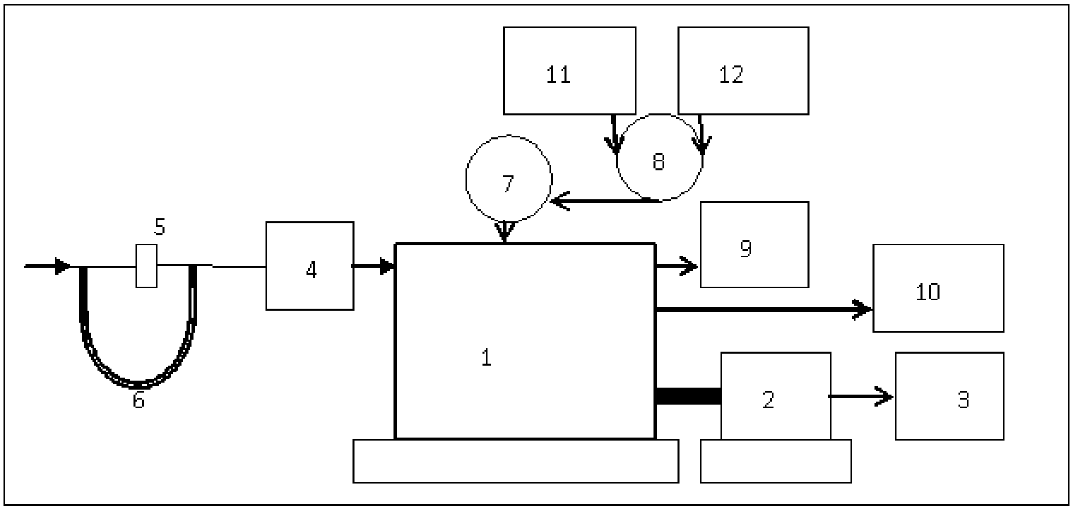

Fig.18 Schematic layout of the test system (4-cyl. 4-stroke diesel engine)

1 – Engine. 2 –Dynamometer (water loading). 3 – Torque display unit. (HPA-Test) 4 – Air box . 5 –Orifice plate. 6 – Air flow pressure difference manometer. 7 – Fuel flow meter with the aid of a stop watch. 8– Control valve for fuel selection. 9 – Exhaust gases

digital analyzer (Eline 6000 –Serial 106036).10 - Speedo-meter. (HPA -Test). 11- Diesel fuel tank. 12- Bio-diesel fuel tank.

Engine specifications: (Fig.18) Mitsubishi 2LT diesel engine, 4-stroke, 4-cylinder inline .Engine capacity 2.4 liter. Cylinder bore 92 mm. Stroke 90.1 mm. Speed, idle 750, max. 4800rpm. Compression ratio17:1.

Tests Procedure

Each engine was directly coupled to the dynamometer equipped with a load controller. The intake engine airflow rate was measured by a sharp edged orifice and a manometer mounted on the side of an air box, connected to the engine inlet. Two fuel tanks and two-way hand operated control valve to allow rapid switching between the standard conventional fuel and the test fuel connected via a fuel meter are used. A volumetric fuel flow meter was used with a stop watch to determine the engine fuel consumption. A probe as a sensor of the gas analyzer was mounted centrally at the end of the engine exhaust pipe to measure the exhaust gases such as CO, NO, NO_2, NO_x, SO_2, and T_{air} & $T_{sens.}$. All the equipments were calibrated in accordance to the respective manufacturer’s specifications, prior to conducting the tests.

Each engine was run at different loads and corresponding speeds, using different types of fuels prepared and specified in section 2.1. Readings were taken for speeds, fuel consumption,air flow rate, exhaust gases (CO, NO, NO_2, NO_x, SO_2), T_{air} and T_{sens}. Then after calculations of power, efficiency, specific fuel consumption and other performance parameters, tables (8 to 15) of results are prepared and shown in appendix 1 and then presented graphically for discussion in section 2.2.3 in figs 19 to 22. Considering each engine as a case and consequently two cases will be explained.

2.2.1 CASE ONE: Using the engine of Fig. 17 (*Single cyl. 4-troke diesel Ruston engine*) and the fuel samples (2.1.1.1 First batch of samples) prepared in section 2.1.1. In this case bio-diesel sample (Ester S_5), denoted by letter "B" and the conventional diesel sample, denoted by letter "A".

