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IGNITION DELAY OF JOJOBA BIO-DIESEL AND ITS BLENDS WITH GAS OIL

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ABSTRACT

In this paper, the ignition delay of jojoba bio-diesel and its blends with gas oil was measured. For this purpose, a shock tube test set up was fully instrumented for delay measurement with two piezo-electric pressure transducers, dual mode charge amplifier, data acquisition card, laptop computer with suitable LabVIEW software. The test variables included the type of fuel, equivalence ratio, ignition temperature and ignition pressure. It was found that increasing the percentage of jojoba bio-diesel in the blend with gas oil exhibited a decrease in the ignition delay. Rich and lean mixtures produced long delays whilst the minimum delay occurred near the stoichiometric mixture. Higher ignition pressures and temperatures reduced the delay. Jojoba biodiesel and its blends were considered to be suitable for running the conventional diesel engine without modification.

KEY WORDS

Biodiesel, Jojoba, Shock tube, Ignition delay

NOMENCLATURE

Symbol		**Suffices**	
P	pressure (bar)	a	air
V	volume (m^3)	f	fuel
R	gas constant (kj/kg.k)	st.	stoichiometric
$\bar{R}$	Universal gas constant,8.31434 (kj/kg.k).	i	initial condition
T	temperature (k)	ig	Ignition
M	molecular weight (Kg/Kmol)	1	initial condition
M_S	shock mach number	**Symbols**	
U_S	shock speed (m/s)	φ	equivalence Ratio
F/A	fuel to air ratio	ρ	density

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INTRODUCTION

As oil and gas reserves gradually dwindle and global warming due to CO_2 emissions become more obvious, the world is going to need to consider alternative fuels, especially where road transport is concerned. Much research has been done to investigate the use of vegetable oils as a road transport fuel. Vegetable oils can be used in diesel engines either in its neat form, called straight vegetable oil that needs many engine modifications, or in forms produced as a result of chemical reactions such as transesterification. There is a number of different recipes for producing shorter chain length chemical structures and these products are called bio-diesel. Vegetable oils are produced from numerous oil seed crops. While all vegetable oils have high energy content, most require some processing to assure safe use in internal combustion engines. Some of these oils have already been evaluated as substitutes for diesel fuels. These include the following vegetable oil fuels and their methyl esters: raw sunflower oil [1], raw cottonseed oil [2], raw soybean oil and their methyl esters [3], distilled opium poppy oil and refined rapeseed oil rapeseed oil [4], jatropha oil [5,6], etc. Of the many renewable sources known, Jojoba oil appears to be a promising diesel fuel with promising scope for cultivation in the relatively hot weather.

In the internal combustion engine laboratory at the University of Helwan, Radwan [7, 8 and 9] has synthesized two types of jojoba bio-fuels. The first one was volatile and was termed "jojoba bio-gasoline". It was examined as an additive to gasoline in a spark ignition engine [9] and was examined as an alternative fuel to gasoline in spark ignition engines [8]. The second synthesized biofuel had properties similar to those of gas oil; hence it was termed as jojoba bio-diesel.

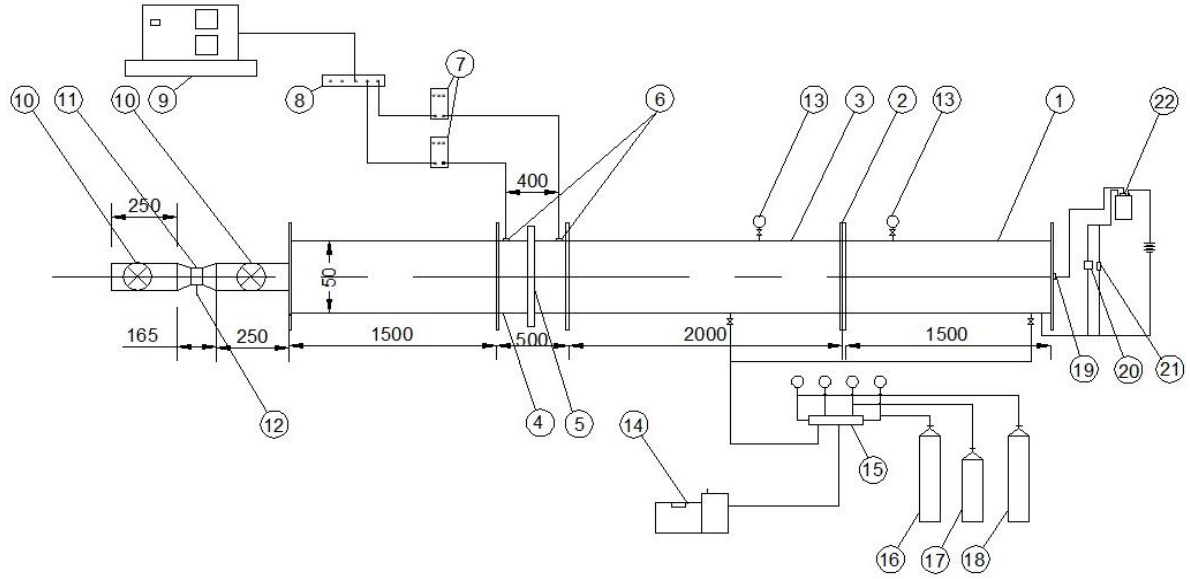
Ignition delay is considered as one of the main important variables that influence the combustion chamber design, rate of pressure rise, peak cylinder pressure, exhaust gas temperature, and exhaust emissions [10, 11]. Therefore, the main objective of this work was to study the ignition delay of jojoba biodiesel and its blends with gas oil as a vegetable fuel for diesel engines in the shock tube and compare the results with those of gas oil in order to indicate whether such fuel can be used in conventional diesel engines. Several terms are used to characterize the ignition delay depending on the criterion used to define the onset of combustion; hence the terms heat release delay, illumination delay and pressure rise delay. However, since the pressure rise delay bears more engineering significance , it shall be used in the present work.

