



**DETERMINATION OF KINEMATIC VISCOSITY OF
DIFFERENT BIODIESEL FUELS AT VARIOUS
TEMPERATURES.**

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

**by
IBUKUN OLUWOYE**

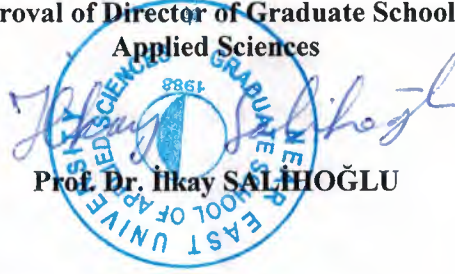
**In Partial Fulfillment of the Requirements for the Degree of
Master of Science
in
Mechanical Engineering**

NICOSIA 2013

**Ibukun Oluwoye : Determination of Kinematic Viscosity of Different Biodiesel Fuels at
Various Temperatures.**



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



Prof. Dr. İlkay SALİHOĞLU

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

Examining Committee in Charge:

Prof. Dr. Mahmut Savaş

Committee Chairman, Mechanical
Engineering Department, NEU

Assoc. Prof. Dr. Özgür Özerdem

Electrical Electronics Engineering Department,
NEU, Chairman of EEE Department

Assist. Prof. Dr. Ali Evcil

Mechanical Engineering Department, NEU
Chairman of Mechanical Engineering Department

Assist. Prof. Dr. Hasan Hacısevki

Mechanical Engineering Department, EMU

Assist. Prof. Dr. Ing. Hüseyin Çamur

Supervisor, Mechanical Engineering Department,
NEU

DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name: Ibukun Oluwoye

Signature:



Date:

30/01/2013

ABSTRACT

Fatty acid composition has a significant effect on the viscosities of fats and oils and in turn biodiesel fuels. The fatty acid composition of fats and oils are feedstock dependent and are also affected by factors such as climatic conditions, soil type, and plant health and maturity upon harvest. Due to the reasons mentioned, there is a need to determined major fuel properties locally for biodiesel samples. The viscosity of five biodiesel fuel in Northern Cyprus are measured up to temperature 140°C; temperature just above the flash point of biodiesel fuel proposed by ASTM.

The temperature – viscosity relationship was determined together with temperature – mixing percentages composition relationship

Keyword: Fuel, Biofuels, Biodiesel, Viscosity, Density, Green Energy, Frying Oil, Canola Oil

ACKNOWLEDGEMENTS

Firstly, my sincere appreciation is to God for the gift of life and balances in which all ingenuity is defined in me.

In like manner, I will also like to extend my thanks to my supervisor Assist. Prof. Dr. Ing. Hüseyin Çamur who had made it possible for me to complete the project. He trusted in my work and I. His priceless awareness of the project has made me do my work with full interest. His friendly behavior toward me and his words of encouragement kept me going in my project.

Conclusively, I am saying a big thank you to Prof. Mahmut Savas, Assist. Prof. Dr. Ali Evcil, Dr. Cemal Gövsa, Dr. Lida E. Vafaei and Mr. Engin Esenel who helped me during my studies in the last six years, providing me with the knowledge that helped me in completing my project. The same knowledge that will stay with me throughout my engineering life.

Dedicated to my parents, families, and my spiritual father; Evangelist Timothy OJOTISA. They encouraged me in every field of life mentally, physically and morally. They enhanced my confidence which makes it possible for to be able to face every difficulty easily. They have been with me through it all. . . .

CONTENTS

DECLARATION	i
ABSTRACT	ii
ACKNOWLEDGMENTS	iii
DEDICATION	iv
CONTENTS	v
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF SYMBOLS USED	x
NOMENCLATURE	xi
CHAPTER 1	1
INTRODUCTION	1
CHAPTER 2	3
METHODS AND MATERIALS	3
2.1 Concept of Viscosity	3
2.1.1 Importance of Viscosity in Fuel Properties	3
2.1.2 Types of Viscosity	5
2.1.3 Factors Affecting Viscosity	7
2.1.4 Measurement of Viscosity	7
2.2 Capillary Viscometers	8
2.2.1 Theory of Capillary Viscometers	8
2.2.2 Types of Capillary Viscometers	11
2.3 Biodiesel Samples	11
2.3.1 Production of Biodiesel	11
2.3.2 Required Standards for Biodiesel	13
2.4 Experimental Set-Up and Methods	14
2.4.1 Ubbelohde Viscometer	14
2.4.2 Electromagnetic Hot Plate and stirrer	18
2.4.3 Silicone Oil	19

2.4.4 Temperature Measurement	20
2.4.5 Accessories	20
2.4.6 Methodology	20
2.4.7 Flow chart for determining kinematic viscosity	23
CHAPTER 3	27
RESULTS AND DISCUSSION	27
3.1 Accuracy and Repeatability	27
3.2 Kinematic Viscosity	28
CHAPTER 4	42
CONCLUSIONS	42
REFERENCES	43
APPENDICES	45
Appendix 1. Viscosity Conversion Factors	46
Appendix 2. ASTM 446-07	47
Appendix 3. Viscometer Manufacturing Certificates	72
Appendix 4. Experimental Data	75

LIST OF TABLES

2.1	ASTM Biodiesel Standard D 6751A	13
2.2	Ubbelohde viscometers for transparent fluid	16
2.3	Properties of silicone oil	19
2.4	Table of kinetic energy correction	22
2.5	Kinematic viscosity calculation of WFME	25
3.1	Ubbelohde viscometer repeatability results for some biodiesel samples	27
3.2	Viscosity correlation constants for the five biodiesel fuel over the range of 20 - 140°C	34
3.3	Polynomial coefficients for kinematic viscosity – composition relationships	39
3.4	Kinematic viscosities of five biodiesel fuels at temperature range of (20°C – 140 °C)	40
3.5	Standardization of kinematic viscosity of the five biodiesel samples	41

LIST OF FIGURES

2.1	Viscosity affecting spray pattern	4
2.2	Simple shear of a liquid film	5
2.3	Shear stress - deformation relationship	6
2.4	Measurement principles of viscometers	7
2.5	Hagen-Poiseuille flow through a vertical pipe	9
2.6	Schematics of transesterification process	12
2.7	Transesterification of Triglycerides; R_1 , R_2 , R_3 , are the hydrocarbon chain length	12
2.8	Experimental set-up	14
2.9	Illustrated diagram of ubbelohde viscometer	17
2.10	Heidolph MR Hei-Tec	18
2.11	Structural formula of silicone oil	19
2.12	Methodology flow chat	24
3.1	Kinematic viscosity of 100% Waste frying methyl ester	29
3.2	Kinematic viscosity of 100% waste canola methyl ester	29
3.3	Kinematic viscosity of 50% waste frying methyl ester – 50% waste canola methyl ester	30
3.4	Kinematic viscosity of 75% waste frying methyl ester – 25% waste canola methyl ester	30
3.5	Kinematic viscosity of 25% waste frying methyl ester – 75% waste canola methyl ester	31
3.6	Empirical model for waste frying methyl ester	32
3.7	Empirical model for waste canola methyl ester	32
3.8	Empirical model for 50% waste frying methyl ester – 50% waste canola ester	33
3.9	Empirical model for 75% waste frying methyl ester – 25% waste canola methyl ester	33
3.10	Empirical model for 25% waste frying methyl ester – 75% waste canola methyl ester	34
3.11	Viscosity – Temperature relationship for all samples	35

3.12	Energy balance of molecules	35
3.13	Viscosity – Composition relationship	36
3.14	Approximated molecular structure of WFME	37
3.15	Approximated molecular structure of WCME	37
3.16	Approximated molecular structures of 25 – WFME	38
3.17	Polynomial regressions for composition percentages at 40°C	38

LIST OF SYMBOLS USED

FLUID DEFORMATION QUANTITY

σ	Shear stress on fluid element
τ	Alternative form of shear stress
ε	Strain rate
t	Shear time

FLOW QUANTITY

v	Flow velocity
v_z	Velocity in flow direction
v_r	Velocity in radian direction
v_θ	Velocity in angular direction
p	Flow pressure
ρ	Flow density
μ	Dynamic viscosity
ν	Kinematic viscosity
g	Acceleration due to gravity
Q	Volume flow rate

GEOMETRY QUANTITY

x	Elemental length
r	Radian length
z	Length in flow direction
H	Capillary height
R	Capillary radius
V	Volume
L	Length of viscometer

DEFINED QUANTITY

K	Viscometer constant
y	Correction factor

NOMENCLATURE

GHG	Greenhouse Gases
FAME	Fatty Acid Methyl Ester
ASTM	American Standard for Testing and Manufacturing
WFCC	World Fuel Charter Committee
CGS	Centimeter-gram-second
WFO	Waste Frying Oil
WCO	Waste Canola Oil
WFME	Waste Frying Methyl Ester
WCME	Waste Canola Methyl Ester
ISO	International Standard Organization
DIN	German Institute for Standardization
K.E	Kinetic Energy

CHAPTER 1

INTRODUCTION

The increasing industrialization and motorization of the world causes a steep rise for the demand of petroleum-based fuel [1]. Today fossil fuels take up to 80% of the primary energy consumed in the world, of which 58% alone is consumed by the transport sector [2]. The source of these fossil fuels are becoming exhausted and found major contribution in greenhouse gases (GHG) emissions by consumption of fossil fuels to fulfill the energy demands which affects global economic activity directly or indirectly. Progressive depletion of convectional fossil fuels with increasing energy consumption and GHG emission have led to a move towards alternative, renewable, sustainable, efficient and cost-effective energy sources with lesser emissions [3,4].