2.2.1.1 Readings of variable loading torques for different samples of fuels, and calculations of final performance parameters were done such (consumption), I.S.F.C(indicated specific fuel consumption), (indicated thermal efficiency),(brake thermal efficiency) and (mechanical efficiency), for different loads & speeds, and for the two types of fuels (A & B), as presented on the following section as tables of results .

2.2.1.2 Results: Tables of results are presented in appendix 1.

Engine performance, results are shown on tables 8 and 9. Exhaust gases tests using the digital analyzer (Eline 6000 –Serial 106036) fig. 9 & 10 (appendix 2), for the two types of fuels, readings and results are shown on tables 10 and 11 .

2.2.2 CASE TWO: Using the engine of Fig. 8 (*Four cyl. 4-stroke diesel engine*) and the fuel samples (2.1.1.2 Second batch of samples: (E_1, E_2, E_3, and E_4,) prepared in section 2.1.1. In this case bio-diesel sample (Ester E_4), denoted by letter "B" and the conventional diesel sample, denoted by letter "A". Most of the measuring equipments were used as in case one with similar procedure.

2.2.2.1 Readings of variable loading torques for different samples of fuels, and calculations of final performance parameters were done such as A/F (air/fuel) ratio, B.S.F.C (brake specific fuel consumption), (brake thermal efficiency) for different loads & speeds, and for the two types of fuels (A & B), as presented on the following section as tables of results after calculation of final parameters.

2.2.2.2 Results: Tables of results are presented in appendix 1.

Engine performance, results are shown on tables 12 and 13.Exhaust gases tests using the digital analyzer (Eline 6000 –Serial 106036) fig.9& 10 (appendix 2), for the two types of fuels, readings and results are shown on tables 14 and 15 .

2.2.3 Graphical presentation of results:

Case 1 results (*Single cylinder, 4-stroke, diesel engine*)

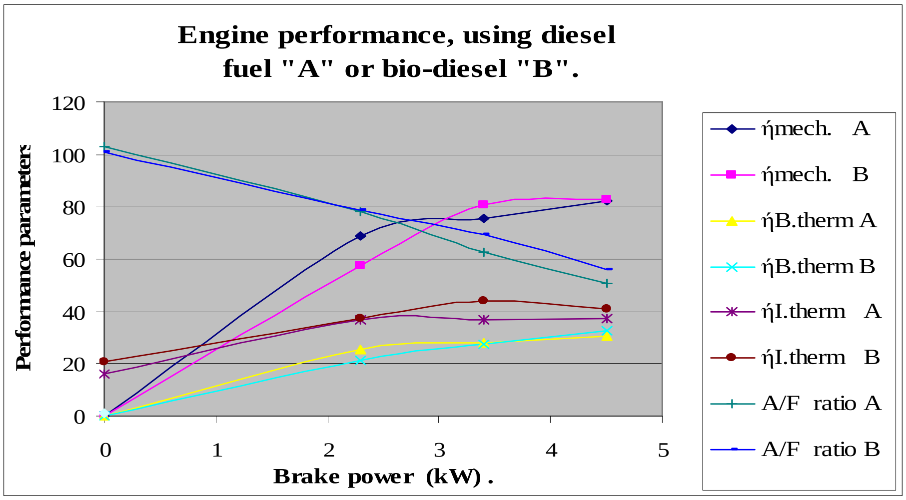

Fig.19 Performance parameters against brake power for case 1.