SHOCK TUBE TEST RIG

General Description

The principle of the shock tube test rig generally relies on containing a relatively high pressure gas in a pipe usually termed the "driver section"; such section is separated by a diaphragm from another pipe containing low initial pressure fuel-air mixture, usually termed the "driven section". Upon rupture of the diaphragm a shock wave propagates through the driven section. If the shock wave strength is sufficiently high, the temperature of the fuel-air mixture in the driven section will rise and thus the ignition temperature be reached and hence the mixture burns.

Figure 1 shows a schematic of the shock-tube test setup. After evacuation by a vacuum pump, the driver section was charged by a combustible mixture of Acetylene, Oxygen and Nitrogen; the gas supply and regulation device and gas bottles shown were used for this purpose. A high-tension, automotive-type ignition system was employed to generate a spark in the sparking plug located in the position shown in the driver section. Thus, the gaseous mixture in the driver section ignites, bursts the diaphragm between the driver and driven section and generates a considerable shock wave in the driven section. The driven section was, however, evacuated by the vacuum pump from a special tapping controlled by a gas-type ball valve. The driven section was then charged by air and the test fuel. The walls of the driven section were heated to a temperature above the boiling point by an electric heater to prevent the condensation of the test fuel on such walls after charging. As the valves to the driven section are opened and the atmospheric air passes through the venture, Fig. 1, the test fuel was injected at the throat of the venturi using an accurate syringe|(accurate to within 0.01 cc). This venturi was externally heated by a gas burner to ensure full vaporization of the fuel during the charging process.



1 Driver Section
2 Diaphragm
3 Driver Section
4 Test Section
5 Quartz Window
6 Piezo Electric Pressure Transducer
7 Charge Amplifier
8 Data Acquisition Card
9 Laptop Computer
10 Ball Valve
11 Venturi
12 Test Fuel Injection Point
13 Vacuum Pressure Gauge
14 Vacuum Pump
15 Gas Supply and Regulation Device
16 Oxygen Bottle
17 Acetylene Bottle
18 Nitrogen Bottle
19 Spark Plug
20 Contactor
21 Ignition Switch
22 Ignition Coil

Fig.1. Schematic of the shock tube test rig.

Two piezo-electric pressure transducers were fitted in the test section in the driven part, as shown in Fig. 1, 400 mm apart. Such transducers were calibrated in a special apparatus using an instantaneous shock in a liquid. The output of such transducers was connected to charge amplifiers and then to 250 kHz NI-DAQmx

data acquisition card, which was connected to a laptop computer. Data acquisition was facilitated by a LabVIEW software for storing the measured data to an MS-Excell sheet. From such record, the delay period was evaluated as will be shown later. The method of varying the pressure, temperature and equivalence ratio of the blends of jojoba biodiesel with gas oil of (0, 5, 10, 25, 50 and 100%) by volume is indicated below.

Driver and Driven Sections

For the proper functioning of a shock tube, Bradley [12] and Gaydon and Hurle [13] have put forward several design recommendations, based on a review of theory and successful designs. Here, two inch, high pressure, seamless tubing was used for the construction of the driver and driven sections. Smaller diameters (e.g. 0.5 inch) can lead to shock attenuation [12]. In the present work, the total length of the driver and driven sections was 110 times the diameter. That lies within the limits of 40 to 150 indicated by Bradley [12]. The reason being to avoid the catching up of the reflected rarefaction wave with the incident shock wave before the incident shock passes the test section.

Here, a length of forty tube diameters was provided between the diaphragm and test section. In fact, Gaydon and Hurle [13] recommended a minimum value for the said distance to be 8 to 10 tube diameters; however, they recommended that such distance should be considerably increased. The reason being to attain a steady shock since the diaphragm rupture is far from being ideal.

The driver section was equipped at the right hand side with a sparking plug fed by the electric energy from a battery and coil automotive-type ignition system as stated earlier. Also a vacuum gauge was installed atop of the driver section to measure the vacuum. The driver section was connected by a gas-type rubber hose to a gas supply and regulation device. At the left hand side of the driver section, a thick plastic diaphragm was fitted.

