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Study of Biodiesel Fuel Production and Spray Performance

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Abstract: *The present study focuses on biodiesel production using conventional transesterification method. Furthermore, the spray performance of the produced biodiesel is investigated and the obtained results are compared with those of the petroleum diesel.Fresh and waste cooking oil are used as a feedstock for biodiesel production. An apparatus, whichconsists of a reactor, wash tank, and dryer tank is constructed for the production purpose. The produced biodiesel meets the required American Society for Testing and Materials standard for biodiesel ASTM D6751. Thespray performanceof biodiesel and petroleum diesel is carried out using a pressure swirl atomizer with an exit nozzle diameter of 0.4 mm and spin chamber angle of 60º.The properties of biodiesel and its blends such as density and viscosity are studied and the results show that the viscosity and density of biodiesel are greater than those of petroleum diesel by about 18% and 3%, respectively. For blends, by increasing biodiesel percentage in the mixture of biodiesel and petroleum diesel (B number) the viscosity and density are increased.There is a significant difference between biodiesel and petroleum diesel in spray shape, spray cone angle, breakup length and spray concentration at the same operating conditions.From the feasibility study, the cost of one liter of produced biodiesel is cheaper than one liter of petroleum diesel by about 40% (based on Egyptian price 2016) and the capital cost will be redeemed after producing 8521 liters of biodiesel.*

Keywords: *Biodiesel; Waste cookingoil; Transesterification; Spray performance; Feasibility study*

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I. Introduction

The increasing in industrialization and motorization of the world have led to a steep rise in the demand for petroleum-based fuels obtained from limited reserveswhich are facing the danger of dwindling. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally such asvegetable oils.Biodiesel, one of the most common biofuels, is created to match theproperties of petroleum diesel and considered a fuel equivalent to petroleum diesel with the exception of its derivation from biological sources. Although biodiesel can be used in its pure form, it is usually blended with petroleum diesel [1].

There are four different main methods of biodiesel production; supercritical process [1-3], microwave assisted process [4-6], ultrasound assisted process [7-9] and transesterification process which is the most common and conventional method [10-12]. In transesterification reaction, homogeneous catalysts (alkali or acid) or heterogeneous catalysts can be used.The catalysts make production easier and faster.Fatty acid alkyl esters are produced by the reaction of triglycerides with an alcohol such as ethanol or methanol in the presence of alkali, acid or enzyme catalyst. Thesodium hydroxide or potassium hydroxide, which is dissolved in alcohol, is generally used as a catalyst in the transesterification reaction.The products of the reaction are fatty acid methyl esters (biodiesel) and glycerin[13-16].

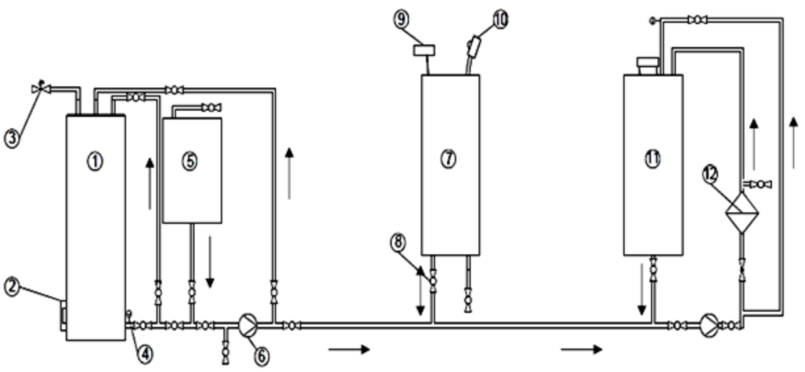
The process of breaking or atomization of the liquid fuel into tiny droplets in the form of a fine spray plays a vital role in various industrial and propulsion applications [17]. The droplets provide a larger surface area than the liquid itself, thus, reducing the liquid vaporization time, which results in better mixing and increase thetime available for complete combustion in liquid-fueled combustion systems [18].The differences in the physical properties of petroleum diesel and biodiesel are expected to significantly alter the inner nozzle flow and spray structure and, thus, the performance and emission characteristics of the engine. Biodiesel cavitated less than petroleum diesel. The higher viscosity of biodiesel resulted in a loss of flow efficiency and reduction in injection velocity [19].

In Egypt, several millions of gallons of waste vegetable oil are produced every year, mainly from industrial deep fat fryers found in potato processing plants, factories manufacturing foods, and restaurants,and this is considered a feedstock for a huge biodiesel production. In the present study the biodiesel is produced from fresh and waste cooking oil by transesterification method. Methanol is used as alcohol and sodium hydroxide as a catalyst. It is also required to determine the properties of the produced fuel and study its spray performance. Therefore, the present work will be extremely helpful for taking rational decision about the development of biodiesel production plant.