In an attempt to replace percentage of world's energy dependence on fossil fuel by biofuel, biodiesel and other biofuels are being produced. Biodiesel; Fatty Acid Methyl Ester (FAME) are been consider as possible replacement or blend for convectional diesel fuel and are produce according to the required standards. This standard poses specific requirement and properties in order to promote high quality and harmonized fuel (biodiesel) on a global basis, considering the need for optimum engine and vehicle performance and durability and for the cleanest possible operation of engine and vehicle technologies [5].

Viscosity is one of the most important fuel properties as it impacts the performance of fuel injection system. The effect of viscosity can also be seen in the quality of atomization and combustion as well as engine wears. FAME generally has improved lubricity; however, their higher viscosity level tends to form larger droplet on injection which can cause poor combustion and increase exhaust smoke under certain operating condition. ASTM D 975 requires a kinematic viscosity range of 1.9 minimum to 4.1 maximum mm^2/s at 40°C and World Fuel Charter Committee (WFCC) requires 2.0 - 5.0 mm^2/s [5,6].

Fatty acid composition has a significant effect on the viscosities of fats and oils and in turn biodiesel fuels. The fatty acid composition of fats and oils are feedstock dependent and are also affected by factors such as climatic conditions, soil type, and plant health and maturity upon harvest [7]. Biodiesel fatty acid composition and fuel properties can vary significantly from one supplier/region to the other even if it is from the same plant/ animal [8]. Due to the fact that viscosity values shows significant variation between different regional feedstock and biodiesel fuel, there is a need to measure the temperature dependent viscosity regionally with necessary prediction models and check if it fall within an acceptable range of value.

The aim of this work is to determine experimentally the viscosity of five biodiesel fuel produced in Northern Cyprus with their temperature relationships up to 140°C; temperature just above the flash point of biodiesel fuel proposed by ASTM. It is a part of a larger project that is aimed to give a general prediction model for all major regions. Additionally, the relationship between the viscosity and mixing composition percentages will also be given.

CHAPTER 2

METHODS AND MATERIALS

The theoretical background of the viscosity and biodiesel fuel is very important in order to fully understand the relationship between temperature and viscosity.

2.1 Concept of Viscosity

Viscosity is a fundamental characteristic property of all liquid. When a liquid flows, it has an internal resistance to flow. Viscosity is a measure of this resistance to flow or shear. Viscosity can also be termed as a drag force and is a measure of the frictional properties of the liquid [9]. It is sometime refers to as the “thickness” of a fluid.

Viscosity is governed by combination of three major factors:

- Intermolecular forced: The stronger the bond between molecules, the more viscous the fluid.
- Molecular size: Smaller molecules flow past one another more easily than larger molecules.
- Molecular shape: This property can be tricky. Sometimes, linear molecules flow past each other than branched molecules. On the other hand, sometimes linear molecules can more easily stack on top of one another than branched molecules, which can increase the intermolecular bonding between linear molecules.

2.1.1 Importance of Viscosity in Fuel Properties

In an engine, fuel is delivered to the cylinder via a fuel system. The major components of the fuel system include the fuel tank, fuel lines, the fuel pump, the fuel filter, and the fuel injectors. When a fuel in pumped into a vehicle, it enters the fuel tank. The fuel is then pumped out when the vehicle is driven through fuel lines and through the fuel filter to fuel injector, which injects a

fine spray of fuel into the cylinders at exactly the right moment. The fuel then explodes. The component of the fuel system are designed to distribute a certain amount of fuel at a certain rate as shown in figure 2.1 , which is affected by fuel viscosity [10].

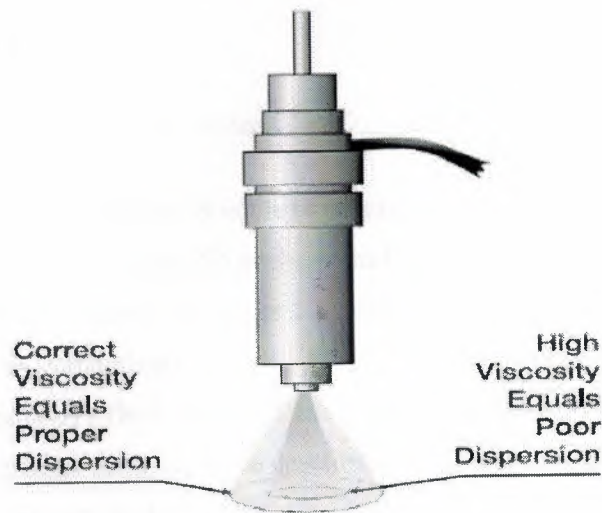


Figure 2.1 Viscosity affecting spray pattern [6].

Additionally, in the fuel system, the viscosity of the fuel is needed to be known at all possible temperature because it is used for the following:

- Continuum Mechanics: The viscosity is needed for the fluid mechanics and rheological analysis of the fuel in the fuel system.
- Thermodynamics: The viscosity is also needed for possible thermodynamic analysis in the fuel system.
- Heat Transfer: It is also needed for the convectional heat transfer parameters in the fuel system.

In general, fuel viscosity is needed by engine design engineers for fixing the optimum conditions for the chemical processes and operations as well as for the determination of the important dimensionless groups like Reynolds number and Prandtl number. Fuel viscosity is also important in the calculation of the power requirement for the unit operation such as mixing, fuel passage

design, necessary pump characteristics, atomization (fuel droplet), storage, injection, and transportation.

By process engineers it is needed for quality control and fuel characteristic.

2.1.2 Types of Viscosity

Viscosity is basically expressed in two distinct forms or types

- I. Absolute or dynamic viscosity: It is the tangential force per unit area required to slide one layer (A) against another layer (B) as shown in Figure 2.2 when the two layer are maintained at a unit distance. In Figure 2.2, force F causes layer A and B to slide at velocity v_1 and v_2 , respectively.

Since the viscosity of a fluid is defined as the measure of how resistive the fluid is to flow, in mathematical form, it can be describe as:

Shear stress = μ (strain or shear rate)

Where μ is the dynamic viscosity

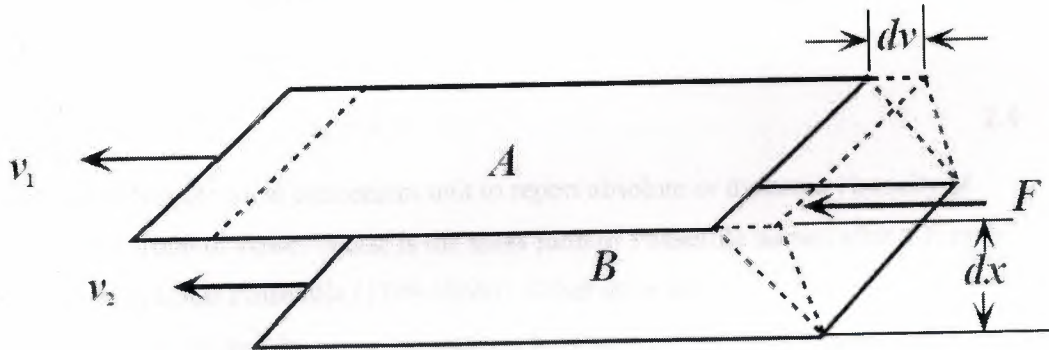


Figure 2.2 Simple shear of a liquid film [9].