The driven section, nevertheless, was furnished by a vacuum gauge for vacuum measurement. It was also connected by tapping, valve and rubber hose to the vacuum pump, Fig. 1, through a special valve in the gas supply and regulation device. The test section was equipped with two quartz windows for observation processes. It was also equipped with two piezo-electric pressure transducers as mentioned above. Atmospheric air and the evaporated test fuel were supplied to the driven section from the left hand side through the heated venturi.

At this point, it is well to point out that charging the shock tube was always carried out under vacuum to avoid high pressures subsequent to combustion. Hence, it was imperative to ensure that the rig holds vacuum well. Thus, vacuum was reduced to 0,04 bar and the variation of vacuum was recorded with time over a 24 hr period. It was found that the maximum leakage rate reduced the vacuum inside the shock tube by less than 0.1×10^{-3} bar/min. That was considered satisfactory and indicates that the test rig was tight enough.

Gas Supply and Regulation Devices

A gas supply and regulation device was designed and built. Three gas-type ball valves were used to adjust the supply of O_2, N_2 and C_2H_2 from the gas bottles shown to the driver section. Each valve was connected to a pressure gauge to record the stagnation gas pressure. Hypodermic needles were installed in special sockets placed downstream each valve. The purpose was to reduce the rate of gas flow and thereby make the charging process more controlled and convenient.

The gas supply device was also provided with a valve to read the vacuum within the device. In addition, two more valves were installed; one for connection to the vacuum pump for evacuation purposes whilst the other was for connection of the driver or driven section to the gas supply device. Moreover, a master connection piece was made, which connects, all valves by rubber hoses. The purpose was to enable gas mixing and simultaneous charging if required.

METHOD OF EXPERMINT AND DATA REDUCTION

The experiment was carried out by fitting a diaphragm between the driver and driven sections of the shock tube and then charging both sections and setting a shock wave to ignite the test fuel-air mixture. The driver section of the shock tube was first evacuated by the vacuum pump through the gas supply and regulation device. Then such section was fitted by in flammable mixture of Acetylene, Oxygen and Nitrogen. The relative quantities of Acetylene and Oxygen were calculated as follows:

For Oxygen:

$$P_{O_2} V_{O_2} = N_{O_2} \bar{R}\, T_{O_2}$$

For Acetylene:

$$P_{C_2H_2} V_{C_2H_2} = N_{C_2H_2} \bar{R}\, T_{C_2H_2}$$

And the equation of state for the mixture of Acetylene and Oxygen is

$$P_T V_T = N_T \bar{R}\, T_T$$

and since V_{O_2}= $V_{C_2H_2}$ =V_T = the volume of the driver section, T_{O_2}=$T_{C_2H_2}$ =T_T = ambient temperature and from Dalton's law P_T=P_{o2}+P_{C2H2}

$$\frac{P_{O_2}}{P_T} = \frac{N_{O_2}}{N_{O_2} + N_{C_2H_2}} = \frac{1}{1 + \frac{N_{C_2H_2}}{N_{O_2}}} \qquad (1)$$

and,

$$\frac{P_{C_2H_2}}{P_T} = 1 - \frac{P_{O_2}}{P_T} \qquad (2)$$

The pressure in the driver section was always chosen to be 1 bar. However, the Acetylene / Oxygen mixture was always diluted by Nitrogen such that the N_2

pressure was always 0.4 bar. Thus P_T mentioned above was invariably 0.6 bar. A stoichiometric mixture of C_2H_2 and O_2 was used throughout, thus the stoichiometric combustion equation gives $\frac{\mathbf{N}_{C_2H_2}}{\mathbf{N}_{O_2}}$ used in equation 1. Hence, P_{O2} and P_{C2H2} were determined from equations (1) and (2), the gas supply and regulation device was used with the aid of the vacuum and pressure gauges and the relevant valves to supply C_2H_2, O_2 and N_2. The driven section was evacuated using the vacuum pump through the gas supply and regulation device after heating its walls to the required temperature of the driven section. Then, the driven section was charged as stated earlier . The quantity of test fuel to be injected was calculated as follows:

$$P_a V_a = \frac{m_a}{M_a} \bar{R}\, T_a$$

and

$$P_f V_f = \frac{m_f}{M_f} \bar{R}\, T_f$$

And since $V_f = V_a$ volume of driven section, $P_T = P_a + P_f$ and $T_a = T_f$ measured temperature of hot air

$$\frac{P_a}{P_T} = \frac{\left(\frac{m_a}{M_a}\right)}{\left(\frac{m_a}{M_a}\right) + \left(\frac{m_f}{M_f}\right)} = \frac{1}{1 + \frac{F}{A}\frac{M_a}{M_f}} \tag{3}$$

and since

$$m_a = \frac{P_a V_a}{R_a T_a} = \frac{\frac{P_a}{P_T} P_T V_a}{R_a T_a} \tag{4}$$

and

$$m_f = m_a \frac{F}{A} = V_f \rho_f \tag{5}$$

The substitution of equation (4) in equation (5) yields

$$V_f = \frac{m_f}{\rho_f} = \frac{m_a \frac{F}{A}}{\rho_f} = \frac{\frac{P_a}{P_T} P_T V_a \frac{F}{A}}{R_a T_a}$$

and since

$$\frac{F}{A} = \varphi \left(\frac{F}{A}\right)_{st.}$$

$$V_f == \frac{\frac{P_a}{P_T} P_T V_a \varphi \left(\frac{F}{A}\right)_{st.}}{\rho_f R_a T_a} \tag{6}$$

