

**INVESTIGATION OF THE FUEL PROPERTIES  
of FOUR BIODIESEL AND THEIR BLENDS  
UNDER VARIOUS OF STORAGE CONDITIONS**

**A THESIS SUBMITTED TO THE GRADUATE  
SCHOOL OF APPLIED SCIENCES  
OF  
NEAR EAST UNIVERSITY**

**By  
EBAA ALASSI**

**In Partial Fulfillment of the Requirements for  
the Degree of Master  
in  
Mechanical Engineering**

**NICOSIA, 2020**

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**Approval of Director of Graduate School of  
Applied Sciences**

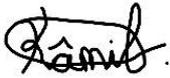


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**We certify this thesis is satisfactory for the award of the degree of Master of Science in  
Mechanical Engineering**

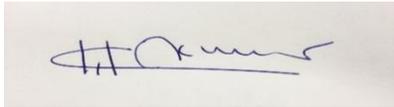
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**To my parents....**

## ABSTRACT

The main aim of this study is to investigate the properties of methyl biodiesel from different residential waste vegetable frying oils (sunflower, canola, a mixture of sunflower and rapeseeds and a mixture of sunflower and corn) as well as of binary blends among them to improve their properties. The results indicate that KV increased by 0.04 mm<sup>2</sup>/s to a maximum at 40 vol% FSME in FCME-FSME blends, 0.04 mm<sup>2</sup>/s to a maximum at 60 vol% FSME in FSCME-FSME blends, 0.06 mm<sup>2</sup>/s to a maximum at 20 vol% FSME in FSME-FSRME blends and 0.09 mm<sup>2</sup>/s to a maximum at 20 vol% FCME in FSRME-FCME blends. Thus, KV of blends is measured at low temperature (20°C) and high temperature (160°C) to ensure the same phenomena taking place at low and high temperatures. The results demonstrated that the variation of kinematic viscosity for low temperatures is very clearly higher than the variation of kinematic viscosity at high temperatures. Also, it is found that mixing FSCME with FCME, FSME and FSRME in varying amounts to form the mixture was improving the properties of the fuel. Moreover, the impact of storage period on kinematic viscosity, density and cold flow properties of biodiesel and their blends is investigated. The samples were stored for 12 months different storage temperatures (5°C, room temperature and 40°C) and the properties were periodically measured.

**Keywords:** Waste frying oil; biodiesel; kinematic viscosity; density; cold flow properties

## ÖZET

Bu çalışmanın temel amacı, farklı evsel atık sebze kızartma yağlarından (ayçiçeği, kanola, ayçiçeği ve kolza tohumu karışımı ve ayçiçeği ve mısır karışımı) metil biyodizelin özelliklerini ve aralarındaki ikili karışımları araştırmaktır. özellikleri. Sonuçlar, KV'nin FCME-FSME karışımlarında  $0.04 \text{ mm}^2 / \text{s}$  kadar maksimum% 40 hacim FSME'ye,  $0.04 \text{ mm}^2 / \text{s}$  kadar FSCME-FSME karışımlarında maksimum% 60 hacim FSME'ye,  $0.06 \text{ mm}^2 / \text{s}$  maksimum seviyeye yükseldiğini göstermektedir. FSME-FSRME karışımlarında hacimce% 20 FSME ve FSRME-FCME karışımlarında hacimce% 20 FCME'de maksimum  $0.09 \text{ mm}^2 / \text{s}$ . Böylece, karışımların KV'si düşük ve yüksek sıcaklıklarda aynı fenomenin gerçekleşmesini sağlamak için düşük sıcaklıkta ( $20 \text{ }^\circ\text{C}$ ) ve yüksek sıcaklıkta ( $160 \text{ }^\circ\text{C}$ ) ölçülür. Sonuçlar, düşük sıcaklıklar için kinematik viskozite varyasyonunun, yüksek sıcaklıklarda kinematik viskozite varyasyonundan çok daha yüksek olduğunu göstermiştir. Ayrıca, karışımı oluşturmak için FSCME'nin FCME, FSME ve FSRME ile değişen miktarlarda karıştırılmasının yakıtın özelliklerini geliştirdiği bulunmuştur. Ayrıca depolama süresinin biyodizelin kinematik viskozitesi, yoğunluk ve soğuk akış özellikleri ve bunların karışımları üzerindeki etkisi araştırılmıştır. Numuneler 12 ay boyunca farklı depolama sıcaklıklarında ( $5 \text{ }^\circ\text{C}$ , oda sıcaklığı ve  $40 \text{ }^\circ\text{C}$ ) saklandı ve özellikleri periyodik olarak ölçüldü.

**Anahtar Kelimeler:** Atık kızartma yağı; biyodizel; kinematik viskozite; yoğunluk; soğuk akış özellikleri

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## LIST OF ABBREVIATIONS AND SYMBOLS

$A_I$	Specific constant
$a$	Intercept
$a_j$	Activation of the unit
$B$	Specific constant
$b$	Negative slope
$E$	Backward propagation of errors
$E$	Correction factor
$E_a$	Activation energy for flow
$g$	Acceleration gravity
$H$	Height
$h$	Hidden layer
$i$	Input layer
$K$	Calibration constant
$L$	Length of vertical pipe
$M_i$	Molecular weight
$N_i$	Number of double bond
$n$	Node number
$o$	Output layer
$p_j$	Potential of unit $j$
$P_i$	Potential of unit $i$
$\frac{\partial p}{\partial z}$	Pressure gradient
$Q$	Volume flow rate
$R$	Radius of capillary
$R$	Universal gas constant
$T$	Temperature
$\frac{\partial u}{\partial z}$	velocity gradient
$v_z$	Velocity of liquid in z-direction

$v_r$	Velocity of liquid in r-direction
$v_\theta$	Velocity of liquid in $\theta$ -direction
$w_i$	Mass fraction
$w_{ij}$	Weight of the connection from unit $i$ to unit $j$
$x$	Input data
$\alpha$	Learning rate
$\beta$	Momentum rate
$\mu$	dynamic viscosity
$\nu$	kinematic viscosity
$\rho$	density of the liquid
$\sigma$	Sigmoid function
$\tau$	shear stress

# CHAPTER 1

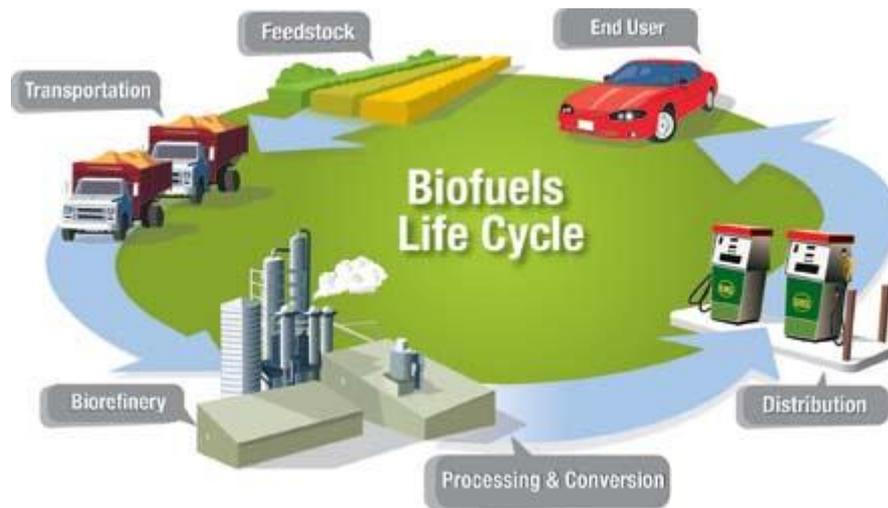
## INTRODUCTION

### 1.1 Biofuel

Decreased energy resources expected to occur prompted many countries to search for alternative sources of fuel and find solutions to overcome the problem of the expected lack of abundance in fossil fuels, so biofuels may be the best alternative.

Biofuels are defined as the sustainable energy of living beings, whether animal or vegetable (Jiang et al., 2020; Sarkar and Sarkar, 2020; Subramaniam et al., 2020) (Figure 1.1). It is considered one of the most important sources of renewable energy, unlike other natural resources.

The term biofuels refers to one of the various forms of solid, liquid or gaseous fuels that are produced from renewable biological sources. Biofuels are energy derived from living organisms, whether plant or animal or microorganisms, and it is one of the most important sources of renewable energy, unlike other natural resources from fossil fuels, oil, coal, and natural gas (and nuclear fuel that is used in nuclear reactors (Jones and Mayfield, 2016). There are two types of Biofuels are renewable bio-ethanol and biodiesel (Adewuyi, 2020; Mączyńska et al., 2019) where bio-ethanol is considered. One of the good alternatives to fuel, which is produced almost entirely by agricultural crops



**Figure 1.1:** Biofuel cycle

Biofuels are produced from a number of plant crops, algae and bacteria (Das and Varanasi, 2019):

- First-generation crops where seeds and grains of plants have been used to produce biofuels, including corn, wheat, soybeans, sugar cane, turnip, barley, and others.
- The second generation relies on plant wastes, such as stems of wheat, corn, sawdust, hay, etc., where cellulosic fuel, ethanol, bio methanol and bio hydrogen are obtained.
- The third generation uses algae to produce biofuels, because they contain a good percentage of oils of up to 60 percent of their weight.
- Fourth Generation: This generation is the latest global trend in biofuel production, and depends on making a change in the genome of a microorganism, a bacterium called Mycoplasma Laboratory, so that it is able to produce fuel from carbon dioxide.
- Algae is distinguished from the rest of the materials used in the production of biofuels as it grows in water and therefore it overcomes one of the main problems facing other materials, which is competition on land with other agricultural crops. Some common forms of algae are seaweed, which are not real plants but

photosynthesize, where algae can store up to 50 percent of their body weight from fat, and therefore wait to convert them into gas to produce ethanol.

## 1.2 Biodiesel

Biodiesel is a type of alternative fuel with a clean burning mechanism (Chao et al., 2019). It is derived from local and renewable sources such as vegetable oil or animal fats (Figure 1.2). This type of fuel does not usually contain oil, but it is possible to create a mixture of biodiesel by mixing it with petroleum diesel fuel.

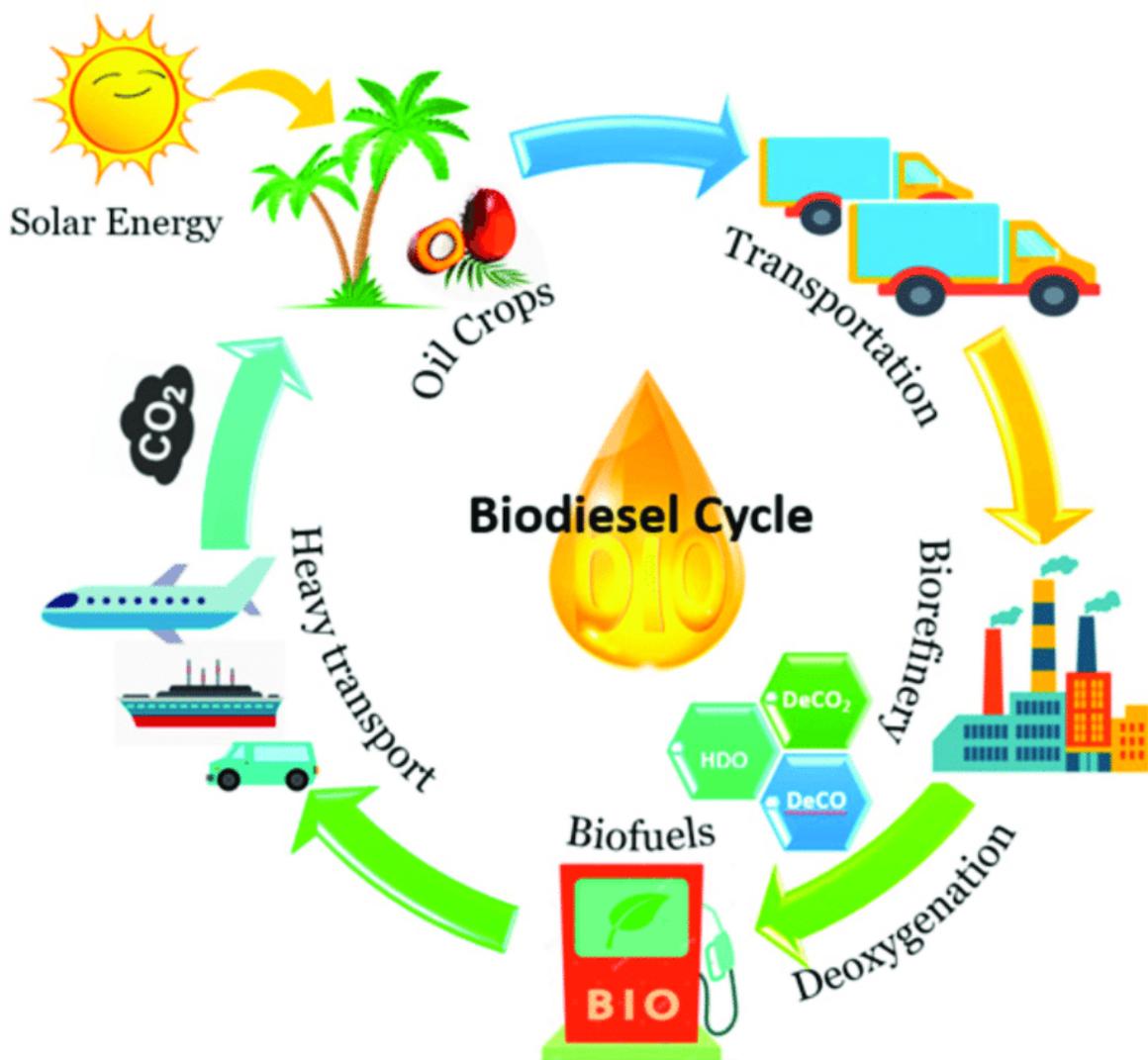


Figure 1.2: Biodiesel cycle

It is a clean, locally regenerated alternative time that is a renewable resource and this fuel is a mixture of fatty alkyl acid esters made from vegetable oils, animal fats or recycled greases where available, biodiesel fuel can be used in the ignition pressure (diesel) engines in its pure shape with little or no modifications.

Biodiesel is easy-to-use, non-toxic, biodegradable, mainly sulfur-free and aromatic. It is usually used as an oil diesel additive to reduce the levels of particulate matter, carbon monoxide, hydrocarbons and toxic substances from diesel cars. When used as an additive, the resulting diesel fuel can be called B5, B10 or B20, which represents the proportion of biodiesel mixed with petroleum diesel.

Biodiesel is produced through a process that combines organically derived oils with alcohol (ethanol or methanol) in the presence of a catalyst to form methyl or ethyl ester. Methyl or ethyl derivative biomass esters can be mixed with conventional diesel fuel or used as a stylish fuel (100% biodiesel). Biodiesel can be made from any vegetable oil, animal fats, waste vegetable oils, or algae oils.

It is intended to use biodiesel in standard diesel engines and thus it differs from vegetable oils and waste used in the operation of converted diesel engines. Biodiesel can be used alone, or mixed with diesel oil in any proportions. Biodiesel mixtures can also be used as heating oil.

### **I.3 Advantages of Biodiesel**

Biodiesel is considered renewable energy and is biodegradable and can be mixed with other (diesel) fuels. It has lower Diesel flammability comparing to diesel, materials used to manufacture biodiesel are cheap and available. Biodiesel may also be used as fuel engine for any other vehicle, such as diesel or other engines. The material used for biodiesel processing, namely animal and vegetable fats, is accessible and cheaper.

Many plants are increasingly harvested and used also for the production of biodiesel. This reduces production and manufacturing costs as compared to diesel which is much more costly to handle.

This type of fuel is completely safe because it is free from any toxic substance and is rapidly degradable. Thus, the effect of biodiesel discharge to the environment in small amounts is less than the effect of discharging the same amount of regular fuel or oil. However, disposal of it in greater quantities is still generally harmful to the environment.

This type of fuel is not expensive because it is made of cheap raw materials: fat, cooking oil, and grease. These items have no other use except to be dumped in the landfill. Production of high-density oil crops, such as palm trees on a large scale, may be economically feasible for low-income countries. For example, vegetable oils devoted to biofuels can be extracted from palm trees, and thus production will be sufficient to meet the demand for this fuel in other countries, thus supporting the local economy.