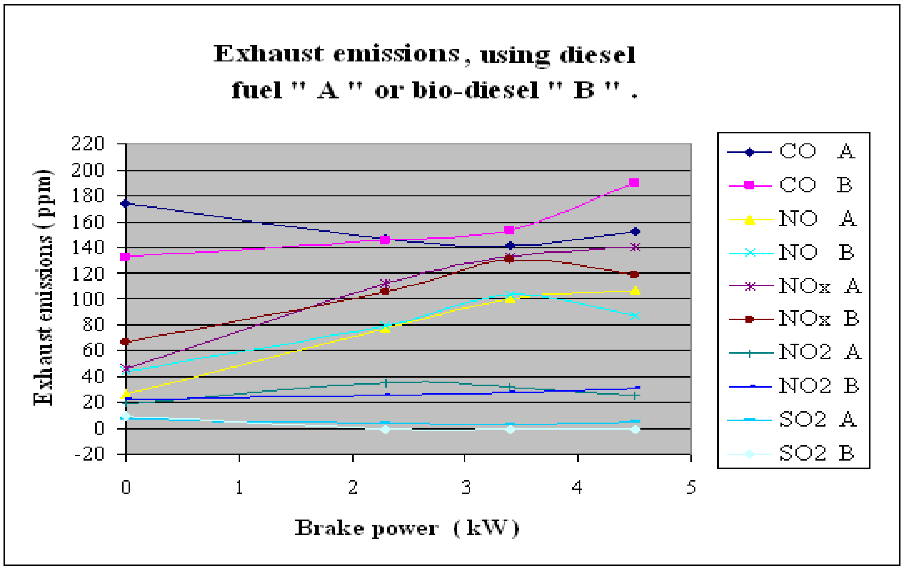

Fig.20 Exhaust emissions against brake power for case 1.

Case 2 results (*4- cylinder* , *4-stroke* , *diesel engine*)

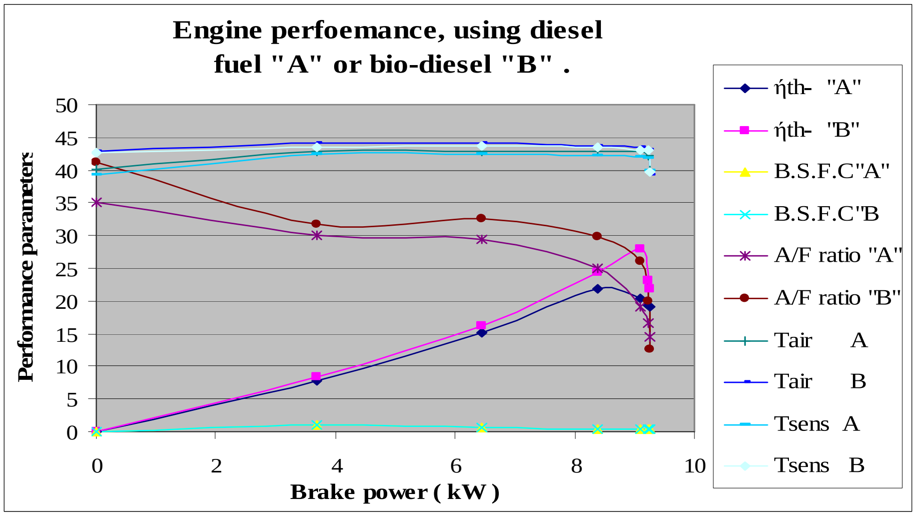

Fig.21 Performance parameters against brake power for case 2.

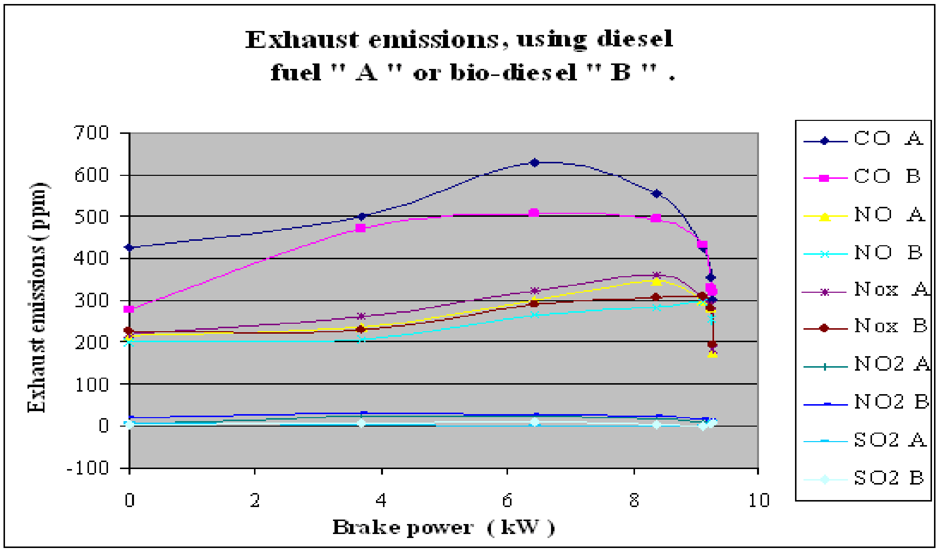

Fig.22 Exhaust emissions against brake power for case 2.