$(F/A)_{st}$ was determined from the stoichiometric equation of combustion for each test fuel. The value of V_f can then be calculate at various values of ϕ and constant predetermined P_T and Ta using equations (3) and (6). Also, V_f was calculated at constant ϕ and T_a for various values of P_T. Similarly, V_f was calculated at constant ϕ and P_T for various values of T_a.

After charging the driver and driven sections of the shock tube, a spark was generated in the sparking plug which ignites the mixtures of C_2H_2, O_2 and N_2 in the driver section. That bursts the diaphragm and the generated shock wave ignites the test fuel-air mixture while the piezo-electric pressure transducers record the pressure –time diagram for the two transducers which appear on the laptop screen; such plot was, however, obtained using the LabVIEW software to be stored as an MS-Excell sheet through a 250 kHz NI-DAQmx data acquisition card. That plot was obtained with gas oil as a fuel in the driven section. The time interval between points O and X in Fig. 2 (a) gives the time taken by the shock wave from the upstream to the downstream transducer. Thus with prior knowledge of the distance between the two transducers, the shock speed (U_g) was calculated. However, the time interval between points X and O in Fig. 2(b) give the thermal ignition delay of the test fuel. It must, however, be pointed out that the time intervals stated above were automatically calculated by the previous stored MS-Excell sheet.

The ignition pressure (P_{ig}) and the ignition temperature (T_{ig}) of the fuel-air mixture in the driven section were calculated from [14]:

$$\frac{P_{ig}}{P_1} = \frac{1}{2}\left\{1+\rho_1\frac{U_s^2}{P_1}+\sqrt{\left(1+\rho_1\frac{U_s^2}{P_1}\right)^2-\frac{4\rho_1 U_s^2}{P_1}}\right\} = \frac{2\gamma M_s^2-(\gamma-1)}{(\gamma+1)} \tag{7}$$

where P_1 = initial total pressure in the driven section and

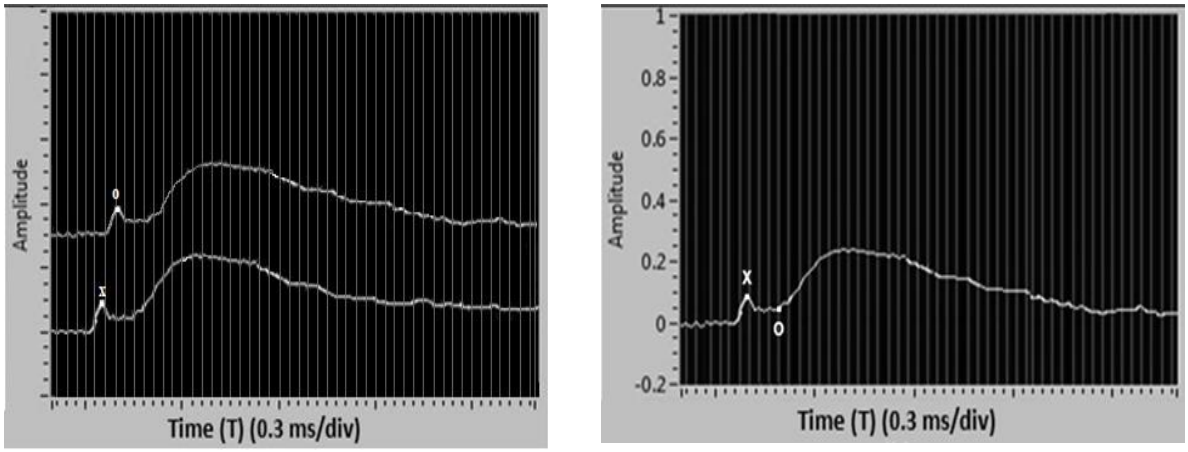
$$\alpha = \frac{T_{ig}}{T_1} = \left\{\frac{\left(\gamma M_s^2-\frac{\gamma-1}{2}\right)\left(\frac{\gamma-1}{2}M_s^2+1\right)}{\left(\frac{\gamma+1}{2}\right)^2 M_s^2}\right\} \tag{8}$$

where T_1 is the temperature of hot mixture inside driven section (T_a) and Ms is given by [14]

$$M_s = U_s\left(\frac{\rho_1}{\gamma P_1}\right)^{\frac{1}{2}} \tag{9}$$

The specific heat ratio, γ, was calculated by iteration as suggested by Kleinschmit [14]. The equivalence ratio, ϕ, was varied as stated above. However, the ignition pressure (P_{ig}) and the ignition temperature (T_{ig}), were varied by varying P_1 and T_1.