If σ is shear stress and ε is strain rate, then the expression becomes:

$$\sigma = \mu \varepsilon \quad 2.1$$

The strain rate is generally expressed as

$$\varepsilon = \frac{1}{x} \frac{dx}{dt} = \frac{v}{x} \quad 2.2$$

Where x is the length, t is the time, and dx/dt is the velocity v . Therefore, the dynamic viscosity can be written as

$$\mu = \sigma \frac{x}{v}$$

2.3

Also by for a Newtonian fluid as in Figure 2.3, the relationship between the shear stress and the deformation is linearly proportional with proportionality constant as μ , where σ could also be replace by τ .

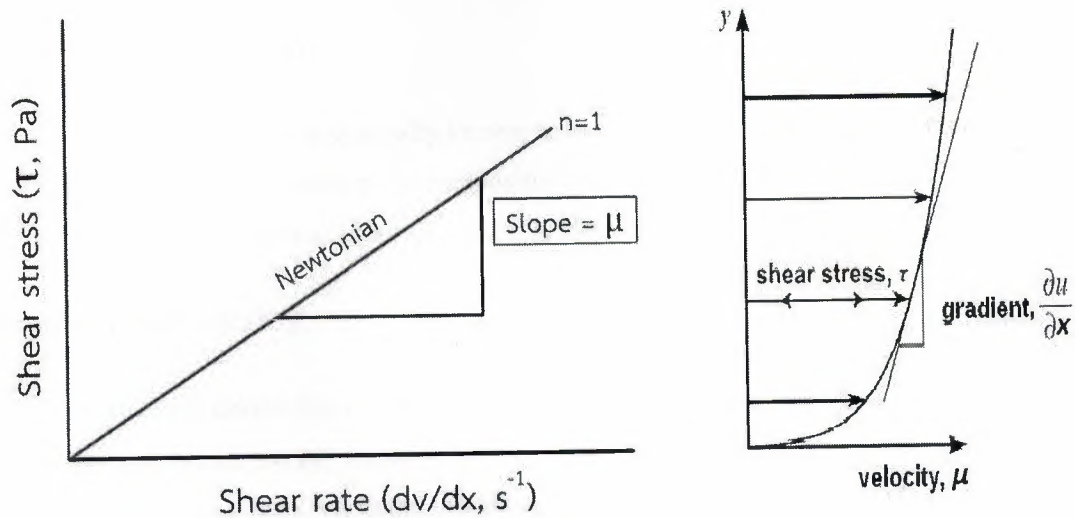


Figure 2.3 Shear stress - deformation relationship [10].

These yield a similar equation to (2.3)

$$\sigma \propto \left(\frac{dv}{dx}\right)^n = \mu \frac{dv}{dx}, \text{ if } n = 1 \quad 2.4$$

Centipoise (cP) is the most convenient unit to report absolute or dynamic viscosity of liquids. It is 1/1000 of Poise. "Poise is the short form of Poiseuille named after a French physician, Jean Louis Poiseuille (1799-1869)". Other units are:

- SI system: Ns/m^2 , Pa.s or kg/m.s where N is Newton and Pa is Pascal, and $1\text{Pa.s} = 1 \text{ N.s/m}^2 = 1 \text{ kg/m.s}$
- Metric system: CGS (centimeter-gram-second) as g/cm.s , dyne.s/cm^2 or poise (P) where, $1 \text{ poise} = \text{dyne.s/cm}^2 = \text{g/cm.s} = 1/10 \text{ Pa.s}$
- British unit system: lb/ft.s or lbf.s/ft^2 . Various conversion factors will be given in appendix 1.

- II. Kinematic viscosity: With the knowledge of density at required temperature and pressure, kinematic viscosity can be defined as

$$v = \frac{\mu}{\rho}$$

2.5

Where ρ is density of the fluid.

For SI system, kinematic viscosity is expressed as m^2/s or reported using stoke (St) or centistokes hundredth of stoke, where $1\text{St} = 10^{-4}\text{m}^2/\text{s}$ [9].

2.1.3 Factors Affecting Viscosity

The viscosity of Newtonian fluid is generally known to be affected by temperature, pressure, and, in the case of solution and mixture, by composition. The effect of temperature and composition is the major concern of this work and it is illustrated in later chapters.

2.1.4 Measurement of Viscosity

The instruments used for measuring viscosity are known as viscometers. The rheological measurement procedures are mainly based on the mechanical methods, since tension and elongation are mechanical values which are determined on the basis of a defined deformation of the sample.

Also simultaneous measurement of the electrical, magnetic, and optical properties which may change during the deformation or flow process of the fluids is becoming more and more interesting.

Figure 2.4 shows the major manners of realizing the deformation of the sample, introducing the principles of determining the viscosity of the sample.

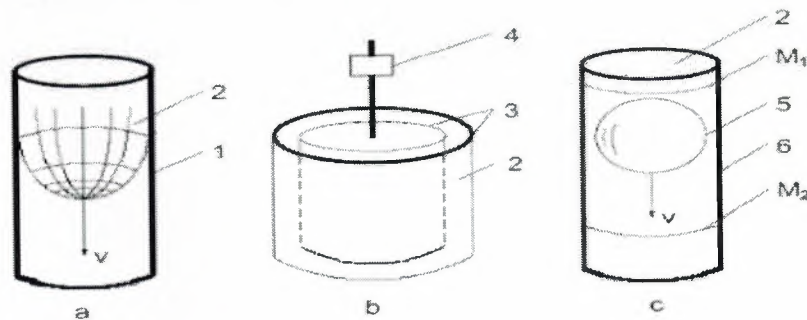


Figure 2.4 Measurement principles of viscometers

Where, a: Capillary viscometer, b: Rotational viscometer, c: Falling-ball viscometer, 1: Capillary, 2: Sample, 3: Coaxial cylinder, 4: Torque sensor, 5: Measurement ball, 6: Glass Cylinder, M_1 , M_2 : Measurement marks [11].

The following subsection illustrates and gives details about capillary viscometer, a type of viscometer chosen for this study.

2.2 Capillary Viscometers

Inside the capillary viscometers, the velocity drop required for the viscosity measurement is built up in the form of a laminar tube flow within a measurement capillary under idealized conditions

- Laminar, isothermal flow condition
- Stationary flow condition
- Newtonian flow behavior of the liquid
- Pressure-independence of viscosity
- Incompressibility of the liquid
- Wall adherence of the liquid
- Neglect of the flow influence at the entry and exit of the capillary of sufficient length

The liquid flows in coaxial layers towards the pressure drop through the capillary.

2.2.1 Theory of Capillary Viscometers

The calculation of viscosity from the data measured using glass capillary viscometer is based on Poiseuille's equation of a Newtonian fluid [9]. Figure 2.5 shows a fully developed laminar flow through a straight vertical tube of circular cross section.

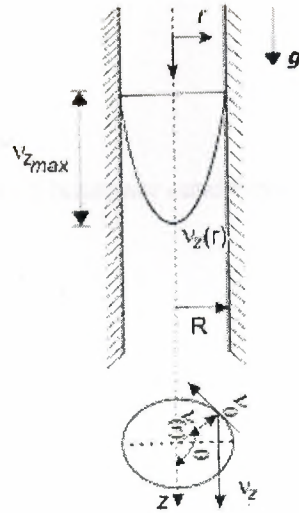


Figure 2.5 Hagen-Poiseuille flow through a vertical pipe.