3-DISCUSSION

3.1 Bio-diesel properties

Fig.14 shows blends of vegetable oil with diesel fuel when increasing the portion of diesel fuel to make samples S_1, S_2, S_3 and S_4 .This affects the properties as follows : ***density*** decreases (917 to 860 kg/m^3) very slightly but ***viscosity*** decreases (38 to 2.5 cst) very significantly, which helps the fuel system operation . ***Flash point*** is reduced from high value of the vegetable oil (290 to 92 ^{o}c) to the lower value of the diesel fuel, which helps for controlling ignition timing. ***Heating value*** is affected very slightly (38 to 42 MJ/kg) and insignificantly. Blending could make properties of the vegetable oil closer to those of diesel fuel but there are some practical problems. National Bio-diesel Board(2006)[11] noted that some fuel system components were affected of released deposits accumulated on tank walls, pipes, nozzles and fuel filters clogs, in addition to bad cold engine starting .

Fig. 15 shows the first sample of bio-diesel (S_5) was made in this research and then blended with diesel fuel (S_4) by different ratios, to see the properties as follows: bio-diesel properties are almost very close to those of diesel fuel so no benefit of blending at all. This was confirmed by Raheman H. and Ghadge S.V. (2008)[16], when using different blends from B20 to B100 at variable settings of C.R and ignition timing would not affect the engine performance. But Agarwal A K (2004)[1] recommended B-20 as an optimum blend for long term engine operation.

Fig.16 shows the second batch of bio-diesel samples made of different constituents to obtain E_1 , E_2 , E_3 , E_4 and compared with diesel fuel 'A' to see the properties as follows: ***density* , *flash point*** and ***heating value*** have no significant change but ***viscosity*** is highly affected and that of sample E_4 is very close to that of 'A'. It is seen that sample E_4 is of optimum condition with the volumetric (40oil: 12meth. : 1NaOH) ratios given on table 3. Consequently sample E_4 is selected for engine tests. Ventura, L.M.(1981)[20] explained that Molar ratio 6 : 1 makes production higher % of ester of about 93 to 98 % ,with reaction time (1 or 2 hrs), reaction temperature (60 to 70 ^{0}C) the boiling point of methanol and the catalyst (1%). This research modified this data to volumetrically 40oil: 12meth. : 1 NaOH in one hour time producing sample E_4 of optimum properties. It is also seen that insignificance of increasing time, temperature or catalyst for bio-diesel processing. Using pure bio-diesel as a substitute for conventional diesel fuel is better than using blends for the reasons discussed before.

Standardization:

Fuel properties shown in this research concerning diesel and bio-diesel are within the international standard values according to Fuel Quality Standards Act 2000, the Fuel Quality Standards Regulations 2001 and the Fuel Standard (Bio-diesel) Determination 2003 and amendment 2007 which are summarized as environmental and operability standards consolidated in the tables 4 and 5 (shown in appendix 1). Australia (2007)[5].

Feasibility in Sudan:

In addition to future increasing demand with limited supply of crude petroleum, maximizing scale economics by developing agricultural and industrial plants capacity will affect bio-diesel feasibility. Sudan has about $200*10^6$ feddans of uncultivated land (25% of total available land) and $37.5*10^9$ m^3/year of water. Local peanut oil production and properties (shown on tables 6[18] & 7[19]) are promising for bio-diesel industry satisfaction. Improvement can be achieved since enough land, water and suitable climate are available. Using modern economic process optimizing pea nut methanol ester constituents using free energy for heating and mixing, produced naturally by burning pea nut disposed matter in the farm. Also adding credit value from crude glycerol as byproduct is about 10 % and its composition depends on the transesterification process parameters as stated by Robert N. H. (2007)[17]. If the valuable components vegetable oil, methanol, and the catalyst are produced cheaply with respect to conventional fuels, economics will be very much enhanced. It is also possible to have economical and ecological systems of energy supply, by means of fossil fuels taken from surrounding environment. Sudan can participate in export of bio-fuel as well as U.S.A and Brazil particularly for European Union market in the future. This is expected not to cause any shortage of edible oils or food as reported by *foodfirst.org/pubs/backgrdrs,* (1998)[21].