Biodiesel is almost ready to use without any modifications, which reduces the cost significantly. It can be used on any type of diesel vehicle without any need for a new type of engine.

Biodiesel is a valuable addition to the list of renewable fuels. Biofuels improve the ability to lubricate and deliver, making it good for performing mechanical functions and for the smooth running of vehicle engines.

#### **I.4 Disadvantage of Biodiesel**

Like any other side of the biodiesel also have disadvantages. It has higher viscosity and lower energy content disadvantage that can be solved by mixing both diesel and biodiesel.

Referring to engine, with long operation, the engine oil must be changed more often. On a first use of biodiesel, the fuel filter must be changed no later than the second full, as biodiesel tends to clean the tank and lines.

Also during cold weather, there is a thickening of biodiesel, which increases its kinematic viscosity and therefore reduces engine performance. This problem is solved by blending the biodiesel with a diesel.

#### **I.4 Aim of the Study**

This study aims to investigate the physicochemical properties including kinematic viscosity, density and cold flow properties of biodiesel and their blends with different

proportions to investigate the possibility of producing mixture physicochemical properties. In this study, four methyl biodiesel samples are produced from residential waste frying oils.

Also, the objective of present study is to investigate the effect of long-term storage period on the properties of the fuel samples including kinematic viscosity, density and cold flow properties with different storage temperatures (5°C, room temperature and 40°C). These storage temperatures were selected based on expected average weather temperature in winter, spring, summer and autumn seasons.

### **I.5 Thesis Outline**

This chapter is discussed the importance of biodiesel to the world. The mathematical equations related to biodiesel properties are presented in Chapter 2. Moreover, the methodology that used to measure the properties of biodiesel is explained in Chapter 3. In Chapter 4 all test results are displayed for the current study. On the end of the dissertation, the conclusions are presented in Chapter 5.

## CHAPTER 2

### PROPERTIES OF BIODEISEL

#### 2.1 Background

Biodiesel is a renewable fuel which can be made from vegetable oils, animal fat / tallow and restaurant grease recycled. Technically, biodiesel is a fuel composed of mono-alkyl ester from a long chain of fatty acids that obeys with the American Society of Testing and Materials (ASTM) D6751 (2003) and the European EN 14214 (2003) necessities. Biodiesel is used in many energy fields, due to its flexibility and various benefits. The raw material required for biodiesel (animal fat restaurant) production is accessible and less expensive. The high use as plant raw material for producing this same biodiesel also creates and develops more jobs in parallel. It is biodegradable and can be mixed with a variety of other sources of energy (diesel). Biodiesel at low temperatures poses a thickening problem that increases viscosity and decreases engine efficiency. Biodiesel also has lower energy content and can be achieved by combining biodiesel with gasoline.

In this chapter, the properties of biodiesel including kinematic viscosity, density, oxidation stability and cold flow properties are discussed.

#### 2.2 Kinematic Viscosity

Viscosity is a quantitative indicator of fluid flow resistance (Lai, 2006). On the other hand, it is known as internal fluid friction, there are normally two types of viscosity measurements: kinematic viscosity and dynamic viscosity. Dynamic viscosity is defined as the measurement of fluid resistance to flow when applying external force, the constant proportionality between shear stress and velocity gradient is also defined in the other hand (Nakra and Chaudhry, 2017). The shear stress ratio with the fluid's velocity gradient is also known as absolute velocity (Crolla et al., 2015; Nakra and Chaudhry, 2017).

$$\tau = \mu \frac{\partial u}{\partial z} \tag{2.1}$$

Where,  $\tau$  is the shear stress ( $\text{N/m}^2$ ),  $\mu$  is the dynamic viscosity ( $\text{Pa}\cdot\text{s}$ ) and  $\frac{\partial u}{\partial z}$  is the velocity gradient or better known as shear rate ( $1/\text{s}$ ).

Eq. (2.2) is used to estimate the kinematic viscosity as function of dynamic viscosity and density of the liquid ( $\rho$ ) at specified condition (Subramanya, 2011).

$$v = \frac{\mu}{\rho} \quad (2.2)$$

Where  $v$  is the kinematic viscosity ( $\text{m}^2/\text{s}$ ),  $\rho$  is the mass density of the liquid ( $\text{m}^3/\text{kg}$ ).

In order to measure the viscosity of biodiesel/liquid, viscometer is used. In general, rotational viscometer (Figure 2.1) and capillary viscometer (Figure 2.2) are the main types of viscometer.



**Figure 2.1:** Rotational viscometers



**Figure 2.2:** Different types of capillary viscometers

### 2.2.1 Capillary Viscometers

Capillary viscometers are preferable utilized to measure fluids which conform to Newtonian theory of fluids (Tropea et al., 2016). Due to their accurate calibration they are used widely. It measures the time of required of fluid to pass through a capillary. These instruments include in their range the Ubbelohde and Ostwald varieties alternatively referred to as U-tube viscometers. They are easy and also unpretentious to use, with a U-like shaped glass tube with two spheres, an upper and a lower. Fluids pass from the upper sphere down to the lower sphere through capillary and the viscosity is recorded by recording the time required for liquid to cross the tube.

The general form of capillary flow viscometers is a U- tube (Totten et al., 2019). The advantages of these types of viscometers can be simplified as (Totten et al., 2019)

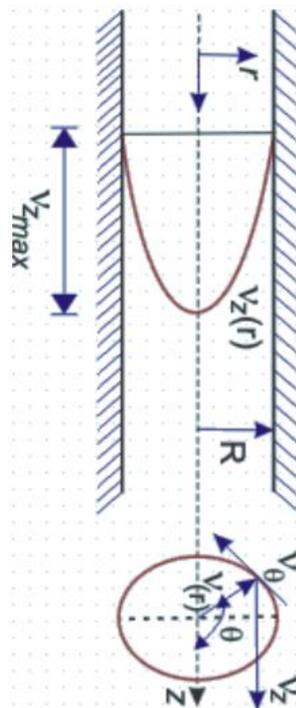
1. Simple.
2. Inexpensive.
3. Suitable for low viscosity of fluid

They are suitable devices for determination of the viscosity of the liquid. Generally, viscosity is estimated by utilizing capillary viscometers. To determine the viscosity, it should be measured the time of liquids needs to pass through the capillary tube.

The principle of the capillary viscometer is based on the Hagen-Poiseuille equation of fluid dynamics (Valyashko, 2009). The derivation of the Hagen-Poiseuille equation for measuring the viscosity of the liquid is based on the following two assumptions (Schaschke, 2005);

1. The capillary is straight with a uniform circular cross section,
2. The fluid is incompressible and Newtonian fluid, and
3. The flow is laminar and there is no slip at capillary wall.

The Hagen-Poiseuille equation can be derived from the Navier Stokes equation and the continuity equation in cylindrical coordinates (Schobeiri, 2014). Figure 2.3 shows a fully developed laminar flow through a straight vertical tube of circular cross section.



**Figure 2.3:** Hagen-Poiseuille flow through a vertical pipe

Continuity equation in cylindrical coordinates for incompressible unsteady flow

$$\frac{\partial \rho}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (\rho r V_r) + \frac{1}{r} \frac{\partial}{\partial \theta} (\rho r V_\theta) + \frac{\partial}{\partial z} (\rho V_z) = 0 \quad (2.3)$$

Navier Stokes equation in cylindrical coordinates for incompressible unsteady flow

$$\begin{aligned} & \rho \left( V_r \frac{\partial V_r}{\partial r} + \frac{V_\theta}{r} \frac{\partial V_r}{\partial \theta} - \frac{V_\theta^2}{r} + V_z \frac{\partial V_r}{\partial z} + \frac{\partial V_r}{\partial t} \right) \\ &= \rho g_r - \frac{\partial p}{\partial r} \\ &+ \mu \left[ \frac{\partial}{\partial r} \left( \frac{1}{r} \frac{\partial}{\partial r} (r V_r) \right) + \frac{1}{r^2} \frac{\partial^2 V_r}{\partial \theta^2} + \frac{1}{r^2} \frac{\partial V_\theta}{\partial \theta} + \frac{\partial^2 V_r}{\partial z^2} \right] \end{aligned} \quad (2.4)$$

$$\begin{aligned} & \rho \left( V_r \frac{\partial V_\theta}{\partial r} + \frac{V_\theta}{r} \frac{\partial V_\theta}{\partial \theta} - \frac{V_r V_\theta}{r} + V_z \frac{\partial V_\theta}{\partial z} + \frac{\partial V_\theta}{\partial t} \right) \\ &= \rho g_\theta - \frac{\partial p}{\partial \theta} \\ &+ \mu \left[ \frac{\partial}{\partial r} \left( \frac{1}{r} \frac{\partial}{\partial r} (r V_\theta) \right) + \frac{1}{r^2} \frac{\partial^2 V_\theta}{\partial \theta^2} + \frac{1}{r^2} \frac{\partial V_r}{\partial r} + \frac{\partial^2 V_\theta}{\partial z^2} \right] \end{aligned} \quad (2.5)$$

$$\begin{aligned} & \rho \left( V_r \frac{\partial V_z}{\partial r} + \frac{V_\theta}{r} \frac{\partial V_z}{\partial \theta} + V_z \frac{\partial V_z}{\partial z} + \frac{\partial V_z}{\partial t} \right) \\ &= \rho g_z - \frac{\partial p}{\partial z} \\ &+ \mu \left[ \frac{\partial}{\partial r} \left( \frac{1}{r} \frac{\partial}{\partial r} (r V_z) \right) + \frac{1}{r^2} \frac{\partial^2 V_z}{\partial \theta^2} + \frac{1}{r^2} \frac{\partial V_r}{\partial r} + \frac{\partial^2 V_z}{\partial z^2} \right] \end{aligned} \quad (2.6)$$

If z-axis is taken as the axis of the tube along which all the fluid particle travels and considering rotational symmetry to make the flow two dimensional axially symmetric. the solution for axially symmetric are

$$v_z \neq 0, v_r = 0, v_\theta = 0 \quad (2.7)$$

From continuity equation,

$$\frac{\partial v_r}{\partial r} + \frac{v_r}{r} + \frac{\partial v_z}{\partial z} = 0 \quad (2.8)$$

For rotational symmetry,

$$\frac{1}{r} \cdot \frac{\partial v_\theta}{\partial \theta} = 0; \quad v_z = v_z(r, t) \quad \text{or} \quad \frac{\partial}{\partial \theta} (\text{any quantity}) = 0 \quad (2.9)$$

as the flow occurs only in z-direction, then Navier Stoke's Equation in cylindrical coordinates (z-direction ) can be simplified as

$$\frac{\partial v_z}{\partial t} = -\frac{1}{\rho} \cdot \frac{\partial p}{\partial z} + \nu \left( \frac{\partial^3 v_z}{\partial r^3} + \frac{1}{r} \cdot \frac{\partial v_z}{\partial r} \right) \quad \text{in } z \text{ direction} \quad (2.10)$$

And for steady flow it becomes

$$\frac{\partial^2 v_z}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial v_z}{\partial r} = \frac{1}{\mu} \frac{dp}{dz} \quad (2.11)$$

Solving differential equation 2.11 with boundary conditions

$$r = 0; \quad v_z \text{ is finite} \quad (2.12)$$

$$r = R; \quad v_z = 0 \quad (2.13)$$

Yields

$$v_z = \frac{R^3}{4\mu} \left( -\frac{dp}{dz} \right) \left( 1 - \frac{r^3}{R^3} \right) \quad (2.14)$$

While

$$-\frac{dp}{dz} = \frac{\Delta p}{L} \quad (2.15)$$

The volume flow rate discharge is given by

$$Q = \int_0^R 2\pi v_z r dr \quad (2.16)$$

Inserting 2.14 and 2.15 into 2.16, we obtain

$$Q = \pi \frac{R^4}{8\mu} \left( \frac{\Delta p}{L} \right) \quad (2.17)$$

Also

$$Q = \frac{V}{t} \quad (2.18)$$

$$v = \frac{\mu}{\rho} \quad (2.19)$$

if  $\Delta p = \rho g H$  as in Pressure – Height relationship,

Then,

$$v = \frac{\pi g H R^4}{8LV} \cdot t \quad (2.20)$$

Declaring a calibration constant K,

$$K = \frac{\pi g H R^4}{8LV} \quad (2.21)$$

Then,

$$v = Kt \quad (2.22)$$

Equation 2.22 is similar to ASTM kinematic viscosity equation with an exception of the correction factor.

$$v = \frac{10 \pi g D^4 H t}{138 V L} - \frac{E}{t^3} \quad (2.23)$$

where E is the correction factor.

### 2.3 Density

This means that the density of a substance should be the same regardless of how much of the material is present. Density is defined as the ratio of the mass over the volume and it is expressed by (Gupta, 2002):

$$\rho = \frac{m}{v} \quad (2.24)$$

Where  $\rho$  is the density in  $\text{kg/m}^3$ , m is the mass in kg and v is the volume in  $\text{m}^3$ .

Biodiesel density is a very important property since it is involved in atomizing fuels during combustion. High density promotes the combustion of the gas mixture needed for good combustion and performance.

Petrochemical diesel has a less value than density compared to Methyl esters. This will cause fuel pumps of diesel engine which are based solely on volume operations, to spray less weight of petrochemical diesel than biodiesel into the engine. So then the air / fuel ratio will be directly affected.

The apparatus that is used for measuring the density of biodiesel according to the standards is called pycnometer. The mass of the pycnometer should be recorded when it's empty and must be used in determination of the density.

## **2.4 Cold Flow Properties of Biodiesel**

Biodiesel liquidity can be explained by biodiesel properties and cold flow properties at low temperatures (Shaw and Hou, 2009). Fuel is often a problem in low temperature ignition due to low flow properties at low fuel temperatures. Cold flow properties are divided into three properties which are cloud point (CP), and pour point (PP) and cold filter plugging point (CFPP).

### ***Cloud point***

The temperature at which the wax crystals become visible is called cloud point. Fuel begins to appear cloudy or transparent. The petrochemical diesel has a lower cloud point than biodiesel; ASTM D2500 should be followed when measuring the Cloud Point.

### ***Pour point***

Pour point is the flow property at which the temperature of fuel is partially loses and hardened. The minimum pour point can be determined as the temperature at which the vehicle can operate. Biodiesel contains most of the crystals collected at this stage that are actually jellied and can no longer flow. It is know that Cloud point is always higher than pour point. Petro-diesel has lower pour point than Biodiesel When we compare biodiesel and petro-diesel, ASTM Standard D97-05 was used for the PP measurements.

## **CHAPTER 3**

### **MATERIAL AND METHOD**

#### **3.1. Preparing Biodiesel Sample**

In this study, four different refined vegetable oils including sunflower, canola, corn, and rapeseed oil were purchased from various companies in Northern Cyprus and Turkey. The frying cooking oils are collected from private households. To obtain residential waste frying oil, the refined oils are used for the frying process i.e., the frying cooking oil sample was obtained by the way of the collection after being used for cooking various dishes including animal fats and vegetables. The base-catalyzed one-step trans-esterification reaction method was used to produce biodiesel samples. Biodiesel production was discussed in Reference [20]. In this work, four different samples of the frying cooking methyl ester with significantly different compositions were prepared. These samples were prepared as follows:

- FSME was prepared from frying cooking sunflower oil.
- FCME was obtained from frying cooking canola oil.
- FSCME was produced from a mixture of frying cooking sunflower and corn oils.
- FSRME was prepared from a mixture of frying cooking sunflower and rapeseed oils.

#### **3.2 Biodiesel Characterization**

Table 3.1 shows the properties of all biodiesel samples produced from four frying cooking vegetable oils and the specification values given in the ASTM D6751 biodiesel standard. It is found that the measured fuel properties are within the limits of ASTM D6751.

