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Faculty of Graduate Studies

Biodiesel Viscosity and Flash Point Determination

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Dedication

This thesis is dedicated to my family with respect and love.

Acknowledgement

I would like to express my sincere appreciation to my supervisors, Prof. Dr. Issam Rashid Abdelraziq for his helpful, and Prof. Sharif Mohammed Musameh, for his cooperation which helped me in the completion of this research. Special thanks to Eng. Fekre Tubasi for his help in completing the experimental work. Thanks to the members working in the laboratories of the physics department for their cooperation, Mr. Mohammad Bahjat, Mr. Sameeh Abed Al azeez.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنون:

Biodiesel Viscosity and Flash Point Determination

اقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تم الإشارة إليه حيثما ورد وأن هذه الرسالة ككل أو جزء منها لم يقدم من قبل لنيل أية درجة أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى .

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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List of Symbols and Abbreviations

AAD%	Percentage of Average Absolute Deviation
B5	Sample Contains 5%Biodesel and 95%Petrodiesel
CGS	Centimeter-Gram-Second
cP	Centipoise
cSt	Centistokes
E_a	Activation Energy
Eq.	Equation
FAAE	Fatty Acid Alkyl Esters
Fig.	Figure
FP	Flash Point
J	Joule
gm	Gram
K	Temperature in Kelvin
N	Newton
n	Refractive Index
P	Poise
Pa	Pascal
R	Gas Constant
RPM	Revolution Per Minute
s	Second
SD	Standard Deviation
SI	System International Unites
T_b	Boiling Point
TAG	Triacylglycerol
X	Percentage of Biodiesel in Sample
ρ	Mass Density

η	Dynamic Viscosity
υ	Kinematic Viscosity
τ	Shear Stress
γ	Shear Rate

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Abstract

In this research, biodiesel samples of different percentages of blend biodiesel (Palestinian biodiesel prepared from waste oil) and petro-diesel were studied. The density, refractive index, flash point and viscosity of the samples were measured.

The flash points were measured as a function of percentage of biodiesel, the results emphasized that the flash points increase as the percentage of biodiesel increases in the sample. Two equations were proposed to obtain more suitable prediction of the flash point. The values of flash points of biodiesel were compared with the standard value of flash point of biodiesel. The comparison shows that samples contain more than 40% biodiesel coincide with standard values.

The values of kinematic viscosity of biodiesel were compared with the Palestinian standard value of biodiesel. The comparison shows that samples contain less than 72% biodiesel coincide with standard value. Taking into consideration results of kinematic viscosity and flash point one can suggest percentage 71% of biodiesel and 29% petro-diesel as the best percentage that the two materials can be mixed and the flash point 115.3 ºC according the Palestinian standards.

Chapter One

Introduction

1.1 Biodiesel

Biodiesel is defined as the mono alkyl esters of long chain fatty acids, derived from renewable vegetable oils or animal fats for use in ignition engines. Vegetable oils which is used in preparing biodiesel is soybean oil, sunflower oil, ground nut oil, canola oil, corn oil, and waste oil which is a mixture of all previous kinds of oil after been utilized(Amit, 2009; Demirbas, 2009).

Biodiesel possesses technical and environmental advantages, low toxicity, derivation from a renewable sources, superior flash point than petrodiesel and biodegradability, and lower overall exhaust emissions(Tyson, 2006; Moser, 2009; Isioma *et al*, 2013). Biodiesel's characteristics strongly depend on various plant feed stocks, growing climate conditions, soil type, plant health and plant maturity upon harvest. These parameters affect the physical and chemical properties, which also have direct relationship with performance and emission of the engine (Tesfa *et al.*, 2010).

Vegetable oils and animal fats are principally composed of triacylglycerols (TAG) consisting of long chain fatty acids chemically bound to a glycerol (1, 2, 3- propanetriol) backbone. The chemical process by which biodiesel is prepared known as the transesterification reaction, which involves a TAG reaction with a short chain monohydric alcohol normally in the presence of a catalyst at elevated temperature to form fatty acid alkyl esters (FAAE) and glycerol (Fig1.1) (Gerpen *et al.*, 2010; Moser, 2009).

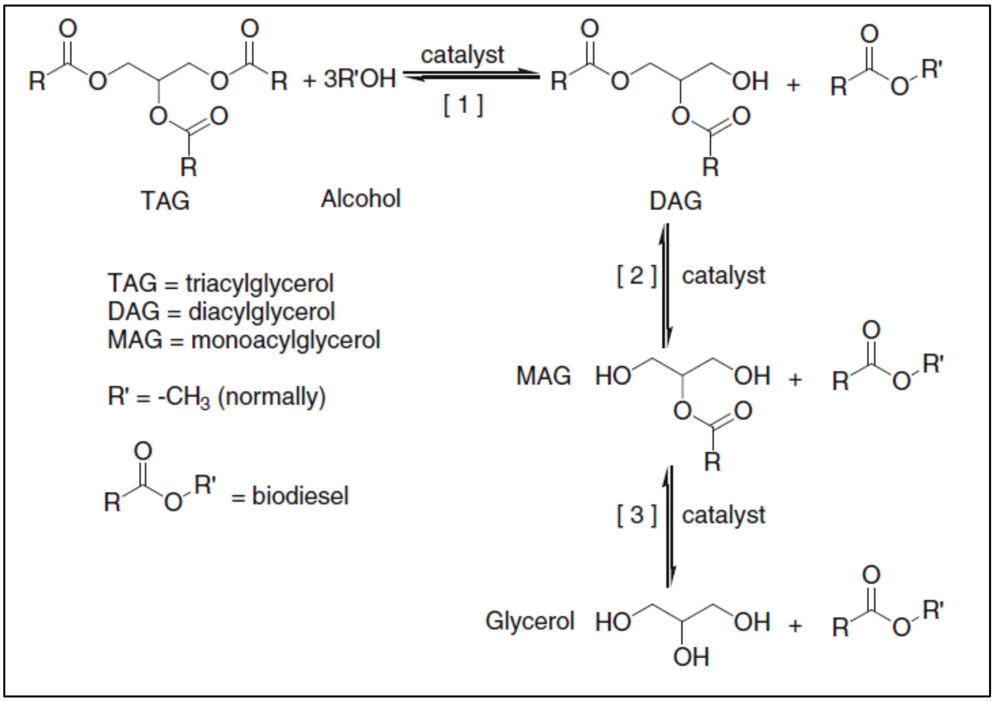

Fig. (1.1) Transesterification of triacylglycerols to yield fatty acid alkyl esters (biodiesel) (Gerpen *et al.*, 2010)

Biodiesel can be used in pure form or blended with petrodiesel to enhance the properties of biodiesel. Dilution reduces the viscosity and engine performance problems such as creation of carbon deposition (Aliyu *et al*, 2011; Babu *et al.*, 2012). The prepared biodiesel must be analyzed using analytical method to ensure it meets the standard biodiesel and to be used commercially as a fuel. There are many characteristics analyzed for biodiesel as oxidation stability, cloud point, flash point, viscosity, and cetane number(NREL, 2009).

1.2 Viscosity of Biodiesel

Fuel viscosity is the main property that plays an important role in the combustion of fuel. The direct injection in the open combustion chamber through the nozzle and pattern of fuel spray decides the ease of combustion and thermal efficiency of the engine. Too low viscosity can lead to excessive internal pump leakage whereas system pressure reaches an unacceptable level and will affect injection during the spray atomization. The effect of viscosity is critical at low speed or light load conditions (Babu *et al.,* 2012).

The viscosity of biodiesel is typically higher than that of petrodiesel often by factor two, the viscosity increases as the percentage of biodiesel increases. Viscosity is greatly affected by temperature, many of the problems resulting from high viscosity are most noticeable under low ambient temperature and cold start engine condition (Amit, 2009). Viscosity increases with chain length of either the fatty acid or alcohol moiety in a fatty ester or in an aliphatic hydrocarbon. The increment in viscosity over a certain number of carbons is smaller in aliphatic hydrocarbons than in fatty compounds (Knothe *et al.*, 2005).

1.3 Flash Point of Biodiesel

The flash point of biodiesel is used as the mechanism to limit the level of unreacted alcohol remaining in the finished fuel. The flash point is important in connection with legal requirements and for the safety precautions involved in fuel handling and storage. It is normally specified to meet the fire regulation (Prugh, 2007).

The flash point of pure biodiesel is considerd higher than prescribed limits but can decrease rapidly with increase residual alcohol. As these two aspects are strictly correlated, flash point used as a regulation for categorizing the transport and storage fuels with different thresholds from region to region, so aligning the standards would possibly require a corresponding alignment of regulation (Amit, 2009).

1.4 Literature Review

Biodiesel is considerable scope for the study. Researchers did a lot of to study the chemical synthesis of biodiesel, physical properties, conformity with international standards specifications, and suitability for diesel engines Kailas team studied the kinematic viscosity, acid value and density of diesel fuel. They used biodiesels (100% methyl ester of soybean oil, and 100% methyl ester of groundnut oil) and their blends with acetone. The biodiesel percentage in the blend biodiesel and acetone was 95%, 85%, 75% and 65%. They found that the kinematic viscosity of test fuels and their blends decrease linearly with increases temperature. The density and acid value of test biodiesels also decreases with increases temperature (Kailas *et al*., 2013).

Nita and Geacai measured the density and the kinematic viscosity and presented data for a vegetable oil, diesel fuel and biodiesel in the temperature range of 20 ºC to 60 ºC. Empirical models were proposed to predict these properties at different temperatures (Nita *et al*., 2011).

Rao and his group made a study to estimate the mathematical relationships between the kinematic viscosity, density, and flash point among various biodiesel samples. (Rao *et al.*, 2010)

Thiago and his group studied the kinematic viscosity and presented an experiment to determine the kinematic viscosity behavior with shear rate and temperature of edible oils such as canola, sunflower, corn, and soybean. They compared the curves obtained for the kinematic viscosity versus temperature with the curves obtained by modeling the kinematic viscosity dependency on temperature. (Thiago *et al.*, 2013).

Moradi and his group studied the effects of temperature and volume fraction of biodiesel and diesel on the density and kinematic viscosity of blends They used five biodiesels: sunflower, canola, soybean, waste cooking oil, and edible tallow. Density and kinematic viscosity of mixtures were measured at several temperatures. Results showed that by reducing temperature and increasing the volume fraction of biodiesel, density and kinematic viscosity are increased (Moradi *et al.*, 2012).

Jahirula calculated the kinematic viscosity of biodiesels over a wide range of temperatures typically encountered in diesel engine operation by using artificial neural network (ANN) model. It is a computational modeling tool used to find an extensive acceptance solution in many disciplines for modeling complex real world problems. In this model, temperature and chemical composition of biodiesel were used as input variables. In order to obtain the necessary data for model development, the chemical composition and temperature dependent fuel properties of ten different types of biodiesels were measured experimentally using laboratory standard testing equipment following internationally recognized testing procedures (Jahirula *et al.*, 2013).

Mundike studied the effects of blending biodiesel obtained from Jatropha with fossil diesel on five parameters. The parameters were kinematic viscosity, specific gravity, flash point temperature and the calculated cetane index value. The blending ratios used were B5, B10, B15 and B20. The results indicated that the specific gravity, cetane index, flash point temperature and the distillation temperature parameters were all suitable for using in internal combustion engines for all the four blending ratios. The kinematic viscosity results for B15 and B20 were above the highest allowable limit. The B20 recorded the highest value for kinematic index of 7.2 x10^{-6} m^2/s, about 31 percent above the upper allowable limit of 5.5 x 10^{-6} m^2/s (Mundike *et al*., 2013).

Esteban and his team studied the temperature dependency of density and kinematic viscosity of several commonly used vegetable oils, diesel fuel and pure biodiesel. Results of this research showed that the analyzed vegetable oils require preheating to 120 ºC minimally to match the studied physical properties of automotive diesel and biodiesel fuels (Esteban *et al.*, 2012).

Aworanti with his team studied the binary and ternary blends of biodiesel and the effect of temperature on their kinematic viscosity and density. They used binary and ternary blends of the soybean biodiesel that were prepared from soybean biodiesel with soy bean oil and petroleum diesel fuel, respectively. The results showed that the viscosities and densities of both the binary and ternary blends are decreased with increasing temperature (Aworanti *et al.*, 2012).

Jibril and his group made transesterification of two oil samples "Jatropha and Neem oils" in methanol with use of potassium hydroxide as a catalyst. The properties of the produced biodiesel such as flash point, density, pour point and cloud point were measured and compared to the properties of automotive gas oil. The biodiesel produced from Jatropha oil has properties within the acceptable range for automotive gas oil while the Neem biodiesel properties are not within the range (Jibril *et al.*, 2012).

Sivaramakrishnan and Ravikumar studied the higher heating values (HHVs) of vegetable oils and their biodiesels. The HHVs measured and correlated using linear least square regression analysis. An equation was developed relating HHV and thermal properties. The higher heating values compare well with the measured higher heating values (Sivaramakrishnan *et al.*, 2011).

Ahmad evaluated the viscosity of vegetable oils, and fitted the viscosity with well - known rheological equations (Bahti, 2014; Bahti *et al*, 2015). Palestinain olive oil studied by Fuqha to measur the concentration of metals and physical properties acidity, density, refractive index and viscosity (Fuqha, 2015). The dynamic viscosity of olive oil samples of different storage ages in yearly and weekly basis from different locations was measured as a function of temperature by Nierat (Nierat *et al.*, 2014). The properties of coconut oil were studied by Nierat (Nierat *et al.*, 2015)

1.5 Objectives of the Study

The objectives of this work are to:

- Measure the kinematic viscosity of biodiesel and compare it with the standard values.
- Study the dependence of dynamic viscosity of biodiesel and its blends on temperature.
- Measure and determine the flash point of the biodiesel and compare it with the standard values.
- Measure the density of biodiesel for different temperatures and compare it with the standard values.
- Measure the refractive index of biodiesel.

Chapter Two

Theory

1. Viscosity

2.1.1 Definitions and Units

Viscosity is a fundamental characteristic property of all liquids. Viscosity is a measure of internal resistance presence in each real fluid causing the fluid to oppose the dynamic variation of its motion and therefore restricting it's tendency to flow (Latini, 2006). Viscosity is expressed in two distinct forms:

a. Absolute or dynamic viscosity

b. Kinematic viscosity

Dynamic viscosity is defined as the ratio of shear stress (force over cross sectional area) to the rate of deformation, it is presented by:

$$\eta = \frac{\tau}{\frac{\partial u}{\partial x}} \tag{2.1}$$

Where, η is the dynamic viscosity (Pa.s), τ is the shear stress (N/m^2) and $\frac{\partial u}{\partial x} = \gamma$ is the rate of deformation or velocity gradient or better known as shear rate (1/s) (Giap *et al*., 2009).

Kinematic viscosity requires knowledge of mass density of the liquid (ρ) at that temperature and pressure and is defined as

$$\upsilon = \frac{\eta}{\rho} \tag{2.2}$$

Where υ is the kinematic viscosity, ρ is the mass density of the liquid (Dabir *et al.*, 2007).

Dynamic viscosity is expressed in poises, centipoises, or micro poises. Apoise (P) denotes dynamic viscosity of 0.1(N. s/m^2) and 1.0 cP = 0.01P. The kinematic viscosity is the ratio of the dynamic viscosity to the density; dynamic viscosity in poises and the density in gm/cm^3, the unit of kinematic viscosity is the stoke, with the units mm^2/s. In the SI system of units, dynamic viscosity is expressed in (N.s/m^2) or (Pa.s) and kinematic viscosity in either m^2/ s (Bruce *et al.,* 2001).

2.1.2 Types of Fluid According to Viscosity

Fluids are classified by their viscosity and divided into two main groups:

(1) Newtonian

(2) Non Newtonian

(1) Newtonian fluids: have a straight line relationship between the shear stress and shear rate with zero intercept. The relation describing the shear stress is given by

$$\tau = - \mu . \gamma \qquad (2.3)$$

where τ is the shear stress, γ rate of shear, μ a constant of proportionality (Skelland *et al.*, 1968).