3.2 Engine performance:

Fig.19 case 1 (single cylinder engine) and **Fig.21** case 2 (4-cylinder engine) show performance parameters variation with respect to brake power output, when using bio-diesel 'B' or conventional diesel fuel 'A' as follows:

Brake thermal efficiency**:** increases with increasing brake power for both 'A' and 'B', but at high brake power values (4.5 kW) the thermal efficiency is higher for 'B' (30%) than 'A' (25%) . This is almost the same for single or 4-cylinder engines but the only difference is that, in the case of 4-cylinder, the efficiency drops sharply at higher values of brake power (9 kW). This indicates successful ignition and combustion improvement.

Indicated thermal efficiency**:** also increases with increasing brake power and of higher values for 'B' (45%) than for 'A'(36%) at about 4 kW power. This indicates bio-diesel fuel has better mixing property with air and compressibility which leads to better combustion.

Mechanical efficiency**:** significantly increases with power and for 'B'(83%) of higher values than for 'A'(75%) at 4 kW power. This indicates lower frictional losses due to efficient lubricity, timing, delay period and combustion without knocking and smooth engine running. This is mainly due to high cetane number of bio-diesel which causes shorter ignition delay and longer combustion duration which also results in lower particulate emissions and carbon deposits on injector nozzles.

***Air/Fuel ratio*:** decreases with increasing brake power and of higher values for 'B' than for 'A' significantly at high powers (2.5 to 4.5 kW for single cylinder but for 4-cylinder engine 4 to 8.4 kW). This indicates much air is consumed with bio-diesel, makes use of oxygen available for better combustion consequently high power with reduced unburned exhaust products.

B.S.F.C. **:** increases very slightly with power and for 'B' is lower than for 'A' . This indicates that enough amount of fuel reacts sufficiently with oxygen which produces high power with less fuel. This of course enhances the economics by using bio-diesel.

***Temperature*:** for exhaust and air are almost the same and slightly vary with power on the range of 38 to 43°c. This indicates high utilization of energy or high effectiveness of the system.

3.3 Exhaust emissions:

Fig. 20 case 1 (single cylinder engine) and **Fig. 22** case 2 (4-cylinder engine) show emission parameters variation with respect to brake power output, when using bio-diesel 'B' or conventional diesel fuel 'A' as follows :

***CO*:** increases with power and for 'B' (300 to 500 ppm) is lower than for 'A'(450 to 650 ppm) specially for 4-cylinder engine but for single cylinder engine in a lower range(140 to 200 ppm).

***NO*:** also increases with power and of lower values for 'B' than for 'A' significantly in 4-cylinder engine in the range of 200 to 350 ppm.

NO_x: similar behavior as NO but slightly higher on range values and no significant difference between single and 4-cylinder engine.

NO_2: also similar behavior as NO and NO_x but of much lower values on the range between 20 to 50 ppm.

SO_2:decreases very slightly with increasing power and of very low values(about 2 to10 ppm).

It is so clear that the exhaust emissions (CO, NO, NO_x, NO_2 and SO_2) are of lower values when using bio-diesel compared with those produced when using conventional diesel fuel, which indicates better combustion and consequently reduced environmental impact.

4-CONCLUSION

In this study, the effect of Sudanese pea nut methanol ester as an alternative fuel on diesel engine performance and exhaust emissions are investigated experimentally. Based on the experimental results of this study, it can be concluded that bio-diesel samples have been produced using transesterification method processing peanut oil, methanol and NaOH showed better properties by using volumetric ratio 40oil: 12meth.: 1 NaOH at a temperature of 60 ^{0}c and stirring for one hour time. Engine performance is seen better for bio-diesel compared with conventional diesel fuel irrespective of cylinder number and without modification in any of the engine systems. More over, engine lifetime is expected to be increased as a result of the extra lubricity and smooth operation. Diesel fuel blend with vegetable oil or with bio-diesel shows significant drawback due to the presence of some negative ingredients' characteristics. Lower exhaust emissions are noticed when using bio-diesel compared with conventional diesel fuel, which confirm that bio-diesel is a better recommended alternative fuel. This result shows a practical solution to the worlds' problem of fossil fuel depletion and environmental degradation. Sudan potential of bio-diesel production is highly promising and can be made feasible since enough land, water, other sources of cheap energies and suitable climate are available, which can make Sudan to be on the top of the world market in producing bio-fuels and food satisfactorily.

5-RECOMMENDATIONS

In order to produce a highly reliable pea nut oil methanol ester as a bio-diesel fuel with optimum properties that reduces exhaust emissions, the research recommends,

- Use a computer to control the amount of water (reduce it to the minimum) in the catalyst mixture and alcohol ratio to the vegetable oil in order to maximize the portion of bio-diesel up to 99% in the product .
- Increase the process of mixing time, temperature, and stirring process for homeginity and easy separation.