**Table 3.1:** Properties of pure biodiesel and their mixtures

<b>Property</b>	<b>FCME</b>	<b>FSME</b>	<b>FSCME</b>	<b>FSRME</b>
Kinematic viscosity at 40°C	4.55	4.62	4.33	4.59
Density at 15 °C	895.44	875.19	910.42	881.63
Cloud Point	-2.0	10.0	7.0	-1.2
Cold Filter Plugging Point	-6.0	7.5	4.5	-3.0
Pour Point	-10.0	5.5	1.6	-6.0
Acid value	0.35	0.37	0.3	0.4
Oxidation Stability (at 110°C)	7.5	7.85	14.0	8.27

### 3.3 Preparation of Blends

In this study. Fresh biodiesel blends are made by mixing biodiesels with a various percentage from 20 to 80 (%v/v) in the step of 20 (%v/v) and homogenized with the aid of magnetic stirrer for 30 min. The following binary mixtures were prepared: FCME-FSME, FSRME-FSCME, FCME-FSRME, FCME-FSCME, FSME-FSRME with various percentages.

Moreover, A series of blends were prepared by blending gasoline with pure biodiesel samples. The percentage of biodiesel added to the fuel, varied from 0, 5, 7, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95 and up to 100% by volume. Biodiesel blends were prepared by weighing with an analytic balance. The uncertainty was  $\pm 0.0001$ g. The system was mixed perfectly into a homogeneous solution by a magnetic stirrer before the experimental measurement.

### 3.4 Storage Conditions

Finding a suitable storage container is necessary particularly for long term biodiesel-Petrofuel blends. In this study, glass containers were selected to the fact that it would not react with biodiesel and its blends, and also it is possible to create different storage conditions. Before filling the container with the fuel sample, they were cleaned with acetone and are left open for a day. Additionally, the samples were filled only up to half of the total volume of the container to avoid contact with the metal lid closures of the containers. To evaluate the effect of storage conditions on the biodiesel properties, the samples are stored under three storage conditions (5°C, room temperature, and 40 $\pm$ 1°C) for a period of 12 months.

- For the storage condition of 5°C, the samples were stored in the refrigerator in which the temperature of the refrigerator was fixed at 5°C.
- For room temperature, the fuel samples were stored in a glass container where the average daily temperature during the storage was about 23°C.
- For the storage condition of 40°C, the samples were temperature-controlled laboratory oven in which the thermostat was used to control the temperature inside the oven and keep it constant.

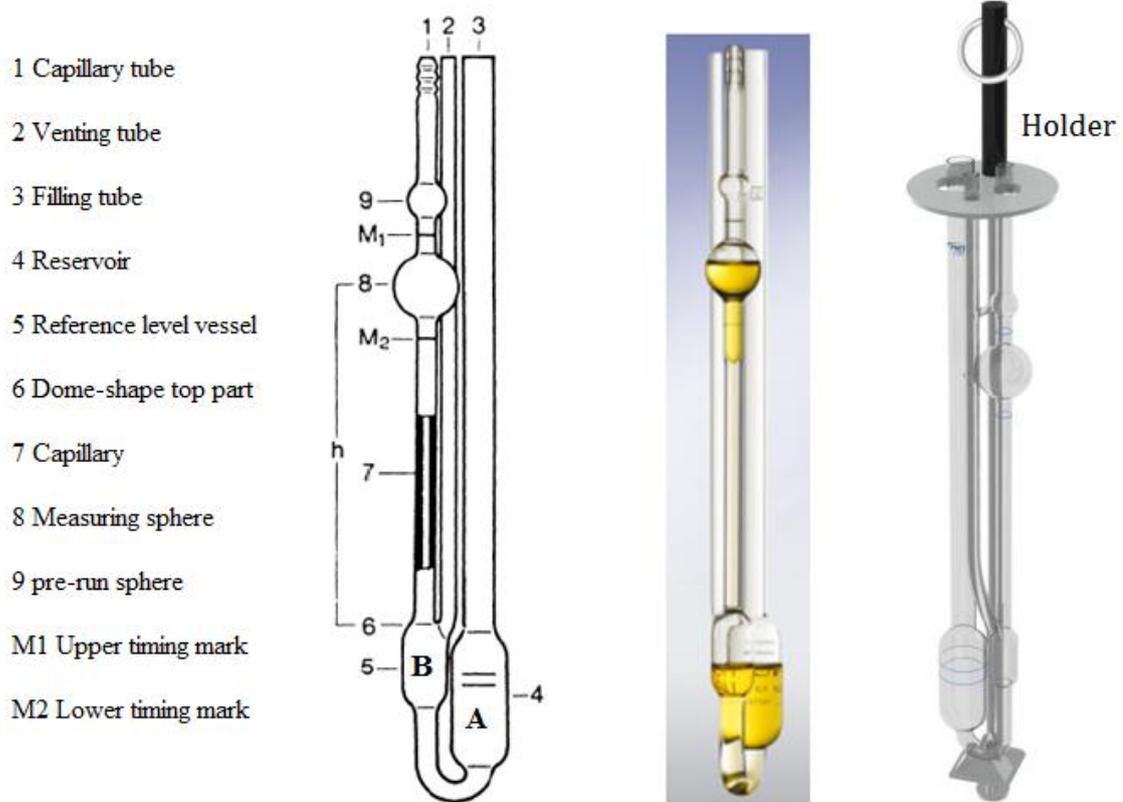
To ensure the temperature of storage remain constant mainly at 5°C and 40°C, the temperature of the storage oven/refrigerator was measured twice a day. It should be noted that the samples were stored in a dark environment. The properties of the fuel samples were determined bimonthly.

### **3.5 Analytical methods**

The biodiesel properties products obtained from frying cooking oils are estimated according to the American Society for Testing and Materials standards (ASTM). The kinematic viscosity and density are measured by using Ubbelohde viscometer and pycnometer with a bulb capacity of 25ml, respectively. Moreover, the cold flow properties in terms of cloud point (CP) and pour point (PP) were measured for each biodiesel sample.

#### **3.5.1 Kinematic Viscosity**

The Ubbelohde viscometer (Figure 3.1) is a tool using a capillary technique to measure viscosity and is recommended for use in high viscosity cellulose polymer solutions. This sort of viscometer has the benefit that obtained values are independent of the total size. The instrument was created by Leo Ubelohade, a German chemist.



**Figure 3.1:** Ubbelohde Viscometer

A liquid is inserted into the reservoir and subsequently sucked through the capillary and measuring sphere. The time it required for the liquid to traverse two calibrated points is the measure of viscosity after the liquid is allowed to pass again through the measuring sphere. The Ubbelohde viscometer comprises a third arm extending from the tip of the capillary and opening into the atmosphere. In this manner the pressure head there is no longer depends on the total volume of liquid but only depends on a fixed height. Due to its broad range of accuracy and using application, the Ubbelohde viscometer was selected. It can be measured transparently and at high temperatures. Two viscometers of type I and Ic were selected in this job to measure kinematic viscosity according to their kinematic viscosity spectrum. The manufacturer calibrated these viscometers. Appendix 8 presents the viscosity manufacturer's certificate.

The constant of the ubbelohde viscometer,  $K$ , [ $(\text{mm}^2/\text{s})/\text{s}$ ] was determined (Table 3.3).

**Table 3.3:** Ubbelohde Viscometer Technical Specifications

<b>Capillary No.</b>	<b>Capillary Dia. I ± 0.01[mm]</b>	<b>Constant , K, (mm<sup>2</sup>/s)/s</b>	<b>Measuring range [mm<sup>2</sup>/s]</b>
<b>I</b>	0.58	0.009820	2 .....10
<b>Ic</b>	0.78	0.02944	6 .....30

For absolute measurement, the flow time between the two timing marks multiplied by the constant viscometer K gives the direct kinematic viscosity (mm<sup>2</sup> / s) as shown in equation (3.1).

$$v = k(t - y) \tag{3.1}$$

Where v the kinematic viscosity

K- The calibration constant.

t - Measured time of flow.

y - Kinetic energy correction.

As shown in Table 3.4 below, the kinetic energy correction is provided by the source in terms of fluid flow time and adjusted to each viscometer.

**Table 3.3:** Table of kinetic energy correction

Flow Time (s)	Capillary no						
	0	0c	0a	I	Ic	Ia	1
40	_B	_B	_B	1.03	0.45	0.15	
50	_B	_B	_B	3.96	0.66	0.29	0.10
60	_B	_B	_B	2.75	0.46	0.20	0.07
70	_B	_B	_B	2.02	0.34	0.15	0.05
80	_B	_B	4.78 <sup>B</sup>	1.55	0.26	0.11	0.04
90	_B	_B	3.78 <sup>B</sup>	1.22	0.20	0.09	0.03
100	_B	7.07 <sup>B</sup>	3.06 <sup>B</sup>	0.99	0.17	0.07	0.02
110	_B	5.84 <sup>B</sup>	2.53	0.82	0.14	0.06	0.02
120	_B	4.91 <sup>B</sup>	2.13	0.69	0.12	0.05	0.02
130	_B	4.18 <sup>B</sup>	1.81	0.59	0.10	0.04	0.01
140	_B	3.61 <sup>B</sup>	1.56	0.51	0.08	0.04	0.01
Flow Time (s)	Capillary no						
	0	0c	0a	I	Ic	Ia	1
150	_B	3.14 <sup>B</sup>	1.36	0.44	0.07	0.03	0.01
160	_B	2.76	1.20	0.39	0.06	0.03	0.01
170	_B	2.45	1.06	0.34	0.06	0.02	0.01
180	_B	2.18	0.94	0.30	0.05	0.02	0.01
190	_B	1.96	0.85	0.28	0.05	0.02	0.01
200	10.33 <sup>B</sup>	1.77	0.77	0.25	0.04	0.02	0.01
225	8.20	1.40	0.60	0.20	0.03	0.01	0.01
250	6.64	1.13	0.49	0.16	0.03	0.01	<0.01
275	5.47	0.93	0.40	0.13	0.02	0.01	<0.01
300	4.61	0.79	0.34	0.11	0.02	0.01	<0.01
325	3.90	0.66	0.29	0.09	0.02	0.01	
350	3.39	0.58	0.25	0.08	0.01	0.01	
375	2.95	0.50	0.22	0.07	0.01	0.01	
400	2.59	0.44	0.19	0.06	0.01	<0.01	
425	2.30	0.66	0.29	0.09	0.01	<0.01	
450	2.05	0.58	0.25	0.08	0.01	<0.01	
475	1.84	0.50	0.22	0.07	0.01		
500	1.66	0.44	0.19	0.06	0.01		
550	1.37	0.23	0.1	0.03	0.01		
600	1.15	0.20	0.09	0.03	0.01		
650	0.98	0.17	0.07	0.03	<0.01		
800	0.65	0.11	0.05				
850	0.51	0.10	0.04				
900	0.46	0.09	0.04				
950	0.42	0.08	0.03				
1000	3.39	0.07	0.03				

<sup>A</sup>The correction seconds stated are related to the respective theoretical constant

<sup>B</sup>For precision measurement, these flow times should not be applied.

Selection of a viscometer with a smaller capillary diameter is suggested

As previously noted, Ubbelohde viscometer was used for measuring the kinematic viscosity. Procedure of measuring the kinematic viscosity was as following steps;

***Step1***

Use the washing products to clean the viscometer. Cleaning content must have the correct ratios. (15% muriatic acid, 15% sulfur peroxide, 70% distilled oil). Then add acetone to complete the method of washing. The capillary tube must be drained to begin the experiment method.

***Step2***

Fill in the viscometer with a fix amount of biodiesel. Should the biodiesel is placed between the two lines on the tube so that the amount of liquid loaded does not block the air tube during use.

***Step3***

Insert the viscometer in a liquid bath at a meant temperature. Sample fluid will takes about 20 minutes to reach the same temperature in the bath.

***Step4***

Sucking up the fluid inside the capillary viscometer, with suction syringe that is shown in Figure 3.2, until liquid fill up the pre run sphere.



**Figure 3.2:** Suction instrument

***Step 5***

Then, let the liquid to flow and record the flow time in seconds between to calibrated marks. Be sure to use the same edges of the two marks (upper and lower). The time required for the liquid to pass through the two marks is a viscosity measure.

***Step 6***

Use equation 3.1 to calculate the kinematic viscosity of the biodiesel sample. Repeat processes 3 times. Calculate the average of the measurements and do the same procedure to measure the kinematic viscosity with the next measurement with a different temperature value.

Figure 3.4 shows the experimental setup for measuring the kinematic viscosity for cooling it contains the following components:

- 1- Cooling bath
- 2- Compressor
- 3- Radiator

- 4- Thermostat with Thermocouple
- 5- Viscometer holder
- 6- Capillary viscometer
- 7- Time recorder
- 8- Coil
- 9- Alcohol



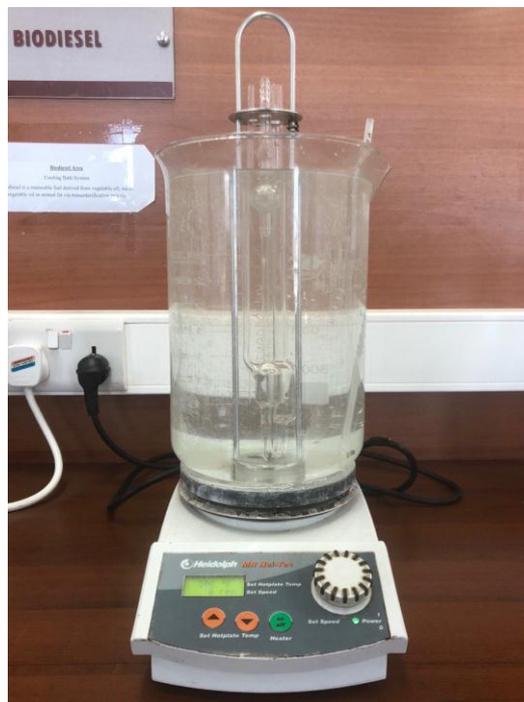
**Figure 3.3:** The Experimental Setup for measuring the viscosity at low temperature

We applied same procedure for measuring kinematic viscosity from 20°C and decrease the temperature by specific steps until the biodiesel sample gets gel formation and freezes that there is no more for fluid to flow. We utilize Alcohol (ethanol) as liquid for cooling bath because the alcohol did not freeze to -114 °C, but water freezes to 0 °C. 97% was the purity of alcohol, that was took up from Cyprus in a local alcohol manufactory. Thick Styrofoam layer was used to isolate the cooling bath to keep the bath temperature constant as match as possible. Using thermostat to control the bath temperature using a compressor

by automatically shutting down and starting up it. To cool down the liquid inside the cooling bath a coil connected between the compressor and the bath, and a radiator used to cool down the compressor.

Moreover, Figure 3.4 shows the experimental setup for measuring the kinematic viscosity for heating it contains the following components:

1. Thermocouple
2. Capillary Viscometer
3. viscometer holder
4. Electromagnetic hot plate
5. Water
6. heat resistant beaker thermometer
7. Time recorder
8. Biodiesel sample



**Figure 3.4:** The Experimental Setup for measuring the viscosity at high temperatures

Water was used as a heating bath liquid by boiling the water inside the baker using electronic hot plate to increase the biodiesel sample temperature. The temperature was controlled by a digital standard thermometer

### 3.5.2 Density

Pycnometer is a device which is used for measuring the density of liquid (biodiesel sample). Usually a pycnometer is produced of glass, with a close-fitting ground glass stopper with a capillary tube through it, A pycnometer is usually made of glass, with a closely fitted ground glass stopper with a capillary tube through it, so the device will allow the surplus fluid and air bubbles to escape from it. This device can accurately measure the density of the fluid with reference to a suitable working fluid, such as water, using an electronic scale. The density of the biodiesel sample was measured for heating and cooling the biodiesel sample. For measuring the biodiesel sample mass, we subtract the empty pycnometer mass from the filled pycnometer mass of biodiesel sample. By dividing the mass of the biodiesel sample with the volume ( $V$ ) of the pycnometer we get the density of the biodiesel sample in  $\text{kg/m}^3$  as given in equation (3.2).

$$\rho = \frac{(m_{full} - m_{empty})}{V} \quad (3.2)$$

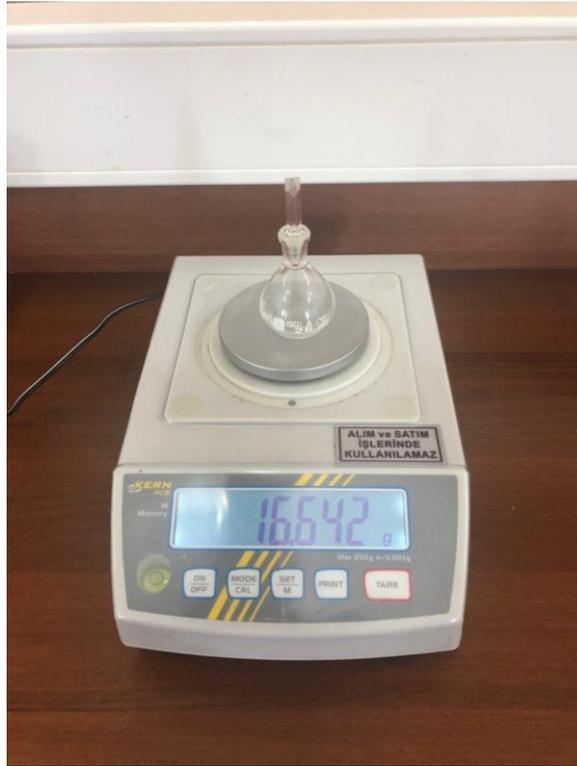
Procedure of measuring the density was as following steps;

#### ***Step1***

Use the washing products to clean the pycnometer. Cleaning content must have the correct ratios. (15% muriatic acid, 15% sulfur peroxide, 70% distilled oil). Then add acetone to complete the method of washing. The pycnometer must be drained to begin the experiment method.