(2) Non-Newtonian fluids is generally a fluid whose flow properties are not described by a single constant value of viscosity represented by a rheological model, or correlation of shear stress and shear rate. According to the relationships between shear stress and shear rate, non-Newtonian fluids are commonly grouped in two general classes:

a) Time independent non-Newtonian fluids.
b) Time dependent non-Newtonian fluids.

a) Time independent fluids which are the rate of shear γ, or the velocity gradient, is a unique but nonlinear function of the instantaneous shear stress τ at that point. For the time-independent fluid, the relationship is given by:

$$\gamma = f(\tau) \tag{2.4}$$

where τ is the shear stress, γ is the shear rate(Chhabra *et al*, 2010).

b) Time-dependent fluids have more complex shear stress and shear rate relationships. In these fluids, the shear rate depends not only on the shear stress, but also on shearing time. These materials are usually classified into two groups, thixotropic fluids and rheopectic fluids, depending upon whether the shear stress decreases or increases in time at a given shear rate and under constant temperature. The time independent non Newtonian fluids can be characterized by the flow curves of τ versus γ shown in Fig.(2.1). These are: (a) Bingham plastics; (b) pseudoplastic fluids; and (c) dilatant fluids (Johnson, 1998; Corapcioglu, 1996).

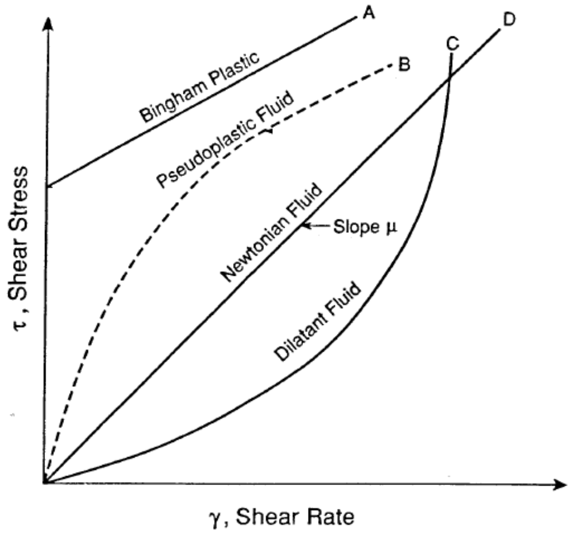

Fig. (2.1) Typical shear stress and shear rate relationships for both Newtonian and non-Newtonian fluids

2.1.3 Effect of Temperature on Viscosity

The viscosities of liquids are affected with temperature either under isobaric conditions or as saturated liquids. Several approaches and theories have been proposed to describe and correlate the viscosity of a fluid as a function of temperature. Viscosity temperature dependent of pure liquid was described by Andrade in the first approximation suggested using the Arrhenius Equation (Dabir *et al.*, 2007).

$$\eta = A\, e^{\frac{E_a}{RT}} \tag{2.5}$$

Where η is dynamic viscosity (Pa.s); A is the pre exponential factor (Pa.s); E_a is the exponential constant that is known as activation energy (J/mol); R is the gas constant (J/mol.K) and T is the absolute temperature (K). The value of A can be approximated as the infinite temperature viscosity (η_∞), which is exact in the limit of infinite temperature. Equation (2.5) can be rewritten in the following form (Giap, 2010).

$$\eta = \eta_\infty\, e^{\frac{E_a}{RT}} \tag{2.6}$$

Many proposed relations were suggested to describe viscosity- temperature relation, it can be classified in three groups

1-Two-Constants Equation.

Among several proposed relations, the simplest form of representation of liquid viscosity as a function of temperature is Andrade equation

$$\ln \eta = A + \frac{B}{T} \tag{2.7}$$

Where η is the dynamic viscosity in cP, T is the temperature in K, A and B are positive constants, and are characteristics of each liquid (Andrade, 1930;Bruce *et al.*, 2001).

2-Three-Constants Equations

Viswanath and Natarajan suggested a three constants equation for both dynamic and kinematic viscosities;

$$\log \eta = \mathrm{A} + \frac{\mathrm{B}}{(\mathrm{C}-\mathrm{T})} \tag{2.8}$$

$$\log \upsilon = \mathrm{A}^{`} + \frac{B^{`}}{(C^{`}-T)} \tag{2.9}$$

where η is the dynamic viscosity in cP, υ is the kinematic viscosity in cStock, T is the temperature in Kelvin, A, B, C, A`, B`, and C` are constants for each liquid (Dabir *et al.*, 2007).

3-Multi-Constants Equations

Some equations with more than three constants have been proposed to improve the accuracy of representation as the equation used by Noureddini

$$\ln \eta = A + \frac{B}{T} + \frac{C}{T^2} + \frac{D}{T^3} \tag{2.10}$$

where η is the dynamic viscosity in cP, T is the temperature in K, while A, B, C, and D are constants for specific liquid(Noureddini, *et al.*, 1992).

Another equation proposed by Nita and Geacai estimated the dynamic viscosity of biodiesel

$$\eta = eT^3 + fT^2 + gT + h \tag{2.11}$$

where η is the dynamic viscosity in cP, T is the temperature in°C, e, f, g, and h are correlation parameters. The values of the correlation coefficients for viscosity calculation with equation (2.11) are reported in Table 2.1 (Nita *et al.*,2012).

Table(2.1) :Correlation parameters of Eq.(2.11)

Fuel	Correlation parameters			
	e in $\frac{cP}{°C^3}$	f in $\frac{cP}{°C^2}$	g in $\frac{cP}{°C}$	h in cP
Vegetable oil	-4×10^{-4}	0.0946	-6.0350	157.670
Diesel fuel	-1×10^{-4}	0.0029	-0.2195	8.159
biodiesel	-2×10^{-4}	0.0045	-0.3440	12.562

2.2 Flash point

2.2.1 Definition

Flash point is the minimum temperature at which a fuel gives off sufficient vapors which can be mixed with air and will ignite momentarily (Amit, 2009). Determination of flash point is needed for every type of biodiesel to classify it as nonhazardous under the National Fire Protection Association (NFPA) code (NERL, 2009).

2.2.2 Flash Point Determination

Hshieh proposed an empirical correlation for the estimation of general organic compounds and organic silicon compounds:

$$FP = -54.37700 + 0.58830\,T_b + 0.00022\,T_b^2 \tag{2.12}$$

where FP is the flash point in °C, T_b in °C is the boiling temperature (Catoire *et al.*, 2005).

Metcalfe proposed a unique empirical equation which depends on density of pure liquid

$$FP = -84.7940 + 0.6208\,T_b + 37.8127\rho \tag{2.13}$$

FP is the flash point in °C, T_b is the boiling temperature in °C, and ρ is the liquid mass density expressed in g/cm^3(Catoire *et al.*, 2005).

Catoire and Naudet proposed an empirical equation for estimating the flash points (FPs) at atmospheric pressure of pure compounds:

$$FP = 1.477\,T_b^{0.74686} * \Delta H^{\circ\,0.16845}_{vap} * c^{0.05948} \tag{2.14}$$

Where FP is the flash point in K, T_b is the boiling point of the compound expressed in K, $\Delta H^{\circ}{}_{vap}$ the standard enthalpy of vaporization at 298.15 K of the compound expressed in kJ. mol^{-1}, and c the number of carbon atoms in the fuel molecule (Catoire, *et al*., 2006; Rowley, *et al*., 2010).

2.3 Mass Density

Fuel mass density (ρ) is the unit of mass per unit of volume. Fuel mass density directly affects fuel performance, such as cetane number, heating value and viscosity which are strongly connected to mass density (Barabas, 2011).

$$\rho = \frac{M}{V} \tag{2.16}$$

where M is the mass of the fuel, V is the volume of the fuel. Density is strongly influenced by temperature. The vegetable oil density decreases linearly with increasing temperature. This relationship can be expressed mathematically as

$$\rho = a + b\,T \qquad (2.17)$$

where ρ is the mass density, a and b are correlation parameters, T is the temperature in °C (Rodenbush *et al*., 1999).

2.4 Refractive Index

The index of refraction for a substance is the ratio of the speed of light in empty space c to the speed of light in the substance v and mathematically it is written as

$$n = \frac{c}{v} \qquad (2.18)$$

Where n is the refractive index (Pedrotti *et al*., 2007).

Chapter Three

Methodology

The dynamic viscosity and density of the biodiesel are measured over range of temperature and different percentages of biodiesel and diesel, to reach the standard values of biodiesel kinematic viscosity which are in the range of [3.5-5 mm^2/s] at 40 ºC, and standard values of density at 15ºC which are in the range [0.86-0.90 g/cm^3]. Flash point also is measured and compared with the standard value which is 101ºC at least. Finally, refractive index is measured at different temperature degrees (Palestine Standards Institution, 2014).

3.1 Samples Preparation

Every sample is prepared such that it contains 80 ml with different percentages of biodiesel and diesel. Biodiesel prepared from waste oil, it is produced in Palestine. Diesel is obtained from gas station licensed from Palestinian General Petroleum. The percentage of samples is given in Table (3.1).

Table (3.1) Percentages of biodiesel and diesel fuel used in preparing samples

Biodiesel Blend	Biodiesel		Diesel	
	Percentage	Amount(ml)	Percentage	Amount(ml)
B100	100%	80	0%	0
B90	90%	72	10%	8
B80	80%	64	20%	16
B76	76%	60.8	24%	19.2
B72	72%	57.6	28%	22.4
B71	71%	56.8	29%	23.2
B70	70%	56	30%	24
B69	69%	55.2	31%	24.8
B68	68%	54.4	32%	25.6
B65	65%	52	35%	28
B60	60%	48	40%	32
B50	50%	40	50%	40
B40	40%	32	60%	48
B30	30%	24	70%	56
B20	20%	16	80%	64
B10	10%	8	90%	72
B0	0%	0	100%	80

The basic measured characteristics of biodiesel and diesel used in this study are given in table (3.2).

Table (3.2) Basic measured characteristics of biodiesel and diesel

Characteristics	Biodiesel	Diesel
Kinematic viscosity at 40 (ºC) in (cSt)	6.74	3.54
Density at 15 (ºC) in (gm/cm^3)	0.8555	0.7949
Refractive index at 27(ºC)	1.4557	1.4579
Flash point in (ºC)	134.1	68.0

3.2 Apparatus and Measurements

3.2.1 Viscosity

A Brookfield Viscometer Model DV-I+ with UL adapter is used to measure the dynamic viscosity. It consists of a set of seven spindles (RV SPINDLE SET) with accuracy ± 1%. The spindles measure viscosity range from 1 up to 13300000 cP. The rotational speeds of the spindles are two set. The first is: 0.0, 0.3, 0.6, 1.5, 3, 6, 12, 30, 60 RPM and the second set is: 0.0, 0.5, 1, 2, 2.5, 4, 5, 10, 20, 50, 100 RPM. UL adapter is used to make accurate measurements with low viscosity. It is used to measure viscosity ranges from 1 up to 2000. A water jacket is provided to control the temperature of the sample. Brookfield Viscometer is shown in Fig. (3.1)

Fig. (3.1) A Brookfield Viscometer Model DV-I+ with UL adapter

Temperature Apparatus:

Temperature was measured using Digital Prima Long Thermometer Fig. (3.2) with accuracy ±1% which measures temperature ranges from –50°C up to +200°C

Fig. (3.2) Digital Prima Long Thermometer

3.2.2 Density

HX-Z Electronic Balance is used to measure the mass with accuracy ± 0.1 % , it is shown in Fig.(3.3).

Fig. (3.3) HX-Z Electronic Balance

Pycnometer:10 ml glass bottle with stopper, was used to keep the volume constant. The Pycnometer was weighed empty and then weighted full of biodiesel. The difference between the two weights was divided by 10 ml to get the density. To measure the density at different temperature the pycnometer was put in hot or cold water bath. Pycnometer is shown in Fig.(3.4).

Fig. (3.4) Pycnometer

3.2.3. Refractive Index

The refractive index of the biodiesel samples was measured by using Boeco digital refractometer Fig. (3.5). The measurements were taken at three different temperatures, 15 ºC, 27 ºC, and 40 ºC.

Fig. (3.5) Boeco digital refractometer

3.2.4 Flash Point:

The flash point of biodiesel is measured by flash point tester which consists of 80 ml closed copper cup, heater, and a source that gives continuous sparks. The source that gives continuous sparks consists of a battery connected to small engine, disporater, coil, and spark plug. The engine is used to rotate a disporater , which is used to fractionate the current to electrical pulses. A coil is used to amplify the electrical pulses, and spark plug is used to create sparks inside the cup. Biodiesel sample is heated and the vapor accumulated inside the cup, at the moment that the vapor was sufficient to ignite the flash light noticed, and the temperature measured. Flash point tester is shown in Fig.(3.6)

Fig. (3.6) Flash point tester

3.3 Standards Values

The European and American standards values for density, kinematic viscosity and flash point of biodiesel are given in Table (3.3)

Table (3.3) The European and American standards values for biodiesel properties (NREL, 2009; Palestine Standards Institution, 2014)

Property	European / Palestinian standards	American standards
Mass density at 15 ºC	0.86-0.90 g/cm^3	————
Kinematic viscosity at 40 ºC	3.5-5 mm^2/s	1.9-6 mm^2/s
Flash point	101ºC at minimum	93 ºC at minimum

3.4 Statistical analysis

The obtained results were tabulated and statistically analyzed. The statistical analysis of the data was done by using Microsoft Office Excel. The equations were fitted using three parameters:

1. The coefficient of determination R^2 gives the proportion of the variance of one variable that is predictable from the other variable.
2. Percentage of average absolute deviation (AAD%) of the data. The AAD% indicates how the calculated values are close to experimental values. The AAD% is given by the following equation :

$$\mathrm{AAD\%} = \left(\frac{1}{\mathrm{N}}\sum \frac{\eta_{\mathrm{experimental}} - \eta_{\mathrm{calculated}}}{\eta_{\mathrm{experimental}}}\right) \times 100\% \qquad (3.1)$$

Where N is the number of experimental points, $\eta_{\mathrm{experimental}}$ the experimental viscosity and $\eta_{\mathrm{calculated}}$ the calculated viscosity (Edreder *et al.,* 2012).

3. standard deviation (SD): A measure of the dispersion of a the calculated data from the experimental data

$$\mathrm{SD} = \sqrt{\frac{1}{\mathrm{N}}\sum (\eta_{\mathrm{experimental}} - \eta_{\mathrm{calculated}})^2} \qquad (3.2)$$

Where N is the number of experimental points, $\eta_{\text{experimental}}$ is the experimental viscosity and $\eta_{\text{calculated}}$ is the calculated viscosity (Dabir *et al.*, 2007).

Chapter Four

Data and Analysis

4.1 Density Results

The density is measured for all samples at three temperature degrees, the overall density results are given in Table (4.1). The density results are tabulated according to percentages of biodiesel in sample.