The main objectives of the present workare producing biodiesel from fresh and waste cooking oil by transesterification method, characterizing the chemical and physical properties of produced biodiesel (a sample of the produced biodiesel is sent to an external lab for ASTM analysis to ensure the fuel met the necessary quality standards), making a feasibility study for produced biodiesel from waste cooking oil, studying the biodiesel spray performance such as spray shape, spray cone angle, breakup length and concentration and comparing the spray performance for biodiesel and petroleum diesel.

II. Biodiesel Production

Biodiesel production apparatus: In the present study,the biodiesel is produced from cooking oil (Fresh and waste) by transesterification method. Biodiesel fatty acid methyl ester (FAME) is prepared using a fresh and waste cooking oil using methanol as alcohol with a purity of 97% and catalyst (sodium hydroxide) with a concentration of 96%. Thebiodiesel production apparatus consists of four main components;reactor, methoxide tank, wash tank (pre-acid wash tank) and dryer tank. The schematic diagram of the used apparatus is shown in Fig. 1. The apparatus is equipped with necessary controlling devices which facilitate its operation and control different experimental parameters.



1- Isolated reactor. 2- Electrical heater with thermostat. 3- Relief valve. 4- Bimetallic temperature gauge. 5- HDPE methoxide tank. 6- Circulation pump. 7- HDPE pre-acid wash tank. 8- Shutoff valve. 9- Air bubbler. 10- Automatic mechanical water timer. 11- Dryer tank. 12- Microfilter.

Fig. 1 Schematic diagram of biodiesel production apparatus

The reactor: The reactor is made of stainless steel seam welded cylinder with a thickness of 6 mm, an insulation layer of glass wool blanket with a thickness of 50 mm, the sheet rolled on the outer periphery of the reactor (diameter of 500 mm and length of 1000 mm).The reactor is equipped with two galvanized seamless pipes of 16 mm diameter and 200 mm length welded to the reactor outer periphery at the lower section as showed in Fig. 2.The lower pipe is arranged to be suitable for draining the reactor after completion of every reaction process.The reactor bottom is manufactured with a slope of 1:100 to ensure the clearness of the reactor from reaction contaminations.The other pipe is connected to the suction ofa centrifugal pumpof 2850 rpm and 0.5 Hp (model QB60).

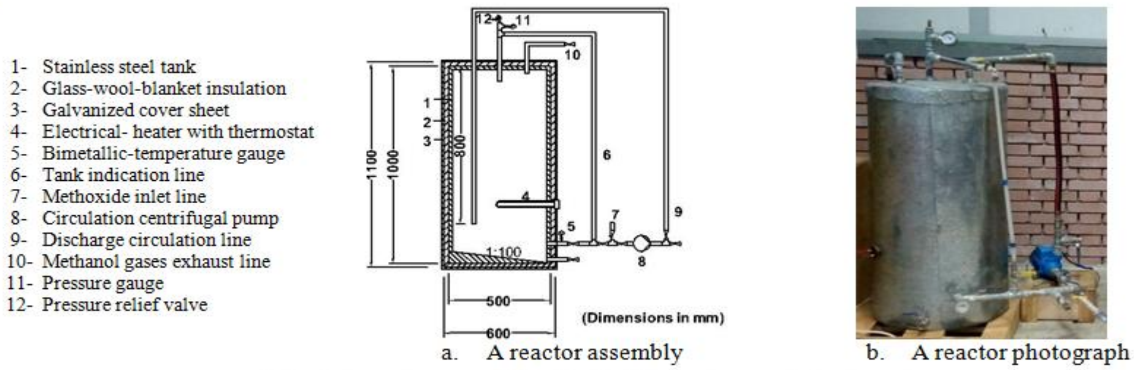


Fig. 2 A reactor assembly, detailed dimensions and photograph

Methoxide tank: The methoxideHigh-Density Polyethylene (HDPE) tank is used to prepare the solution of sodium hydroxide dissolves in methanol alcohol.

Wash tank: The wash tank, shown in Fig. 3, is used for washing the crude biodiesel, i.e. removes residual contamination within the biodiesel fuel, mainly methanol. The wash tank is a cylindrical 6 mmthickness HDPE tank of 500 mm diameter and 1200 mm height.A measured amount of sulfuric acid (99% concentration) is added into wash tank to stop both the reaction between unreacted methanol and the reaction to reverse and then crude biodiesel is transferred from the reactor to wash tank. A reactor centrifugal pump is used for crude biodiesel transformation through a 16 mm galvanized pipe fixed at wash tank bottom, submerged 200 mm inside the tank for washed biodiesel.This pipe is attached to a control valve to be shut off after completing the transfer process of the crude biodiesel.An air bubbler tube of 3 mm diameter is pushed through by means of weight which needed to keep the air bubbler tube end submerged into biodiesel fuel. The air bubbler is turned on to push air inside the biodiesel to generate air paths through the fuel helping methanol to escape to the fuel surface. After approximately 30 minutes, a water source connected to a mechanical water timer that is adjusted to allow the water to flow into sprinklers for 2 hours.