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 axisymmetry, then,

$$v_z \neq 0, v_r = 0, v_\theta = 0 \quad 2.6$$

From continuity equation,

$$\frac{\partial v_r}{\partial r} + \frac{v_r}{r} + \frac{\partial v_z}{\partial z} = 0 \quad 2.7$$

For rotational symmetry,

$$\frac{1}{r} \cdot \frac{\partial v_\theta}{\partial \theta} = 0; \quad v_z = v_z(r, t) \quad \text{or} \quad \frac{\partial}{\partial \theta} (\text{any quantity}) = 0 \quad 2.8$$

Inserting 2.6, 2.7 & 2.8 into the Navier Stoke's Equation, we obtain

$$\frac{\partial v_z}{\partial t} = -\frac{1}{\rho} \cdot \frac{\partial p}{\partial z} + \nu \left(\frac{\partial^2 v_z}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial v_z}{\partial r} \right) \text{ in } z \text{ direction} \quad 2.9$$

And for steady flow it becomes

$$\frac{\partial^2 v_z}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial v_z}{\partial r} = \frac{1}{\mu} \frac{dp}{dz} \quad 2.10$$

Solving differential equation 2.10 with boundary conditions

$$r = 0 ; v_z \text{ is finite} \quad 2.11$$

$$r = R ; v_z = 0 \quad 2.12$$

Yields

$$v_z = \frac{R^2}{4\mu} \left(-\frac{dp}{dz} \right) \left(1 - \frac{r^2}{R^2} \right) \quad 2.13$$

While

$$-\frac{dp}{dz} = \frac{\Delta p}{L} \quad 2.14$$

The volume flow rate discharge is given by

$$Q = \int_0^R 2\pi v_z r \, dr \quad 2.15$$

Inserting 2.13 & 2.14 into 2.15, we obtain

$$Q = \pi \frac{R^4}{8\mu} \left(\frac{\Delta p}{L} \right) \quad 2.16$$

Also

$$Q = \frac{V}{t} \quad 2.17$$

$$v = \frac{\mu}{\rho} \quad 2.18$$

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

Then,

$$v = \frac{\pi g H R^4}{8 L V} \cdot t \quad 2.19$$

Declaring a calibration constant k,

$$k = \frac{\pi g H R^4}{8 L V} \quad 2.20$$

Then,

$$v = k t \quad 2.21$$

Equation 2.19 is similar to ASTM kinematic viscosity equation [12] with an exception of the correction factor.

$$v = (10 \pi g D^4 H t / 128 V L) - E / t^2 \quad 2.22$$

where E is the correction factor.

2.2.2 Types of Capillary Viscometers

The list and specification of different types of capillary viscometers are given in appendix 2. The Ubbelohde viscometer used in this work will be explained in details in later subsections.

2.3 Biodiesel Samples

Five different samples of biodiesel were used. Biodiesel can be produced by different methods and numbers of possible different routes [13]. The similarities in the constitution of the vegetable oils/animal fats and petroleum derived diesel that make the vegetable oils suitable for conversion to biodiesel [14,15,16].

2.3.1 Production of Biodiesel

In these work the biodiesel samples are produced by transesterification technique which is one of the most promising method [3]. The Transesterification of oil with alcohol in the presence of a

catalyst produced biodiesel and glycerol. The reaction is normally a sequence of three consecutive reversible reactions. In this process, triglyceride is converted stepwise into diglyceride, monoglyceride, and finally, glycerol in which 1 mol of alkyl esters formed in each step [13, 17]. Figure 2.6 and figure 2.7 gives an illustration.

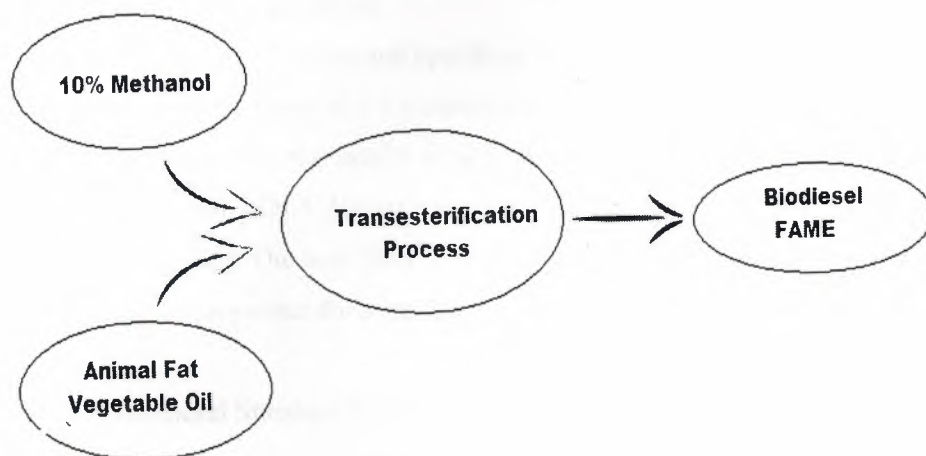


Figure 2.6 Schematics of transesterification process.

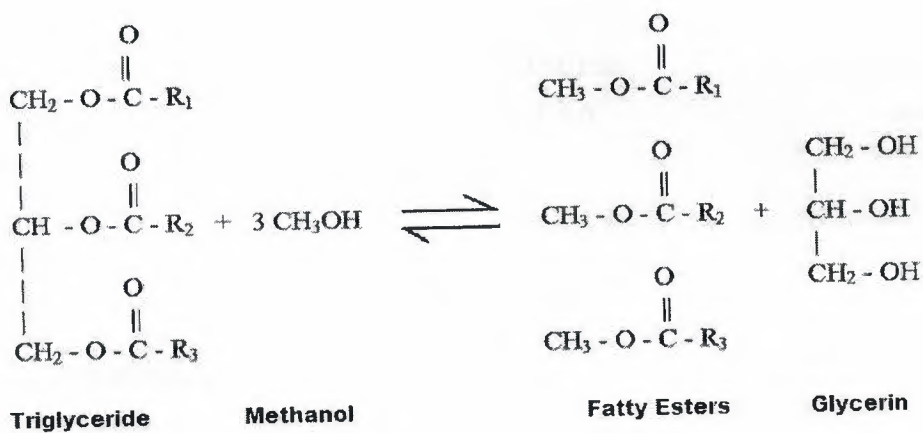


Figure 2.7 Transesterification of triglycerides; R_1, R_2, R_3 , are the hydrocarbon chain length.

In order to avoid the negative impacts of biofuels on food prices and supplies [18], waste frying oil (WFO), waste canola oil (WCO) and different percentage mixture of WFO and WCO were used for the transesterification process. For this work 100% methyl esters of WFO,

100% methyl esters of WCO, 100% methyl esters of 25% WFO plus 75% WCO, 100% methyl esters of 50% WFO plus 50% WCO, and 100% methyl esters of 75% WFO plus 25% WCO were used. These are referred to WFME, WCME, 25-WFME, 50-WFME, 75-WFME in this paper.

2.3.2 Required Standards for Biodiesel

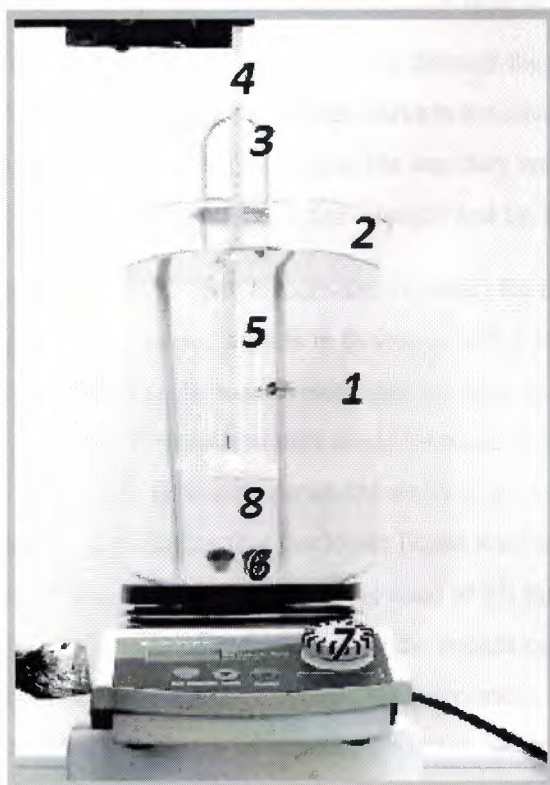
By process engineering, quality control and specification of fuel characteristic, ASTM D 975 requires a kinematic viscosity range of 1.9 minimum to 4.1 maximum mm^2/s at 40°C , biodiesel per ASTM D 6751 requires 1.9 – 6.0 mm^2/s at 40°C , biodiesel per EN 590 requires 2.0 – 4.5 mm^2/s at 40°C , biodiesel per DIN 51606 requires 3.5 – 5.0 mm^2/s at 40°C and WFCC requires 2.0 - 5.0 mm^2/s at 40°C [5,6]. The unit “ mm^2/s ” can be replace directly by cSt. Table 2.1 gives some necessary standard properties for a biodiesel.

Table 2.1. ASTM Biodiesel Standard D 6751A.

Property	Test method	Limits	Units
Flash point (closed cup)	D 93	130.0 min	$^\circ\text{C}$
Water and sediment	D 2709	0.050 max	% volume
Kinematic viscosity, @ 40°C	D 445	1.9–6.0	mm^2/s
Sulfated ash	D 874	0.020 max	% mass
Sulfur	D 5453	0.0015 max (S15) 0.05 max (S500)	
Copper strip corrosion	D 130	No. 3 max	
Certane number	D 613	47 min	
Cloud point	D 2500	Report	$^\circ\text{C}$
Carbon residue	D 4530	0.050 max	% mass
Acid number	D 664	0.50 max	mg KOH/g
Temperature, 90% recovered	D 1160	360 max	$^\circ\text{C}$

2.4 Experimental Set-up and Methods

Figure 2.8 show an illustrated diagram of the experimental set-up.