Table (4.1) Measured densities (gm/cm^3) of biodiesel samples at different percentages and different temperature

Biodiesel Blend	Density at 15 ºC gm/cm^3	Density at 27 ºC gm/cm^3	Density at 40º C gm/cm^3
B100	0.856	0.841	0.836
B90	0.845	0.839	0.827
B80	0.842	0.834	0.821
B76	0.841	0.827	0.821
B72	0.838	0.826	0.819
B71	0.839	0.825	0.818
B70	0.839	0.824	0.818
B69	0.833	0.823	0.815
B68	0.827	0.822	0.815
B65	0.832	0.822	0.813
B60	0.831	0.819	0.812
B50	0.820	0.813	0.806
B40	0.819	0.807	0.806
B30	0.811	0.800	0.790
B20	0.806	0.794	0.788
B10	0.800	0.786	0.785
B0	0.795	0.784	0.777

The maximum measured value of biodiesel density at 15 ºC is 0.856 gm/cm^3 for B100 biodiesel blend and the minimum value at15 ºC is 0.800 gm/cm^3 for B10 biodiesel blend so the range is (0.800 - 0.856) (gm/cm^3).The standard values of biodiesel blend density at 15 ºC are in the range (0.860 – 0.900) (gm/cm^3). The standard values of biodiesel blend density do not coincide with the measured values. The relationship between density and biodiesel percentage at 15 ºC is given in Fig.(4.1)

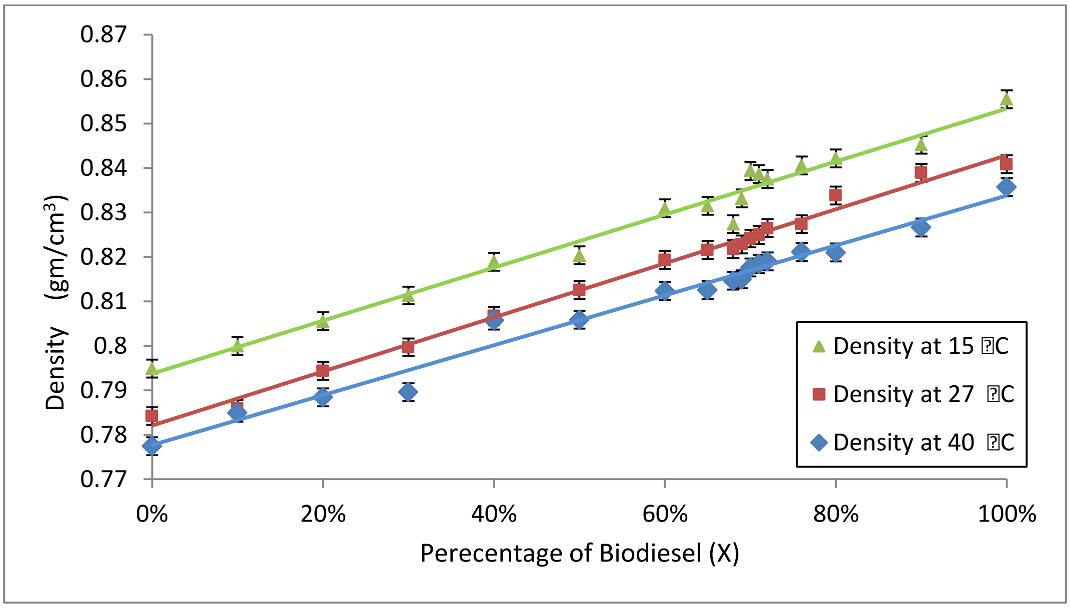

Fig. (4.1) Measured densities as function of temperature of all biodiesel samples at 15 ºC, 27 ºC, and 40 ºC

Fig.(4.1) Density versus percentage of biodiesel at 15 ºC

The density shows a linear proportional relationship with percentage of biodiesel. The linear relation at 15 ºC is described by Eq. (4.1.a) with coefficient of determination R^2 equals 0.9779.

$$\rho = 0.0596\ X + 0.7938 \tag{4.1.a}$$

The linear relation at 27 ºC is described by Eq. (4.1.b) with coefficient of determination R^2 equals 0.9925.

$$\rho = 0.0608\ X + 0.7821 \tag{4.1.a}$$

The linear relation at 40 ºC is described by Eq. (4.1.c) with coefficient of determination R^2 equals 0.9811.

$$\rho = 0.0561 X + 0.7777 \tag{4.1.c}$$

The relationship between biodiesel density and temperature for B71 is illustrated in Fig.(4.2).

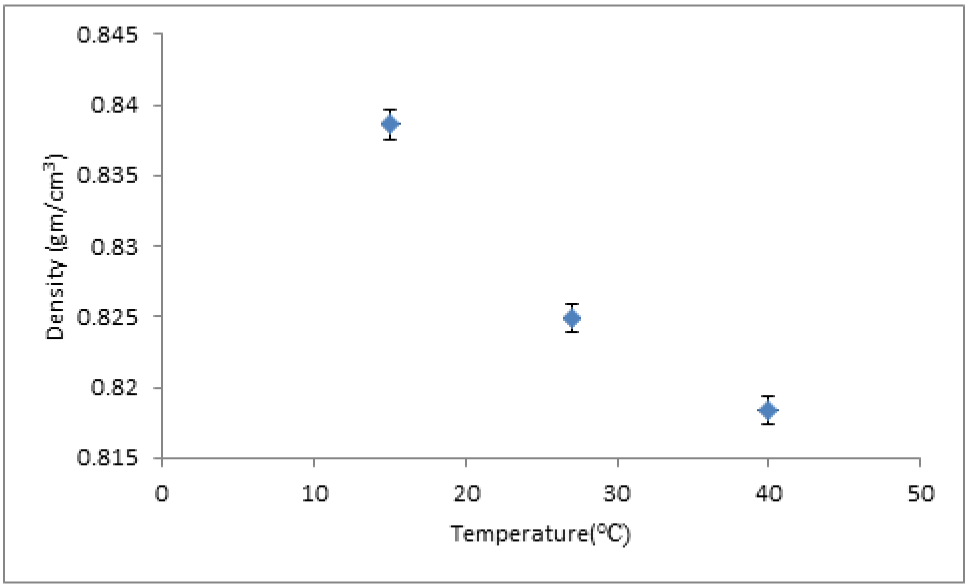

Fig. (4.2) Measured densities as function of temperature for sample B71

4.2 Refractive Index Results

The refractive indices of biodiesel for all samples were measured at three different temperature degrees, the values measured are given in Table (4.2).

Table (4.2) Measured refractive indices of biodiesel samples of different percentages of biodiesel at T = 15ºC, T = 27ºC, andT = 40ºC

Biodiesel Blend	Refractive Index at (15ºC)	Refractive Index at (27ºC)	Refractive Index at (40ºC)
B100	1.4574	1.4557	1.4542
B90	1.4574	1.4567	1.4554
B80	1.4582	1.4563	1.4557
B76	1.4575	1.4565	1.4555
B72	1.4579	1.4563	1.4561
B71	1.4573	1.4562	1.4550
B70	1.4580	1.4565	1.4553
B69	1.4578	1.4563	1.4561
B68	1.4582	1.4560	1.4549
B65	1.4584	1.4562	1.4556
B60	1.4581	1.4569	1.4556
B50	1.4583	1.4559	1.4558
B40	1.4586	1.4562	1.4551
B30	1.4569	1.4564	1.4559
B20	1.4579	1.4566	1.4562
B10	1.4584	1.4574	1.4563
B0	1.4586	1.4579	1.4563
Average	1.4579	1.4565	1.4556

The average value of the refractive indices of biodiesel is 1.4567. The range of refractive indices values of all samples extends from 1.4542 to 1.4586. The refractive indices values decrease with temperature increases for the same sample. The relations between refractive indices and temperature of biodiesel samples B100, B50, B10 are shown in Fig.(4.3).

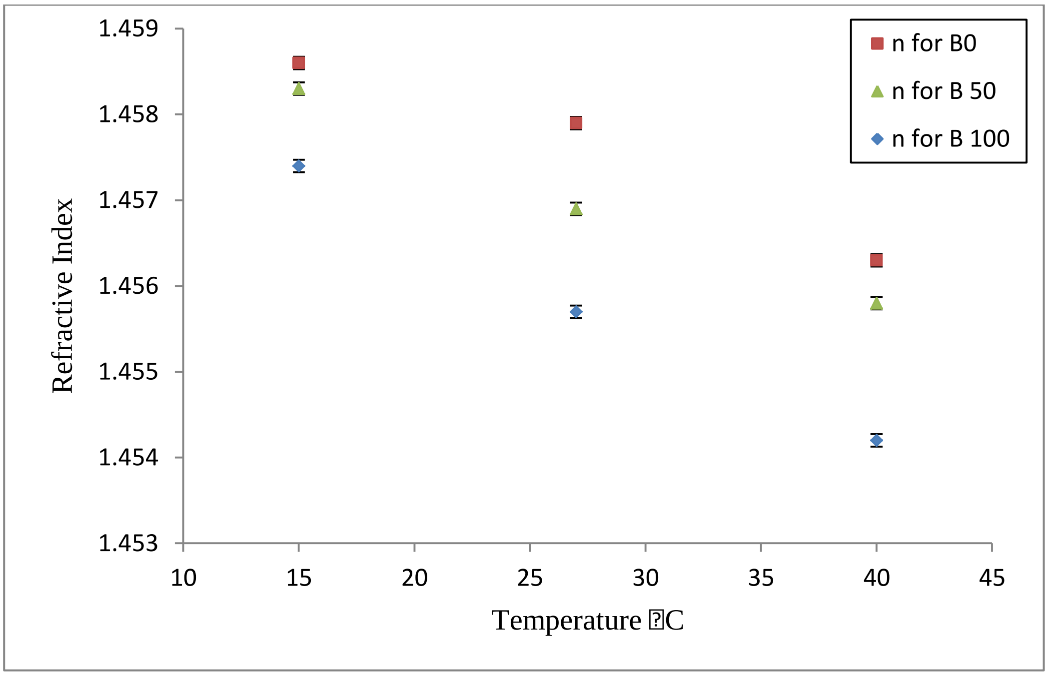

Fig.(4.3) Measured refractive indices versus temperature for B0, B50, and B100

Fig.(4.3) shows the relationship between refractive indices and temperature for three selected samples of different percentages of biodiesel B10, B50, and B100. The relations of the three samples show that the refractive indices values decrease with temperature increases.

The relations between refractive indices and temperature for the samples (B90, B80, B76, B72, B71, B70, B69, B68, B65, B60, B40, B30, B20, andB0) are shown in appendix(B).

4.3 Flash Point Results

4.3.1 Analysis of Experimental Data

The flash points and boiling points were measured for all samples. The results are recorded in the Table (4.3).

Table (4.3) Measured flash point and boiling point.

Biodiesel Blend	Flash Point ºC	Boiling Point
B100	134.1	197.1
B90	130.9	191.3
B80	118.4	183.8
B76	116.7	181.3
B72	115..8	180.2
B71	115.3	179.9
B70	115.0	179.6
B69	114.8	178.0
B68	114.5	177.5
B65	113.3	175.7
B60	112.8	174.3
B50	103.7	166.6
B40	103.4	165.2
B30	96.6	157.9
B20	95.1	156.3
B10	86.5	150.9

The maximum flash point is 134.1ºC measured for B100 biodiesel sample, and the minimum is 86.5 ºC measured for B10 biodiesel sample. The European and Palestinian standard flash point values of biodiesel are 101 ºC at minimum, and the American standard flash point values are 93 ºC at minimum. The European and Palestinian standard values of biodiesel flash point coincide with measured one for samples contain more than 40% biodiesel. American standard values of the flash point coincide with measured one for all samples contain more than 20% biodiesel. The relationship between flash points and percentages of biodiesel in the samples is shown in Fig.(4.4).

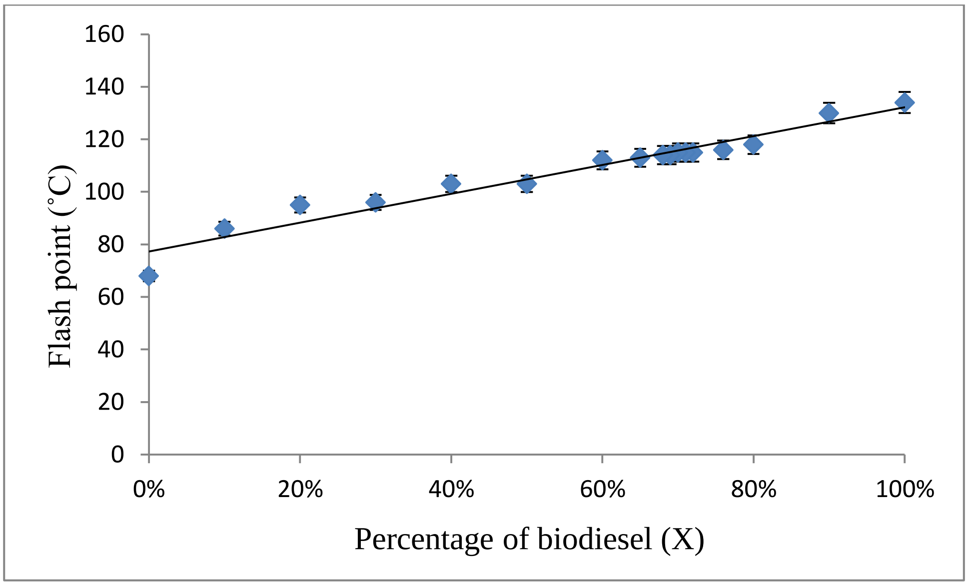

Fig. (4.4) Measured flash points versus percentage of biodiesel

4.3.2 Flash Point and Theoretical Prediction

The experimental results of flash point were compared with calculated values from equations obtained by Hshieh and Metcalfe. The percentage of absolute deviations AAD% and standard deviation SD between the measured and theoretical data were calculated.

The Hshieh's equation used to fit the experimental data in this study is

$$FP = -54.377 + 0.5883\, T_b + 0.00022\, T_b^2 \qquad (2.12)$$

Where FP in ºC is the flash point temperature, T_b in °C is the boiling temperature. The measured and theoretical values of flash point were calculated from equation (2.12) are given in Table (4.4).

Table (4.4) Measured and calculated values of flash points using Hsheih's equation

Sample Blend	Boiling Point	Calculated Flash Point Eq.(2.12)	The Measured Flash Point
B100	197.1	70.1	134.1
B90	191.3	66.2	130.9
B80	183.8	61.2	118.4
B76	181.3	59.5	116.7
B72	180.2	58. 8	115.8
B71	179.9	58.6	115.3
B70	179.6	58. 4	115.0
B69	178.0	57.3	114.8
B68	177.5	57.0	114.5
B65	175.7	55. 8	113.3
B60	174.3	54.8	112.8
B50	166.6	49.7	103.7
B40	165.2	48.8	103.4
B30	157.9	44.0	96.6
B20	156.3	42.9	95.1
B10	150.9	39.4	86.5
AAD%	50.8%		
SD	56.7		

The value of AAD % is 50.8%. The value of AAD % is very high value which means that the equation of Hshieh does not represent a good fit for the measured results. Fig. (4.5) shows the measured and calculated flash points using Hsheih’s equation of biodiesel samples.

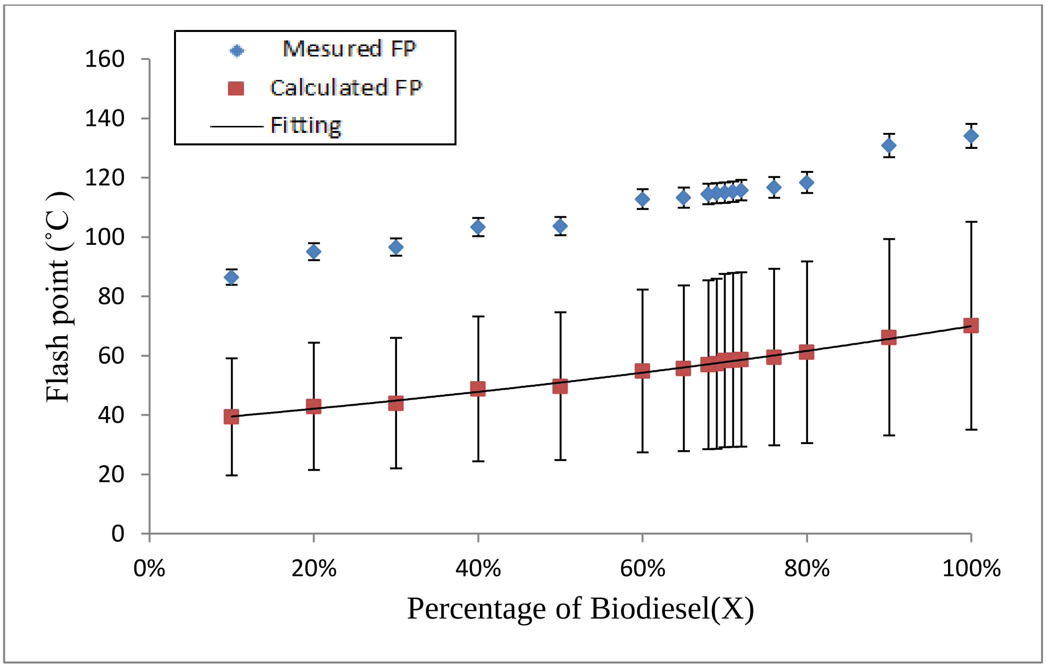

Fig.(4.5) Measured and calculated values of flash points using Hsheih's equation of all Biodiesel samples

The Metcalfe 's equation used to fit the experimental data of this work is

$$FP = -84.794 + 0.6208\,T_b + 37.8127\rho \qquad (2.14)$$

Where FP in °C is the flash point temperature, T_b in °C is the boiling temperature, ρ is the liquid density expressed in g/cm^3.The experimental and theoretical values of flash point calculated from equation (2.14) are given in Table(4.5).