In order to ensure the consistency of the experimental results, preliminary tests were carried out with the present shock tube on gas oil at different equivalence ratios and the results agreed with those given in the literature [10, 15 and 16].



(a) (b)

Fig. 2. Pressure–time diagram of the triggering and triggered transducers –Fuel :gas oil at P_{ig}=24bar, T_{ig}=1489K and ϕ=0.9.

RESULTS AND DISCUSSION

The characteristics of jojoba bio-diesel and gas oil were measured in the Laboratory. Such characteristics will be discussed in the following section to illustrate the effect of these characteristics on the ignition delay.

In addition, a series of shock tube experiments were performed to study the ignition delay of jojoba bio-diesel and its blends with gas oil. The blends had a volumetric percentage of 0, 5, 10, 25, 50, 75 and 100% of Jojoba bio-diesel.

Measurements were carried out in the ignition temperature range of 1450 to 1525 K, ignition pressure range of 16 to 24 bar with equivalence ratios varying from 0.7 to 1.2 using the shock tube set up.

Effect of Fuel Characteristics

Table 1 indicates the characteristics of the Jojoba biodiesel and gas oil as measured in the Laboratory . It ought to be stated that the Jojoba bio diesel proved to conform to the American standard ASTM D-6751 for bio-diesel.

The different of the ignition delay of jojoba bio-diesel from that of gas oil is stipulated to be due to the changes in the physical properties. Table 1 illustrates that the molecular weight, density, viscosity and cetane number are different as jojoba bio-diesel fuel has a lower density(by about 5%), higher viscosity (by 5.8%) than those of gas oil and these properties lead to shorter ignition delay times [10]. Also, the ignition delay time is affected by the cetane number of the fuel. The cetane number of jojoba bio-diesel was considerably higher (by 23.4%) than gas oil, hence leading to a shorter ignition delay period. Referring to Fig. 3, the relationship of the ignition delay with the cetane number is indicated.

Table 1. Characteristics of Jojoba Biodiesel and Gas oil.

Fuel	Jojoba bio-diesel	Gas oil
C, %	87	88.01
H, %	13	11.82
API gravity	40.2	34.3
Sp. gravity @60/60 F	0.8241	0.86
Density @ 60/60F	0.8241	0.86
Viscosity @ 40◦C(c St)	4.78	4.5
Pour point ◦C	- 15	4.5
Calorific value MJ/Kg	46	43.1
Cetane no.	64	49
Initial boiling point ◦C	120	120
Final boiling point ◦C	380	325
Ash content % wt	0.0014	0.01
Water content mg/kg	0.04	0.15
Carbon residue % wt	0.1	0.1
Sediment % wt	0.011	0.02
Sulpher content	Nil	1.5

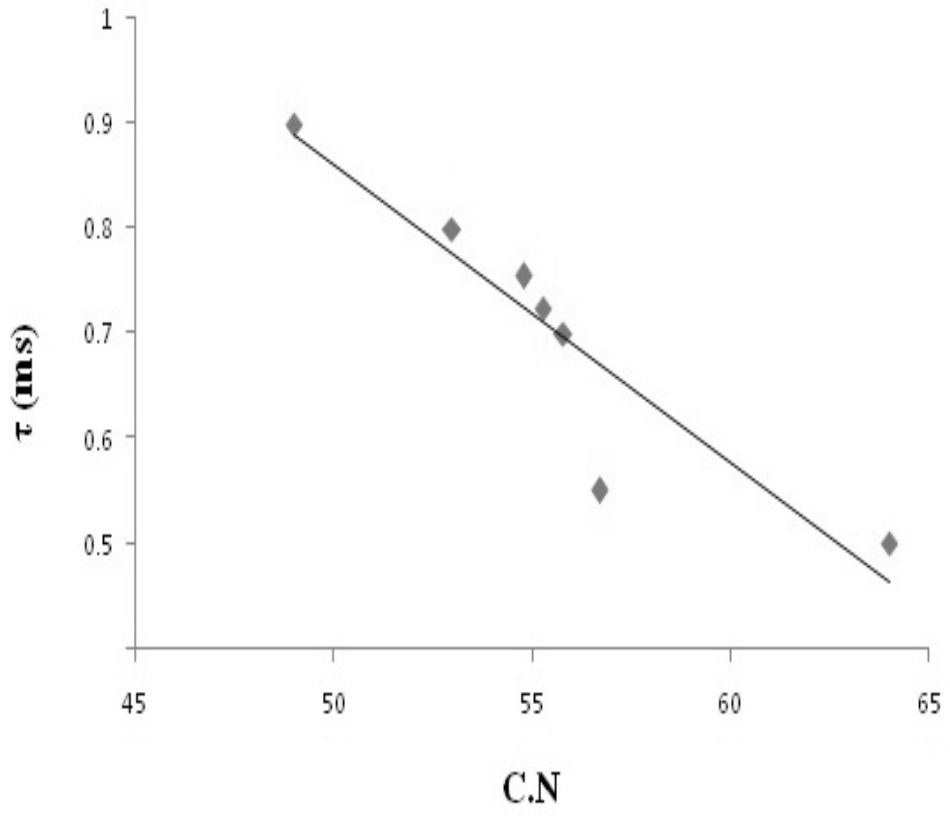


Fig. 3. Ignition delay versus cetane number (C.N) for jojoba bio-diesel blends with gas oil