- Place the plant of bio-diesel production in the farm of peanut seeds, while considering the utilization of other types of free energy available.

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APPENDICES

Appendix 1 *Tables*

Fuel properties tables:

2.1.1 First batch of samples: Properties tables:

Table 1. Results of samples S_1, S_2, S_3,S_4, S_5, S_6, S_7, and S_8 .

Test	Units	Test method	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Flash point	°C	ASTMD93	224	104	85	73	31	34	43	50
Fire point	°C	ASTMD97	290	155	106	92	55	49	54	60
Density @15 c	Kg/m^3	ASTMD1298	917	898	876	860	866	859	848	841
Kin.Viscosity@40c	cst	ASTMD445	38	19	10.4	2.50	4.20	3.50	4.50	5
Kin.Viscosity@100c	cst	ASTMD445	6	2.50	3	1	1.5	1	1.5	1
Calorific Value	MJ/kg	ASTMD240	36.2	36.9	37.7	40.1	41.4	40.7	39.4	38.6

2.1. 2 Second batch of samples:

Table 2. Bio-diesel samples made of different ratios :

Sample code	Oil : SMO Mix. ratio	oil :	meth :	NaOH
E_1	3:01	9	2	1
E_2	3:01	8	2	1
E_3	6:01	16	2	1
E_4	3:01	40	12	1

Notice : SMO for sodium methoxide, Oil for pea nut vegetable oil, Meth. for methanol, A for fossil fuel, E fo ester produced as bio-diesel, S_5 for first batch sample, E_4 for second batch sample

Table 3. Diesel & Bio-diesel samples properties:

Property	Units	A	E_1	E_2	E_3	E_4
Viscosity	Stoke	5.5	12	31.57	33.38	4.6
Density	Kg/m^3	870	914.8	915.3	916.6	866
Flash point	°C	57	51	47	57	55
Water cont.	+ve or-ve	0.05	+ve	+ve	+ve	-ve
C. V.	MJ/Kg	42.112	42.660	42.550	42.529	44.104
Ash cont.	% W	0.01	0.001	o.006	0.002	-ve
Sulphur	% W	1.00	0.110	0.1344	0.1664	-ve

E_4 was selected as the best optimized sample to be used for the engine test explained in section 2.2.

Standardization tables:

Table 4. Fuel Standard (Bio-diesel) Determination 2003

Parameter	Standard	Test Method
Sulfur	50 mg/kg (max), 10 mg/kg (max)	ASTM D5453
Density	860 to 890 kg/m 3	ASTM D1298 or EN ISO 3675
Distillation T90	360C (max)	ASTM D1160
Sulfated ash	0.020% mass (max)	ASTM D874
Viscosity	3.5 to 5.0 mm 2 /s @ 40°C	ASTM D445
Flashpoint	120.0°C (min)	ASTM D93
Carbon residue : (10% distillation residue) (100% distillation sample)	0.30 % mass (max) OR 0.050 % mass (max)	EN ISO 10370 ASTM D4530
Water and sediment	0.050 % vol (max)	ASTM D2709
Acid value	0.80 mg KOH/g (max)	ASTM D664
Cetane number	51.0 (min)	EN ISO 5165 , ASTM D613 ASTM D6890 , IP 498/03

Table 5. Fuel Standard (Diesel) Determination (as amended)

Parameter	Standard	Test Method
Sulfur	500 ppm (max) , 50 ppm (max) , 10ppm (max) .	ASTM D5453
Cetane Index	46 (min) index	ASTM D4737
Density	820(min) to 860 (max)kg/m3 , 820 (min) to 850 (max) kg/m3	ASTM D4052
Distillation T95	370°C (max) , 360°C (max)	ASTM D86
Viscosity	2.0 to 4.5 cSt @ 40°C	ASTM D445
Carbon Residue (10% distillation residue)	0.2 mass % max	ASTM D4530
Water and sediment	0.05 vol % max	ASTM D2709
Flash point	61.5°C min	ASTM D93
Filter block. tendency	2.0 max	IP 387
Lubricity	0.460 mm(max)(all diesel containing less than 500ppm sulfur)	IP 450

Tables of Sudan bio-diesel potential:

Table 6[18] Sudan oil productivity and properties:

Veg.oils	Peanut	sesame	sun flower	cotton seeds
productivity	60 %	20 %	10 %	10 %
Heating value (MJ/kg)	39.8	39.3	39.6	39.5
Cetane number	41.8	40.2	37.1	41.8
Density (kg/l)	0.90	0.91	0.92	0.91
Flash point (^{o}c)	271	260	274	234

Table 7[19] Sudan peanut seeds production :

/ Year	2000/2001	2005/2006	2006/2007	2007/2008
Used area 10^3 Feddan	3971	1615	1932	3260
Production 10^3 met.tons.	939	555	564	716
Productivity kg/Feddan	287	389	393	315

Engines tests Results tables:

2.2.1 CASE ONE: in single cylinder engine.

Table 8. Engine performance when using diesel fuel (A), C.V. = 40.112 MJ/kg.

Loads W lbs	N r.p.m	m_{air} kg/s	m_f*10^{-4} kg/s	A/F atio	$m_{f/hr}$ kg/hr	I.S.F.C $m_{f/hr}$/ I.P.	B.S.F.C $m_{f/hr}$ / B.P	I.P. kW	B.P. kW	$ή_{I.therm.}$ %	$ή_{B.therm.}$%	$ή_{mech.}$ %
0.0	475	0.0186	1.799	103.4	0.648	0.555	------	1.16	0.0	16.2	0.0	0.0
20	470	0.0192	2.337	82.2	0.841	0.243	0.354	3.46	2.37	36.9	25.3	68.6
30	460	0.0197	3.141	62.7	1.131	0.245	0.324	4.62	3.48	36.7	27.7	75.5
40	450	0.0199	3.701	53.8	1.332	0.241	0.293	5.53	4.54	37.3	30.6	82.2

Table 9. Engine performance when using bio-diesel fuel (B), C.V. = 41.474 MJ/kg.

Loads W lbs	N r.p.m	m_{air} kg/s	m_f*10^{-4} kg/s	A/F ratio	$m_{f/hr}$ kg/hr	I.S.F.C $m_{f/hr}$ / I.P.	B.S.F.C $m_{f/hr}$ / B.P.	I.P. kW	B.P. kW	$ή_{I.therm.}$%	$ή_{B.them}$ %	$ή_{mech.}$ %
0.0	475	0.020	1.980	101.0	0.713	0.417	-----	1.71	0.00	20.8	0.00	0.00
20	465	0.021	2.673	78.6	0.962	0.234	0.284	4.11	2.35	37.1	21.2	57.2
30	457	0.021	3.023	69.5	1.088	0.197	0.314	5.53	3.46	44.1	27.6	62.6
40	445	0.022	3.945	55.8	1.420	0.262	0.316	5.42	4.50	19.8	27.5	83.0

Table 10. Engine exhaust emissions when using diesel fuel (A)

	Units	1	2	3	4
Torque	Nm	0.0	20	30	40
Speed	r.p.m	475	470	460	450
Fuel cons.	ml / sec	0.209	0.272	0.365	0.43
Air flow	mm H_2O	4.2	4.5	4.8	5.4
CO	ppm	174	147	141	152
NO	ppm	27	77	100	118
NO_x	ppm	46	112	132	143
NO_2	ppm	19	35	32	25
SO_2	ppm	7	4	3	5
T_{air}	0 c	35.6	37.6	38.2	38.4
T_{senser}	0 c	35.4	36.8	37.2	37.5

Table 11. Engine exhaust emissions when using bio-diesel fuel (B)

	Units	1	2	3	4
Torque	Nm	0.0	20	30	40
Speed	r.p.m	475	465	460	450
Fuel cons.	ml / sec	0.229	0.309	0.349	0.456
Air flow	mm H_2O	5	5.5	5.6	6
CO	ppm	132	156	173	236
NO	ppm	44	80	103	87
NO_x	ppm	66	105	130	118
NO_2	ppm	22	25	28	31
SO_2	ppm	9	0	0	0
T_{air}	0 c	38.3	38.4	38.3	38.3
T_{senser}	0 c	37.7	30	37.9	37.8

2.2.2 CASE TWO: in 4-cylinders engine .

Table12. Engine performance when using diesel fuel (A),ρ=870kg/m^3,C.V.=42.112 MJ/kg