Table (4.5) Measured and calculated values of flash points using Metcalfe's equation

Biodiesel Blend	Boiling Point	Density g/cm^3	FP Clalculated from. Metcalfe Eq.	Measured FP
B100	197.1	0.8440	69.5	134.1
B90	191.3	0.8369	65.6	130.9
B80	183.8	0.8323	60.8	118.4
B76	181.3	0.8297	59.1	116.7
B72	180.2	0.8277	58.4	115..8
B71	179.9	0.8273	58.2	115.3
B70	179.6	0.8270	58.0	115.0
B69	178.0	0.8236	56.9	114.8
B68	177.5	0.8212	56.6	114.5
B65	175.7	0.8219	55.4	113.3
B60	174.3	0.8209	54.4	112.8
B50	166.6	0.8129	49.4	103.7
B40	165.2	0.8104	48.4	103.4
B30	157.9	0.8002	43.5	96.6
B20	156.3	0.7961	42.3	95.1
B10	150.9	0.7903	38.8	86.5
AAD%	51.3%			
SD	57.1			

The value of AAD% is very high 51.3%. The high value of AAD% means that the equation of Metcalfe does not represent a good fit for the measured results. Fig. (4.6) shows the measured and calculated flash points of biodiesel samples using Metcalfe’s equation.

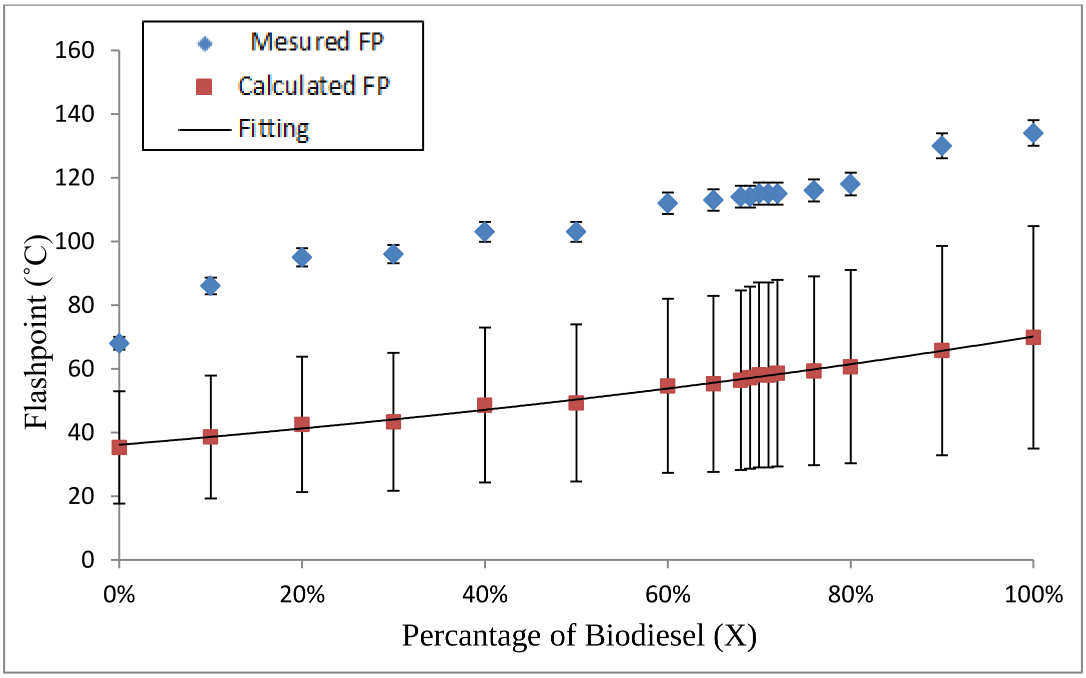

Fig.(4.6) Measured and calculated values of flash points using Metcalfe's equation of all Biodiesel samples

Using Metcalfe's and Hsheih's equations failed to determine the flash point temperature. New proposed equations should be imposed to describe the experimental data. In the following section, new equations are proposed to determine the flash point temperature.

4.3.3 Our Proposed Equations

a. Exponential Formula

The measured flash points are fitted using the proposed formula (4.2)

$$FP = 23.189\, e^{0.009T_b} \qquad (4.2)$$

Where FP is the flash point in ºC is, T_b is the boiling point in ºC. The results of this fitting in addition to experimental values, AAD%, and SD are given in Table 4.6.

Table (4.6) Measured and the calculated values of flash point using our proposed equation(exponential formula)

Biodiesel Blend	Boiling Point (ºC)	Measured FP (ºC)	Proposed FP (ºC)*
B100	197.1	134.1	136. 7
B90	191.3	130.9	129.7
B80	183.8	118.4	121.3
B76	181.3	116.7	118.6
B72	180.2	115..8	117.4
B71	179.9	115.3	117.1
B70	179.6	115.0	116.8
B69	178.0	114.8	115.1
B68	177.5	114.5	114.6
B65	175.7	113.3	112.7
B60	174.3	112.8	111.3
B50	166.6	103.7	103.9
B40	165.2	103.4	102.6
B30	157.9	96.6	96.0
B20	156.3	95.1	94.7
B10	150.9	86.5	90.2
AAD%	1.2%		
SD	1.7		

***The calculated FP from our proposed equation (4.2)**

The value of AAD% is 1.2%; it is very small compared to AAD% result from Metcalfe's and Hsheih's equations. This result implies that the proposed formula (4.2) is suitable to predict flash point temperature. Fig.(4.6) shows the experimental and calculated values of the flash point.

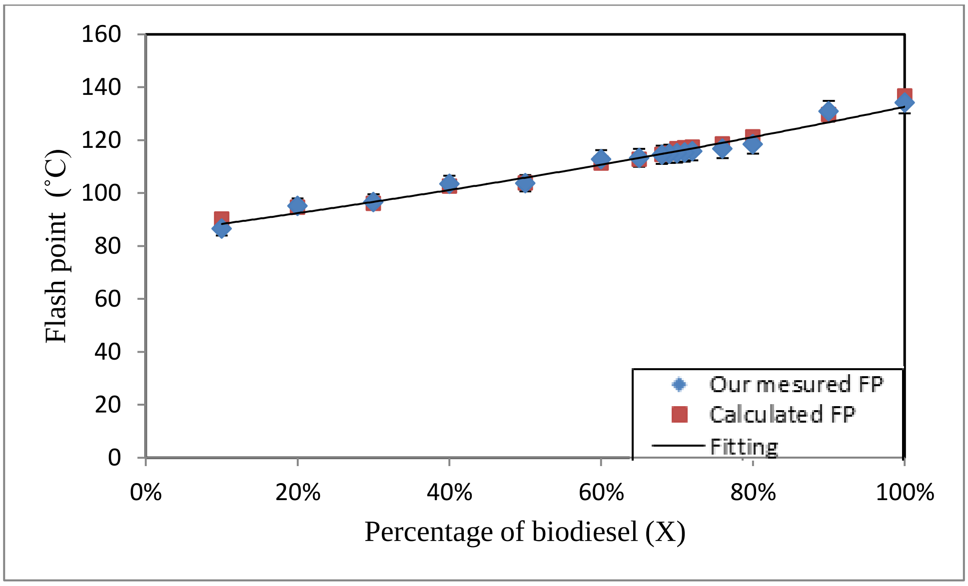

Fig. (4.7) Measured and calculated values of flash points using exponential formula Eq.(4.2)

Fig(4.7) shows that the measured values of the flash point decrease exponentially, and shows that the measured values of flash point agreable with the calculated value of flash point from the exponential formula Eq.(4.2).

b. Linear Formula

The measured flash points temperature degrees are fitted using the proposed linear formula:

$$FP = 1.1248\, T_b - 103.9907\, \rho \qquad (4.3)$$

Where FP is the flash point in ºC, T_b is the boiling point in ºC, and ρ is the mass density in gm/cm^3. The fitting values are given in Table (4.7).

Table (4.7) Measured and calculated values of flash point using our proposed equation (linearformula)

Biodiesel Blend	Boiling Point (ºC)	Measured FP (ºC)	Proposed FP (ºC)*
B100	197.1	134.1	133.9
B90	191.3	130.9	128.1
B80	183.8	118.4	120.2
B76	181.3	116.7	117.6
B72	180.2	115..8	116.6
B71	179.9	115.3	116.3
B70	179.6	115.0	116.0
B69	178.0	114.8	114. 6
B68	177.5	114.5	114.3
B65	175.7	113.3	112. 2
B60	174.3	112.8	110.7
B50	166.6	103.7	102.9
B40	165.2	103.4	101.5
B30	157.9	96.6	94.4
B20	156.3	95.1	93.0
B10	150.9	86.5	87.6
AAD%	1.2%		
SD	1.5		

*** calculated flash point using proposed Eq. 4.3(linear formula)**

The value of AAD% is 1.2% and the value of SD is 1.5. The values of AAD% and SD are less than the value calculated from Metcalfe’s and Hsheih’s equations. Fig.(4.8) shows the experimental and calculated values of the flash point from linear formula.

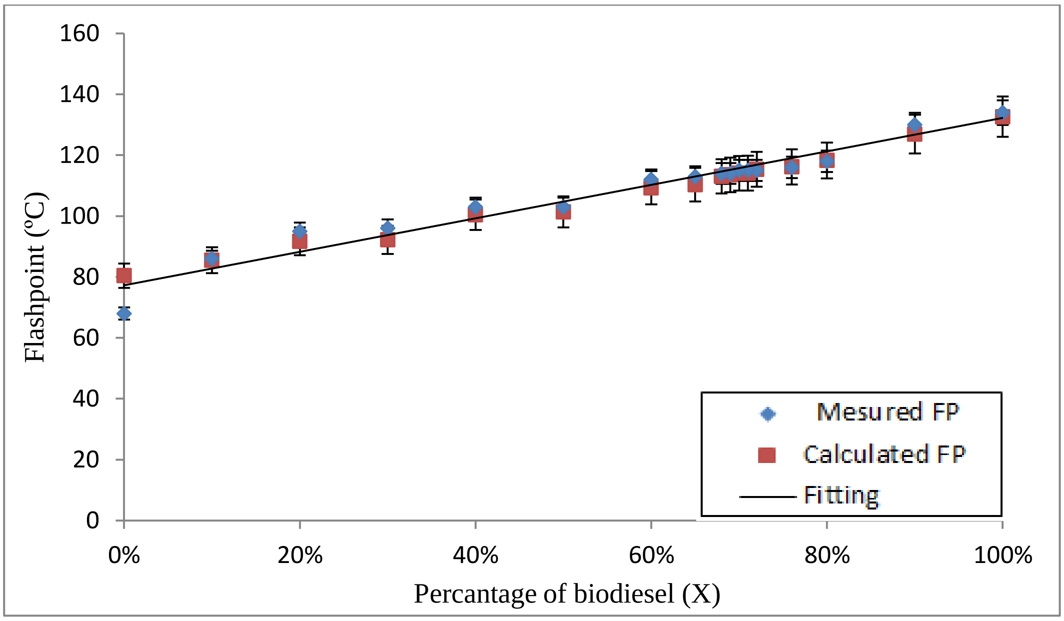

Fig. (4.8) Measured and calculated values of flash points using linear formula Eq. (4.3)

Fig (4.8) shows the measured and calculated values of the flash point from equation (4.3). They are close to each other which indicate a good prediction of flash point.

4.4 Viscosity Result

4.4.1 Analysis of Measured Data

The dynamic viscosity was measured for all samples at seven different temperature degrees. The results for B100 recorded at the Table (4.7).

Table (4.8) Results of dynamic viscosity of B100 sample for different temperature

T(ºC)	η (cP)
25.0	8.51
30.0	7.36
35.0	6.34
38.0	5.98
40.0	5.63
42.0	5.28
45.0	4.99

The dynamic viscosity decreases with temperature increases at a given percentage of biodiesel. The relationship between dynamic viscosity and temperature of B100 sample is shown in Fig.(4.9).

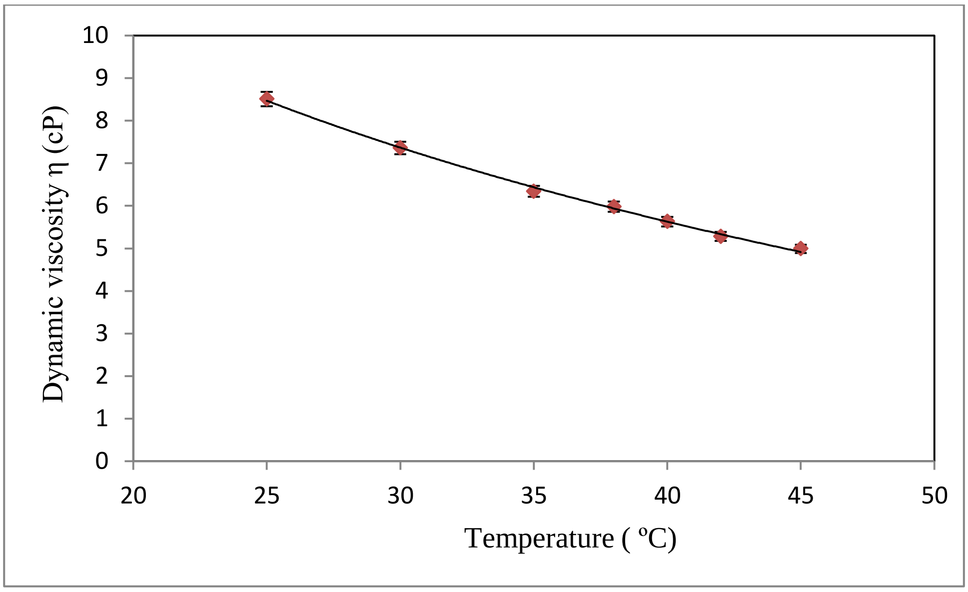

Fig.(4.9) Measured values dynamic viscosity as a function of temperature for B100 sample

The relation between dynamic viscosities and temperature for all samples are shown in the appendix C. The Kinematic viscosities of biodiesel samples were calculated at 40 ºC and tabulated in Table (4.9).

Table(4.9) Measured values of dynamic and kinematic viscosity at 40 ºC

Biodiesel Blend	Kinematic Viscosity at 40 ºC (cSt)	Dynamic Viscosity at 40 ºC(cP)
B100	6.74	5.63
B90	5.73	4.74
B80	5.23	4.29
B76	5.14	4.22
B72	5.08	4.16
B71	5.00	4.09
B70	4.93	4.03
B69	4.83	3.94
B68	4.69	3.82
B65	4.63	3.75
B60	4.57	3.71
B50	4.53	3.65
B40	3.97	3.20
B30	3.93	3.10
B20	3.58	2.82
B10	3.57	2.80
B0	3.54	2.75

The minimum measured value of biodiesel kinematic viscosity at 40 ºC is 3.57 cSt for B10 biodiesel blend and the maximum value at 40 ºC is 6.74 cSt for B 100 biodiesel blend so the range is (3.57-6.74) (cSt). The standard value of kinematic viscosity of biodiesel at 40 ºC is in the range of (3.5-5) (cSt). The standard values of biodiesel kinematic viscosity coincide with the kinematic viscosity of samples contain less than72% biodiesel (Palestine Standards Institution, 2014). The relation between kinematic viscosity and percentage of biodiesel is shown in Fig. (4.10)

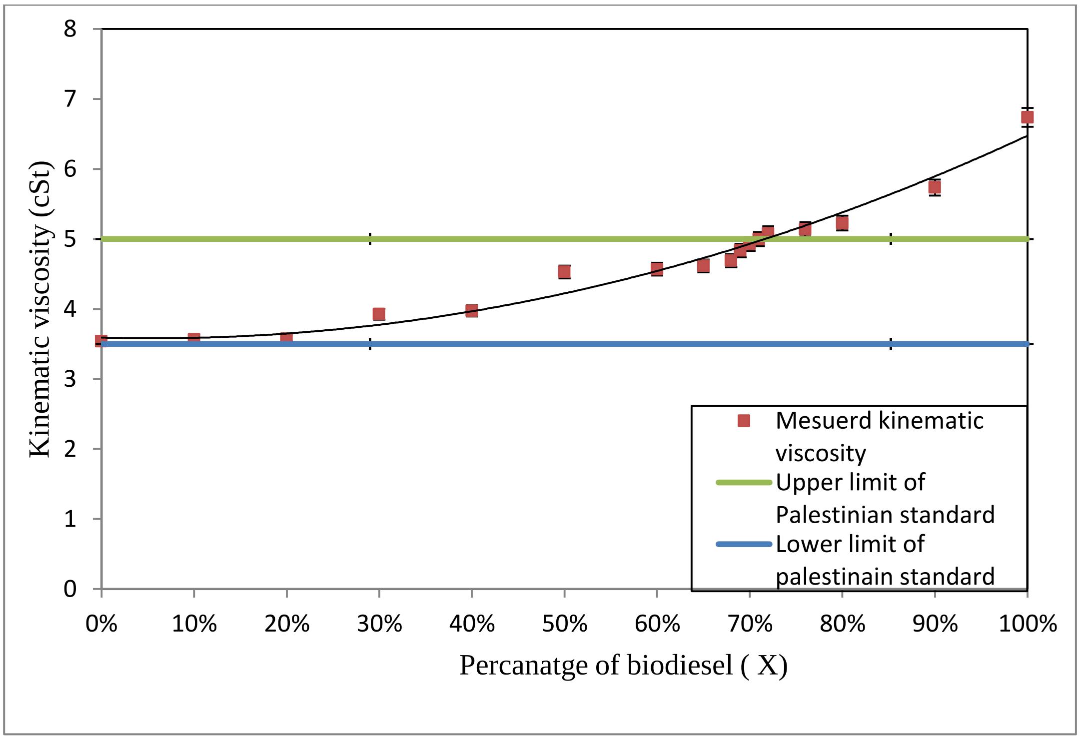

Fig.(4.10) The relationship between kinematic viscosity and percentage of biodiesel at 40 ºC

The kinematic viscosity increases as percentage of biodiesel increases as shown in Fig.(4.10) .