Effect of the Equivalence Ratio

The experiments were performed at an ignition temperature of 1489 K and an ignition pressure of 24 bar while varying the equivalence ratio from the lean side at 0.7 to the rich side at 1.2 to cover a wide range of engine operating conditions.

Figure 4 shows the effect of equivalence ratio on the ignition delay of jojoba bio-diesel and its blends with gas oil. It is clear that the variation of the ignition delay with the equivalence ratio exhibit the familiar bell-shaped behaviour. Also, it will be observed that the minimum ignition delay times occur near the stoichiometric condition and that agrees with the results of diesel and bio-diesel fuels which, were noticed by many investigators including Saleh [16]. That is stipulated to be due to the higher pre-flame reactions at this condition which reduced the ignition delay.

It will be observed that the ignition delay times steeply increased at the lean side and modestly increased at the rich side. Such increase is stipulated to be due to the fact that pre-flame reactions appear to have slow down leading to a long ignition delay period.

Figure 4 also gives a comparison at all equivalence ratios between jojoba bio-diesel blends and pure gas oil. The results show that the ignition delay of pure jojoba bio-diesel is always shorter than that of gas oil. Moreover, it will also be observed that, the higher percentages of bio-diesel in the blend lead to a gradual decrease of the ignition delay time.

As shown in Fig. 5, the effect of increasing of the percentages of jojoba bio-diesel fuel with gas oil blends of 0, 5, 10, 25, 50, 75 and 100% is a decrease in the ignition delay times at $\varphi = 0.7$- a characteristic value at full engine load.

The results show that, for low and high compression ratio direct injection diesel engines jojoba bio-diesel and its blends can be used safely where the ignition delay of such blends lie within the ranges noticed by Watson [17] and Haywood [18].

Effect of the Ignition Temperature

The effect of ignition temperature on the ignition delay for the test fuels is presented in Fig. 6. The experiments were performed at an equivalence ratio of 0.9, ignition pressure of 24 bar and ignition temperature varying from 1450 to1525 K. It will be seen that increasing the ignition temperature leads to a decrease in the ignition delay for all blends. Such decrease is stipulated to be due to the fact that, increasing temperature increases the number and velocity of molecular collisions accompanied by an increase in the activated complexes. Thus, the energy acquired by the molecules increases, enabling to overcome the bond energy more readily as indicated by Radwan et al [10] and Rutland [15]. It will also be seen that higher percentages of jojoba bio-diesel in the blend leads to a decrease in the ignition delay period.

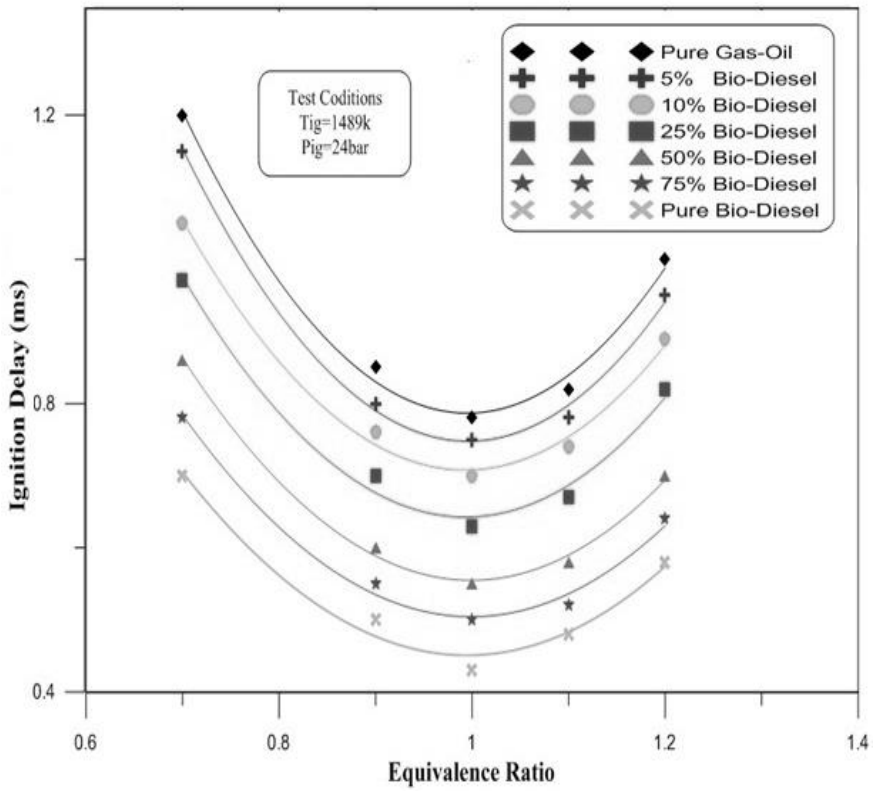


Fig.4. Effect of the equivalence ratio on the ignition delay of jojoba bio-diesel and its blends with gas oil**.**