- 1: Silicone Oil
- 2: 3000ml Standard Beaker / Oil Bath
- 3: Capillary Holder
- 4: Thermometer
- 5: Capillary Viscometer
- 6: Electromagnetic mixer
- 7: Electromagnetic plate
- 8: Biodiesel sample

Figure 2.8 Experimental set-up

Silicon oil (1) in a standard beaker (2) is used as oil bath. The capillary viscometer (5) is placed in its holder (3) which holds it in an upright position in the oil bath. The oil bath is heated by an electromagnetic plate (7) and its temperature is controlled by a standard thermometer (4).

2.4.1 Ubbelohde Viscometer

An Ubbelohde type viscometer or suspended-level viscometer is a measuring instrument which uses a capillary based method of measuring viscosity. It is recommended for higher viscosity cellulosic polymer solutions. The advantage of this instrument is that the values obtained are independent of the total volume. The device was invented by the German chemist Leo Ubbelohde (1877-1964) [19].

The Ubbelohde viscometer is closely related to the Ostwald viscometer. Both are U-shaped pieces of glassware with a reservoir on one side and a measuring bulb with a capillary on the other. A liquid is introduced into the reservoir then sucked through the capillary and measuring bulb. The liquid is allowed to travel back through the measuring bulb and the time it takes for the liquid to pass through two calibrated marks is a measure for viscosity. The Ubbelohde device has a third arm extending from the end of the capillary and open to the atmosphere. In this way the pressure head only depends on a fixed height and no longer on the total volume of liquid.

Ubbelohde suspended level viscometer, is useful for the determination of the kinematic viscosity of transparent Newtonian liquids in the range of 0.3 to 100,000 mm²/s. An Ubbelohde viscometer possesses the same viscometer constant at all temperatures. This property is advantageous when measurements are to be made at a number of different temperatures. The liquid is induced to flow only down the walls of the bulb below the capillary, thus forming a suspended level, ensuring that the lower liquid level is automatically fixed and coincides with the lower end of the capillary, avoiding the need to fill the viscometer with a definite volume of the liquid and application of corrections for the expansion of glass due to changes in temperature. The viscometer is charged by vertical the instrument, with the reservoir below the capillary, by introducing the liquid into filling tube up to the lower filling line. Care should be taken to see that the liquid does not go above the upper filling line when the viscometer is brought to the vertical position. The U-tube must be filled completely at the bottom and should be free from air bubbles and particulate matter. The viscometer is positioned in a bath-temperature maintained at the required temperature. After desired temperature is attained, a plug is placed over venting tube and suction is applied to capillary tube, until the liquid reaches the center of the pre-run sphere. The suction is disconnected from capillary tube; the plug is removed from venting tube and is immediately placed over capillary tube until sample drops away from the lower end of the capillary. The plug is removed and the efflux time is noted. The advantages of Ubbelohde type viscometers are speed, accuracy (within $\pm 0.1\%$), small sample size (about 15 mL is sufficient), low susceptibility to errors (due to drainage, and alignment), and cost effectiveness (the equipment is cheaper than the other models providing the same type of accuracy). The main concern with this viscometer is the prospect of clogging (specially, in small capillaries) [20, 21].

There are 16 types of Ubbelohde viscometers covering the kinematic viscosity in the range of 0.3 to 100,000 cSt. In Table 2.1 is listed the size number of Ubbelohde viscometers and corresponding kinematic viscosity range.

Table 2.2 Ubbelohde viscometers for transparent fluid [21].

Size no:	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range mm ² /s	Inside Diameter of Tube ,R , mm (±2%)	Volume, Bulb C,ml (±5%)	Inside Diameter of Tube P,ml (±5%)
0	0.001	0.3 ^A to 1	0.24	1.0	6.0
0C	0.003	0.6 to 3	0.36	2.0	6.0
0B	0.005	1 to 5	0.46	3.0	6.0
1	0.01	2 to 10	0.58	4.0	6.0
1C	0.03	6 to 30	0.78	4.0	6.0
1B	0.05	10 to 50	0.88	4.0	6.0
2	0.1	20 to 100	1.03	4.0	6.0
2C	0.3	60 to 300	1.36	4.0	6.0
2B	0.5	100 to 500	1.55	4.0	6.0
3	1.0	200 to 1000	1.83	4.0	6.0
3C	3.0	600 to 3000	2.43	4.0	6.0
3B	5.0	1000 to 5000	2.75	4.0	6.5
4	10	2000 to 10,000	3.27	4.0	7.0
4C	30	6000 to 30,000	4.32	4.0	8.0
4B	50	10,000to50,000	5.20	5.0	8.5
5	100	20,000to100,000	6.25	5.0	10.0

^A300-s minimum flow time;200-s minimum flow time for all other units

The ubbelohde viscometer (ASTM) was choosing because of its wide known application and accuracy. It enables transparent and high temperature measurement. Two viscometers of size 0c and 1 are used, they are both calibrated with constants for manual measurements. Appendix 4 shows the technical specifications of the viscometers.

The viscometer in figure 2.9 basically consists of the capillary tube (1), venting tube (2) and the filling tube (3), the capillary (7) with the measuring sphere (8), the pre-run sphere (9) and reference level vessel (5). Above and below the measuring sphere (8) are printed on timing marks M_1 and M_2 . These marks not only define the flow-through volume of the sample, but also the mean hydrostatic head (h). the capillary ends in the upper part of the reference level vessel (5). The sample runs down from the capillary (7) as a thin film on the inner surface of the reference level vessel (5) (suspended level bulb). Figure 2.9 shows an illustrated diagram of the ubbelohde viscometer.

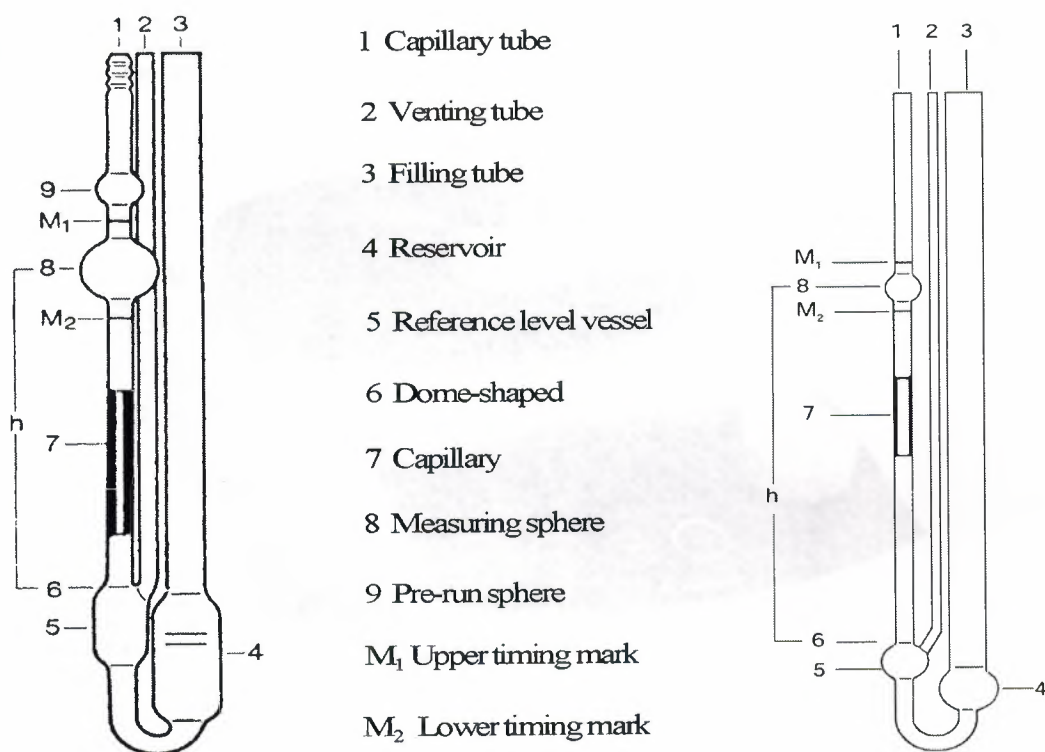


Figure 2.9 Illustrated diagram of ubbelohde viscometer

2.4.2 Electromagnetic Hot Plate and Stirrer

For the purpose safe heating and mixing, the Hiedolph MR Hei-tec electromagnetic heater and stirrer was used. It is made of aluminum, thus making it to provide fast heating times and the water-thin ceramic coating makes the heating plate both chemically and scratch resistant. Figure 2.10 gives a sample of the used plate.