4.4.2 Theoretical Predictions of Viscosity Results

In this section, a new equation is proposed to describe the dynamic viscosity relationship of biodiesel versus temperature.

Logarithmic Formula

Two- constants logarithmic equation is proposed to describe the dynamic viscosity as a function of temperature

$$\eta = A\,Ln\,T + B \qquad (4.4)$$

Where η is the dynamic viscosity in cP, T is the temperature in ºC, and A, B are two specific constants for every percentage of blend biodiesel and diesel in cP. The values of A and B are given in Table 4.10

Table(4.10) The values of A and B constants which are given in Eq.(4.4)

Biodiesel Blend	A (cP)	B (cP)	R^2
B100	-6.045	27.929	0.9978
B90	-5.463	24.948	0.9976
B80	-4.719	21.703	0.9979
B76	-4.828	22.109	0.9915
B72	-4.705	21.586	0.9962
B71	-4.672	21.442	0.9966
B70	-4.563	21.046	0.9907
B69	-4.334	19.691	0.9747
B68	-3.910	18.265	0.9712
B65	-4.331	19.869	0.9884
B60	-4.117	19.004	0.9865
B50	-3.683	17.197	0.9988
B40	-3.179	14.924	0.9548
B30	-3.072	14.334	0.9763
B20	-3.558	16.002	0.9921
B10	-2.627	12.528	0.9908
B0	-1.920	9.854	0.9703

The experimental results of dynamic viscosity were compared with results obtained by logarithmic formula Eq.(4.4). The values of AAD%, and SD, of measured and theoretical data were calculated and given in Table (4.11) for sample B100.

Table (4.11) Measured and calculated values of dynamic viscosity for B100 sample from Eq.(4.4)

100% Biodiesel		
T (ºC)	Measured η in(cP)	Calculated η from Eq.4.4 in(cP)
25	8.51	8.47
30	7.36	7.37
35	6.34	6.44
38	5.98	5.94
40	5.63	5.63
42	5.28	5.33
45	4.99	4.92
AAD%	0.75%	
SD	0.05	

The value of AAD% is 0.75%, it is a small value. R^2 value is 0.9978 which means that 99.78 % of viscosity values can be expressed by Eq.(4.4). Fig.(4.11) shows the experimental and calculated values of the dynamic viscosity.

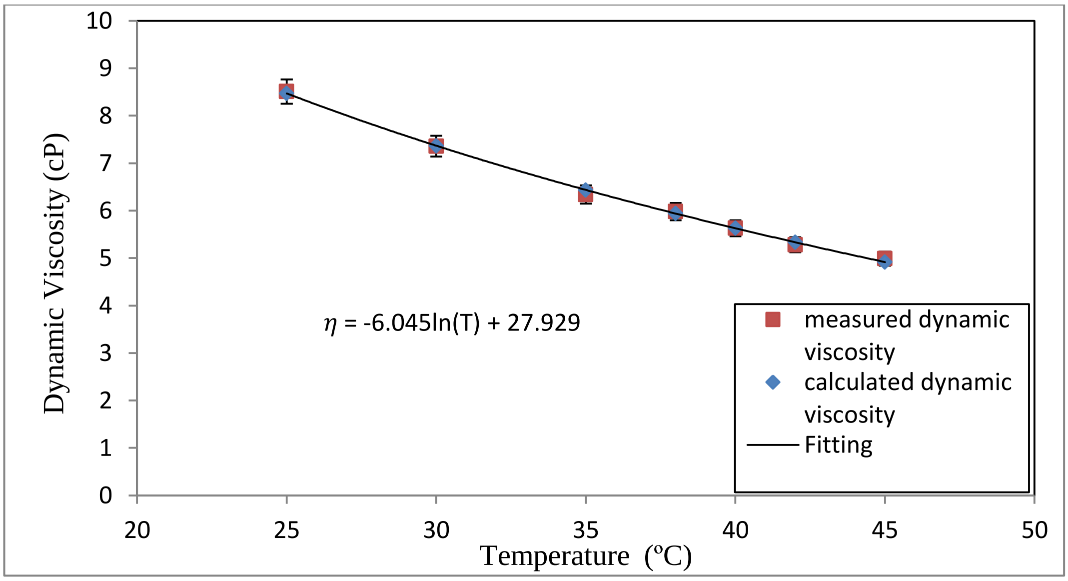

Fig.(4.11) Measured and calculated values of dynamic viscosity as a function of temperature for B100 sample from Eq.(4.4)

The measured and calculated values of the dynamic viscosity for B100 sample shown in Fig.(4.11) decrease in a logarithmic shape as temperature increases. The measured and calculated values of the dynamic viscosity for B71 is given in Table(4.12)

Table (4.12) Measured and calculated values of dynamic viscosity for B71 sample from Eq.(4.40

71% biodiesel		
T°C	Measured η (cP)	Calculated η (cP) from Eq.(4.4)
25.0	6.39	6.40
30.0	5.59	5.55
35.0	4.84	4.83
38.0	4.47	4.45
40.0	4.09	4.21
42.0	4.02	3.98
45.0	3.69	3.66
AAD%	0.91%	
SD	0.00	

The range of the measured dynamic viscosity values is (3.69 – 6.39) cP . The measured values decrease as temperature increases. The values of AAD% is 0.91%, SD is 0.00, and R^2 is 0.9966. These values are small. The relations between the measured and calculated values of dynamic viscosity as function of temperature for B71 are shown in Fig (4.12)

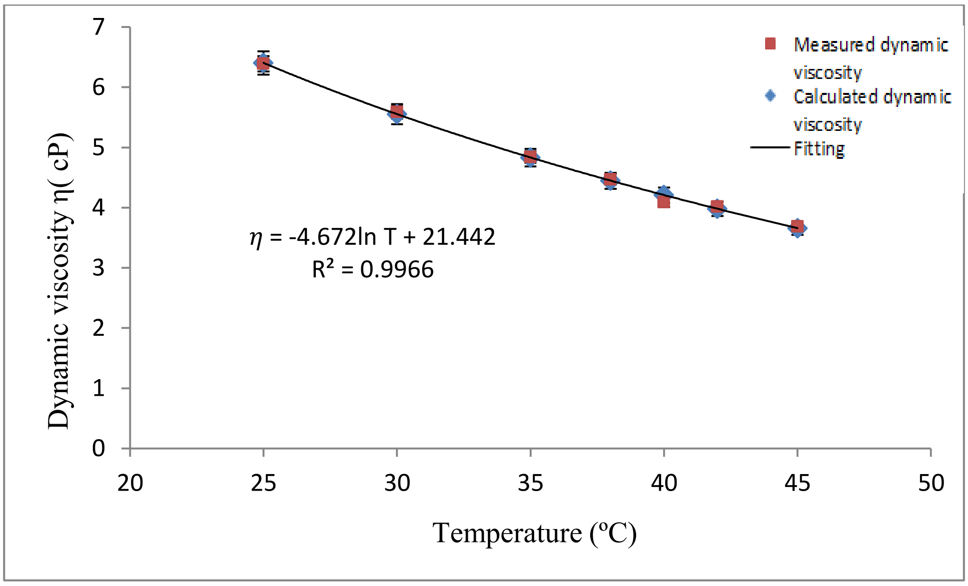

Fig.(4.12) Measured and calculated values of dynamic viscosity as a function of temperature for B71 sample from Eq.(4.4)

Fig.(4.12) shows that the dynamic viscosity of B71 sample decreases as the temperature increases, and shows that the measured and calculated values from the logarithmic equation are in agreement with each other . The measured and calculated values from the logarithmic formula Eq.(4.4) of dynamic viscosity of B0 sample are given in Table (4.13)

Table (4.13) Measured and calculated values of dynamic viscosity for B0 sample from Eq.(4.4)

0 % biodiesel		
T (ºC)	Measured η(cP)	Calculated η in (cP) from Eq.(4.4)
25.0	3.61	3.67
30.0	3.33	3.32
35.0	3.14	3.03
38.0	2.94	2.87
40.0	2.75	2.77
42.0	2.61	2.68
45.0	2.5	2.55
AAD%	1.87%	
SD	0.06	

The range of dynamic viscosity for B0 sample is (2.5-3.61) cP. The values of AAD%, SD, and R^2 are 1.87, 0.06, and 0.9703 respectively. The values of AAD% and SD for the samples B100, B71, B0 are comparable and close to each other which indicates that the logarithmic equation is acceptable. The relations between the measured and calculated values of dynamic viscosity with temperature are shown in Fig. (4.13).

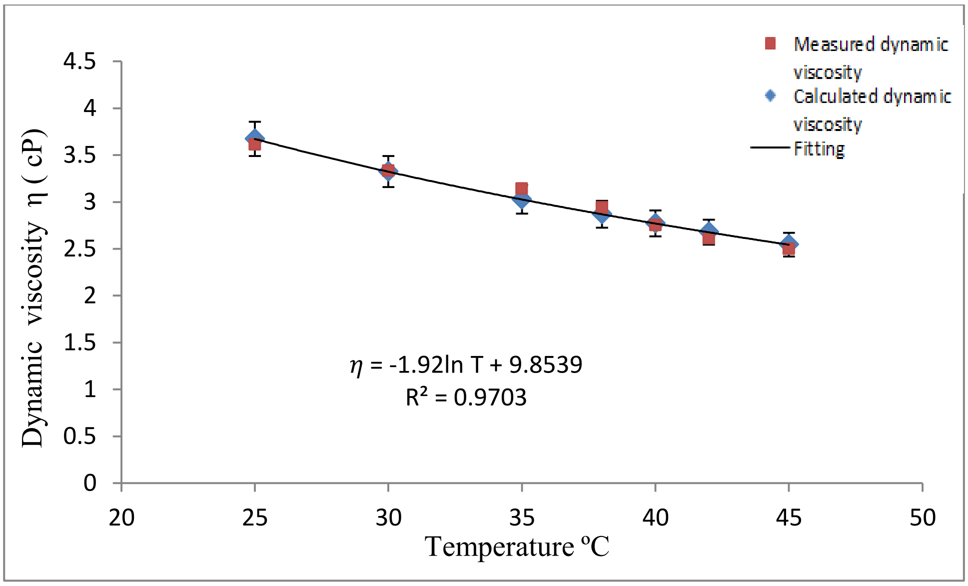

Fig.(4.13) Measured and calculated values of dynamic viscosity as a function of temperature for B0 sample from Eq.(4.4)

The relations in Fig.(4.13) show that the dynamic viscosity decreases in logarithm shape as the temperature increases for B0 sample. The measured and calculated values of dynamic viscosity from logarithmic Eq.(4.4) for the other samples (B90, B80, B76, B72, B70, B69, B68, B65, B60, B50, B40, B30, B20, and B10) are given in tables C.1-C.14 in Appendix C. The relation between dynamic viscosity as function of temperature for measured and calculated dynamic viscosity from logarithmic Eq.(4.4) are also given in Fig.(C.1-C.14).

Chapter Five

Discussion and Conclusion

5.1 Density

The biodiesel-diesel blend density increases as percentage of biodiesel increases in the sample. The biodiesel is denser than diesel because biodiesel has a higher degree of unsaturation. The degree of unsaturation of the molecule is an indicator of the number of double bonds present in its fatty acid chain, a higher number of double bonds representing a higher degree of unsaturation. Density increases as the degree of unsaturation increases.

The Biodiesel density decreases linearly as a function of temperature. As temperature of biodiesel increases, biodiesel particles speed up and spread out. This causes the biodiesel to expand, its volume increases. This causes the density to decrease with temperature.

The range of measured values of biodiesel density at 15 ºC is (0.800 - 0.856) (gm/cm^3). The standard value of biodiesel density at 15 ºC is in the range (0.860 – 0.900) (gm/cm^3). The range of measured values of biodiesel density does not agreeable with the range of standard values of density of biodiesel.

5.2 Refractive Index

The measured values of refractive indices decrease as temperature increases. High temperature makes the biodiesel less dense and less viscous; this causes light to travel faster in the biodiesel which makes the refractive index decreases

5.3 Flash Point

The measured values of flash points increase as the percentage of biodiesel in the sample increases. The value of flash point depends on the boiling point which increases as the molecular weight increases; so the flash point of biodiesel is higher than diesel as a result of increases in the molecular weight of the biodiesel.

Two theoretical predictions are tested to describe the relationship between flash point, boiling point, and density. The tested models are Hsheih and Metacalfe equations. The two models failed to predict the flash point temperature. Two equations are proposed (exponentioal and linear formulas) to describe the relation between flash point, boiling point, and density. The proposed equations presented the best fit for the experimental results. The equations are used to predict the flash points are given in table (5.1).

Table(5.1) The equations that predict the flash point with AAD% and SD values

Equation	Formula	AAD%	SD
Hshieh's Equation	$FP = -54.377 + 0.5883\,T_b + 0.00022\,T_b^2$	50.8%	56.7
Metcalfe's Equation	$FP = -84.794 + 0.6208\,T_b + 37.8127\rho$	51.3%	57.1
Our Proposed Exponential Formula	$FP = 23.189\,e^{0.009T_b}$	1.2%	1.7
Our Proposed Linear Formula	$FP = 1.1248\,T_b - 103.9907\,\rho$	1.2%	1.5

The values of AAD% and SD for the proposed linear and exponential formulas are much smaller than the other equations. The proposed equations are more suitable to predict the flash point of biodiesel.

5.4 Viscosity

Kinematic viscosity of biodiesel was studied as function of percentage of biodiesel at 40 ºC. The relation between kinematic viscosity and the percentage of biodiesel in the sample shows that the kinematic viscosity increases as the percentage of biodiesel increases in the sample, this is because biodiesel is more viscous than diesel. The higher viscosity of biodiesel refer to a main reason which is the higher molecular weight of the biodiesel than diesel (Amit, 2009). The measured values of kinematic viscosity coincide with the standard values of kinematic viscosity for samples contains less than 72% biodiesel.

The relation between dynamic viscosity and temperature was described by a logarithmic relation. The logarithmic relation presented good fit for the experimental results. The values of the coefficient of determination R^2 for all samples were in the range of (0.9548 - 0.9987) .

5.5 Standard Values

The standard values of biodiesel are compared with the measured values in order to find the best percentage that can be used to produce biodiesel which can be described as a renewable commercial fuel. Table (5.2) gives comparison between measured values and standard values of biodiesel.

Table (5.2) Comparison between the measured values and standard values of biodiesel

Property	European/ Palestinian Standards	Measured Values	Samples has Standard Properties
Mass Density at 15 ºC (g/cm^3)	0.860-0.900	0.800 - 0.856	No sample
Kinematic Viscosity at 40 ºC (mm^2/s)	3.50-5.00	3.54-6.74	B0-B71
Flash Point ºC	101.0 ºC at minimum	86.5-134.1	B40-B100

Table (5.2) gives that the samples contain (40% - 71%) biodiesel agree with flash point and Kinematic viscosity standard values of biodiesel. The sample contains 71% biodiesel and 29% petrodiesel is the best combination that agrees with the standard values of biodiesel

5.6 Future Studies

Future studies are needed to study the other properties of the biodiesel as cetane number, acid number, and phosphorus content. Some researches could be conducted to study the properties of other kinds of biodiesel for oils available in Palestine such as corn oil, sun flower oil, and biodiesel from animal fats.