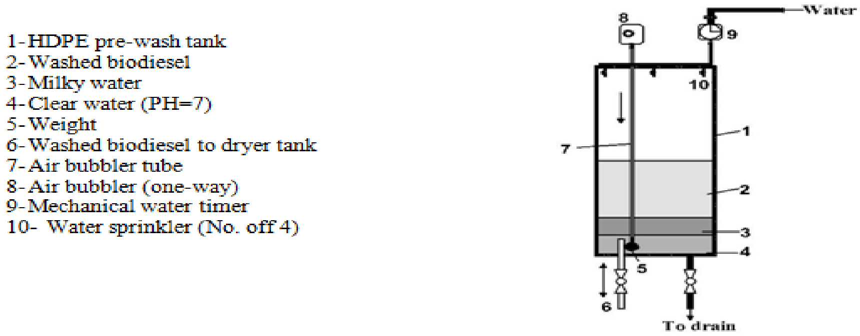


Fig. 3 Wash tank detailed assembly

Dryer tank: The dryer tank, shown in Fig. 4, isa cylindrical HDPE tank of 500 mm diameter, 800 mm height and 6 mm thickness. The dryer tank contains the washed biodiesel coming from the wash tank. A centrifugal circulation pump of 2850 rpm and 0.5 Hp (model QB60) is used to circulate the biodiesel through a 16 mm galvanized pipe and delivered it to microfilter or bypass the biodiesel through a 16 mm galvanized pipe to the atomizer. Microfilter is used to filterbiodiesel from any ashes and solid particles before delivered to the atomizer. Atomizer or sprinkler can be used during heating in the dryer to increase biodiesel surface area exposed to the surrounded air which helps in evaporation of methanol and/or water exists in biodiesel.

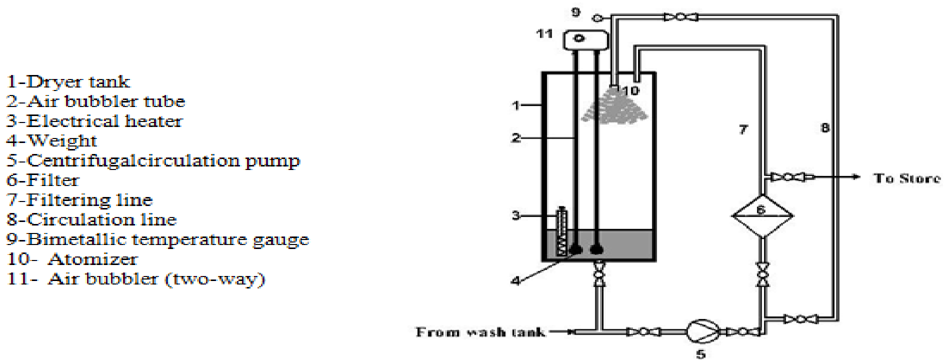


Fig. 4 Dryer tank detailed assembly

Biodiesel production results: The production of biodiesel passes through several stages; the first stage iscollecting the oil (fresh/waste) and filling the reactor with 200 L, then heating the oil by an electrical heater to a fixed temperatureof 100ºC for oil to be homogenous. The second stage is the titration test stage which starts parallel to oil heating.The titration value is the required amount of alkali for oil-free fatty acids to be inequilibrium and is found to be 1.8. The third stage begins with the preparation of methoxide solution (methanol + alkali) which is added to the oil in the reactor with an oil/methanol ratio of 1:0.22 at 54ºC in order to start the reaction process (transesterification)with a reaction timeof three hours. After the reaction process finishes the produced crude biodiesel is ready for starting the fourth stage; wash stage.In this stage water is used for washing crude biodiesel until the PH of water and washed biodiesel becomes 7. The final stage, drying stage, starts in the dryer tank to dry the washed biodiesel from excess methanol and/or water to get the biodiesel fuel. Several lab examinations are carried out before the produced biodiesel samplesare delivered to specialist labs in EGYPT. The first test examines the formation of glycerol as a byproduct (in reactor).The second test is applied on water and biodiesel after washing process to have PH = 7 for both.The third testincludestaking a biodiesel sample mixes with water. It is found that the separation occurs very fast and the water kept very clear which meant that there is no any contamination at produced biodiesel (Fast separation water/B100).Thefourth test examines a taken sample of biodieselwith ten times of methanol added, i.e. biodiesel/methanol(1:10), the result showed that there is no unreacted FFAs and there is no more reaction occurred which explained that all FFAs yielded to biodiesel and the sample is succeeded 100%(Passed sample).The last test is adding 1ml of oil on a passed sample which showed that a reaction happened and a glycerol formed as a byproduct, which indicates that, biodiesel produced has a purity more than 99.99 percent (Failed sample), as shown in Fig. 5.Theproperties of produced biodiesel can be summarized in Table no1.