Figure 2.10 Heidolph MR Hei-Tec [22].

2.4.3 Silicone Oil

Due to the selected temperature range, it is impossible to use water as an appropriate temperature bath. A wacker silicone fluid AK oil was used. Wacker silicone fluid AK are dimethyl polysiloxane whose un-branched chains are made up of alternate silicon and oxygen atoms, the free valences of the silicon being saturated by methyl group. While the carbon chains of organic compounds show little resistance to certain external influences, the stability of inorganic Si-O linkage is, in many ways, like the chemical inertness of silicate minerals. The structure of silicone fluid AK can be represented by the following general formula as in figure 2.11

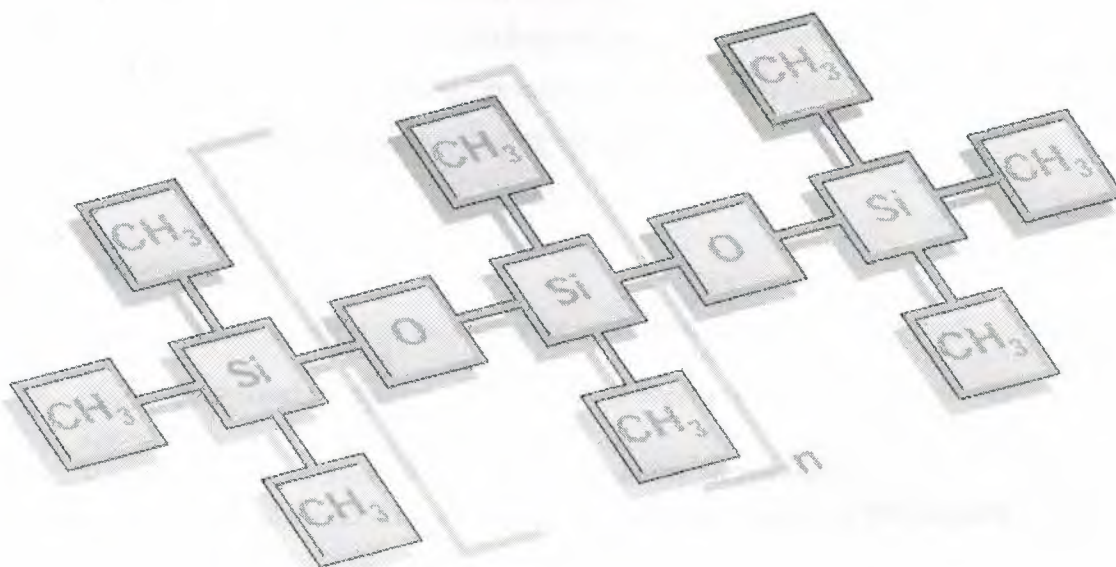


Figure 2.11 Structural formula of silicone oil.

The selected silicone oil was AK 350 with the following properties in table 2.2

Table 2.3 Properties of silicone oil

Kinematic Viscosity at 20°C ^A mm ² /s	Dynamic Viscosity at 20°C mPa.s	Viscosity- Temperature Coefficient ^B	Coefficient of Thermal expansion at 0 - 150°C cm ³ .10 ⁻⁴ /cm ³ °C	Thermal conductivity at 50°C Wk ⁻¹ m ⁻¹	Flash point ISO 2592 °C	Pour point °C	Volatility ³⁾ %	Density g/cm ³
350	340	0.595	9.25	0.15	>300	-50	<1.5	0.968

^A The tolerance for up to 50 mm²/s is $\pm 10 \%$, for higher viscosity fluids $\pm 5 \%$

^B Viscosity-temperature coefficient: $1 - \frac{\text{kinematic viscosity at } 99^\circ\text{C}}{\text{kinematic viscosity at } 38^\circ\text{C}}$

- 1) Percentage weight loss of a 5-g sample weighed into a 10-cm³ metal capsule and heated at 230 °C for two hours [23].

2.4.4 Temperature Measurement

A standard, calibrated mercury thermometer is used to control the temperature in the bath. It is required by the standard of ASTM D445 to keep the temperature constant to avoid or reduce unnecessary errors. To ensure that the temperature in the oil bath is uniform, two thermometers are used. One for fixed control and the other for varying control.

2.4.5 Accessories

For a conservative and an effective measurement, additional accessories were used. This includes

- Glass pipette: used for transporting a measured volume of Biodiesel sample into the viscometer.
- Vacuumed Syringe: used for suction process during measurement.
- Stop watch: used for accurate measurement of time as required by the standard procedure.
- Beaker Insulator: used to prevent heat loss to the environment at relatively high elevated temperature.
- Viscometer Holder: used to keep the Ubbelohde capillary viscometer vertically upright in the oil bath.

2.4.6 Methodology

The following explains the necessary procedure in measuring the kinematic viscosity of the biodiesel sample.

1. Before use, first clean with 15 % H₂O₂ and 15 % HCl. Thereafter rinse viscometer with a suitable solvent (Acetone is chosen for our case). It must be completely dry and dust-free before it is put to use for either manual measuring.

2. If there is a possibility of lint, dust, or other solid material in the liquid sample, filter the sample through a fritted glass filter or fine mesh screen.
3. Charge the viscometer by introducing sample through filling tube into the lower reservoir; introduce enough sample to bring the level between lines which placed on the reservoir.
4. Place the viscometer into the holder, and insert it into the constant temperature bath. Vertically align the viscometer in the bath if a self-aligning holder has not been used.
5. Allow approximately 20 minutes for the sample to come to the bath temperature.
6. Apply vacuum to venting tube (2) as in figure 2.9, closing venting tube (2) by a finger or rubber stopper. This will cause the successive filling of the reference level vessel (5), the capillary tube (1), the measuring sphere (8), and the pre-run sphere (9). Fill to approximately 10 mm above the upper timing mark M_1 . Now suction is discontinued and the venting tube (2) opened again. This causes the liquid column to separate at the lower end of the capillary (7) and to form the suspended level at the dome-shaped top part (6).
7. What is measured in the time interval (efflux time t) it takes the leading edge of the meniscus of the sample to descend from the upper edge of the upper timing mark M_1 to the upper edge of the lower timing mark M_2 .
8. Calculate the kinematic viscosity of the sample by multiplying the efflux time t by the viscometer constant k in (Table 2.2). We choose the kinetic energy correction for calculating " ν " using formula in equation 2.22
9. Without recharging the viscometer, make check determinations by repeating steps 6 to 8 four or five times for each experiment.

Additionally, the following must be noted.

- Calibration: In order to determine the relationship between the time of flow and the kinematic viscosity, a calibration of the instrument is needed. The calibration was done by the manufacturer, SI Analytics GmbH, Mainz according to ASTM D 2525/ D 446 and ISO/DIS 3105. The instrument constant k were determined and given as in table 2.2. The calibration constant can be used up to the temperature of 140°C. The influence of the temperature on the capillary constant due to thermal expansion of the glass is very small, $3.3 \times 10^{-6} \frac{1}{K}$ [24].

- Kinematic Viscosity: in place of equation 2.21, for absolute measurement, the corrected flow time multiplied by the viscometer constant k gives the kinematic viscosity [mm²/s] directly.

$$v = k(t - y)$$

2.22

Where y is the kinetic energy correction (HC) described in table 2.4.

Table 2.4 Table of kinetic energy correction

Ubbelohde Viscometer ISO 3105/DIN51 562/Part1/BS188/NFT 60-100

Ref.No.501...530...532..

Correction seconds ^A:

Flow time	Capillary no						
	0	0c	0a	I	lc	la	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 ^B	1.55	0.26	0.11	0.04
90	_B	_B	3.78 ^B	1.22	0.20	0.09	0.03
100	_B	7.07 ^B	3.06 ^B	0.99	0.17	0.07	0.02
110	_B	5.84 ^B	2.53	0.82	0.14	0.06	0.02
120	_B	4.91 ^B	2.13	0.69	0.12	0.05	0.02
130	_B	4.18 ^B	1.81	0.59	0.10	0.04	0.01
140	_B	3.61 ^B	1.56	0.51	0.08	0.04	0.01
150	_B	3.14 ^B	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 ^B	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	
700	0.85	0.14	0.06	0.02	<0.01	
750	0.74	0.13	0.05	0.02	<0.01	
800	0.65	0.11	0.05	0.01		
850	0.57	0.10	0.04	0.01		
900	0.51	0.09	0.04	0.01		
950	0.46	0.08	0.03	0.01		
1000	0.42	0.07	0.03	0.01		

^A The correction seconds stated are related to the respective theoretical constant

^B For precision measurement, these flow times should not be applied. Selection of a viscometer with a smaller capillary diameter is suggested.