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Appendix A

Density Results

The relation between density and percentage of biodiesel at 27 ºC is shown in Fig. (A.1)

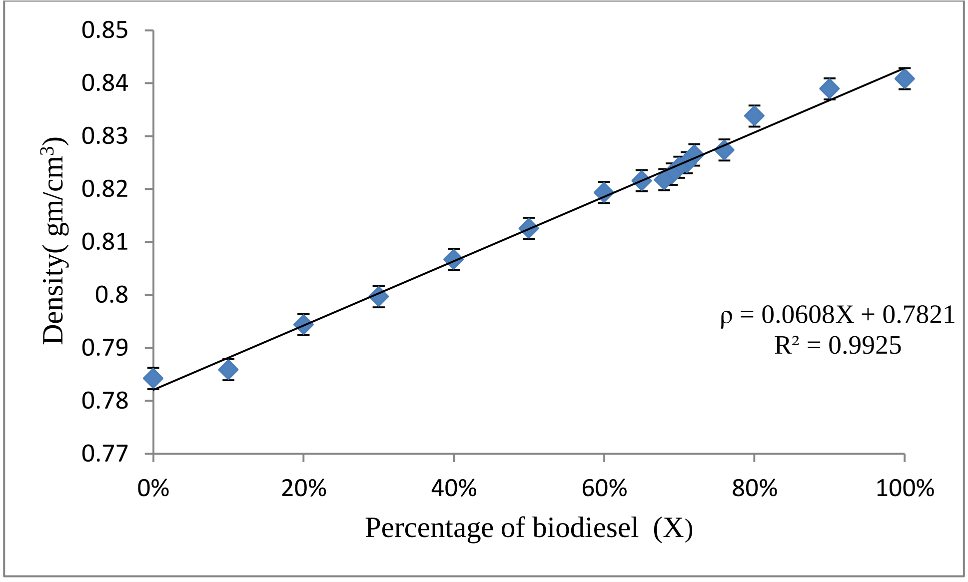

Fig.(A.1) Density versus percentage of biodiesel at 27 ºC

The density at 27 ºC increases as the percentage of biodiesel increases. Fig(A.1) shows a linear proportional relationship between the density and percentage of biodiesel with coefficient of determination R^2 equals 0.9925. The linear relation is described by Eq.

$$\rho = 0.0608X + 0.7821 \qquad (A.1)$$

The relation between density and percentage of biodiesel at 40 ºC is shown in Fig(A.2)

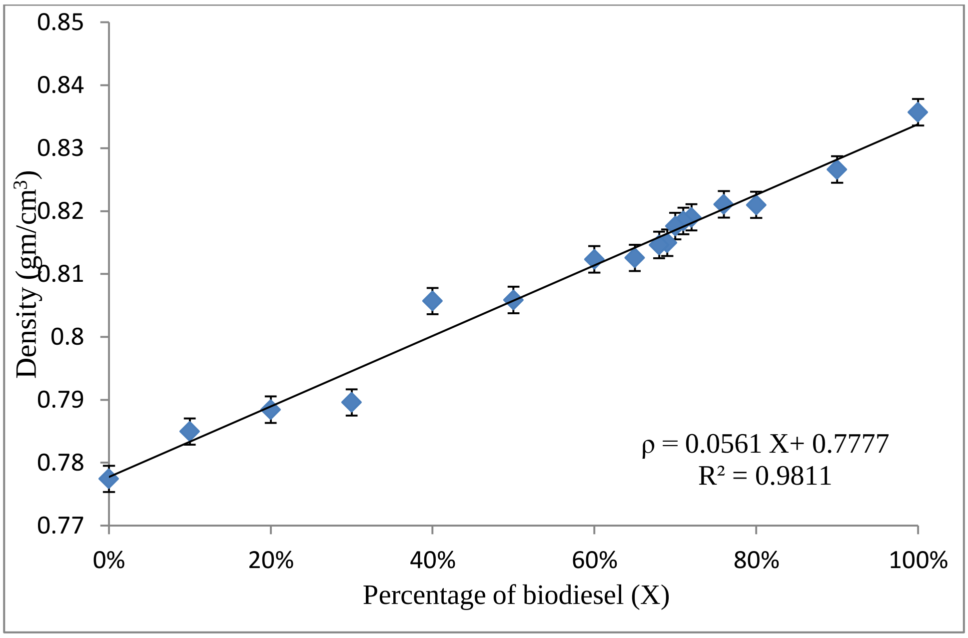

Fig. (A.2) Density versus percentage of biodiesel at 40 ºC

Fig.(A.2) shows that the density at 40 ºC linearly proportional to the percentage of biodiesel with coefficient of determination R^2 equals 0.9811. The linear relation is described by Eq.

$$\rho = 0.0561X + 0.7777 \qquad (A.2)$$

Appendix B

Refractive Index Results

The relations between refractive indices and temperature for B10, B20, B30, and B40 are shown in Fig.(B.1).

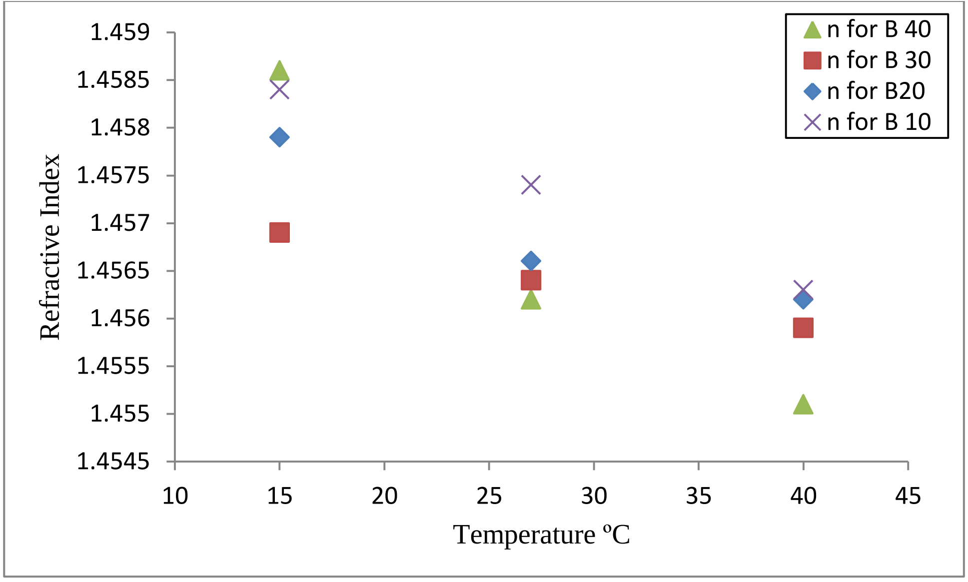

Fig.(B.1) Refractive index versus temperature for B10, B20, B30, and B40**.**

The relations illustrated in Fig.(B.1) show that the refractive indices decrease as temperature increases for B10, B20, B30, and B40**.** The relations between refractive indices and temperature for B90, B80, B76, B71, B65, and B60 are shown in Fig.(B.2).

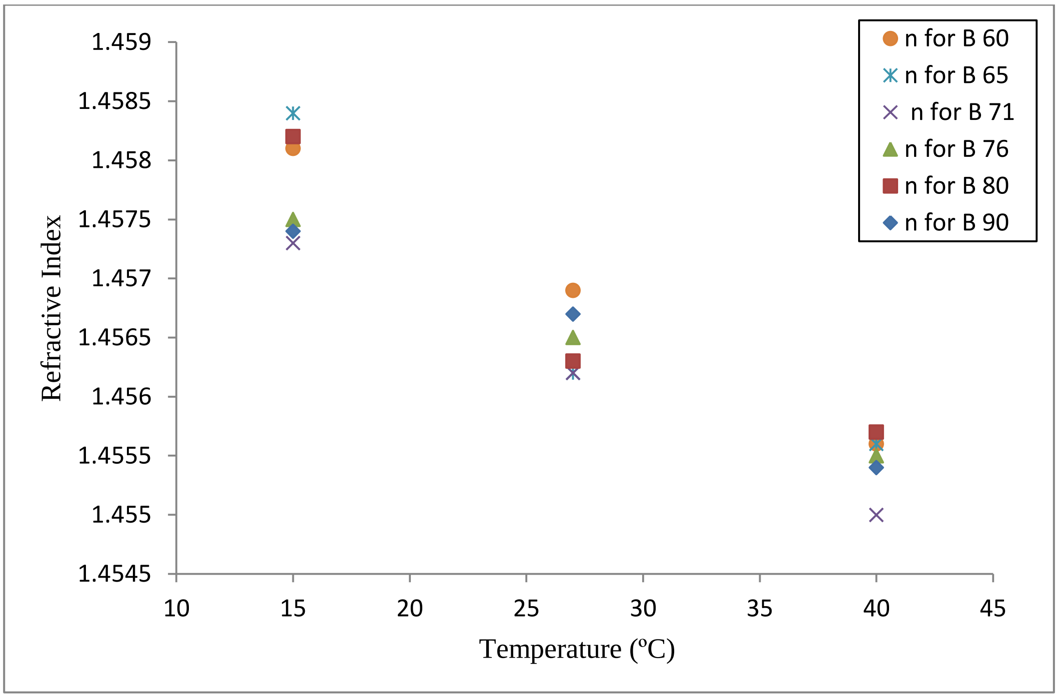

Fig. (B.2) Refractive index versus temperature for B90, B80, B76, B71, B65, and B60

The refractive indices of the samples B90, B80, B76, B71, B65, and B60 decrease as the temperature increases.

Appendix C

Viscosity Results

The measured values of the dynamic viscosities and calculated values of dynamic viscosities from logarithmic Eq. 4.4 (η = A LnT + B) for B90, B80, B76, B72, B70, B68, B65, B60, B50, B40, B30, B20, and B10 are given in Tables C.1 to C.14, these tables show the values of AAD% and SD. The relation between the dynamic viscosities and temperature for B90, B80, B76, B72, B70, B68, B65, B60, B50, B40, B30, B20, and B10 are shown in Fig. (C.1) to C.(14), also show the relation between the calculated values of dynamic viscosity and temperature.

C.1: Sample B90

Table (C.1) Measured and calculated values of dynamic viscosity for B 90 sample from Eq. (4.4)

90% biodiesel		
T (ºC)	Measured η in (cP)	Calculated η (cP) from Eq.(4.4)
25.0	7.30	7.39
30.0	6.46	6.40
35.0	5.57	5.56
38.0	5.06	5.11
40.0	4.74	4.83
42.0	4.53	4.57
45.0	4.16	4.19
AAD%	0.97%	
SD	0.06	

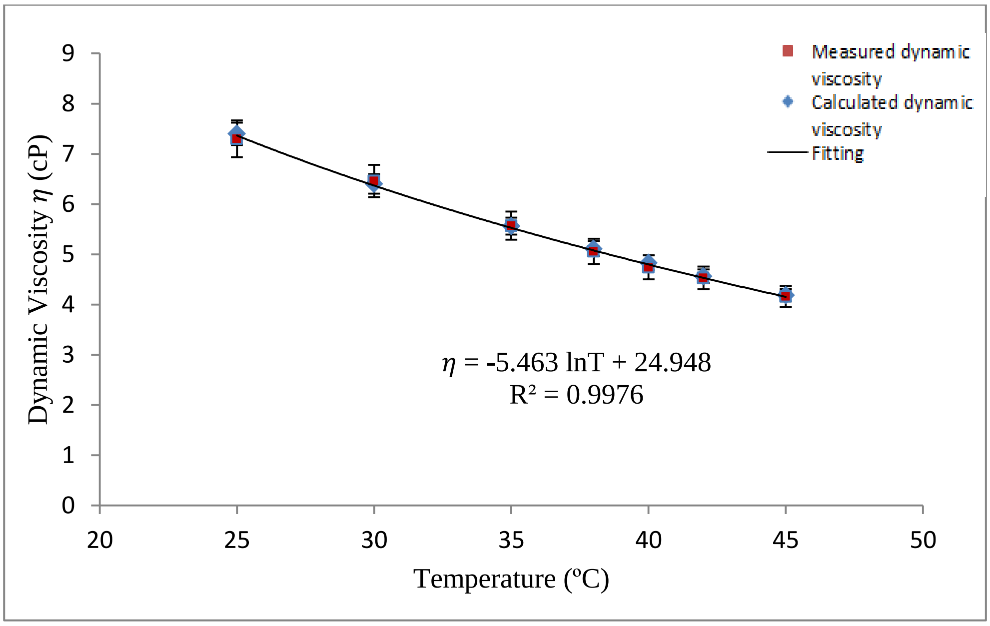

Fig.(C.1) Measured values and calculated values of dynamic viscosity asa function of temperature for B90 sample from Eq.(4.4)

Fig.(C.1) shows the relation between measured dynamic viscosity and temperature, it is a logarithmic relation can be described by Eq.(4.4). The values of A and B are -5. 463cP, 24.948cP respectively. Eq.(4.4)becomes.

$$\eta = -5.463 \text{ LnT} + 24.948$$

C.2: Sample B80

Table (C.2) Measured and calculated values of dynamic viscosity for B 80 sample from Eq. (4.4)

80% biodiesel		
T (ºC)	Measured η (cP)	Calculated η (cP) from Eq.(4.4)
25.0	6.46	6.52
30.0	5.73	5.66
35.0	4.96	4.94
38.0	4.58	4.55
40.0	4.29	4.31
42.0	4.07	4.08
45.0	3.71	3.75
AAD%	0.71	
SD	0.04	

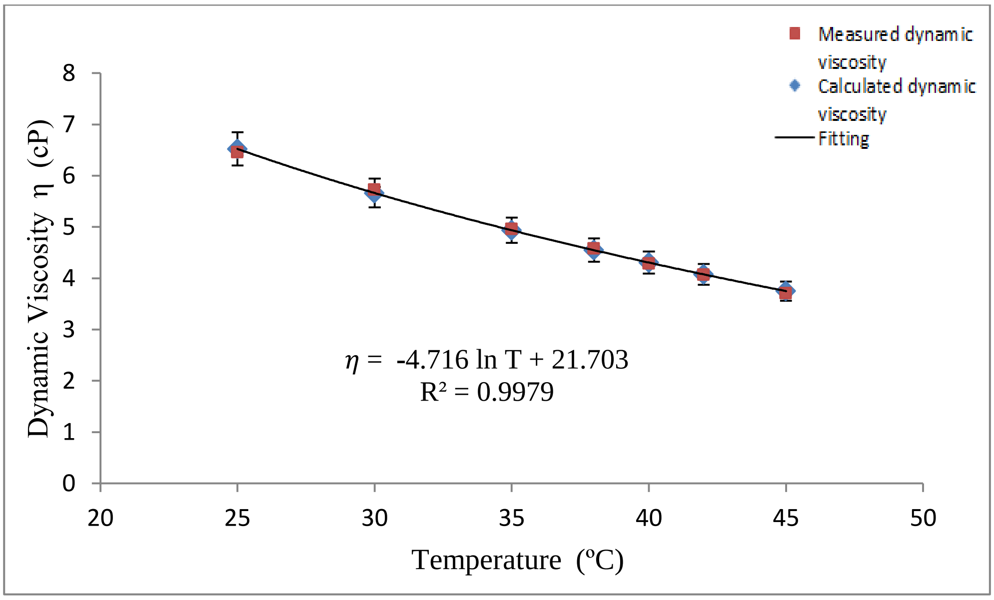

Fig.(C.2) Measured values and calculated values of dynamic viscosity as a function of temperature for B80 sample from Eq.(4.4)

The values of A= -4.716 cP and B= 21.703 cP. Eq.(4.4) for B80 can be written as η =-4.716 LnT +21.703

C.3 Sample B76

Table (C.3) Measured and calculated values of dynamic viscosity for B 76 sample from Eq.(4.4)

76 % biodiesel		
T (ºC)	Measured η in (cP)	Calculated η (cP) from Eq.(4.4)
25.0	6.59	6.57
30.0	5.7	5.69
35.0	4.99	4.94
38.0	4.48	4.55
40.0	4.22	4.30
42.0	3.97	4.06
45.0	3.90	3.73
AAD%	1.64%	
SD	0.09	