Fast separation water/B100 Failed sample Passed sample

Fig. 5 Laboratory examination samples

Table no 1: ASTM standard satisfaction for produced biodiesel

Experiment	Method	Result		Standard
		Biodiesel from fresh oil	Biodiesel from waste oil	
Total acid number, mg KOH/gm	ASTM D-664	0.38	0.35	0.80 max
Kinematic viscosity, cst, @ 40°C	ASTM D-445	4.79	6.31	1.9-6.0
Cloud point, °C	ASTM D-2500	12	-3	Report
Flashpoint, °C	ASTM D-93	179	198	130.0 min
BS & W, vol. %	ASTM D-2709	0.05	Nil	0.05 max
Carbon residue, wt. %	ASTM D-189	0.05	Nil	0.05 max
Copper corrosion	ASTM D-130	la	la	No. 3 max
Sulfated ash	ASTM D-874	Nil	Nil	0.020 max
Cetane Index	ASTM D-976	Not Measured	61.2	47 min.
Calorific Value, kJ/kg	ASTM D-240	Not measured	38880	37270 avg.

Properties of biodiesel and blends: Biodiesel blends with petroleum diesel fuel are defined by "Bx", where "x" is the volume percentage of biodiesel in the blends,for example, "B10" indicates a blend with 10% biodiesel and 90% petroleum diesel fuel; in consequence, B100 indicates pure biodiesel. In the present work, several biodiesel blends are obtained. Fig. 6 shows a photograph of some blends such as B10, B30, and B100 beside pure petroleum diesel.

P-D B100 B30 B10

Fig. 6 Biodiesel blends

Viscosityis an important property of biodiesel since it affects the operation of fuel injection.Higher viscosity of fuel leads to poorer atomization of fuel spray and less accurate operation of fuel injector.Fig.7shows the effect of biodiesel blends on viscosity(mPa.s), from this figure, it can be clearly seen that increasing the B number (i.e. increasing the volume percentage of biodiesel in the blends) the viscosity increased. By increasing the B number from B10 to B100, the viscosity increased by about 73%. It is also seen that the viscosity of biodiesel, B100, is higher than that ofpetroleum diesel (P-D) by about 15%. The higher viscosity of biodiesel is due to its higher resistance to shearing force.

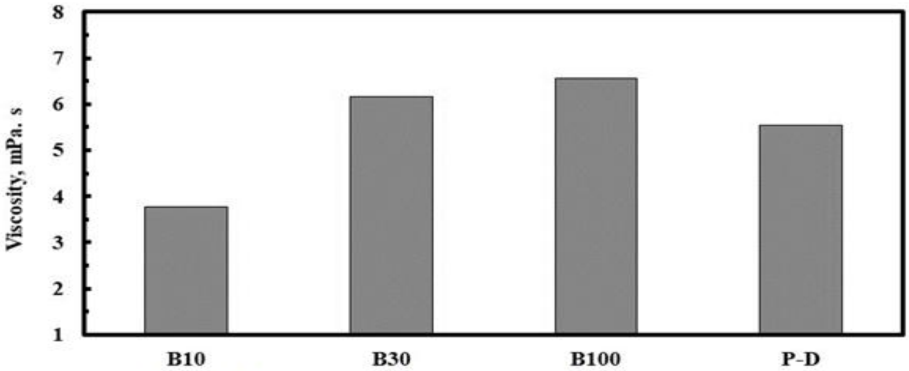


Fig. 7 Viscosity of biodiesel blends and petroleum diesel

Density is another important property of biodiesel since it affects the fluid to resist acceleration, Fig.8shows the effect of biodiesel blends on density. from this figure, it can be clearly seen that increasing the B number the density increased. By increasing the B number from B10 to B100, the density increased by about 6 %. It is also seen that the density of biodiesel, B100, is higher than that of petroleum diesel by about 3%.