2.4.7 Flow Chart for Determining Kinematic Viscosity

For full understanding of methodology, a system flow chart is designed. Figure 2.12 illustrate the methodology flow chart for determination of kinematic viscosity using an ubbelohde viscometer.

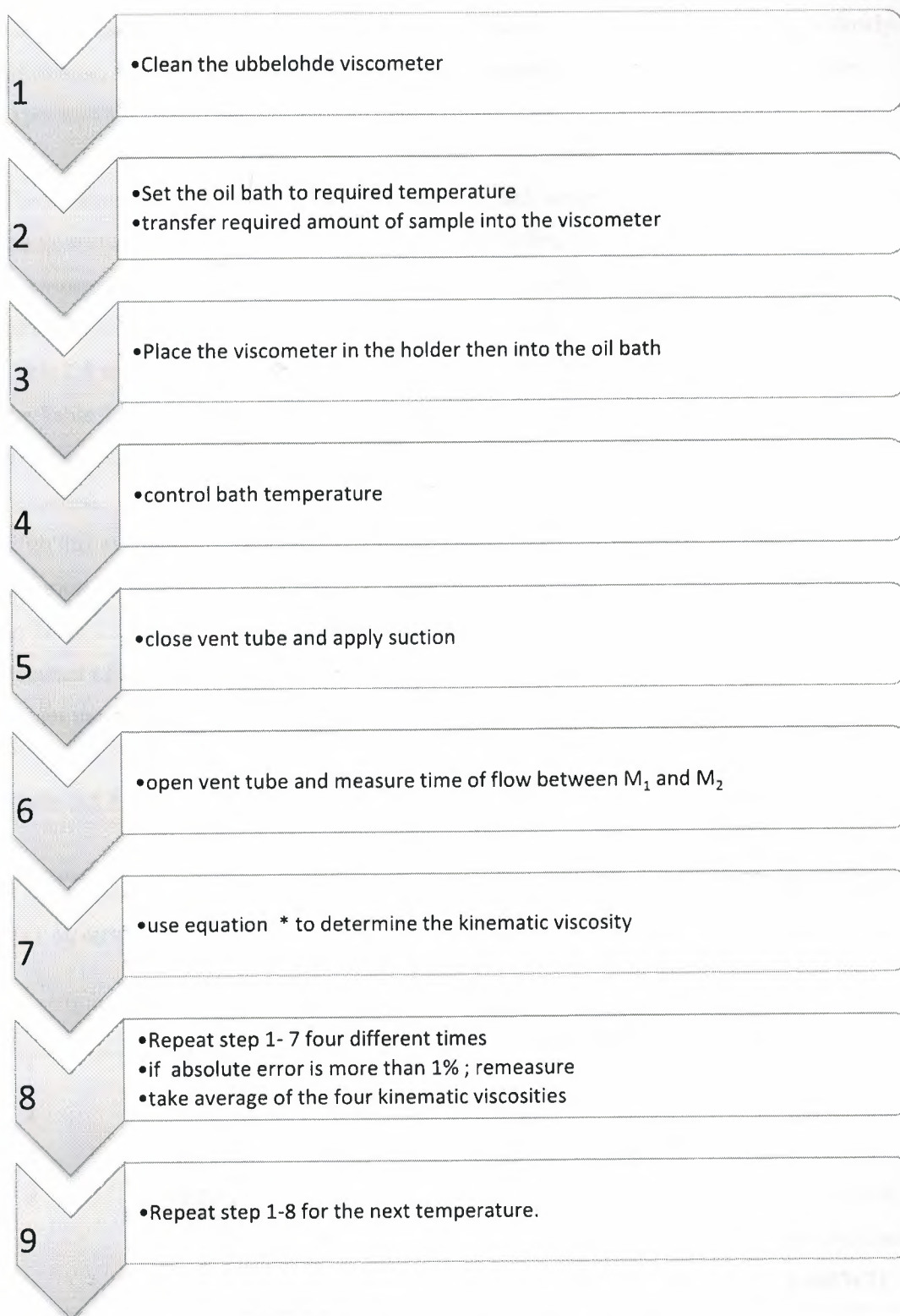


Figure 2.12 Methodology flow chat.

These measurements may be done at room temperature. Always pour the solutions slowly. Otherwise, they will entrain air bubbles that are very slow to escape and can affect the experimental results.

The measurements of the kinematic viscosity for each sample have been performed according to the flow chart given in figure 2.12. As mentioned before, for each sample four experiments (measurements) have been conducted at the same temperature, and the average value has been taken for foregoing calculations of kinematic viscosities.

Table 2.5 shows the results of four experiments, at 40°C for biodiesel sample, WFME. As seen in the Table 2.5, the flow times measured are very close to each other. They are $\pm 1\%$ below or up to the average time flow, which is allowable in the standard norms $\pm 5\%$ of the average value is permitted.

With this average flow time, the average kinematic viscosity has been calculated by using equation 2.22.

In Table 2.5, the other parameters are also given for calculation of the viscosity such as “k” (k is constant of capillary) and “HC” or “y” (HC is kinetic energy correction) kinematic viscosity values used are the average kinematic viscosity values in table and figures.

Table 2.5 Kinematic Viscosity Calculation of WFME.

Experiments (T @ 40°C)	Time(min)	Time(sec)	Constant k for Capillary no "T")	Kinetic Energy Correction (HC)	Kinematic Viscosity(mm ² /s)
1	8.31:47	511.47	0.009132	0.04	4.67037876
2	8.30:78	510.78	0.009132	0.04	4.66407768
3	8.31:29	511.29	0.009132	0.04	4.668735
4	8.30:32	510.32	0.009132	0.04	4.65987696
					Ave.Viscosity
					4.6657671

In the same manner and using the flow chart, the kinematic viscosity of all samples has been calculated from 20°C up to 140°C stepwise 10°C and it is shown and discussed in the next chapter.

CHAPTER 3

RESULTS AND DISCUSSIONS

The hypothesis of this work is balanced with result and necessary discussions that follows.

3.1 Accuracy and Repeatability

To ensure the accuracy of the devices we measure the kinematic viscosity of a fluid of which it's kinematic viscosity is known. That fluid is pure water. The kinematic viscosity of the pure water is given in the literature and is $0.80908 \text{ mm}^2/\text{s}$ at 30°C [20].

When we use the same experimental conditions and measured the kinematic viscosity of pure H_2O with using Ubbelohde Viscometer we obtained the kinematic viscosity $0.803 \text{ mm}^2/\text{s}$.

The absolute error calculated is less than 1% (0.75). It shows that the devices we used are well calibrated.

To ensure a precise measurement, repeatability test was carried out. Table 3.1 shows an Ubbelohde viscometer repeatability results.

Table 3.1 Ubbelohde viscometer repeatability results for some biodiesel samples.

Fluid type	Temperature ($^\circ\text{C}$)	Measured kinematic viscosity (mm^2/s)	Average Kinematic viscosity (mm^2/s)	Absolute error (mm^2/s)	Percent absolute error (%)
WFME	40	4.67037876	4.665767	0.004612	0.098743
		4.66407768		0.001689	0.036222
		4.668735		0.002968	0.06357
		4.65987696		0.00589	0.126401
	80	2.3553432	2.353344	0.001999	0.084879
		2.3510592		0.002285	0.097182
		2.3536296		0.000286	0.012134
		2.353344		0	0
WCME	40	4.6988706	4.678278	0.020593	0.438247
		4.66407768		0.0142	0.30446
		4.65896376		0.019314	0.41456
		4.69119972		0.012922	0.275447
50-WFME	40	5.42185104	5.421151	0.0007	0.012913
		5.41838088		0.00277	0.051123
		5.42322084		0.00207	0.038168

From the results in table 3.1, it can be discussed that the measurement by the viscometer are precise. The repeatability is below 1% error compare to the average value. With this notion, there is 99% probability that the kinematic viscosity results to be discussed in the next sub-section are true value.

The accuracy and repeatability tests posed a very high tendency of genuine results.