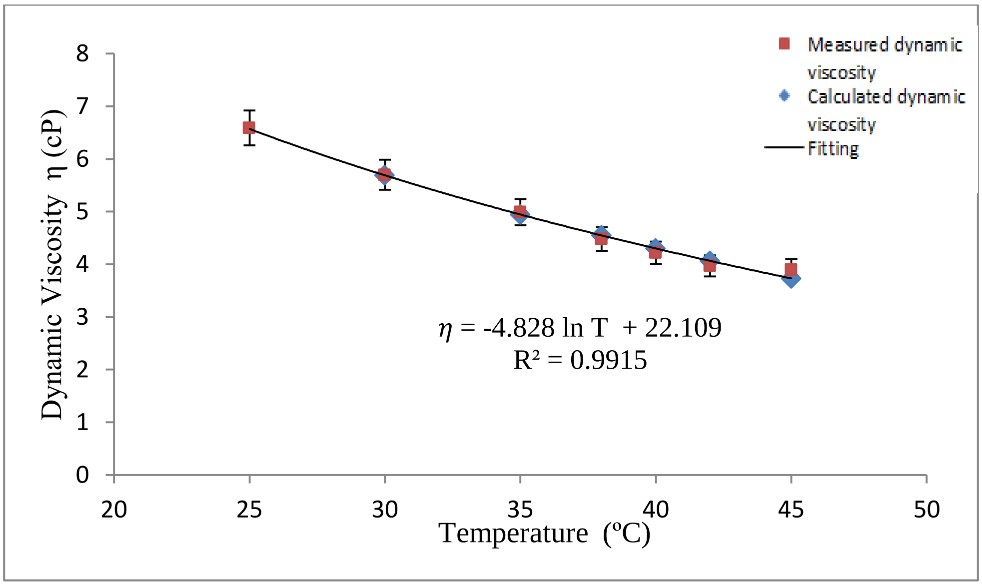

Fig.(C.3) Measured and calculated values of dynamic viscosity as a function of temperature for B76 sample from Eq.(4.4)

A=-4.828 cP and B= 22.109 cP for B76. Eq.(4.4) can be represented by

$$\eta = -4.828\ \mathrm{Ln}T + 22.109$$

C.4 Sample B72

Table (C.4) Measured and calculated values of dynamic viscosity for B 72 sample from Eq.(4.4)

72% biodiesel		
T (ºC)	Measured η in (cP)	Calculated η (cP) from Eq.(4.4)
25.0	6.43	6.44
30.0	5.63	5.58
35.0	4.8	4.86
38.0	4.48	4.47
40.0	4.16	4.23
42.0	4.10	4.00
45.0	3.65	3.68
AAD%	1.03%	
SD	0.06	

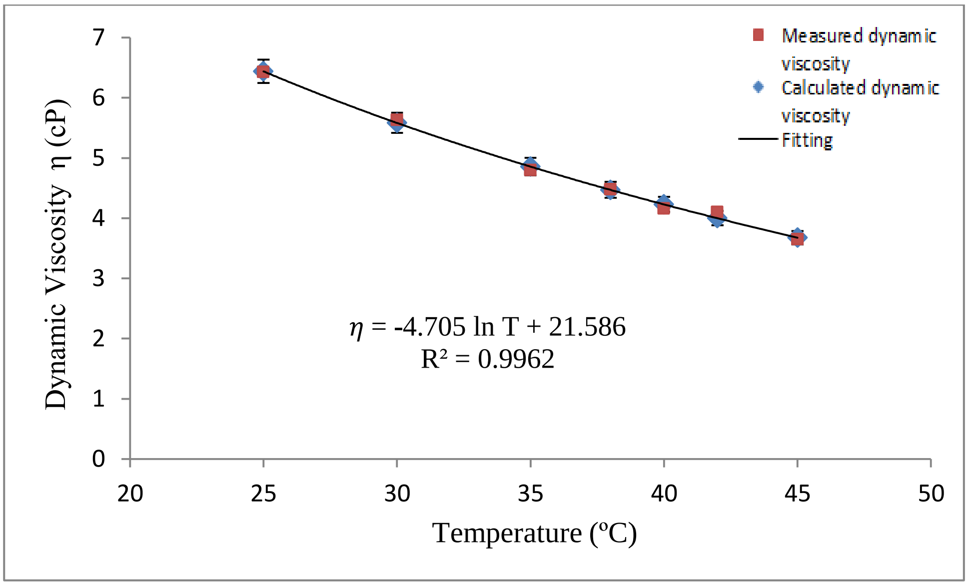

Fig.(C.4) Measured and calculated values of dynamic viscosity as a function of temperature for B72 sample from Eq.(4.4)

The values of A= -4.705 cP and B=21.586 cP for B72. Eq. (4.4) becomes

$$\eta = -4.828 \, \mathrm{Ln}T + 22.109$$

C.5 Sample B70

Table (C.5) Measured and calculated values of dynamic viscosity for B 70 sample from Eq. (4.4)

70% biodiesel		
T (ºC)	Measured η(cP)	Calculated η (cP) from Eq.(4.4)
25.0	6.34	6.36
30.0	5.57	5.53
35.0	4.86	4.82
38.0	4.48	4.45
40.0	4.03	4.21
42.0	3.97	3.99
45.0	3.78	3.68
AAD%	1.48	
SD	0.08	

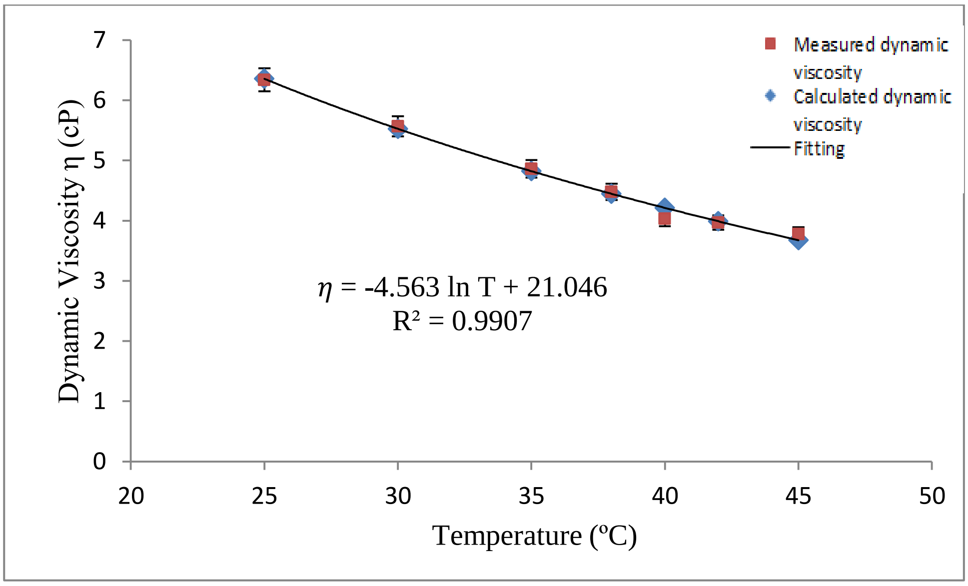

Fig.(C.5) Measured and calculated values of dynamic viscosity as a function of temperature for B70 sample from Eq.(4.4)

The values of A= -4.563 cP and B= 21.046 cP for B70. Eq. (4.4) becomes

$$\eta = -4.563 \, \mathrm{Ln}T + 21.046$$

C.6 Sample B69

Table (C.6) Measured and calculated values of dynamic viscosity for B 69 sample from Eq.(4.4)

69% biodiesel		
T (ºC)	Measured η(cP)	Calculated η (cP) from Eq.(4.4)
25.0	6.01	6.01
30.0	5.38	5.22
35.0	4.47	4.55
38.0	3.96	4.20
40.0	3.94	3.97
42.0	3.77	3.76
45.0	3.65	3.46
AAD%	2.24	
SD	0.13	

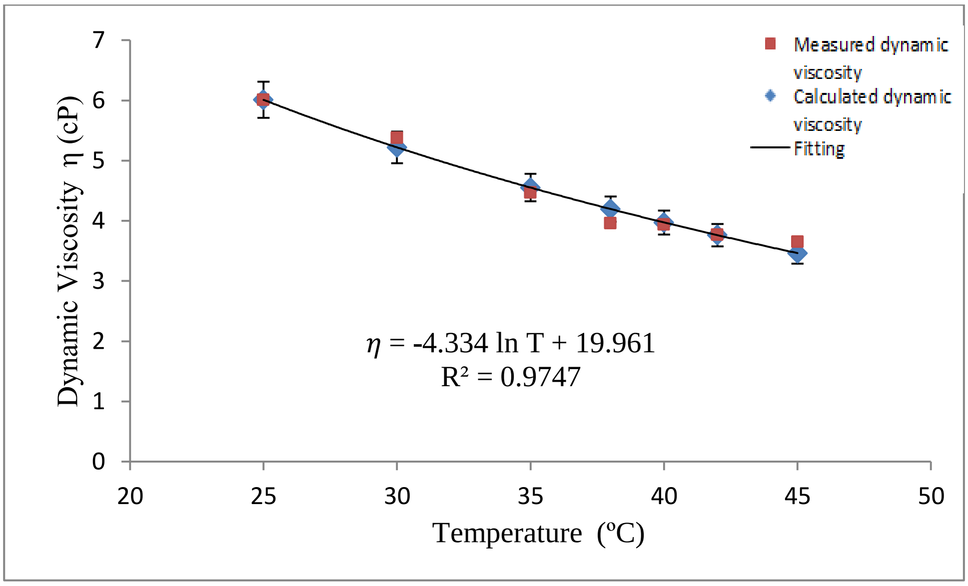

Fig.(C.6) Measured and calculated values of dynamic viscosity as a function of temperature for B69 sample from Eq.(4.4)

The values of A= -4.334 cP and B= 19.961 cP for B69. Eq.(4.4) represented by $\eta = -4.334 \, \mathrm{Ln}T + 19.961$

C.7 Sample B68

Table(C.7) Measured and calculated values of dynamic viscosity for B 68 sample from Eq.(4.4)

68% biodiesel		
T (°C)	Measured η(cP)	Calculated η (cP) from Eq.(4.4)
25.0	5.79	5.68
30.0	4.99	4.97
35.0	4.16	4.36
38.0	3.9	4.04
40.0	3.82	3.84
42.0	3.68	3.65
45.0	3.58	3.38
AAD%	2.55%	
SD	0.13	

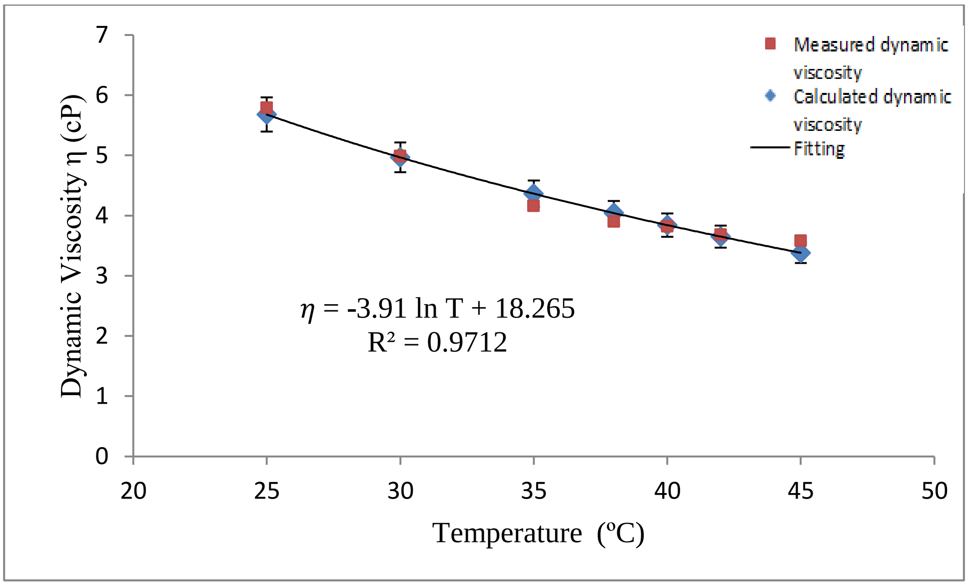

Fig.(C.7) Measured and calculated values of dynamic viscosity as a function of temperature for B68 sample from Eq.(4.4)

The values of A= -3.910 cP and B = 18.265 cP for B68. Eq.(4.4) can be written as

$$\eta = -3.910 \, \mathrm{Ln}T + 18.265$$

C.8 Sample B65

Table (C.8) Measured and calculated values of dynamic viscosity for B 65 sample from Eq.(4.4)

65% biodiesel		
T (ºC)	Measured η(cP)	Calculated η (cP) From Eq.(4.4)
25.0	5.89	5.93
30.0	5.18	5.14
35.0	4.61	4.47
38.0	4.03	4.11
40.0	3.75	3.89
42.0	3.68	3.68
45.0	3.46	3.38
AAD%	1.81%	
SD	0.09	

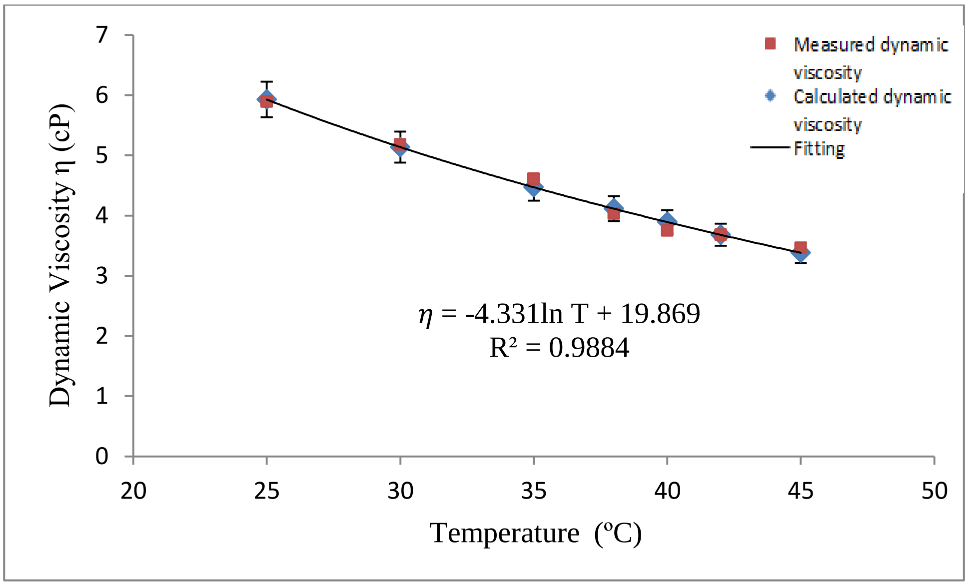

Fig.(C.8) Measured and calculated values of dynamic viscosity as a function of temperature for B65 sample from Eq.(4.4)

The values of A= -4.331 cP and B= 19.869 cP for B 65. Eq.(4.4) can represent by the form

$$\eta = -4.331 \, \mathrm{Ln}T + 22.109$$

C.9 Sample B60

Table(C.9) Measured and calculated values of dynamic viscosity for B 60 sample from Eq. (4.4)

60% biodiesel		
T (ºC)	Measured η (cP)	Calculated η (cP) from Eq.(4.4)
25.0	5.82	5.75
30.0	4.99	5.00
35.0	4.35	4.37
38.0	3.9	4.03
40.0	3.71	3.81
42.0	3.65	3.62
45.0	3.49	3.33
AAD%	1.91%	
SD	0.09	

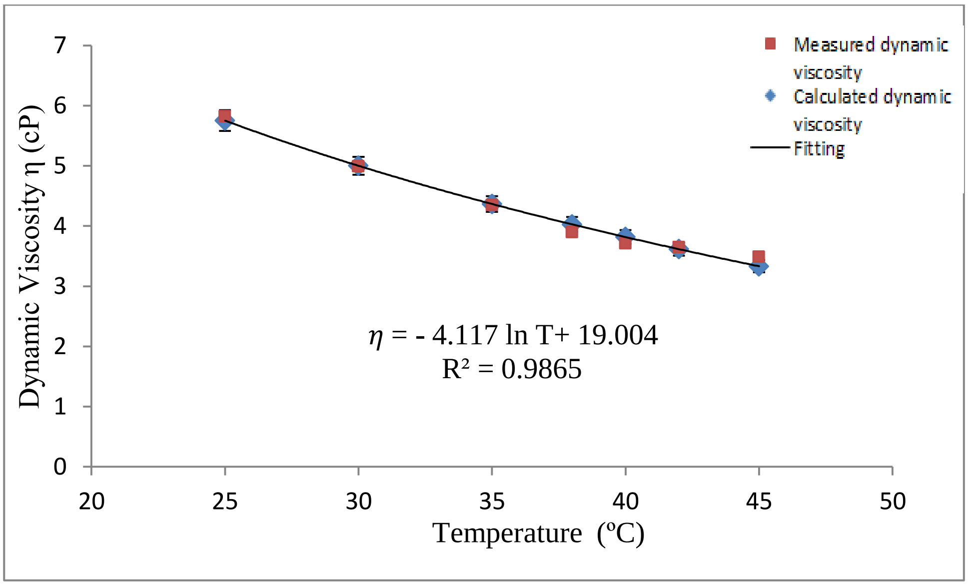

Fig.(C.9) Measured and calculated values of dynamic viscosity as a function of temperature for B60 sample from Eq.(4.4)