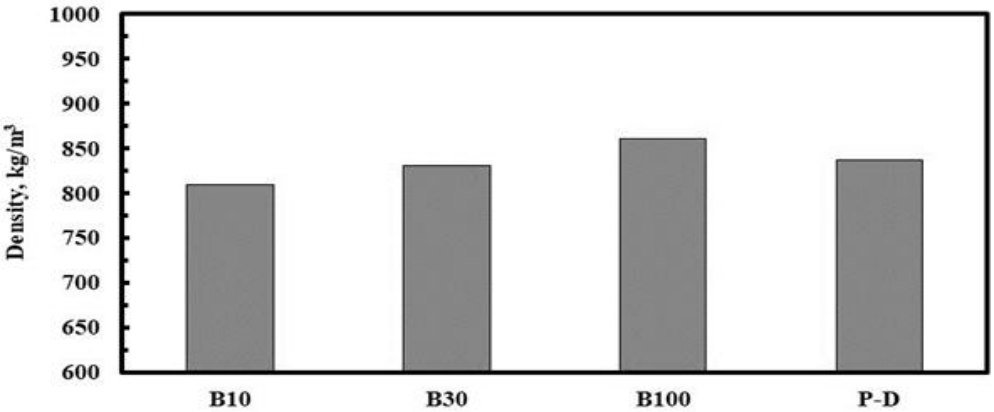
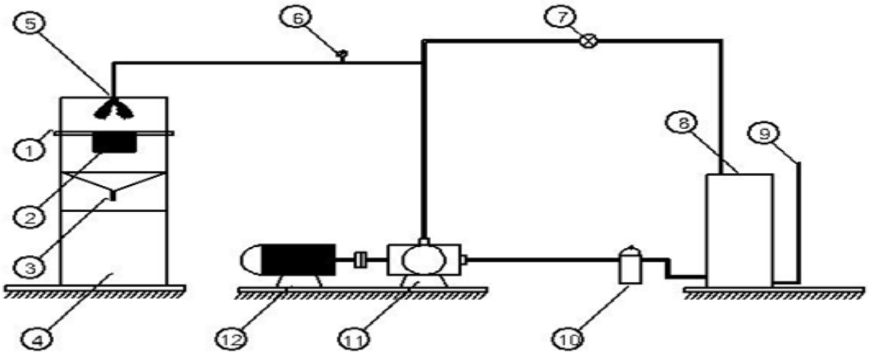


Fig. 8 The density of biodiesel blends and petroleum diesel

Feasibility study: Feasibility studyis an analysis of how successfully a project can be complete, accounting for factors that affect it such as economics, technological, legal and scheduling factors. Project managers use feasibility studies to determine the potential positive and negative outcomes of a project before investing a considerable amount of time and money.Feasibility studies can also lead to the development of marketing strategies that convince investors or a bank that investing in the business is a wise choice. In the present work the feasibility studyincludescapital cost and running cost is carried out. Capital cost includes the costs of thereactor,auxiliary tank,wash tank, and dryer tank with all theircomponents.However, running costs includes the costs of feedstock oil, methanol,sodium hydroxide, sulfuric acid, phenolphthalein, isopropyl alcohol, distilled water,electricity consumed and all other alternative cost.From the feasibility study, the cost of one liter of produced biodiesel is cheaper than one liter of petroleum diesel by about 40% (based on Egyptian price 2016) and the capital cost will be redeemed after producing 8521 liters of biodiesel.

III. Biodiesel Spray Performance

Spray performance test rig: The produced biodiesel spray performance and petroleum diesel fuels are analyzed to study the influence of higher viscosity of the biodiesel on the atomization performance. The influence of biodiesel and petroleum diesel fuels injection pressure on the developed spray cone angle, breakup length and the radial distribution of the fuel concentrations are examined.The development of the spray with the variation of injection pressure is also demonstrated. For satisfying the requirements needed for spray performance study a test rig isdesigned and constructed.The atomization test rig consists of the fuel tank, atomization chamber,atomizer and gear pump.Moreover, control valves and pressure gauges are connected to the fuel system lines. Fig.9 shows the schematic diagram of the atomization test rig where the liquid fuel (biodiesel or petroleum diesel) is fed to the atomizerby a gear pump driven by 0.5 kW electric motor.



1-Spray chamber. 2- Spray patternator. 3- Fuel collector. 4- Fuel collecting tank. 5- Pressure swirl atomizer. 6- Pressure gauge.7- By-pass valve. 8- Fuel tank. 9- Fuel level indicator. 10- Filter. 11- Gear pump. 12- Electrical motor.

Fig. 9 Schematic diagram of the spray performance test rig

Fuel spray chamber and collector: Figure10 shows the spray chamber arrangement (500 mm width, 500 mm depth and 1200 mm height) which is used. At the chamber top, a pressure swirl atomizer consists ofa cup with orifice diameter (dn)of 0.4 mm,spin chamber with inclination angle of 60º and inner guiding tube [20-23] is usedfor sole purpose of performing fuel atomization.At 20 cm from the atomizer exit, apatternator consists of twenty-three contact in-line graduated sampling tubes of equal inner diameters of 10 mm and withvery thin thickness. The patternator centerline is adjusted to be coaxial with the atomizer axis and the spray chamber.At the bottom of the chamber, a collecting fuel tank is used for collecting the sprayed fuel downstream the patternator