#### ***Step2***

Measure the filled pycnometer mass of biodiesel sample. But before that, we must measure the empty pycnometer mass, using an electronic balance scale as shown in Figure 3.5. Eq. (3.2) is used to determine the density of the fuel.



**Figure 3.5:** Pycnometer weight

***Step3***

The pycnometer should be fully filled with biodiesel. As shown in Figure 3.6, air gaps and Excess biodiesel will leak from the pycnometer.



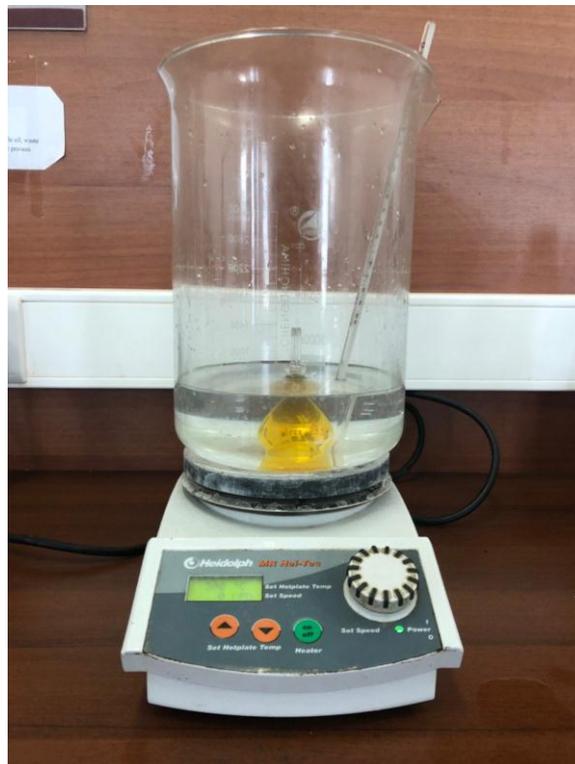
**Figure 3.6:** The pycnometers' over flow gap

***Step 4***

The Pycnometer located in cooling bath (Figure 3.7) and heating bath (Figure 3.8), and wait for the needed temperature. Wait for at least 15 minutes at the necessary temperature until the temperature in the beaker or cooling bath becomes homogeneous.



**Figure 3.7:** Experimental setup used for measuring the density at 15°C



**Figure 3.8:** Experimental setup used for measuring density at high temperature

### *Step5*

Figure 3.9 shows the electronic balance that used to measure the mass of the full Pycnometer.



**Figure 3.9:** Electronic balance for measuring the Pycnometer mass

### *Step 6*

Calculate the density using Eq. (3.2). Repeat 3 or 4 times in these steps and calculate the average density value.

### **3.5.3 Cold Flow Properties**

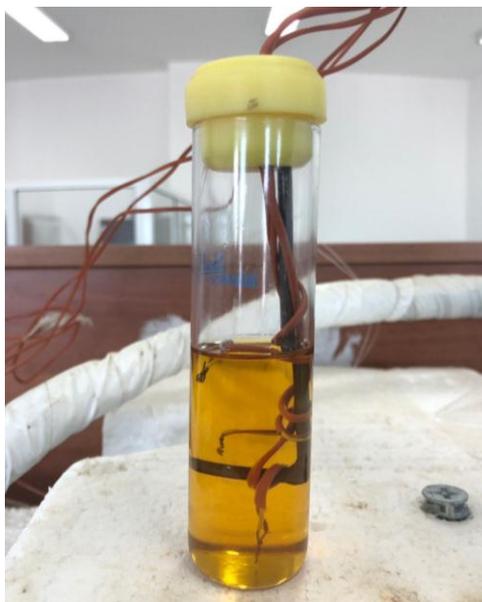
Cloud Point and Pour Point are the cold flow properties and can be measured here, with a special glass jar test and a data logger with four thermocouples, between these two points, the Cold Filter Plugging Point is discovered. Both the ASTM D 97-05 and the ASTM 2500 have been pursued for these properties. It is possible to do both experiments concurrently.

As previously noted, a special glass jar test and a data logger with four thermocouples was used for measuring the cold flow properties. Procedure of measuring the cloud point and pour point was as following steps;

### *Step1*

Measuring a 45 ml of the biodiesel sample using a (Measuring cylinder) as shown in (Figure 3.10), and then claim it in a special glass jar test for measuring the cloud point and

pour point. The thermocouples must be arranged as shown in figure 3.14. The upper thermocouple computes the Cloud point and the upper thermocouple computes the Pour point.



**Figure 3.10:** Glass jar test with thermocouples

***Step 2***

When we turn on the cooling bath, we have to wait until the temperature inside the bath being (-16°C, then we will put the special glass jar in the jacket cylinder, and the level of alcohol must be noted before we placed the glass jar.

***Step 3***

We have to check the biodiesel sample inside the glass jar every 2 or 3 minutes (every 1 °C temperature drop) continuously.

***Step 4***

The cloud point will be reached when we see small grains like crystals at the bottom of the glass jar test. We record the temperature according to the meant thermocouple shown on the computer.

***Step 5***

Continue step 3 process.

### ***Step 6***

The pour point will be reached, when the sample get a gel formation and is no longer to flow as shown on (Figure 3.11). We record the temperature according to the meant thermocouple shown on the computer.



**Figure 3.11:** The formation of biodiesel sample when reaches the Pour Point

### ***Step 7***

The data acquired digitally from the data logger will constant and compare with the outcomes results of the cooling curve.

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **4.1 Physicochemical Properties of Pure Biodiesel and Their Blends**

The measured kinematic viscosity and densities of biodiesel and their blends at atmospheric pressure and testing temperature of 40°C and 15°C, respectively are listed in Table 4. It is observed that the viscosity and densities of all samples are within the range of the ASTM D445 and ASTM D854, respectively.

**Table 4.** Measured kinematic viscosity (KV) and densities (D) for all samples

<b>Blend</b>	<b>Designation</b>	<b>VF [%]</b>	<b>KV [mm<sup>2</sup>/s]</b>	<b>D [kg/m<sup>3</sup>]</b>
FCME-FSME	FCME	100-0	4.55	895.44
	20-FSME	80-20	4.58	879.77
	40-FSME	60-40	4.66	902.18
	60-FSME	40-60	4.64	892.34
	80-FSME	20-80	4.63	882.50
	FSME	0-100	4.62	875.19
FSCME-FSRME	FSCME	100-0	4.33	910.42
	20-FSRME	80-20	4.36	904.64
	40-FSRME	60-40	4.49	898.96
	60-FSRME	40-60	4.51	893.16
	80-FSRME	20-80	4.57	887.42
	FSRME	0-100	4.59	881.63
FSRME-FCME	FSRME	100-0	4.59	895.44
	20-FCME	80-20	4.63	900.95
	40-FCME	60-40	4.60	892.15
	60-FCME	40-60	4.58	889.94
	80-FCME	20-80	4.56	886.10
	FCME	0-100	4.55	881.63
FSCME-FCME	FSCME	100-0	4.33	910.42
	20-FCME	80-20	4.37	907.42
	40-FCME	60-40	4.42	904.43
	60-FCME	40-60	4.59	912.93
	80-FCME	20-80	4.57	903.44
	FCME	0-100	4.55	895.44
FSME-FSRME	FSME	100-0	4.62	875.19
	20-FSRME	80-20	4.65	892.28
	40-FSRME	60-40	4.63	887.76
	60-FSRME	40-60	4.61	885.85
	80-FSRME	20-80	4.60	883.32
	FSRME	0-100	4.59	881.63
FSCME-FSME	FSCME	100-0	4.33	910.42
	20-FSME	80-20	4.37	903.37
	40-FSME	60-40	4.43	896.33
	60-FSME	40-60	4.48	889.28
	80-FSME	20-80	4.55	882.24
	FSME	0-100	4.62	875.19

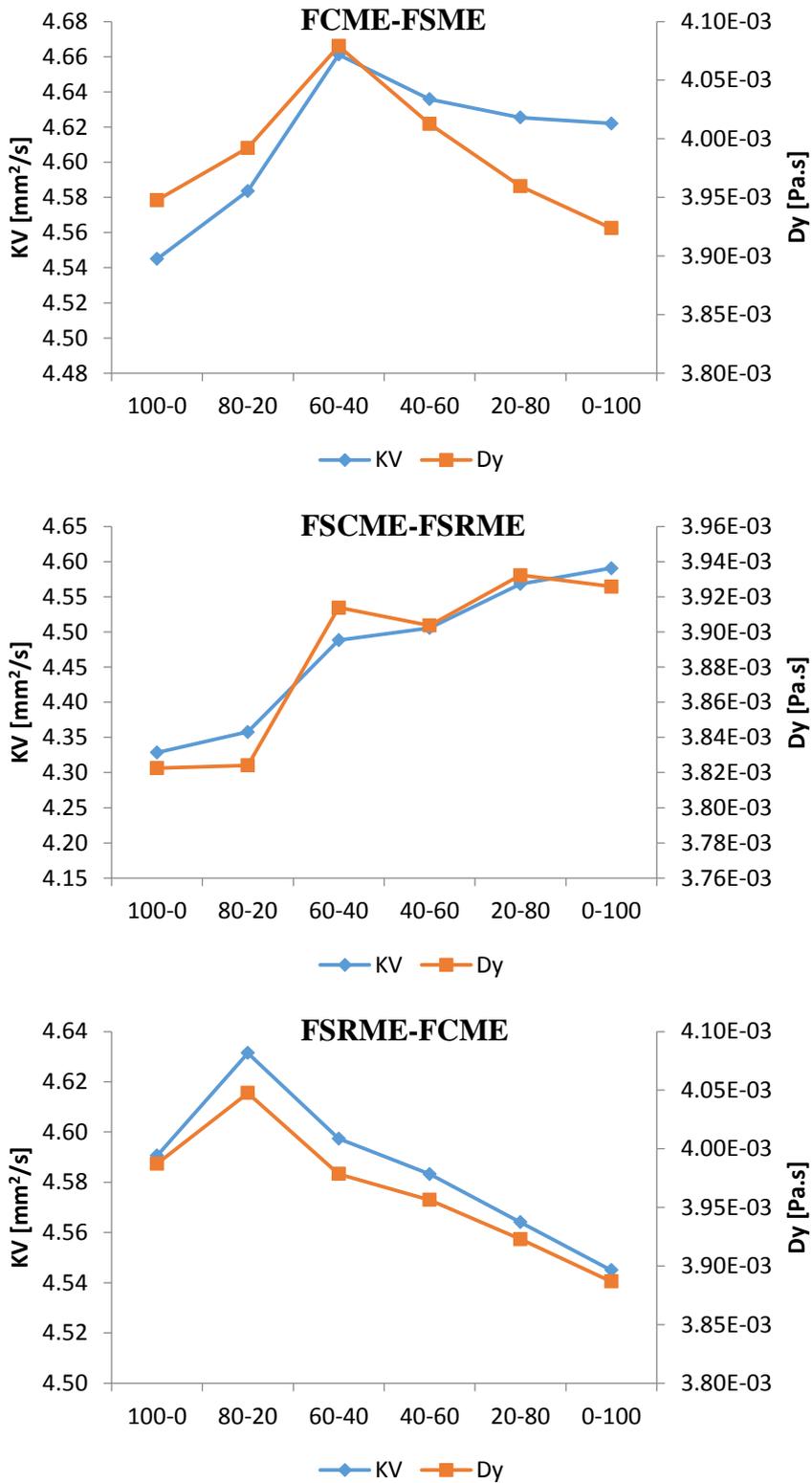
Generally, according to standard mixing rules for FAME mixtures suggest that the viscosity of biodiesel blends does not vary greatly from this value for different mixture compositions. It is found that viscosity and density of FSCME-FSRME blends and FSCME-FSME blends are within the range of kinematic viscosity of pure samples. The

viscosities of FSCME-FSRME and FSCME-FSME blends and FSCME-FSME mixture are increased as the amount of FCME and FSME increase in the blend, respectively. Based on the analysis, it is noticed that 40-FSME has maximum kinematic viscosity compared to pure biodiesels (FSME and FCME) and other blends (20-FSME, 60-FSME and 80-FSME). Additionally, it is found that 20-FCME has the maximum viscosity compared to other samples of the FSME-FSRME mixture. Also, 60-FCME and 20-FSRME have the highest viscosity with value of  $4.59\text{mm}^2/\text{s}$  and  $4.65\text{mm}^2/\text{s}$  compared to other blends of FSCME-FCME and FSME-FSRME, respectively. This study reports the following

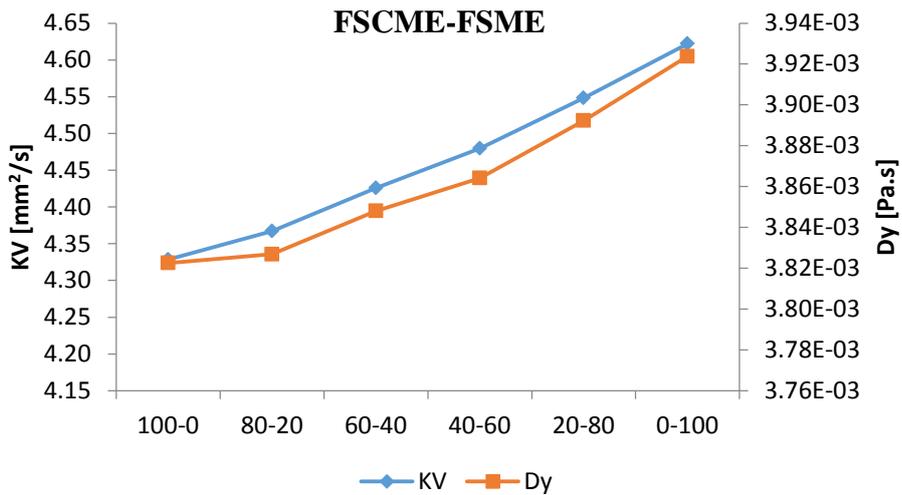
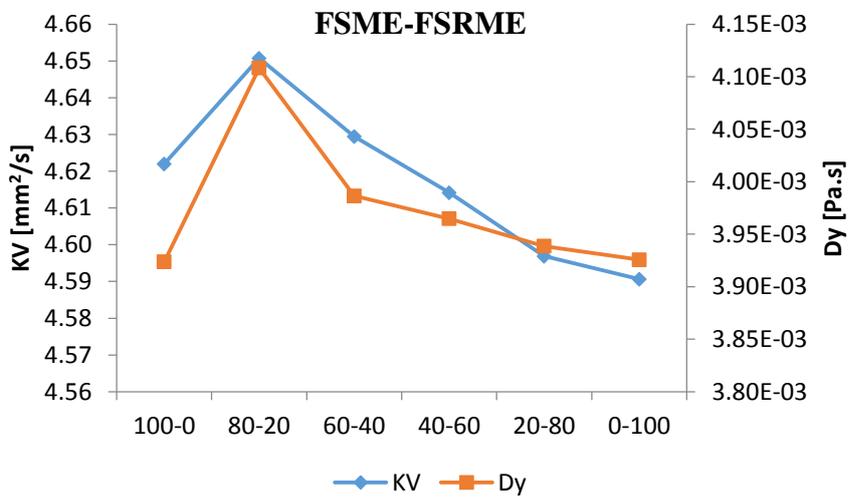
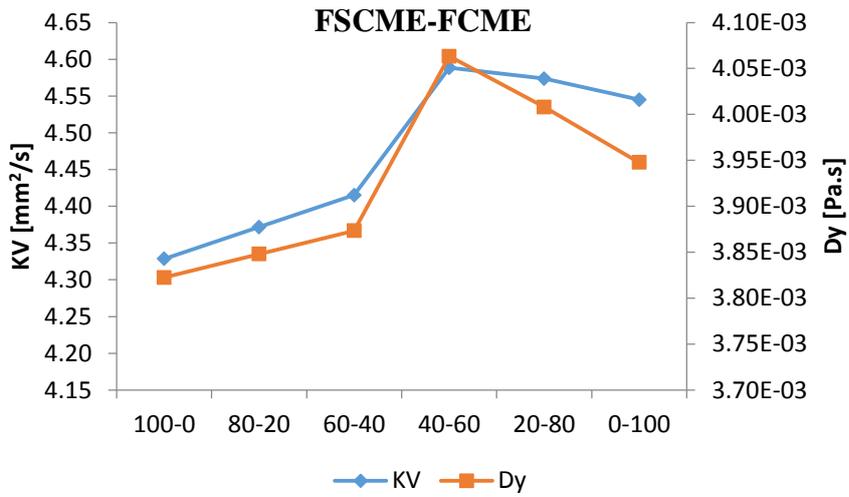
- The kinematic viscosity increased by  $0.04\text{ mm}^2/\text{s}$  to a maximum at 40 vol% FSME in FCME-FSME blends
- The kinematic viscosity increased by  $0.04\text{ mm}^2/\text{s}$  to a maximum at 60 vol% FSME in FSCME-FSME blends
- The kinematic viscosity increased by  $0.06\text{ mm}^2/\text{s}$  to a maximum at 20 vol% FSME in FSME-FSRME blends
- The kinematic viscosity increased by  $0.09\text{ mm}^2/\text{s}$  to a maximum at 20 vol% FCME in FSRME-FCME blends