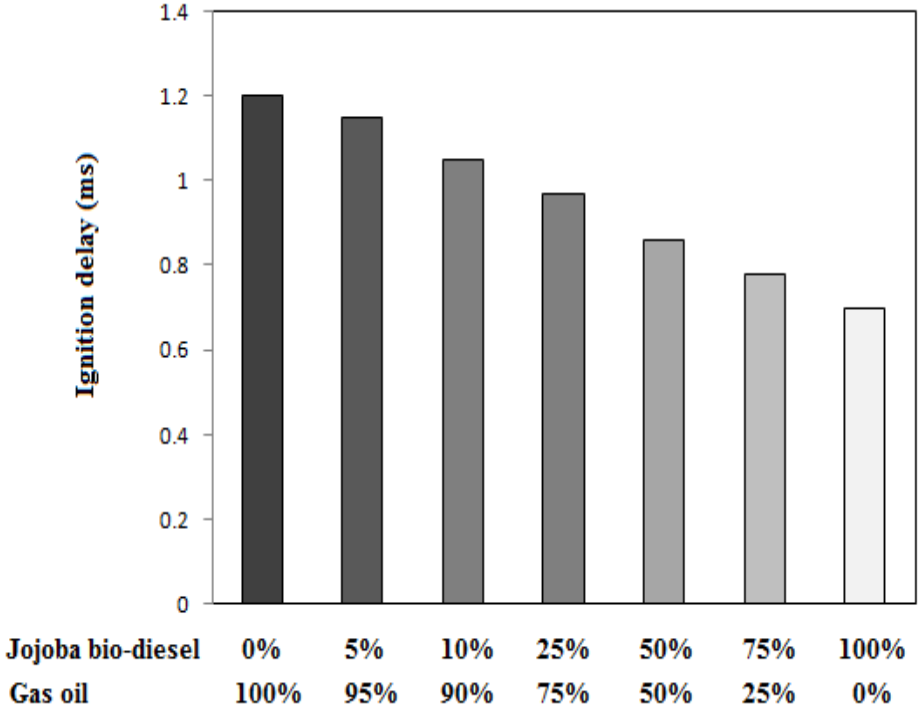


Fig. 5. Effect of jojoba bio-diesel content.

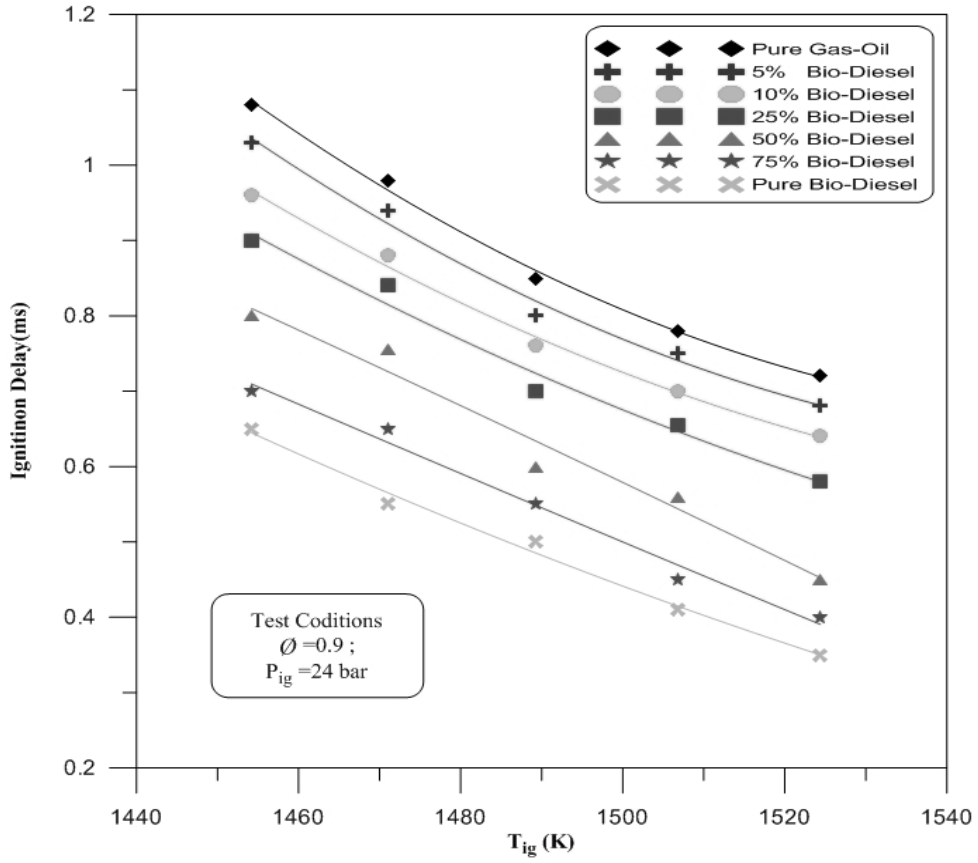


Fig.6. Effect of ignition temperature on the ignition delay of jojoba bio-diesel and its blends with gas oil.