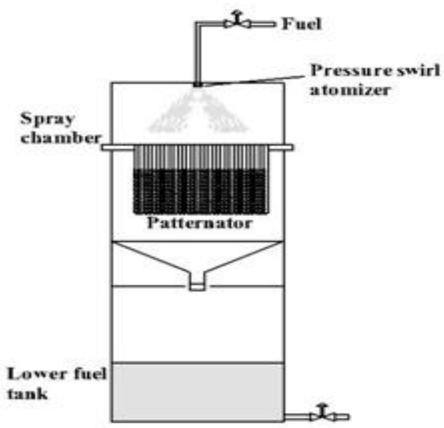


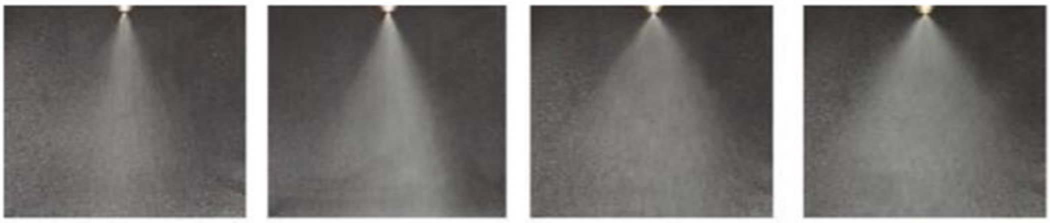
Fig. 10 Spray chamber andpatternator tubes

Spray performance results: The second session of the present work is concerned with the spray performance of the produced biodiesel with a pressure swirl atomizer and compared with petroleum diesel spray performance. The applied pressure is varied from 0.5: 3 bar and the spray performance are detected by a digital camera.In the present work, the fuel sprays are issued from a pressure swirl atomizer in a stagnant air medium. The hollow cone spray structure is affected by physical properties of the injected fuel and injection pressure,therefore, the investigated parameters are, fuel type and fuel injected pressure. The test rig facility permits examination of the effects of all different parameters on spray performance. This performance is determined by measuring spray shape, the developed spray cone angle, spray breakup length and radial distribution of fuel concentration along the axial downstream distances of the test section.

The spray is photographed to show the spray shape and consequently.The spray cone angle and breakup length under the different operating conditions are measured.Fig. 11 and Fig.12 show the spray shapes for the petroleum diesel and biodiesel (B100) fuels under different injection pressure, respectively.Fig. 11 shows that at lower injection pressure the spray pattern of petroleum diesel fuel is weak, i.e. the bulk liquid fuel is not good broken up. The injection pressure is not high enough to fragmentize the fuel for injection pressure = 0.5

bar. However, the injection pressure increases, the petroleum fuel is fragmentized and fine droplets clearly appear in the form of spray. By increasing injection pressure, the spray quality increases due to good breaking up of the petroleum diesel fuel.Fig.12 shows that for biodiesel at lower injection pressure the spray also is very weak. The injection pressure of 0.5 bar is not high enough for fragmentizing the fuel. When higher injection pressure is applied the flow rate through the nozzle orifice thus, results in larger dispersion size and a signification increase of spray coverage. By increasing the injection pressure, the spray quality increases due to good breaking up of the petroleum diesel fuel. Increasing the injection pressure, the projection coverage area of the spray increased resulting in an increase in the spray cone angle as will be shown later.

In comparison between petroleum diesel and biodiesel fuel, there is a relation between the chemical properties of biodiesel fuel and petroleum diesel and spray shapes. Because density for biodiesel is higher than that for petroleum diesel it causes a fluid to resist acceleration. Meanwhile, the relative viscosity for biodiesel is higher than that for petroleum diesel which, causes the fluid to resist agitation, tends to prevent its breakup and leads to large average droplet size which is clearly observed.Hence, biodiesel spray shape coverage area is smaller than that for petroleum diesel at acertain injection pressure. This can be due to the higher density compared to petroleum diesel. Another physical characteristic that affects the spray shape is the viscosity of the liquid fuel. High relative viscosity leads to the poorer atomization of the fuel spray and less accurate operation of fuel injectors.