These deviations from standard mixing rules cannot be explained by variations in the fatty acid concentration profiles in the mixtures. Thus, this observation can be explained based on fundamental aspects of fuel chemistry i.e., the properties of residential waste frying oils depend on the condition of frying.

In order to ensure the density and kinematic viscosity have the same investigation phenomena, the determined dynamic viscosities at  $40^\circ\text{C}$  are illustrated as shown in Figure 4.1. It is noted that the dynamic viscosity of all samples was calculated by multiplying the experimental results of density and kinematic viscosity. It is found that dynamic viscosity has the same characteristics as the kinematic viscosity for all samples.

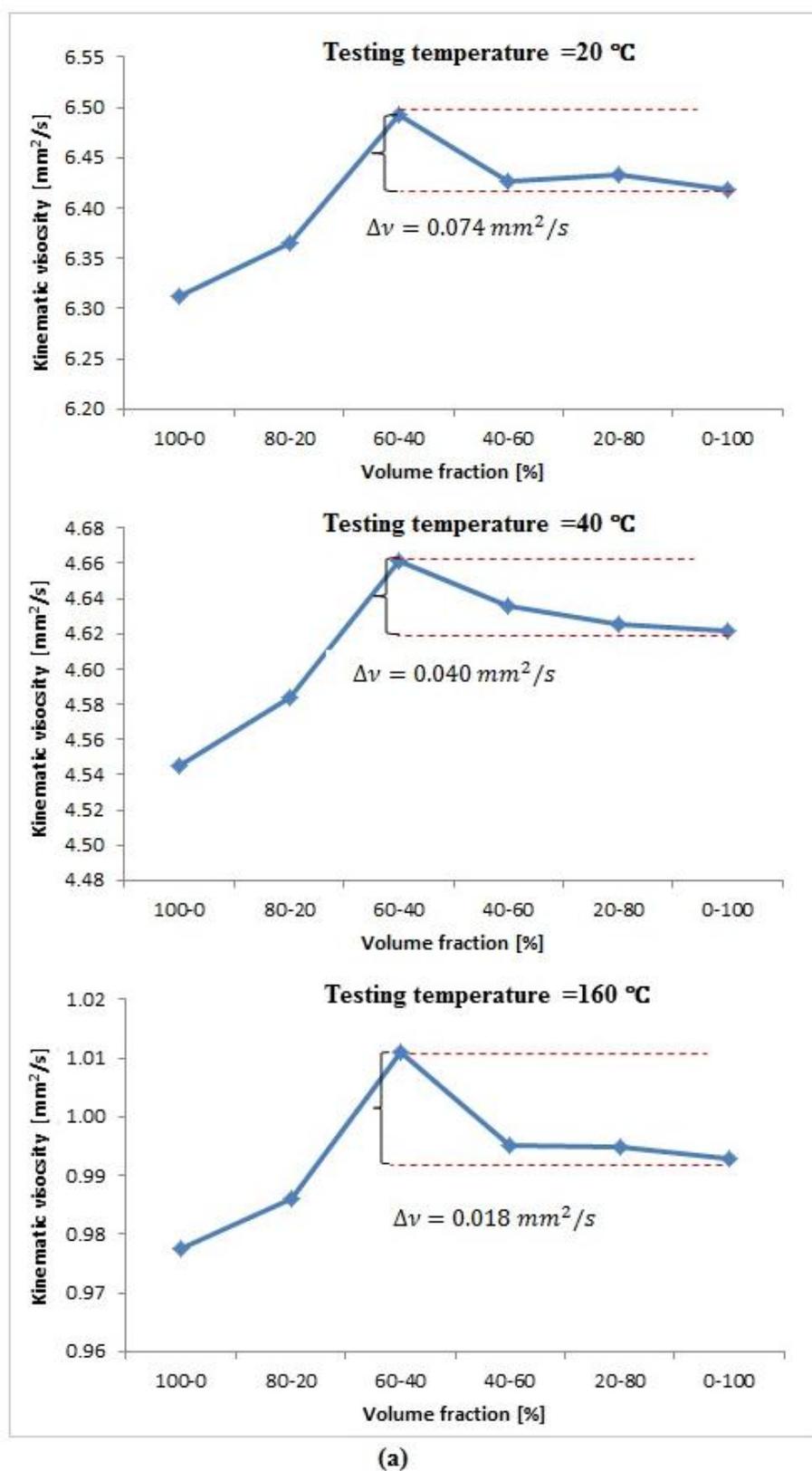


**Figure 4.1:** Kinematic viscosity and dynamic viscosity biodiesel blends

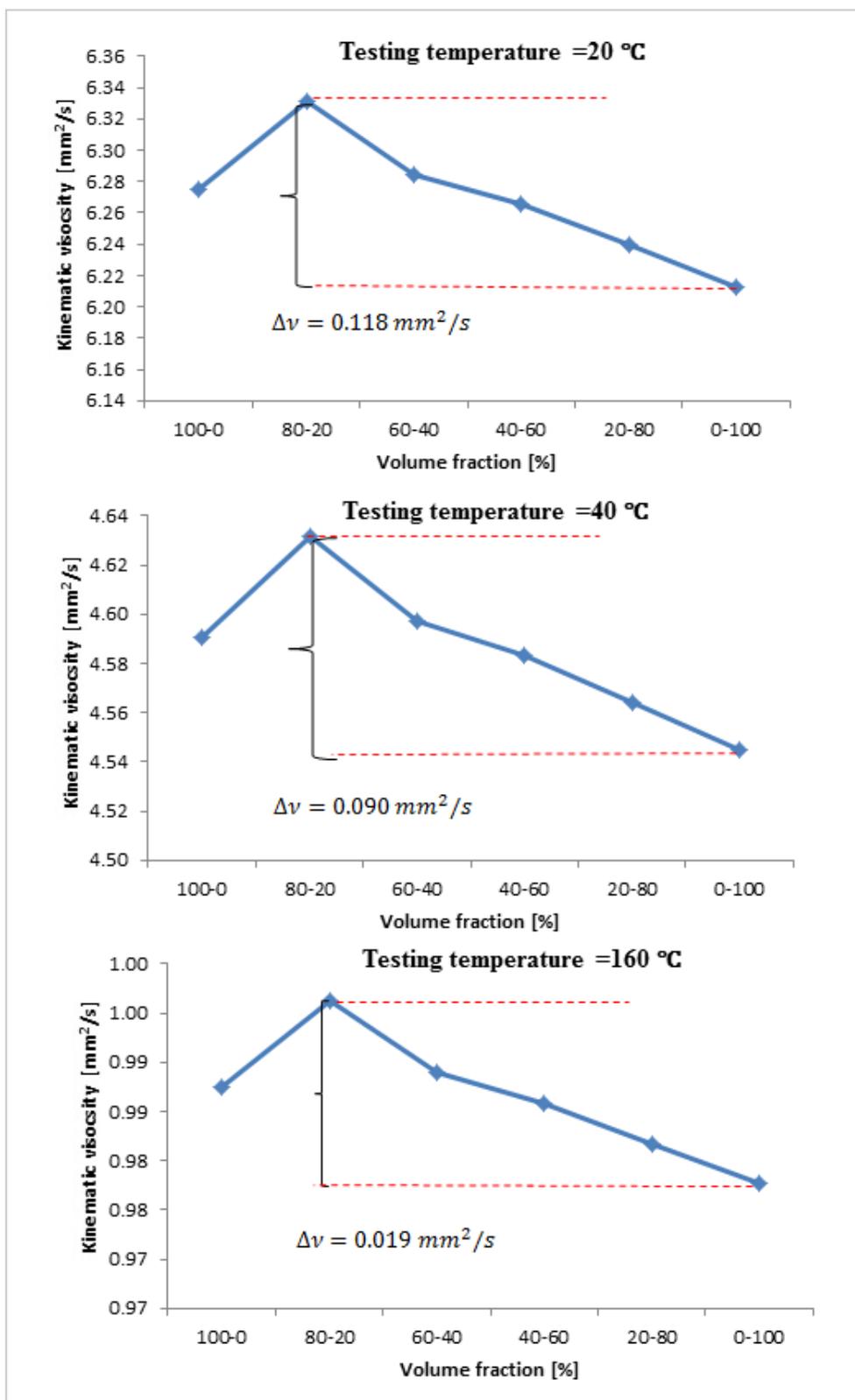


**Figure 4.1:** Continued

Referring to Table 4.1, kinematic viscosities were measured for unmixed biodiesel at only 40°C. At these temperatures, these values deviated from the kinematic viscosity of unmixed biodiesel (FCME, FSME, FSCME and FSRME) by ranged of 0.03-0.22mm<sup>2</sup>/s. This evidence suggests that the kinematic viscosities of pure biodiesels are nearly equivalent, an observation that is supported by the results in Table 4. Given these considerations, it is difficult to attribute the results for mixtures at 40°C showing large increases in viscosity to maximum values at ~ 60 vol% FSME in FSCME-FSME blends and ~20 vol% FSME in FSME-FSRME blends and ~20 vol% FCME in FSRME-FCME blends on variances in the fatty acid composition of the methyl esters. Since the increases are greater than can be explained by experimental error, there is likely another phenomenon taking place in the mixtures. Furthermore, at lower and higher temperatures (20°C and 160°C), thermal degradation may be taking place that ameliorates the phenomena resulting in little or no maxima being observed in the curves in Figure 4.2. As seen in Figure 4.2, the variation of kinematic viscosity ( $\Delta\nu$ ) for low temperatures is very clearly higher than the variation of kinematic viscosity ( $\Delta\nu$ ) at high temperatures. It means that the same tendency also occurs at high temperatures with little variations.

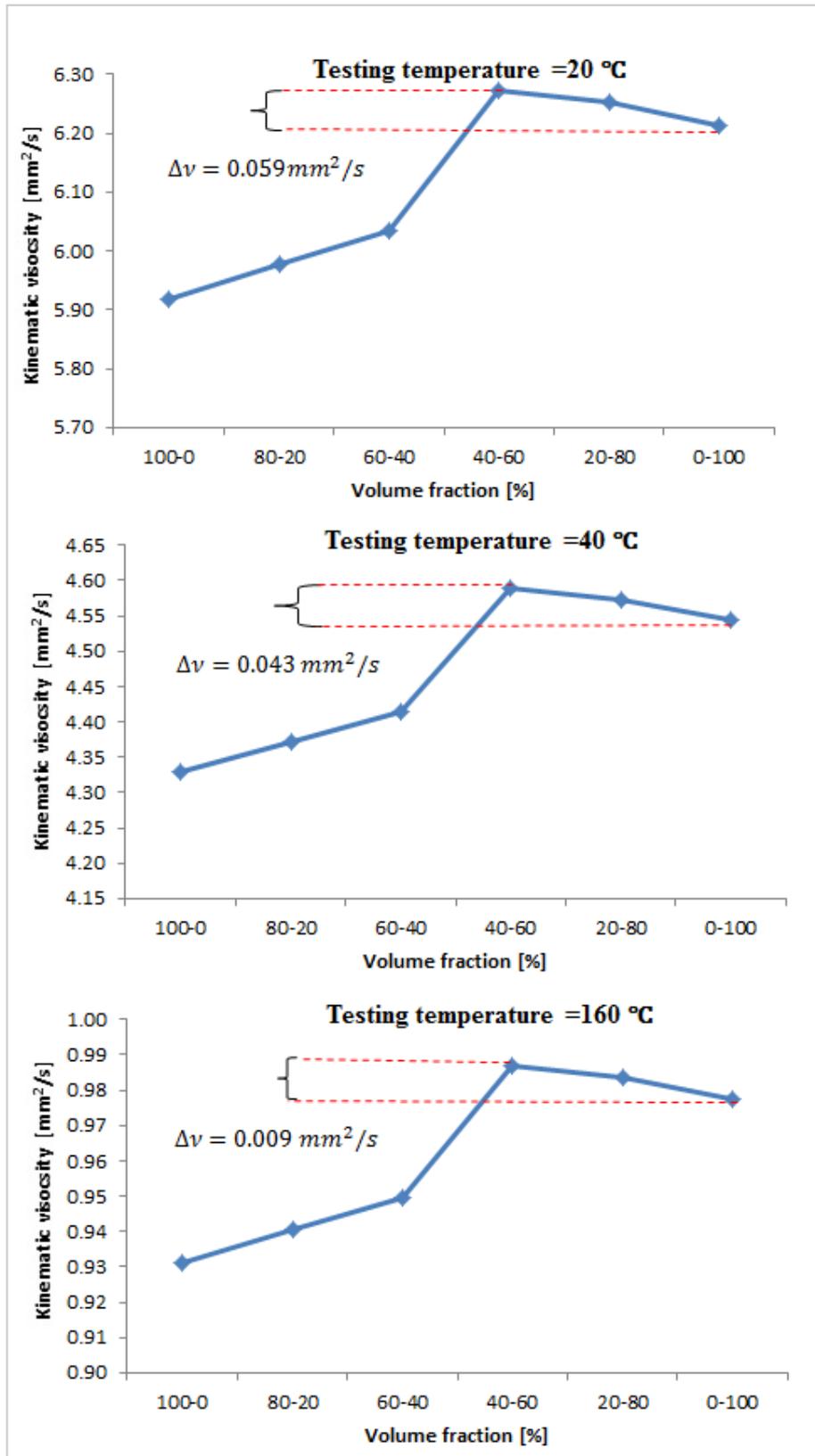


**Figure 4.2:** Kinematic viscosity of some selected blends at various testing temperature: (a) FCME-FSME, (b) FSRME-FCME, (c) FSCME-FCME and (d) FSME-FSRME