Effect of the Ignition Pressure

The effect of ignition pressure on the ignition delay for the test fuels is elucidated in Fig.7. The experiments were performed at an equivalence ratio of 0.9, ignition temperature 1489 K with the ignition pressure varying from 16 to 24 bar. It will be noticed that higher ignition pressures decrease the ignition delay. The primary reason is apparently due to the fact that higher pressures mean higher collision efficiency and more proximity of the air molecules with the fuel molecules, improving the pre-ignition reaction activity.

CONCLUSIONS

From the study presented in this work, the following conclusions may be drawn:

1. The ignition delay of jojoba bio-diesel blends was found to run in step with cetane rating; the effect was a shorter delay with higher cetane number.
2. The minimum ignition delay times occur near the stoichiometeric condition. Richer or leaner mixtures result in a longer delays.
3. Jojoba bio-diesel exhibits a shorter ignition delay period than gas oil at all conditions.
4. Jojoba bio-diesel and its blends with gas oil have a gradual decrease in the ignition delay time as the fraction of bio-diesel fuel increases.

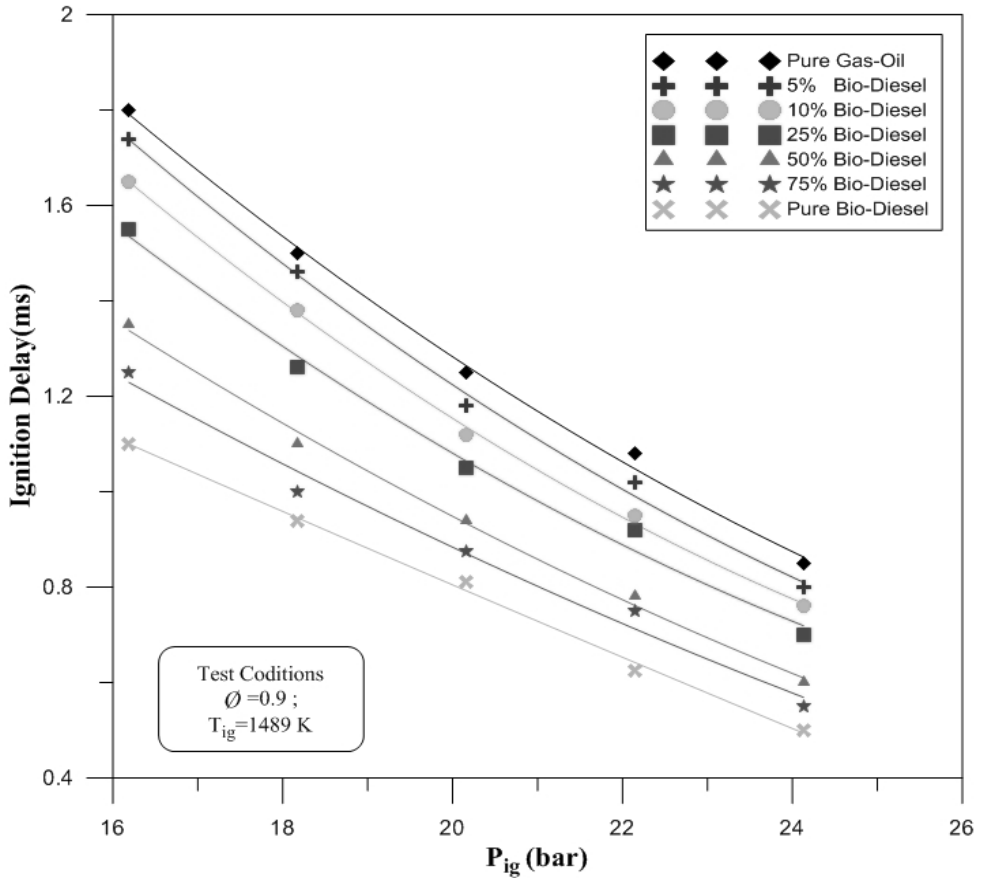


Fig.7. Effect of ignition pressure on the ignition delay of jojoba bio-diesel and its blends with gas oil

5. For all blends, as the ignition temperature increased, the ignition delay times tended to decrease.
6. Higher ignition pressures lead to shorter ignition delays. Thus any design or operational factor that affects the ignition pressure and / or temperature will affect the ignition delay.
7. Jojoba bio-diesel blends as alternative diesel engine fuels can be used successfully without modifications to the engine or the injection system.

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