0.5 bar 1 bar 2 bar 3 bar

Fig. 11 Effect of injection pressure on spray shape for petroleum diesel fuel

The spray cone angle is defined as the angle formed by the cone of liquid leaving a nozzle orifice where two straight lines wrapped with the maximum outer side of the spray. It is well known that the spray cone angle is governed by the relative magnitudes of the axial and swirl components of the injected liquid velocity at the nozzle exit.The effect of changing the injection pressure for petroleum diesel and biodiesel fuels on spray cone angles is investigated. The spray cone angles are obtained from the spray shape which obtained from photographs obtained by the digital camera.Fig. 13 shows the effect of injection pressure on spray cone angle for petroleum diesel and biodiesel (B100) fuels, the results indicate that for petroleum diesel, the spray cone angle is directly proportional to the injection pressure,by increasing the injection pressure from 0.5 to 3 bar, the spray cone angle increased by about 100%.For biodiesel fuel,it is found that by increasing the injection pressure from 0.5 to 1 bar, there is no spray formed, consequently, there is no spray cone angle. At injection pressure greater than 1 bar, the spray starts to be formed. By increasing the injection pressure from 1 to 3 bar, the spray cone angle increased by about 77%.It is clearly shown that, the spray cone angle for petroleum diesel is greater than that for biodiesel at different injection pressures as a result of higher density and relative viscosity for biodiesel than that forpetroleum diesel.

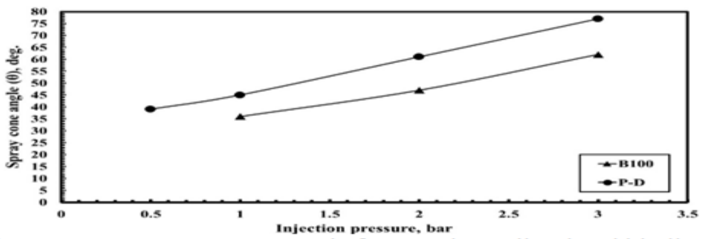


Fig. 13 Effect of injection pressure on spray cone angle for petroleum diesel and biodiesel (B100) fuels

The spray breakup length is defined by the distance from the nozzle tip to the point at which the spray starts to be formed. Spray breakup length is another important factor that affect by the different operating conditions. In the present study, the effect of changing the injection pressure for petroleum diesel and biodiesel fuels on spray breakup length is investigated. The spray breakup lengths are also obtained from the spray shape.Fig. 14 shows the effect of changing the injection pressure on the spray breakup length for the two different fuels (petroleum diesel and biodiesel fuels). For both petroleum diesel and biodiesel fuels, the results show that the spray breakup length is clearly decreased by increasing the injection pressure. It is shown that the rate of decreasing in breakup length for biodiesel is greater than that for the petroleum diesel. By increasing the injection pressure from 0.5 to 3 bar, the breakup length decreased by about 77% for petroleum diesel. However, for biodiesel, by increasing the injection pressure from 1 to 3 bar, the breakup length decreased by about 70%.In general, the breakup length for biodiesel is greater than that for petroleum fuel at the same injection pressure due to the different values of densities and relative viscosities.

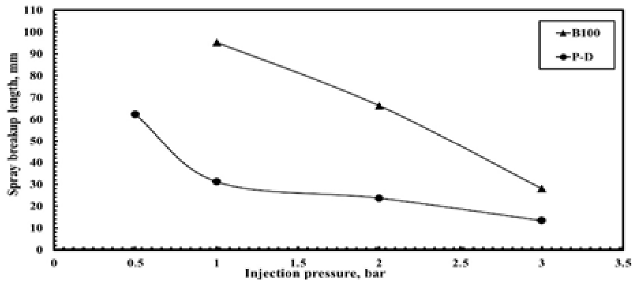


Fig. 14 Effect of injection pressure on breakup length for petroleumdiesel and biodiesel (B100) fuels

Radial distribution of fuel concentrations: One effective method for determining the fuel distribution of the spray is by collecting the fuel spray by spray patternator located at a specified constant vertical level of 20 cm from fuel nozzles exit for all the experiments. The amount of the fuel in the patternatoris measured to determine the spray fuel concentration. The spray volume flow rate fraction, (Q/Q_t), is the ratio of the measured of the local volume flow rate at a certain radius relative to the total volume flow rate at a certain condition. The total spray amount, Q_t, is integrated from the collected volume of the total tubes of the patternator, then radial spray volume fraction in a certain position is determined by dividing the spray amount collected in this position to the total spray amount.Figure 15 shows the effect of changing the injection pressure for petroleum diesel on radial spray concentration distribution.It is shown that, the minimum value of petroleum diesel fuel concentrations is at the spray cone center of the pressure swirl atomizer, so that the spray pattern is hollow cone. The radial spread in spray concentration is increased by increasing the injection pressure. It is also shown that, increasing the injection pressure, the projection area of the spray increases due to the increase of the spray cone angle, so that the spray covers larger radial area for higher injection pressure. It is also showed that the peak value moves outward radially.