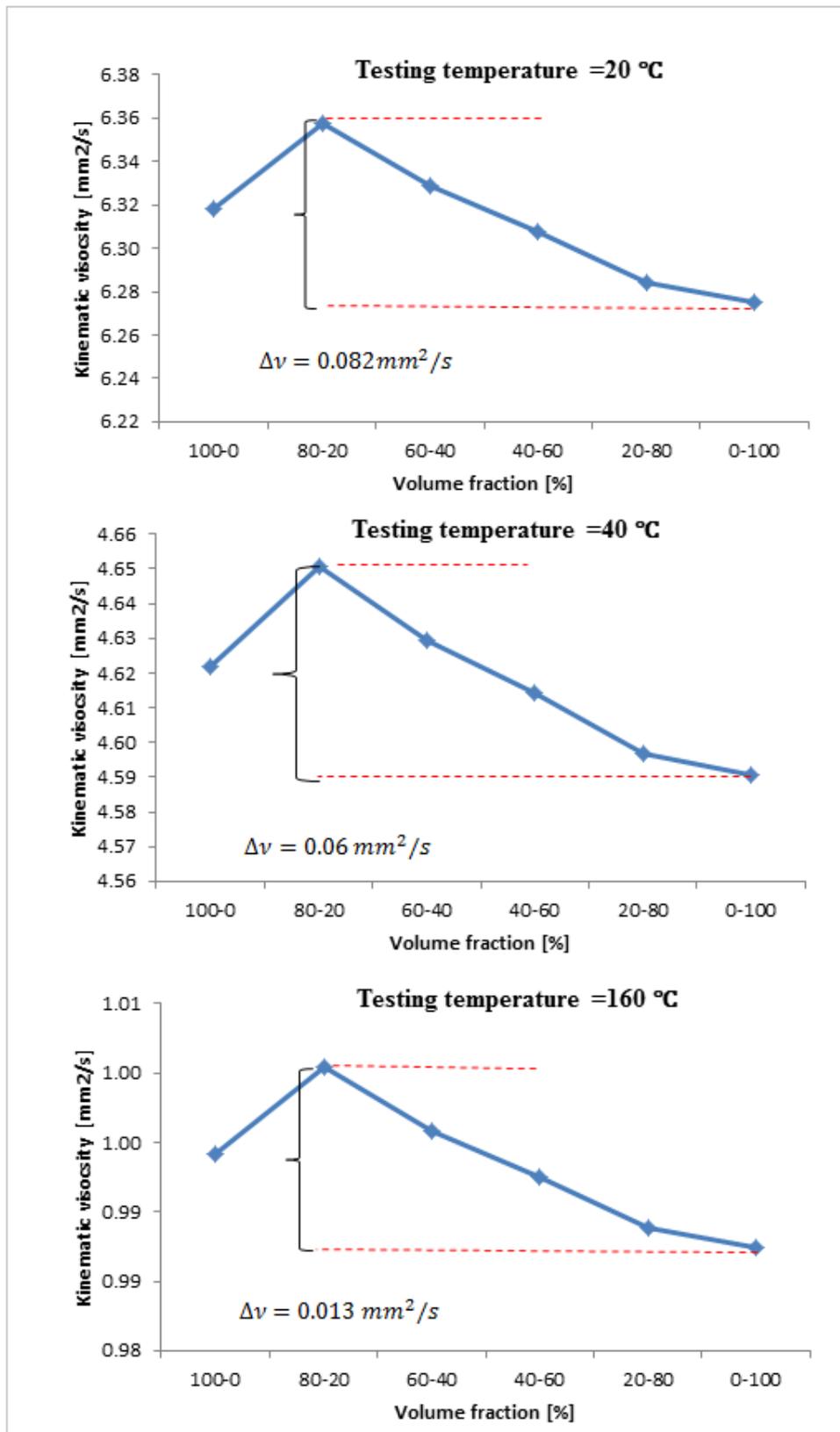
(b)

Figure 4.2: Continued



(c)

Figure 4.2: Continued



(d)

Figure 4.2: Continued

## 4.2 Influence of Storage Conditions on Kinematic Viscosity

Experimental results of the kinematic viscosity of biodiesel samples as a function of storage temperature (ST) and storage period (SP) at 40°C are summarized in Table 4.2. It is observed that the viscosities for all samples increased as the SP increased for all storage conditions. Also, it is found that the higher ST, the higher kinematic viscosity is obtained. Moreover, it is found that the kinematic viscosities of biodiesel were varied in the range of 4.33–4.62 mm<sup>2</sup>/s. According to the ASTM D445 standard requiring viscosity values at 40°C higher 1.9 mm<sup>2</sup>/s, all biodiesel samples fulfill this requirement for all storage periods at all storage temperatures, except for FCME, kinematic viscosity was above the maximum limit of viscosity specification in ASTM D455 after 10 months at ST of 40°C. Moreover, the obtained kinematic viscosity data for all unmixed biodiesel samples correspond with the recommended EN 14214 (3.5–5.0 mm<sup>2</sup>/s) at 40°C during the storage periods of 12 months and ST of 5°C. Additionally, storage over an extended period 2, 4 and 6 months at ST of 40°C resulted in precipitous rising in the kinematic viscosity for FCME, FSME and FSRME, respectively. Additionally, as reported in Table 6, the viscosity of FSCME remained within the range of 3.5–5 mm<sup>2</sup>/s during the study duration at ST of 40°C. Furthermore, data from Table 4.2 shows that kinematic viscosities of all samples are not in accordance with standard demand for diesel fuel (ASTM D975 recommended values: 1.9–4.10 mm<sup>2</sup>/s). Furthermore, kinematic viscosity values of FSCME and some blends are fulfilling with the European regulations EN 590, which establishes that viscosity at 40 °C must be in the range of 2.0–4.5 mm<sup>2</sup>/s as shown in Table 4.2.

**Table 4.2:** Influence of storage conditions on viscosity in mm<sup>2</sup>/s at 40°C

Blend	VF [%]	ST [°C]	Storage period [month]							
			0	2	4	6	8	10	12	
FCME- FSME	100-0	5	4.55	4.56	4.57	4.58	4.59	4.60	4.61	
		25	4.55	4.64	4.73	4.82	4.91	5.00	5.09	
		40	4.55	4.82	5.09	5.36	5.63	5.90	6.17	
	80-20	5	4.58	4.59	4.60	4.61	4.62	4.63	4.64	
		25	4.58	4.62	4.65	4.69	4.72	4.75	4.79	
		40	4.58	4.77	4.95	5.13	5.31	5.49	5.68	
	60-40	5	4.66	4.67	4.68	4.69	4.70	4.71	4.72	
		25	4.66	4.71	4.76	4.81	4.85	4.90	4.95	
		40	4.66	4.87	5.07	5.27	5.48	5.68	5.89	
	40-60	5	4.64	4.65	4.66	4.67	4.68	4.69	4.70	
		25	4.64	4.70	4.76	4.82	4.88	4.95	5.01	
		40	4.64	4.86	5.09	5.31	5.54	5.77	5.99	
	20-80	5	4.63	4.64	4.65	4.66	4.67	4.68	4.69	
		25	4.63	4.70	4.78	4.85	4.93	5.01	5.08	
		40	4.63	4.87	5.12	5.37	5.62	5.87	6.11	
	0-100	5	4.62	4.63	4.64	4.65	4.66	4.67	4.68	
		25	4.62	4.64	4.66	4.68	4.70	4.72	4.74	
		40	4.62	4.78	4.94	5.10	5.26	5.42	5.58	
	FSCME- FSRME	100-0	5	4.33	4.34	4.35	4.36	4.37	4.38	4.39
			25	4.33	4.35	4.37	4.39	4.41	4.43	4.45
			40	4.33	4.38	4.43	4.48	4.53	4.58	4.63
		80-20	5	4.36	4.37	4.38	4.39	4.40	4.41	4.42
			25	4.36	4.37	4.40	4.42	4.45	4.46	4.49
			40	4.36	4.42	4.49	4.55	4.61	4.68	4.74
60-40		5	4.49	4.50	4.51	4.52	4.53	4.54	4.55	
		25	4.49	4.50	4.54	4.55	4.58	4.60	4.63	
		40	4.49	4.57	4.64	4.72	4.80	4.88	4.96	
40-60		5	4.51	4.52	4.53	4.54	4.55	4.56	4.57	
		25	4.51	4.52	4.56	4.57	4.61	4.62	4.66	
		40	4.51	4.60	4.69	4.78	4.87	4.97	5.06	
20-80		5	4.57	4.58	4.59	4.60	4.61	4.62	4.63	
		25	4.57	4.58	4.62	4.63	4.68	4.69	4.74	
		40	4.57	4.67	4.78	4.89	4.99	5.10	5.20	
0-100		5	4.59	4.60	4.61	4.62	4.63	4.64	4.65	
		25	4.59	4.60	4.65	4.66	4.71	4.72	4.77	
		40	4.59	4.71	4.83	4.95	5.07	5.19	5.31	

**Table 4.2:** Continued

Blend	VF [%]	ST [°C]	Storage period [month]							
			0	2	4	6	8	10	12	
FSRME-FCME	100-0	5	4.59	4.60	4.61	4.62	4.63	4.64	4.65	
		25	4.59	4.60	4.65	4.66	4.71	4.72	4.77	
		40	4.59	4.71	4.83	4.95	5.07	5.19	5.31	
	80-20	5	4.63	4.64	4.65	4.66	4.67	4.68	4.69	
		25	4.63	4.65	4.72	4.74	4.80	4.82	4.88	
		40	4.63	4.78	4.93	5.08	5.23	5.38	5.53	
	60-40	5	4.60	4.61	4.62	4.63	4.64	4.65	4.66	
		25	4.60	4.64	4.71	4.74	4.81	4.85	4.92	
		40	4.60	4.78	4.96	5.14	5.32	5.50	5.68	
	40-60	5	4.58	4.59	4.60	4.61	4.62	4.63	4.64	
		25	4.58	4.64	4.72	4.77	4.85	4.90	4.98	
		40	4.58	4.79	5.00	5.21	5.42	5.63	5.84	
	20-80	5	4.56	4.57	4.58	4.59	4.60	4.61	4.62	
		25	4.56	4.64	4.72	4.79	4.88	4.95	5.03	
		40	4.56	4.80	5.04	5.28	5.52	5.76	6.00	
	0-100	5	4.55	4.56	4.57	4.58	4.59	4.60	4.61	
		25	4.55	4.64	4.73	4.82	4.91	5.00	5.09	
		40	4.55	4.82	5.09	5.36	5.63	5.90	6.17	
	FSCME-FCME	100-0	5	4.33	4.34	4.35	4.36	4.37	4.38	4.39
			25	4.33	4.35	4.37	4.39	4.41	4.43	4.45
			40	4.33	4.38	4.43	4.48	4.53	4.58	4.63
		80-20	5	4.37	4.38	4.39	4.40	4.41	4.42	4.43
			25	4.37	4.41	4.44	4.47	4.51	4.54	4.58
			40	4.37	4.47	4.56	4.65	4.75	4.84	4.94
60-40		5	4.42	4.43	4.44	4.45	4.46	4.47	4.48	
		25	4.42	4.46	4.51	4.56	4.61	4.66	4.70	
		40	4.42	4.55	4.69	4.83	4.97	5.11	5.24	
40-60		5	4.59	4.47	4.48	4.49	4.50	4.51	4.52	
		25	4.59	4.52	4.58	4.64	4.71	4.77	4.83	
		40	4.59	4.64	4.82	5.00	5.19	5.37	5.55	
20-80		5	4.57	4.58	4.59	4.60	4.61	4.62	4.63	
		25	4.57	4.65	4.73	4.80	4.88	4.95	5.03	
		40	4.57	4.80	5.03	5.25	5.48	5.70	5.93	
0-100		5	4.55	4.56	4.57	4.58	4.59	4.60	4.61	
		25	4.55	4.64	4.73	4.82	4.91	5.00	5.09	
		40	4.55	4.82	5.09	5.36	5.63	5.90	6.17	

**Table 4.2:** Continued

Blend	VF [%]	ST [°C]	Storage period [month]							
			0	2	4	6	8	10	12	
FSME-FSRME	100-0	5	4.62	4.63	4.64	4.65	4.66	4.67	4.68	
		25	4.62	4.64	4.66	4.68	4.70	4.72	4.74	
		40	4.62	4.78	4.94	5.10	5.26	5.42	5.58	
	80-20	5	4.65	4.66	4.67	4.68	4.69	4.70	4.71	
		25	4.65	4.67	4.69	4.71	4.74	4.76	4.78	
		40	4.65	4.80	4.95	5.11	5.26	5.41	5.56	
	60-40	5	4.63	4.64	4.65	4.66	4.67	4.68	4.69	
		25	4.63	4.64	4.68	4.69	4.73	4.74	4.77	
		40	4.63	4.77	4.92	5.06	5.21	5.35	5.49	
	40-60	5	4.61	4.62	4.63	4.64	4.65	4.66	4.67	
		25	4.61	4.62	4.67	4.68	4.72	4.73	4.77	
		40	4.61	4.75	4.89	5.02	5.16	5.29	5.43	
	20-80	5	4.60	4.61	4.62	4.63	4.64	4.65	4.66	
		25	4.60	4.60	4.65	4.66	4.71	4.72	4.76	
		40	4.60	4.72	4.85	4.98	5.11	5.24	5.36	
	0-100	5	4.59	4.60	4.61	4.62	4.63	4.64	4.65	
		25	4.59	4.60	4.65	4.66	4.71	4.72	4.77	
		40	4.59	4.71	4.83	4.95	5.07	5.19	5.31	
	FSCME-FSME	100-0	5	4.33	4.34	4.35	4.36	4.37	4.38	4.39
			25	4.33	4.35	4.37	4.39	4.41	4.43	4.45
			40	4.33	4.38	4.43	4.48	4.53	4.58	4.63
		80-20	5	4.37	4.38	4.39	4.40	4.41	4.42	4.43
			25	4.37	4.39	4.41	4.43	4.45	4.47	4.49
			40	4.37	4.44	4.51	4.58	4.66	4.73	4.80
60-40		5	4.43	4.44	4.45	4.46	4.47	4.48	4.49	
		25	4.43	4.45	4.47	4.49	4.51	4.53	4.55	
		40	4.43	4.52	4.61	4.71	4.80	4.90	4.99	
40-60		5	4.48	4.49	4.50	4.51	4.52	4.53	4.54	
		25	4.48	4.50	4.52	4.54	4.56	4.58	4.60	
		40	4.48	4.60	4.71	4.83	4.94	5.06	5.18	
20-80		5	4.55	4.56	4.57	4.58	4.59	4.60	4.61	
		25	4.55	4.57	4.59	4.61	4.63	4.65	4.67	
		40	4.55	4.69	4.82	4.96	5.10	5.24	5.38	
0-100		5	4.62	4.63	4.64	4.65	4.66	4.67	4.68	
		25	4.62	4.64	4.66	4.68	4.70	4.72	4.74	
		40	4.62	4.78	4.94	5.10	5.26	5.42	5.58	

### **4.3 Influence of Storage Conditions on Density**

Table 4.3 summarizes the experimental results of fuel densities at several storage periods and conditions. The results showed that storage for 12 months resulted in higher density for all biodiesel samples with the increases more pronounced at higher storage temperatures. It is found that all methyl esters remained within the ranges listed in ASTM D6751 for the duration of the study at all temperatures. Furthermore, according to the EN14214 standard requiring density values at 15°C, it is seen that the density values of FCME, FSME, and FSRME fulfill the requirement of EN14214 standard (860-900kg/m<sup>3</sup>) for the duration of the study at ST of 5°C with the exception of WCME after 12 months. After extended storage (6 and 8 months) at RT, the density values of FSME and FSRME are not within the range of the EN14214 standard requiring density values at 15°C (Table 4.3). Also, it is seen that density values of FSCME are not prescribed in biodiesel standards with the ranges being 860-900kg/m<sup>3</sup> (EN14214 standard).