The values of A= -4.117 cP and B= 19.004 cP for B60. Eq.(4.4) becomes

$$\eta = -4.117 \, \mathrm{Ln}T + 19.004$$

C.10 Sample B50

Table (C.10) Measured and calculated values of dynamic viscosity for B 50 sample from Eq. (4.4)

50% biodiesel		
T (ºC)	Measured η(cP)	Calculated η (cP) from Eq.(4.4)
25.0	5.34	5.34
30.0	4.67	4.67
35.0	4.10	4.10
38.0	3.78	3.80
40.0	3.65	3.61
42.0	3.46	3.43
45.0	3.14	3.18
AAD%	0.53%	
SD	0.02	

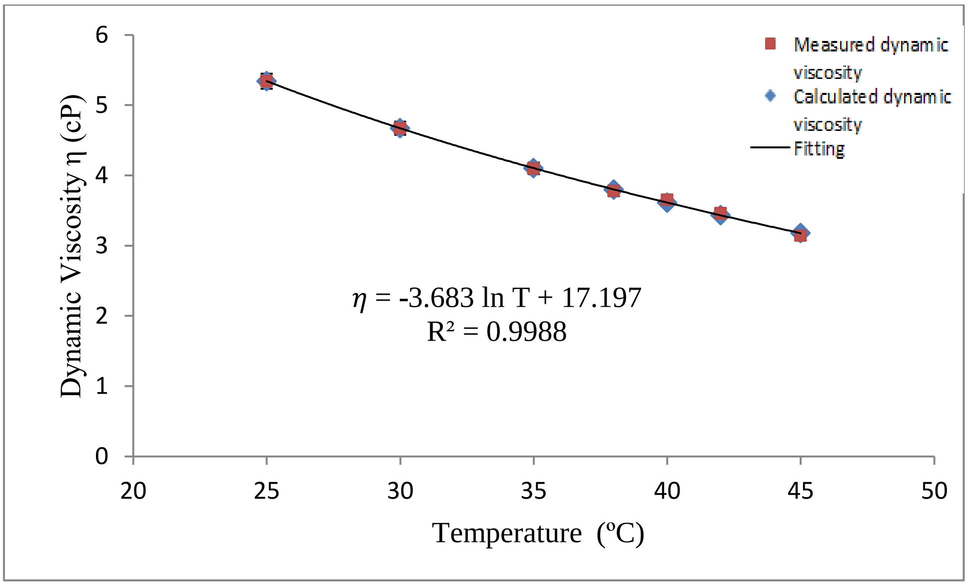

Fig.(C.10) Measured and calculated values of dynamic viscosity as a function of temperature for B50 sample from Eq.(4.4)

The values of A= -3.683 cP and B= 17.197 cP for B50. Eq. (4.4) can be represented by $\eta = -3.683 \,\mathrm{Ln}T + 17.197$

C.11 Sample B40

Table (C.11) Measured and calculated values of dynamic viscosity for B 40 sample from Eq. (4.4)

40% biodiesel		
T (ºC)	Measured η(cP)	Calculated η (cP) from Eq.(4.4)
25.0	4.86	4.69
30.0	4.03	4.11
35.0	3.42	3.62
38.0	3.26	3.36
40.0	3.20	3.20
42.0	3.07	3.048
45.0	3.01	2.82
AAD%	3.1%	
SD	0.13	

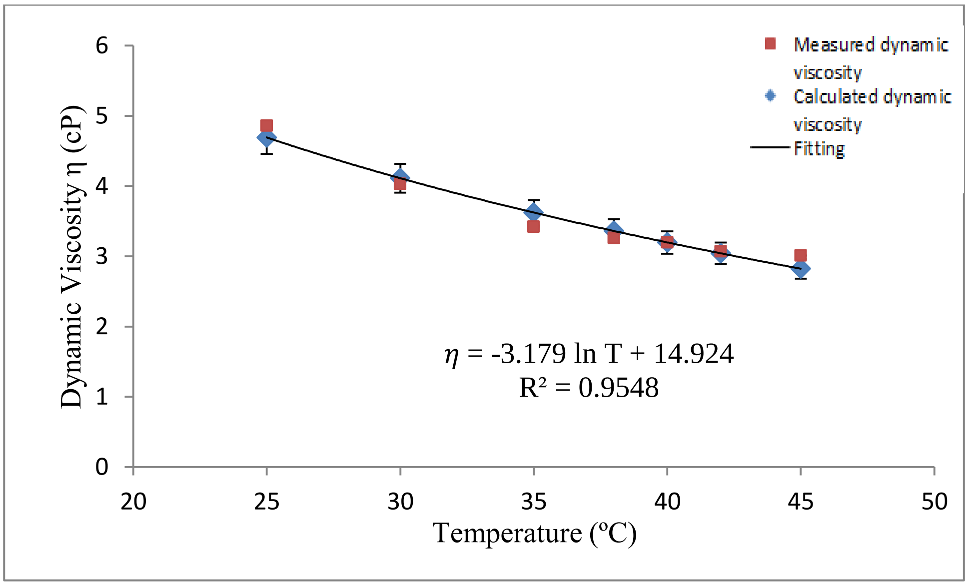

Fig.(C.11) Measured and calculated values of dynamic viscosity as a function of temperature for B40 sample from Eq.(4.4)

The values of A= -3.179 cP and B=14.924 cP for B40. Eq. (4.4) becomes

$$\eta = -3.179 \, \mathrm{Ln}T + 14.924$$

C.12 Sample B30

Table (C.12)The measured and calculated values of dynamic viscosity for B 30 sample from Eq. (4.4)

30% biodiesel		
T (ºC)	Measured η(cP)	Calculated η (cP) from Eq.(4.4)
25.0	4.70	4.59
30.0	3.96	4.04
35.0	3.52	3.57
38.0	3.23	3.32
40.0	3.10	3.17
42.0	3.04	3.02
45.0	2.96	2.81
AAD%	2.35%	
SD	0.09	

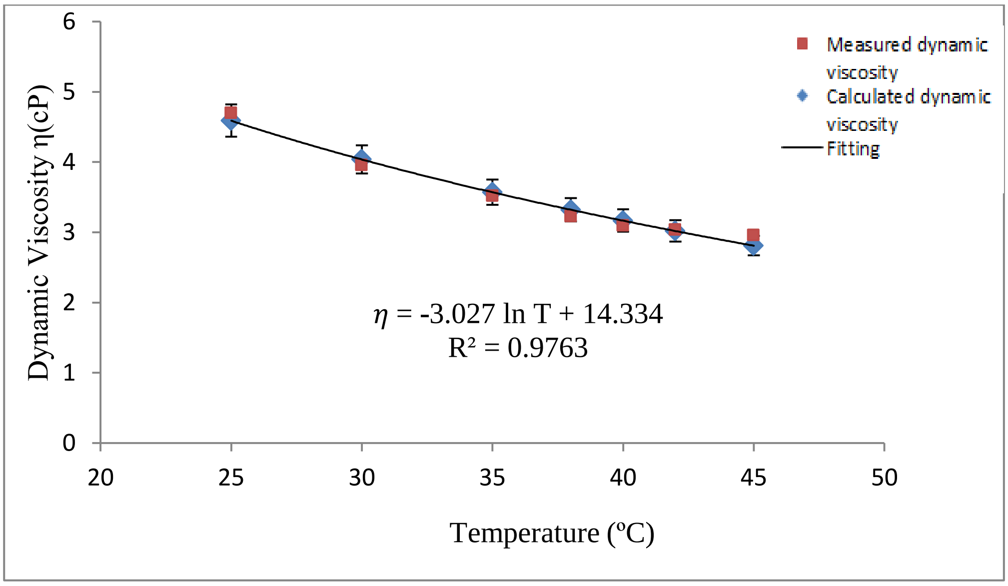

Fig.(C.12) Measured and calculated values of dynamic viscosity as a function of temperature for B30 sample from Eq.(4.4)

The values of A= -3.027 cP and B= 14.334 cP for B30. Eq. (4.4) becomes = -3.027 LnT + 14.334

C.13 Sample B20

Table (C.13) Measured and calculated values of dynamic viscosityfor B 20 sample from Eq.(4.4)

20 % biodiesel		
T (ºC)	Measured η (cP)	Calculated η (cP) from Eq.(4.4)
25.0	4.54	4.55
30.0	3.97	3.90
35.0	3.33	3.35
38.0	3.02	3.06
40.0	2.82	2.87
42.0	2.65	2.70
45.0	2.57	2.46
AAD%	1.76%	
SD	0.06	

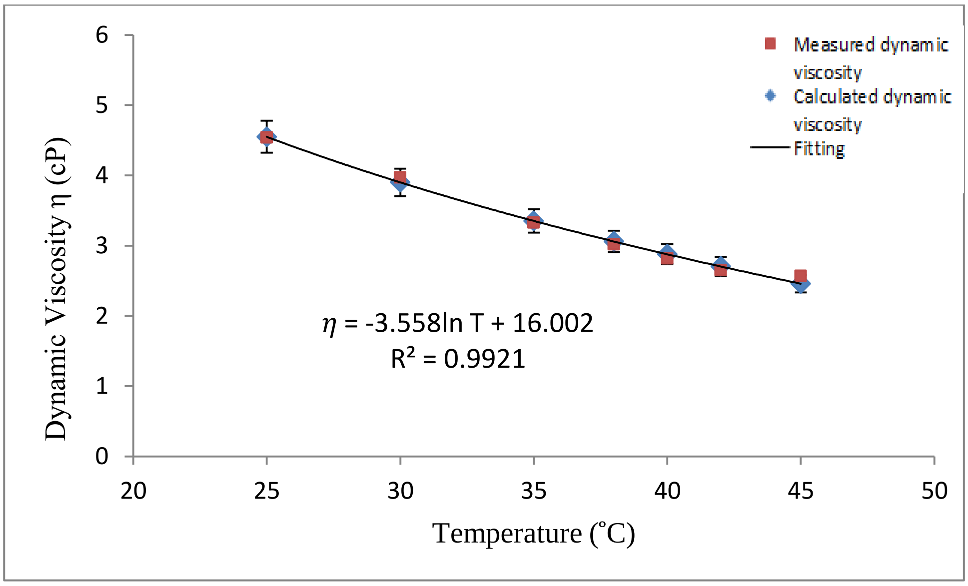

Fig.(C.13) Measured and calculated values of dynamic viscosity as a function of temperature for B20 sample from Eq.(4.4)

The values of A= -3.558 cP and B= 16.002 cP for B20. Eq.(4.4) becomes

$$\eta = -3.558 \, \mathrm{Ln}T + 16.002$$

C.14 Sample B10

Table (C.14) Measured and calculated values of dynamic viscosity for B 10 sample from Eq. (4.4)

10 % biodiesel		
T (ºC)	Measured η (cP)	Calculated η (cP) from Eq.(4.4)
25.0	4.06	4.07
30.0	3.58	3.59
35.0	3.26	3.19
38.0	3.01	2.97
40.0	2.80	2.84
42.0	2.63	2.71
45.0	2.57	2.53
AAD%	1.44%	
SD	0.05	

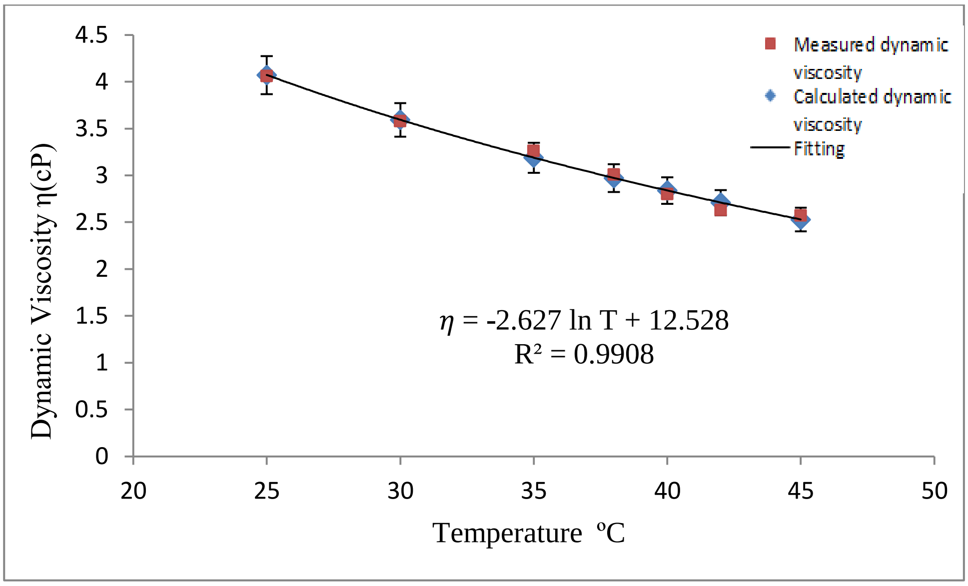

Fig.(C.14) Measured and calculated values of dynamic viscosity as a function of temperature for B10 sample from Eq.(4.4)

The values of A = -2.627 cP and B = 12.528 cP for B10. Eq.(4.4) becomes

η = -2.627 LnT + 12.528

جامعة النجاح الوطنية
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تحديد لزوجة الوقود الحيوي ودرجة الوميض

إعداد
إيمان علي عتيق

إشراف
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قدمت هده الاطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في الفيزياء بكلية الدراسات العليا في جامعة النجاح الوطنية نابلس، فلسطين.

2015

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الملخص

تم دراسة عينات تحتوي على نسب مختلفة من خليط الوقود الحيوي (البيوديزل) المصنع في فلسطين من اصل الزيت المستخدم والديزل البترولي. حيث تم دراسة اللزوجة والكثافة ومعامل الانكسار ودرجة الوميض عند كل نسبة. تم دراسة الكثافة كعلاقة مع زيادة نسبة الوقود الحيوي في العينة ومع درجة الحرارة وأظهرت النتائج أن الكثافة تزيد مع زيادة نسبة الوقود الحيوي في العينة وتقل مع ازدياد درجة الحرارة. ومن ثم تم ايضا دراسة معامل الانكسار كعلاقة مع درجة الحرارة وتبين ان معامل الانكسار يقل مع زيادة درجة الحرارة.

وقد تم دراسة درجة الوميض كعلاقة مع نسبة الوقود الحيوي في العينة واظهرت النتائج ان درجة الوميض تزداد مع ازدياد نسبة الوقود الحيوي في العينة، وتم اقتراح معادلتين تحتوي كل منهما على ثابتين للتنبؤ بدرجة الوميض. وتم مقارنة درجة الوميض للعينات مع المعايير الفلسطينية للوقود الحيوي، واظهرت المقارنة ان العينات التي تحتوي على نسبة أعلى من 40% من الوقود الحيوي تتوافق مع المعايير الفلسطينية.

وتم ايضا دراسة اللزوجة كعلاقة مع درجة الحرارة واظهرت النتائج ان اللزوجة تقل بازدياد درجة الحرارة وقد تم اقتراح معادلة من ثابتين لوصف العلاقة بين اللزوجة الديناميكية والحرارة. تم مقارنة قيم اللزوجة الكينماتية للعينات مع قيم اللزوجة الكينماتية في المعايير الفلسطينية واظهرت المقارنة توافق القيم المقاسة مع قيم المعايير للعينات التي تحتوي على اقل من 72% وقود حيوي .

وبمقارنة نتائج درجة الوميض واللزوجة الكينماتية تم اقتراح نسبة 71% من الوقود الحيوي و29% من الديزل البترولي كأفضل نسبة يمكن فيها خلط المادتين ودرجة الوميض 115.3 °C والوصول الى وقود حيوي مقارب للمواصفات والمعايير الفلسطينية.