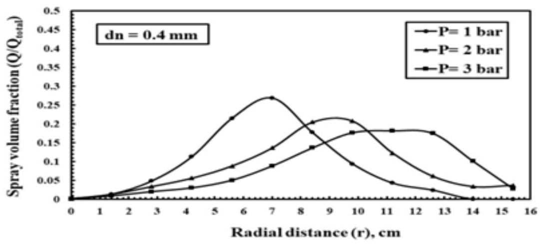


Fig. 15 Effect of injection pressure on petroleum diesel spray volume fraction distribution (20 cm vertical level from fuel nozzle exit)

Figure 16 shows the effect of changing the injection pressure for biodiesel fuel on radial spray concentration distribution. It is shown that the biodiesel fuel concentrations at the spray cone center of the pressure swirl atomizer is not equal zero at low injection pressure (P = 1bar), thereforethe spray pattern is solid cone. It is also shown that by increasing the injection pressure, the projection area of the spray increases due to the increase of the spray cone angle, so that the spray covers larger radial area for higher injection pressure. Furthermore, the spray pattern becomes hollow at centerline.From Figs. 15 and 16, it is clearly shown that, by increasing injection pressure, the peak value decreases and shifts its radial position outward, improves the uniformity of biodiesel distribution and increases the spray diameter to becomes a hollow cone to take the same behavior of petroleum diesel fuel.

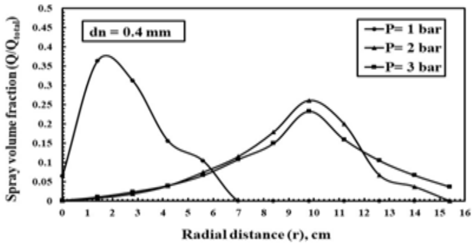


Fig. 16 Effect of injection pressure on biodiesel spray volume fraction distribution (at 20 cm vertical level from nozzle exit)

Biodiesel has the higher values of density and relative viscosity than those of petroleum diesel, as a result, it is smallest radial distribution than petroleum diesel. It is observed that at low injection pressure (P = 1 bar), the spray quality is better for petroleum diesel than that for biodiesel as shown in Fig. 17. It is clearly shown that at low injection pressure (1 bar), the spray cone is solid for biodiesel fuel while it is a hollow cone for petroleum diesel fuel.

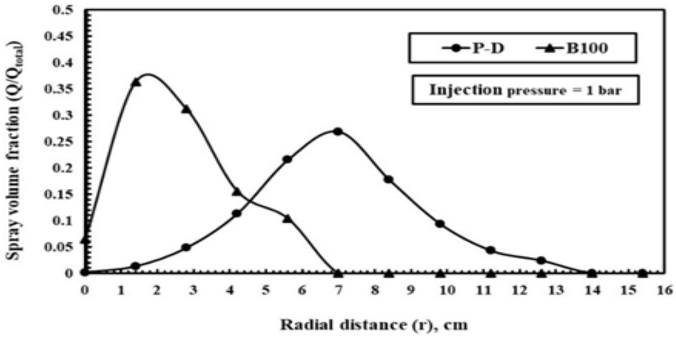


Fig. 17 Spray volume fraction distribution of petroleum diesel and biodiesel

IV. Conclusion

From the experimental results of the present work, the biodiesel fuel is produced from fresh at waste cooking oil by transesterification method by using methanol as alcohol and sodium hydroxide as catalyst and the spray performance of the produced fuel is compared with that of the petroleum diesel.The following conclusions can be summarized:

1. The biodiesel produced from the transesterification method meets ASTM standards.
2. An optimum condition for biodiesel (99% purity) is observed to be 1 liter of oil / 0.22 of alcohol with priority not less than 97%, NaOH catalyst at least 96% concentration 5.5 times the amount of oil.
3. The production time is 58 hours duration which, divides as; 3 hours preparing for oil, 1 hour stirring oil with methoxide, 3 hours chemical reaction time, 48 hours separating and washing and finally 3 hours filtering and drying the produced biodiesel.
4. By increasing the B number (i.e. increasing the volume percentage of biodiesel in the blends) the viscosity and density were increased. By increasing the B number from B10 to B100, the viscosity and the density increased by about 73% and 6 %, respectively.
5. The spray cone angle for petroleum diesel is greater than that for biodiesel at the same operating conditions. For biodiesel at injection pressure greater than 1 bar, the spray starts to be formed. By increasing the injection pressure from 1 to 3 bar, the spray cone angle increased by about 77%.
6. By increasing the injection pressure from 0.5 to 3 bar, the breakup length decreased by about 77% for petroleum diesel. While for biodiesel, by increasing the injection pressure from 1 to 3 bar, the breakup length decreased by about 70%.
7. For biodiesel fuel, at low injection pressure (P=1 bar) the spray cone angle is solid while for injection pressure greater than 1 bar, the spray cone is hollow.
8. The cost of one liter of produced biodiesel is cheaper than one liter of petroleum diesel by about 40% (based on Egyptian price 2016).
9. The capital cost will be redeemed after producing 8521 liters of biodiesel by transesterification method.

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