**Table 4.3:** Influence of storage conditions on density in kg/m<sup>3</sup> at 15°C

Blend	VF [%]	ST [°C]	Storage period [month]							
			0	2	4	6	8	10	12	
FCME- FSME	100-0	5	895.44	896.03	896.62	897.22	897.81	898.40	898.99	
		25	895.44	900.81	906.22	911.66	917.13	922.63	928.17	
		40	895.44	907.48	912.93	918.40	923.91	929.46	935.03	
	80-20	5	879.77	880.35	880.93	881.51	882.09	882.68	883.26	
		25	879.77	885.05	890.35	895.69	901.06	906.47	911.90	
		40	879.77	891.59	896.94	902.32	907.73	913.17	918.65	
	60-40	5	902.18	902.76	903.35	903.93	904.52	905.10	905.68	
		25	902.18	907.48	912.81	918.18	923.57	929.00	934.46	
		40	902.18	914.06	919.43	924.83	930.27	935.73	941.24	
	40-60	5	892.34	892.93	893.51	894.10	894.69	895.27	895.86	
		25	892.34	897.67	903.02	908.41	913.83	919.28	924.77	
		40	892.34	904.27	909.67	915.09	920.56	926.05	931.57	
	20-80	5	882.50	883.09	883.68	884.27	884.86	885.45	886.04	
		25	882.50	887.85	893.23	898.64	904.09	909.57	915.08	
		40	882.50	894.49	899.91	905.36	910.84	916.36	921.91	
	0-100	5	875.19	875.77	876.35	876.92	877.50	878.08	878.66	
		25	875.19	880.44	885.72	891.04	896.38	901.76	907.17	
		40	875.19	886.96	892.28	897.63	903.02	908.44	913.89	
	FSCME- FSRME	100-0	5	910.42	911.02	911.62	912.22	912.83	913.43	914.03
			25	910.42	915.88	921.38	926.91	932.47	938.06	943.69
			40	910.42	922.66	928.20	933.77	939.37	945.00	950.67
		80-20	5	904.64	905.24	905.83	906.43	907.03	907.63	908.23
			25	904.64	910.07	915.53	921.02	926.55	932.11	937.70
			40	904.64	916.80	922.30	927.84	933.40	939.00	944.64
60-40		5	898.96	899.55	900.14	900.74	901.33	901.93	902.52	
		25	898.96	904.35	909.78	915.24	920.73	926.25	931.81	
		40	898.96	911.04	916.51	922.01	927.54	933.10	938.70	
40-60		5	893.16	893.75	894.34	894.93	895.52	896.12	896.71	
		25	893.16	898.52	903.91	909.34	914.79	920.28	925.80	
		40	893.16	905.17	910.60	916.07	921.56	927.09	932.65	
20-80		5	887.42	888.00	888.59	889.17	889.76	890.35	890.94	
		25	887.42	892.74	898.10	903.48	908.91	914.36	919.84	
		40	887.42	899.35	904.74	910.17	915.63	921.12	926.65	
0-100		5	881.63	882.21	882.79	883.37	883.96	884.54	885.12	
		25	881.63	886.92	892.24	897.59	902.98	908.39	913.85	
		40	881.63	893.48	898.84	904.23	909.66	915.12	920.61	

**Table 4.3:** Continued

Blend	VF [%]	ST [°C]	Storage period [month]							
			0	2	4	6	8	10	12	
FCME-FSRME	100-0	5	895.44	896.03	896.62	897.22	897.81	898.40	898.99	
		25	895.44	900.81	906.22	911.66	917.13	922.63	928.17	
		40	895.44	907.48	912.93	918.40	923.91	929.46	935.03	
	80-20	5	900.95	901.53	902.12	902.70	903.29	903.87	904.46	
		25	900.95	906.26	911.59	916.96	922.37	927.80	933.27	
		40	900.95	912.84	918.22	923.63	929.07	934.55	940.05	
	60-40	5	892.15	892.74	893.32	893.91	894.50	895.08	895.67	
		25	892.15	897.48	902.83	908.22	913.64	919.09	924.57	
		40	892.15	904.08	909.47	914.90	920.36	925.85	931.38	
	40-60	5	889.94	890.52	891.11	891.70	892.29	892.88	893.47	
		25	889.94	895.28	900.65	906.05	911.49	916.96	922.46	
		40	889.94	901.90	907.31	912.76	918.23	923.74	929.28	
	20-80	5	886.10	886.69	887.28	887.87	888.46	889.05	889.64	
		25	886.10	891.46	896.84	902.26	907.72	913.20	918.72	
		40	886.10	898.10	903.53	908.99	914.48	920.01	925.57	
	0-100	5	881.63	882.21	882.79	883.37	883.96	884.54	885.12	
		25	881.63	886.92	892.24	897.59	902.98	908.39	913.85	
		40	881.63	893.48	898.84	904.23	909.66	915.12	920.61	
	FSCME-FCME	100-0	5	910.42	911.02	911.62	912.22	912.83	913.43	914.03
			25	910.42	915.88	921.38	926.91	932.47	938.06	943.69
			40	910.42	922.66	928.20	933.77	939.37	945.00	950.67
		80-20	5	907.42	908.02	908.62	909.22	909.82	910.42	911.02
			25	907.42	912.87	918.35	923.86	929.40	934.98	940.59
			40	907.42	919.62	925.14	930.69	936.28	941.90	947.55
60-40		5	904.43	905.03	905.62	906.22	906.82	907.42	908.02	
		25	904.43	909.86	915.31	920.81	926.33	931.89	937.48	
		40	904.43	916.59	922.09	927.62	933.19	938.79	944.42	
40-60		5	912.93	913.53	914.12	914.72	915.32	915.91	916.51	
		25	912.93	918.34	923.78	929.26	934.76	940.30	945.88	
		40	912.93	925.05	930.53	936.05	941.60	947.18	952.79	
20-80		5	903.44	904.03	904.62	905.22	905.81	906.41	907.00	
		25	903.44	908.83	914.25	919.71	925.20	930.72	936.27	
		40	903.44	915.52	920.98	926.48	932.00	937.57	943.16	
0-100		5	895.44	896.03	896.62	897.22	897.81	898.40	898.99	
		25	895.44	900.81	906.22	911.66	917.13	922.63	928.17	
		40	895.44	907.48	912.93	918.40	923.91	929.46	935.03	

**Table 4.3:** Continued

Blend	VF	ST	Storage period [month]							
			0	2	4	6	8	10	12	
FSME- FSRME	100-0	5	875.19	875.77	876.35	876.92	877.50	878.08	878.66	
		25	875.19	880.44	885.72	891.04	896.38	901.76	907.17	
		40	875.19	886.96	892.28	897.63	903.02	908.44	913.89	
	80-20	5	892.28	892.86	893.43	894.01	894.59	895.17	895.75	
		25	892.28	897.54	902.83	908.15	913.50	918.89	924.31	
		40	892.28	904.06	909.39	914.75	920.15	925.57	931.03	
	60-40	5	887.76	888.34	888.92	889.50	890.08	890.67	891.25	
		25	887.76	893.03	898.33	903.66	909.02	914.42	919.84	
		40	887.76	899.57	904.90	910.27	915.67	921.11	926.57	
	40-60	5	885.85	886.43	887.01	887.59	888.18	888.76	889.34	
		25	885.85	891.13	896.43	901.77	907.14	912.54	917.98	
		40	885.85	897.67	903.02	908.39	913.80	919.24	924.72	
	20-80	5	883.32	883.90	884.48	885.06	885.65	886.23	886.81	
		25	883.32	888.60	893.92	899.26	904.64	910.05	915.49	
		40	883.32	895.16	900.51	905.89	911.31	916.76	922.24	
	0-100	5	881.63	882.21	882.79	883.37	883.96	884.54	885.12	
		25	881.63	886.92	892.24	897.59	902.98	908.39	913.85	
		40	881.63	893.48	898.84	904.23	909.66	915.12	920.61	
	FSCME- FSME	100-0	5	910.42	911.02	911.62	912.22	912.83	913.43	914.03
			25	910.42	915.88	921.38	926.91	932.47	938.06	943.69
			40	910.42	922.66	928.20	933.77	939.37	945.00	950.67
		80-20	5	903.37	903.97	904.57	905.16	905.76	906.36	906.96
			25	903.37	908.79	914.25	919.73	925.25	930.80	936.39
			40	903.37	915.52	921.01	926.54	932.10	937.69	943.32
60-40		5	896.33	896.92	897.51	898.10	898.70	899.29	899.88	
		25	896.33	901.71	907.12	912.56	918.03	923.54	929.08	
		40	896.33	908.38	913.83	919.31	924.83	930.38	935.96	
40-60		5	889.28	889.87	890.46	891.04	891.63	892.22	892.81	
		25	889.28	894.62	899.99	905.39	910.82	916.28	921.78	
		40	889.28	901.24	906.65	912.09	917.56	923.06	928.60	
20-80		5	882.24	882.82	883.40	883.98	884.57	885.15	885.74	
		25	882.24	887.53	892.85	898.21	903.60	909.02	914.48	
		40	882.24	894.10	899.46	904.86	910.29	915.75	921.24	
0-100		5	875.19	875.77	876.35	876.92	877.50	878.08	878.66	
		25	875.19	880.44	885.72	891.04	896.38	901.76	907.17	
		40	875.19	886.96	892.28	897.63	903.02	908.44	913.89	

#### 4.4 Influence of storage conditions on cold flow properties

The cloud point (CP) and pour point (PP) values of pure biodiesel samples were measured according to ASTM D 2500 and ASTM D 97, respectively. It is found that the initial CP values of FCME, FSME, FSRME and FSCME were -2.0, 10.0, -1.2, 7.0°C, respectively as shown in Table 4.4. The corresponding values for PP were -10.0, 5.5, -6.0, 1.6°C as shown in Table 4.5. It is seen that FSME has the highest value of CP and PP. The considerably higher CP and PP values obtained for FSME were attributed to the presence of a higher percentage of SFAME (42.61 wt%) as it is known that the melting point increases with decreasing double bond content. It should be noted that the concept of comparing effects on CP or PP using an "absolute changing ratio" (ACR) is flawed for two reasons. First, absolute temperatures (in K) should be used and this would significantly decrease the percentage changes in the temperatures. Using temperature values on the Celsius-scale to calculate temperature ratios is reckless and can lead to misleading results. Therefore, in order to show the effect of storage conditions on CP and PP results, the temperature differentials in °C ( $\Delta T = T [t = 0 \text{ months}] - T [t = 12 \text{ months}]$ ) is used and listed in Tables 4.4 and 4.5.

As seen in Tables 4.4 and 4.5 as supplementary material, storage for 12 months resulted in a slight change in CP and PP values for all unmixed methyl esters, with the increases small pronounced at higher storage temperatures. The results show that the effect of storage conditions on biodiesel blends was observed in the blends mainly at ST of RT and 40°C because  $\Delta T$  values were ranged from -2.49°C to 0.49 °C for ST of RT and -5.11°C to 1°C for ST of 40°C, which depend on the concentration of biodiesel in the mixture.

**Table 4.4:** Influenced of storage period and conditions on cloud Point

Blend	VF [%]	ST [°C]	Storage period [month]						
			0	2	4	6	8	10	12
FCME- FSME	100-0	5	-2.00	-2.0	-2.1	-2.1	-2.2	-2.2	-2.3
		25	-2.00	-2.1	-2.2	-2.2	-2.3	-2.4	-2.5
		40	-2.00	-2.2	-2.3	-2.5	-2.7	-2.9	-3.1
	80-20	5	0.40	0.4	0.4	0.4	0.4	0.4	0.5
		25	0.40	0.4	0.4	0.4	0.5	0.5	0.5
		40	0.40	0.4	0.5	0.5	0.5	0.6	0.6
	60-40	5	2.80	2.9	2.9	3.0	3.0	3.1	3.2
		25	2.80	2.9	3.0	3.1	3.3	3.4	3.5
		40	2.80	3.0	3.2	3.5	3.7	4.0	4.3
	40-60	5	5.20	5.3	5.4	5.5	5.6	5.7	5.9
		25	5.20	5.4	5.6	5.8	6.1	6.3	6.6
		40	5.20	5.6	6.0	6.5	6.9	7.5	8.0
20-80	5	7.60	7.8	7.9	8.1	8.2	8.4	8.6	
	25	7.60	7.9	8.2	8.5	8.9	9.2	9.6	
	40	7.60	8.2	8.8	9.4	10.1	10.9	11.7	
0-100	5	10.00	10.2	10.4	10.6	10.8	11.0	11.3	
	25	10.00	10.4	10.8	11.2	11.7	12.2	12.7	
	40	10.00	10.8	11.6	12.4	13.4	14.4	15.4	
FSCME- FSRME	100-0	5	7.00	7.1	7.3	7.4	7.6	7.7	7.9
		25	7.00	7.3	7.6	7.9	8.2	8.5	8.9
		40	7.00	7.5	8.1	8.7	9.3	10.0	10.8
	80-20	5	5.36	5.5	5.6	5.7	5.8	5.9	6.0
		25	5.36	5.6	5.8	6.0	6.3	6.5	6.8
		40	5.36	5.8	6.2	6.7	7.2	7.7	8.3
	60-40	5	3.72	3.8	3.9	3.9	4.0	4.1	4.2
		25	3.72	3.9	4.0	4.2	4.4	4.5	4.7
		40	3.72	4.0	4.3	4.6	5.0	5.3	5.7
	40-60	5	2.08	2.1	2.2	2.2	2.3	2.3	2.3
		25	2.08	2.2	2.2	2.3	2.4	2.5	2.6
		40	2.08	2.2	2.4	2.6	2.8	3.0	3.2
20-80	5	0.44	0.4	0.5	0.5	0.5	0.5	0.5	
	25	0.44	0.5	0.5	0.5	0.5	0.5	0.6	
	40	0.44	0.5	0.5	0.5	0.6	0.6	0.7	
0-100	5	-1.20	-1.2	-1.2	-1.3	-1.3	-1.3	-1.4	
	25	-1.20	-1.2	-1.3	-1.3	-1.4	-1.5	-1.5	
	40	-1.20	-1.3	-1.4	-1.5	-1.6	-1.7	-1.9	

**Table 4.4:** Continued

Blend	VF [%]	ST [°C]	Storage period [month]						
			0	2	4	6	8	10	12
FSRME-FCME	100-0	5	-1.20	-1.2	-1.2	-1.3	-1.3	-1.3	-1.4
		25	-1.20	-1.2	-1.3	-1.3	-1.4	-1.5	-1.5
		40	-1.20	-1.3	-1.4	-1.5	-1.6	-1.7	-1.9
	80-20	5	-1.36	-1.4	-1.4	-1.4	-1.5	-1.5	-1.5
		25	-1.36	-1.4	-1.5	-1.5	-1.6	-1.7	-1.7
		40	-1.36	-1.5	-1.6	-1.7	-1.8	-2.0	-2.1
	60-40	5	-1.52	-1.6	-1.6	-1.6	-1.6	-1.7	-1.7
		25	-1.52	-1.6	-1.6	-1.7	-1.8	-1.8	-1.9
		40	-1.52	-1.6	-1.8	-1.9	-2.0	-2.2	-2.3
	40-60	5	-1.68	-1.7	-1.7	-1.8	-1.8	-1.9	-1.9
		25	-1.68	-1.7	-1.8	-1.9	-2.0	-2.0	-2.1
		40	-1.68	-1.8	-1.9	-2.1	-2.2	-2.4	-2.6
	20-80	5	-1.84	-1.9	-1.9	-2.0	-2.0	-2.0	-2.1
		25	-1.84	-1.9	-2.0	-2.1	-2.2	-2.2	-2.3
		40	-1.84	-2.0	-2.1	-2.3	-2.5	-2.6	-2.8
	0-100	5	-2.00	-2.0	-2.1	-2.1	-2.2	-2.2	-2.3
		25	-2.00	-2.1	-2.2	-2.2	-2.3	-2.4	-2.5
		40	-2.00	-2.2	-2.3	-2.5	-2.7	-2.9	-3.1
FSCME-FCME	100-0	5	7.00	7.1	7.3	7.4	7.6	7.7	7.9
		25	7.00	7.3	7.6	7.9	8.2	8.5	8.9
		40	7.00	7.5	8.1	8.7	9.3	10.0	10.8
	80-20	5	5.20	5.3	5.4	5.5	5.6	5.7	5.9
		25	5.20	5.4	5.6	5.8	6.1	6.3	6.6
		40	5.20	5.6	6.0	6.5	6.9	7.5	8.0
	60-40	5	3.40	3.5	3.5	3.6	3.7	3.8	3.8
		25	3.40	3.5	3.7	3.8	4.0	4.1	4.3
		40	3.40	3.7	3.9	4.2	4.5	4.9	5.2
	40-60	5	1.60	1.6	1.7	1.7	1.7	1.8	1.8
		25	1.60	1.7	1.7	1.8	1.9	1.9	2.0
		40	1.60	1.7	1.8	2.0	2.1	2.3	2.5
	20-80	5	-0.20	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
		25	-0.20	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3
		40	-0.20	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3
	0-100	5	-2.00	-2.0	-2.1	-2.1	-2.2	-2.2	-2.3
		25	-2.00	-2.1	-2.2	-2.2	-2.3	-2.4	-2.5
		40	-2.00	-2.2	-2.3	-2.5	-2.7	-2.9	-3.1