Variables	Units	1	2	3	4	5	6	7
Torque	N,m	0.0	15	30	45	60	75	90
Speed	r.p.m	2500	2450	2200	1950	1550	1250	1045
Fuel cons	ml/s	1.2434	1.356	1.2372	1.1461	1.294	1.383	1.411
Air flow	cm H_2O	1.8	1.6	1.3	0.8	0.6	0.5	0.4
Fuel cons	Kg/s	0.00108	0.00118	0.00108	0.00100	0.00113	0.00120	0.00123
P_b	kW	0	3.85	6.91	9.19	9.74	9.82	9.85
P_{th}	kW	45.48	49.69	45.48	42.11	47.59	50.53	51.80
$\acute{\eta}_{th}$	%	0	7.75	15.19	21.82	20.47	19.43	19.02
B.S.F.C	kg/kWhr	-	1.122	0.573	0.392	0.407	0.45	0.439
T_{air}	0 k	313.2	315.8	315.8	315.8	315.8	315.3	313
Air m_{airA}	Kg/s	0.0377	0.0354	0.0319	0.0250	0.0217	0.0200	0.0178
A/F ratio	ratio	35	30	29.5	25	19.2	16.7	14.5

Table13. Engine performance when using bio-diesel fuel (B), ρ=866kg/m^3,C.V= 44.104 J/kg

Variables	Units	1	2	3	4	5	6	7
Torque	N,m	0.0	15	30	45	60	75	90
Speed	r.p.m	2500	2250	1900	1600	1350	1100	920
Fuel cons	ml/s	1.0474	1.2419	1.218	0.9747	0.8822	1.0314	1.1406
Air flow	cm H_2O	1.8	1.5	1.4	0.8	0.5	0.4	0.2
Fuel cons	Kg/s	0.00091	0.00108	0.00105	0.00084	0.00076	0.00089	0.00099
P_b	kW	0	3.53	5.97	7.54	8.48	8.64	8.67
P_{th}	kW	36.40	42.20	42.00	33.60	30.40	35.60	39.60
$\acute{\eta}_{th}$	%	0	8.36	14.21	22.44	27.89	23.17	21.89
B.S.F.C	kg/kWhr	-	1.122	0.663	0.382	0.34	0.375	0.415
T_{air}	0 c	315.8	317.2	317.1	316.8	316.5	316.1	312.2
Air m_{airB}	Kg/s	0.0375	0.0342	0.0342	0.0250	0.0198	0.0177	0.0126
A/F ratio	ratio	41.2	31.7	32.6	29.8	26.1	19.9	12.7

Table 14. Engine exhaust emissions when using diesel fuel (A)

Variables	Units	1	2	3	4	5	6	7
Torque	N,m	0.0	15	30	45	60	75	90
Speed	r.p.m	2500	2450	2200	1950	1550	1250	1045
CO	Ppm	427	471	630	556	425	356	299
NO	Ppm	217	237	301	344	299	280	173
NO_x	Ppm	219	261	323	360	307	287	183
NO_2	Ppm	2	24	22	16	9	7	6
SO_2	Ppm	5	4	1	0.0	0.0	2	9
T_{air}	0 c	40.2	42.8	42.8	42.8	42.8	42.3	40
T_{sens}	0 c	39.2	42.5	42.4	42.2	42.1	41.9	39.9

Table 15. Engine exhaust emissions when using bio-diesel fuel (B)

Variables	Units	1	2	3	4	5	6	7
Torque	N,m	0.0	15	30	45	60	75	90
Speed	r.p.m	2500	2250	1900	1600	1350	1100	920
CO	Ppm	276	473	476	495	431	330	320
NO	Ppm	200	206	266	284	296	256	183
NO_x	Ppm	225	230	291	305	311	282	192
NO_2	Ppm	19	30	25	21	15	13	9
SO_2	Ppm	2	5	10	2	0.0	3	8
T_{air}	0 c	42.8	44.2	44.1	43.8	43.5	43.1	39.2
T_{sens}	0 c	42.7	43.5	43.6	43.4	43.1	43.1	39.8

Appendix 2 *Equipments*

Fig. 1. Densometer.

Fig. 2. Redwood viscometer

Figs. 3. & 4. Firing & ignition point equipments.

Fig. 5. Water content test equipment.

Fig. 6. Ash content test equipment.

Fig. 7. Sulpher content test equipment.

Fig. 8. Kinematic viscosity test equipment.

Figs. 9.&10. Exhaust gases digital analyzer (Eline 6000 –Serial 106036)