**Table 4.4:** Continued

Blend	VF [%]	ST [°C]	Storage period [month]							
			0	2	4	6	8	10	12	
FSME-FSRME	100-0	5	10.00	10.2	10.4	10.6	10.8	11.0	11.3	
		25	10.00	10.4	10.8	11.2	11.7	12.2	12.7	
		40	10.00	10.8	11.6	12.4	13.4	14.4	15.4	
	80-20	5	7.76	7.9	8.1	8.2	8.4	8.6	8.7	
		25	7.76	8.1	8.4	8.7	9.1	9.4	9.8	
		40	7.76	8.3	9.0	9.6	10.4	11.1	12.0	
	60-40	5	5.52	5.6	5.7	5.9	6.0	6.1	6.2	
		25	5.52	5.7	6.0	6.2	6.5	6.7	7.0	
		40	5.52	5.9	6.4	6.9	7.4	7.9	8.5	
	40-60	5	3.28	3.3	3.4	3.5	3.6	3.6	3.7	
		25	3.28	3.4	3.5	3.7	3.8	4.0	4.2	
		40	3.28	3.5	3.8	4.1	4.4	4.7	5.1	
	20-80	5	1.04	1.1	1.1	1.1	1.1	1.1	1.2	
		25	1.04	1.1	1.1	1.2	1.2	1.3	1.3	
		40	1.04	1.1	1.2	1.3	1.4	1.5	1.6	
	0-100	5	-1.20	-1.2	-1.2	-1.3	-1.3	-1.3	-1.4	
		25	-1.20	-1.2	-1.3	-1.3	-1.4	-1.5	-1.5	
		40	-1.20	-1.3	-1.4	-1.5	-1.6	-1.7	-1.9	
	FSCME-FSME	100-0	5	7.00	7.1	7.3	7.4	7.6	7.7	7.9
			25	7.00	7.3	7.6	7.9	8.2	8.5	8.9
			40	7.00	7.5	8.1	8.7	9.3	10.0	10.8
		80-20	5	7.60	7.8	7.9	8.1	8.2	8.4	8.6
			25	7.60	7.9	8.2	8.5	8.9	9.2	9.6
			40	7.60	8.2	8.8	9.4	10.1	10.9	11.7
60-40		5	8.20	8.4	8.5	8.7	8.9	9.1	9.2	
		25	8.20	8.5	8.9	9.2	9.6	10.0	10.4	
		40	8.20	8.8	9.5	10.2	11.0	11.8	12.7	
40-60		5	8.80	9.0	9.2	9.3	9.5	9.7	9.9	
		25	8.80	9.2	9.5	9.9	10.3	10.7	11.1	
		40	8.80	9.5	10.2	10.9	11.8	12.6	13.6	
20-80		5	9.40	9.6	9.8	10.0	10.2	10.4	10.6	
		25	9.40	9.8	10.2	10.6	11.0	11.4	11.9	
		40	9.40	10.1	10.9	11.7	12.6	13.5	14.5	
0-100		5	10.00	10.2	10.4	10.6	10.8	11.0	11.3	
		25	10.00	10.4	10.8	11.2	11.7	12.2	12.7	
		40	10.00	10.8	11.6	12.4	13.4	14.4	15.4	

**Table 4.5:** Influenced of storage period and conditions on Pour Point

Blend	VF [%]	ST [°C]	Storage period [month]						
			0	2	4	6	8	10	12
FCME- FSME	100-0	5	-10.00	-9.9	-9.8	-9.7	-9.6	-9.5	-9.4
		25	-10.00	-9.6	-9.2	-8.8	-8.5	-8.2	-7.8
		40	-10.00	-9.3	-8.6	-7.9	-7.3	-6.8	-6.3
	80-20	5	-6.90	-6.8	-6.8	-6.7	-6.6	-6.6	-6.5
		25	-6.90	-6.6	-6.4	-6.1	-5.9	-5.6	-5.4
		40	-6.90	-6.4	-5.9	-5.5	-5.1	-4.7	-4.3
	60-40	5	-3.80	-3.8	-3.7	-3.7	-3.7	-3.6	-3.6
		25	-3.80	-3.6	-3.5	-3.4	-3.2	-3.1	-3.0
		40	-3.80	-3.5	-3.3	-3.0	-2.8	-2.6	-2.4
	40-60	5	-0.70	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
		25	-0.70	-0.7	-0.6	-0.6	-0.6	-0.6	-0.5
		40	-0.70	-0.6	-0.6	-0.6	-0.5	-0.5	-0.4
	20-80	5	2.40	2.4	2.4	2.5	2.5	2.5	2.5
		25	2.40	2.5	2.6	2.7	2.8	2.9	3.0
		40	2.40	2.6	2.8	3.0	3.2	3.4	3.7
	0-100	5	5.50	5.6	5.6	5.7	5.7	5.8	5.8
		25	5.50	5.7	5.9	6.2	6.4	6.7	7.0
		40	5.50	5.9	6.4	6.8	7.3	7.9	8.5
FSCME- FSRME	100-0	5	1.60	1.6	1.6	1.6	1.7	1.7	1.7
		25	1.60	1.7	1.7	1.8	1.9	1.9	2.0
		40	1.60	1.7	1.8	2.0	2.1	2.3	2.5
	80-20	5	0.08	0.1	0.1	0.1	0.1	0.1	0.1
		25	0.08	0.1	0.1	0.1	0.1	0.1	0.1
		40	0.08	0.1	0.1	0.1	0.1	0.1	0.1
	60-40	5	-1.44	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4
		25	-1.44	-1.4	-1.3	-1.3	-1.2	-1.2	-1.1
		40	-1.44	-1.3	-1.2	-1.1	-1.1	-1.0	-0.9
	40-60	5	-2.96	-2.9	-2.9	-2.9	-2.8	-2.8	-2.8
		25	-2.96	-2.8	-2.7	-2.6	-2.5	-2.4	-2.3
		40	-2.96	-2.7	-2.5	-2.3	-2.2	-2.0	-1.9
	20-80	5	-4.48	-4.4	-4.4	-4.3	-4.3	-4.3	-4.2
		25	-4.48	-4.3	-4.1	-4.0	-3.8	-3.7	-3.5
		40	-4.48	-4.1	-3.8	-3.5	-3.3	-3.0	-2.8
	0-100	5	-6.00	-5.9	-5.9	-5.8	-5.8	-5.7	-5.6
		25	-6.00	-5.8	-5.5	-5.3	-5.1	-4.9	-4.7
		40	-6.00	-5.6	-5.1	-4.7	-4.4	-4.1	-3.8

**Table 4.5:** Continued

Blend	VF [%]	ST [°C]	Storage period [month]						
			0	2	4	6	8	10	12
FSRME-FCME	100-0	5	-6.00	-5.9	-5.9	-5.8	-5.8	-5.7	-5.6
		25	-6.00	-5.8	-5.5	-5.3	-5.1	-4.9	-4.7
		40	-6.00	-5.6	-5.1	-4.7	-4.4	-4.1	-3.8
	80-20	5	-6.80	-6.7	-6.7	-6.6	-6.5	-6.5	-6.4
		25	-6.80	-6.5	-6.3	-6.0	-5.8	-5.5	-5.3
		40	-6.80	-6.3	-5.8	-5.4	-5.0	-4.6	-4.3
	60-40	5	-7.60	-7.5	-7.4	-7.4	-7.3	-7.2	-7.2
		25	-7.60	-7.3	-7.0	-6.7	-6.5	-6.2	-5.9
		40	-7.60	-7.0	-6.5	-6.0	-5.6	-5.1	-4.8
	40-60	5	-8.40	-8.3	-8.2	-8.2	-8.1	-8.0	-7.9
		25	-8.40	-8.1	-7.7	-7.4	-7.1	-6.8	-6.6
		40	-8.40	-7.8	-7.2	-6.6	-6.1	-5.7	-5.3
	20-80	5	-9.20	-9.1	-9.0	-8.9	-8.8	-8.7	-8.7
		25	-9.20	-8.8	-8.5	-8.1	-7.8	-7.5	-7.2
		40	-9.20	-8.5	-7.9	-7.3	-6.7	-6.2	-5.8
	0-100	5	-10.00	-9.9	-9.8	-9.7	-9.6	-9.5	-9.4
		25	-10.00	-9.6	-9.2	-8.8	-8.5	-8.2	-7.8
		40	-10.00	-9.3	-8.6	-7.9	-7.3	-6.8	-6.3
FSCME-FCME	100-0	5	1.60	1.6	1.6	1.6	1.7	1.7	1.7
		25	1.60	1.7	1.7	1.8	1.9	1.9	2.0
		40	1.60	1.7	1.8	2.0	2.1	2.3	2.5
	80-20	5	-0.72	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
		25	-0.72	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6
		40	-0.72	-0.7	-0.6	-0.6	-0.5	-0.5	-0.5
	60-40	5	-3.04	-3.0	-3.0	-2.9	-2.9	-2.9	-2.9
		25	-3.04	-2.9	-2.8	-2.7	-2.6	-2.5	-2.4
		40	-3.04	-2.8	-2.6	-2.4	-2.2	-2.1	-1.9
	40-60	5	-5.36	-5.3	-5.3	-5.2	-5.1	-5.1	-5.0
		25	-5.36	-5.1	-4.9	-4.7	-4.6	-4.4	-4.2
		40	-5.36	-5.0	-4.6	-4.2	-3.9	-3.6	-3.4
	20-80	5	-7.68	-7.6	-7.5	-7.5	-7.4	-7.3	-7.2
		25	-7.68	-7.4	-7.1	-6.8	-6.5	-6.3	-6.0
		40	-7.68	-7.1	-6.6	-6.1	-5.6	-5.2	-4.8
	0-100	5	-10.00	-9.9	-9.8	-9.7	-9.6	-9.5	-9.4
		25	-10.00	-9.6	-9.2	-8.8	-8.5	-8.2	-7.8
		40	-10.00	-9.3	-8.6	-7.9	-7.3	-6.8	-6.3

**Table 4.5:** Continued

Blend	VF [%]	ST [°C]	Storage period [month]							
			0	2	4	6	8	10	12	
FSME-FSRME	100-0	5	5.50	5.6	5.6	5.7	5.7	5.8	5.8	
		25	5.50	5.7	5.9	6.2	6.4	6.7	7.0	
		40	5.50	5.9	6.4	6.8	7.3	7.9	8.5	
	80-20	5	3.20	3.2	3.3	3.3	3.3	3.4	3.4	
		25	3.20	3.3	3.5	3.6	3.7	3.9	4.0	
		40	3.20	3.4	3.7	4.0	4.3	4.6	4.9	
	60-40	5	0.90	0.9	0.9	0.9	0.9	0.9	1.0	
		25	0.90	0.9	1.0	1.0	1.1	1.1	1.1	
		40	0.90	1.0	1.0	1.1	1.2	1.3	1.4	
	40-60	5	-1.40	-1.4	-1.4	-1.4	-1.3	-1.3	-1.3	
		25	-1.40	-1.3	-1.3	-1.2	-1.2	-1.1	-1.1	
		40	-1.40	-1.3	-1.2	-1.1	-1.0	-0.9	-0.9	
	20-80	5	-3.70	-3.7	-3.6	-3.6	-3.6	-3.5	-3.5	
		25	-3.70	-3.6	-3.4	-3.3	-3.1	-3.0	-2.9	
		40	-3.70	-3.4	-3.2	-2.9	-2.7	-2.5	-2.3	
	0-100	5	-6.00	-5.9	-5.9	-5.8	-5.8	-5.7	-5.6	
		25	-6.00	-5.8	-5.5	-5.3	-5.1	-4.9	-4.7	
		40	-6.00	-5.6	-5.1	-4.7	-4.4	-4.1	-3.8	
	FSCME-FSME	100-0	5	1.60	1.6	1.6	1.6	1.7	1.7	1.7
			25	1.60	1.7	1.7	1.8	1.9	1.9	2.0
			40	1.60	1.7	1.8	2.0	2.1	2.3	2.5
		80-20	5	2.38	2.4	2.4	2.5	2.5	2.5	2.5
			25	2.38	2.5	2.6	2.7	2.8	2.9	3.0
			40	2.38	2.6	2.8	3.0	3.2	3.4	3.7
60-40		5	3.16	3.2	3.2	3.3	3.3	3.3	3.4	
		25	3.16	3.3	3.4	3.6	3.7	3.8	4.0	
		40	3.16	3.4	3.7	3.9	4.2	4.5	4.9	
40-60		5	3.94	4.0	4.0	4.1	4.1	4.1	4.2	
		25	3.94	4.1	4.3	4.4	4.6	4.8	5.0	
		40	3.94	4.2	4.6	4.9	5.3	5.7	6.1	
20-80		5	4.72	4.8	4.8	4.9	4.9	5.0	5.0	
		25	4.72	4.9	5.1	5.3	5.5	5.7	6.0	
		40	4.72	5.1	5.5	5.9	6.3	6.8	7.3	
0-100		5	5.50	5.6	5.6	5.7	5.7	5.8	5.8	
		25	5.50	5.7	5.9	6.2	6.4	6.7	7.0	
		40	5.50	5.9	6.4	6.8	7.3	7.9	8.5	

## CHAPTER 5

### CONCLUSIONS

#### 5.1 Conclusions

This study supported that the raw material composition largely influences the properties of biodiesel including oxidation stability, viscosity, density, cold flow properties of the biodiesel. The cold flow properties of high-temperature biodiesels were always improved by blending it with low-temperature biodiesels. The experimental results demonstrated that the properties of blends including the kinematic viscosity, density, and cold flow properties increased with the time as well as oxidative stability was significantly reduced upon extended storage with these effects more pronounced at high storage temperatures.

Storage for 12 months resulted in a slight change in CP and PP values for all unmixed methyl esters, with the increases small pronounced at higher storage temperatures. The results show that the effect of storage conditions on biodiesel blends was observed in the blends mainly at ST of RT and 40°C because  $\Delta T$  values were ranged from -2.49°C to 0.49 °C for ST of RT and -5.11°C to 1°C for ST of 40°C, which depend on the concentration of biodiesel in the mixture.

Moreover, the obtained kinematic viscosity data for all unmixed biodiesel samples correspond with the recommended EN 14214 (3.5–5.0 mm<sup>2</sup>/s) at 40°C during the storage periods of 12 months and ST of 5°C. Additionally, storage over an extended period 2, 4 and 6 months at ST of 40°C resulted in precipitous rising in the kinematic viscosity for FCME, FSME and FSRME, respectively. Also, kinematic viscosities of all samples are not in accordance with standard demand for diesel fuel (ASTM D975 recommended values: 1.9–4.10 mm<sup>2</sup>/s). Furthermore, kinematic viscosity values of FSCME and some blends are fulfilling with the European regulations EN 590, which establishes that viscosity at 40 °C must be in the range of 2.0–4.5mm<sup>2</sup>/s.

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## **APPENDICES**

**APPENDIX 1**

**ETHICAL APPROVAL LETTER**



**YAKIN DOĞU ÜNİVERSİTESİ**  
**ETHICAL APPROVAL DOCUMENT**

Date: 24/08 /2020

To the **Graduate School of Applied Sciences**

The research project titled “Investigation of the Fuel Properties of Four Biodiesel and Their Blends under Various of Storage Conditions” has been evaluated. Since the researcher(s) will not collect primary data from humans, animals, plants or earth, this project does not need through the ethics committee.

**Title:** Assoc. Prof. Dr.

**Name Surname:** Hüseyin ÇAMUR

**Signature:**

**Role in the Research Project:** Supervisor

**Title:**

**Name Surname:**

**Signature:**

**Role in the Research Project:** Co-Supervisor

## APPENDIX 2

### SIMILARITY REPORT



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