3.2 Kinematic Viscosity

Figure 3.1 – 3.5 show the relationship between the kinematic viscosity and temperature of WFME, WCME, 50-WFME, 75-WFME and 25-WFME, respectively. The viscosity of a desire sample can be gotten from the charts at a know temperature. There has been no comprehensive theory on the viscosity of the liquids so far because of its complex nature. Theoretical methods of calculating liquid viscosities like those proposed by Kirkwood [25]. And the molecular dynamic approaches reported by cummings and evan [26] are useful in providing valuable insights into the theory even though they result in large deviations from the measure viscosity data. In contrast, semi-empirical and empirical methods provide reasonable results but lack generality of approach. At temperature below the normal boiling point, the logarithm of liquid viscosity varies linearly with the reciprocal of the absolute temperature as described by the model;

$$\ln(v) = A + \left(\frac{B}{T}\right) \quad \text{or} \quad v = A' \exp\left(\frac{B}{T}\right) \quad 3.1$$

With the constants A and B determined empirically. At temperature above the normal boiling point, the $\ln v$ versus $(1/T)$ relationship becomes non-linear and is described by a number of semi-empirical methods including those based on the principle of corresponding state. At this state kinematic viscosity is often represented by the Andrade equation or a modified form proposed by Tat and Van Gerpen [27].

$$\ln(v) = A + \left(\frac{B}{T}\right) + \frac{C}{T^2} \quad 3.2$$

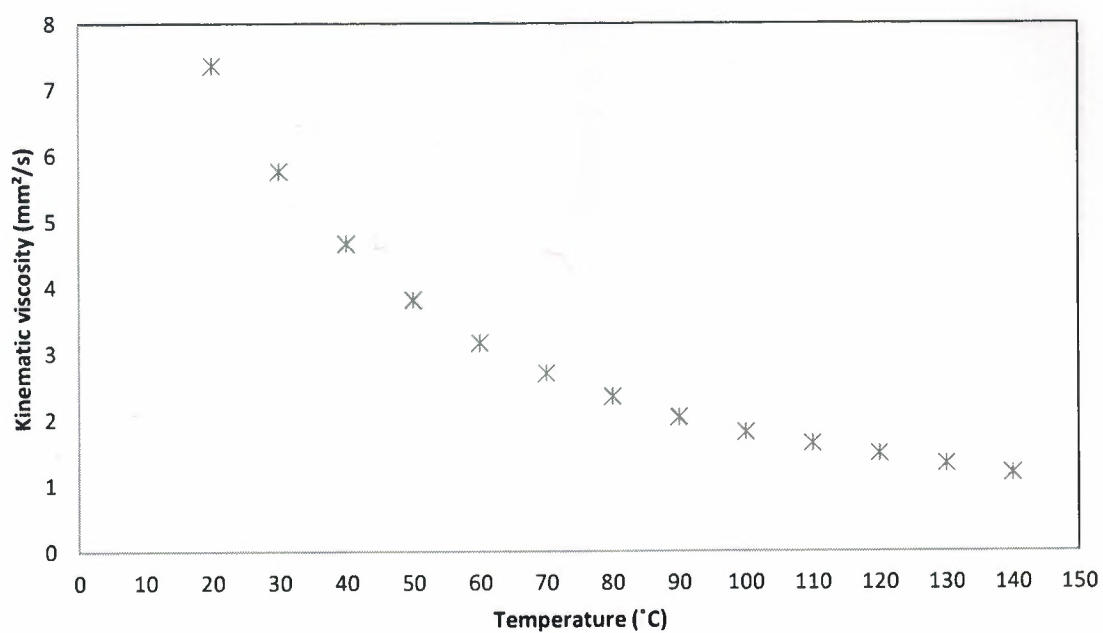


Figure 3.1 Kinematic viscosity of 100% waste frying methyl ester (WFME).

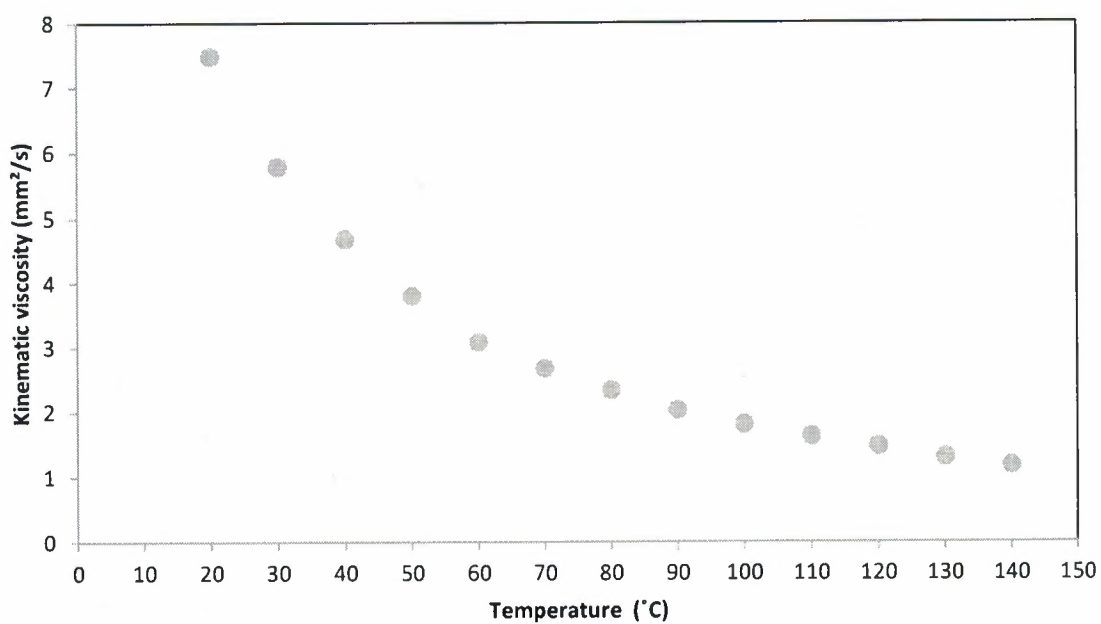


Figure 3.2 Kinematic viscosity of 100% waste canola methyl ester (WCME).

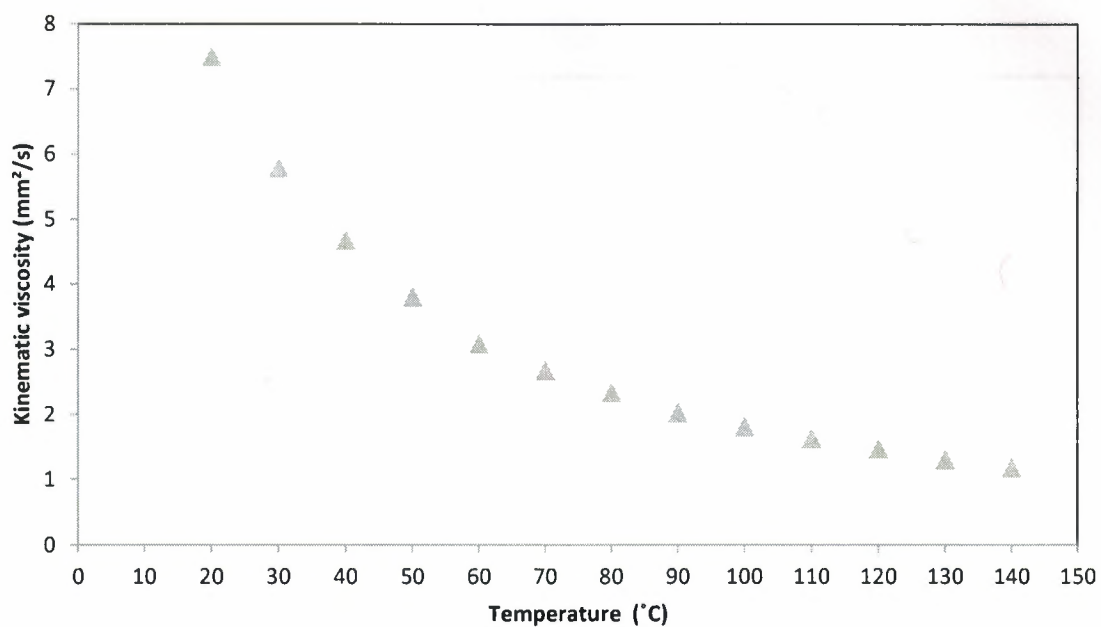


Figure 3.3 Kinematic viscosity of 50% waste frying methyl ester – 50% waste canola methyl ester (50 – WFME).

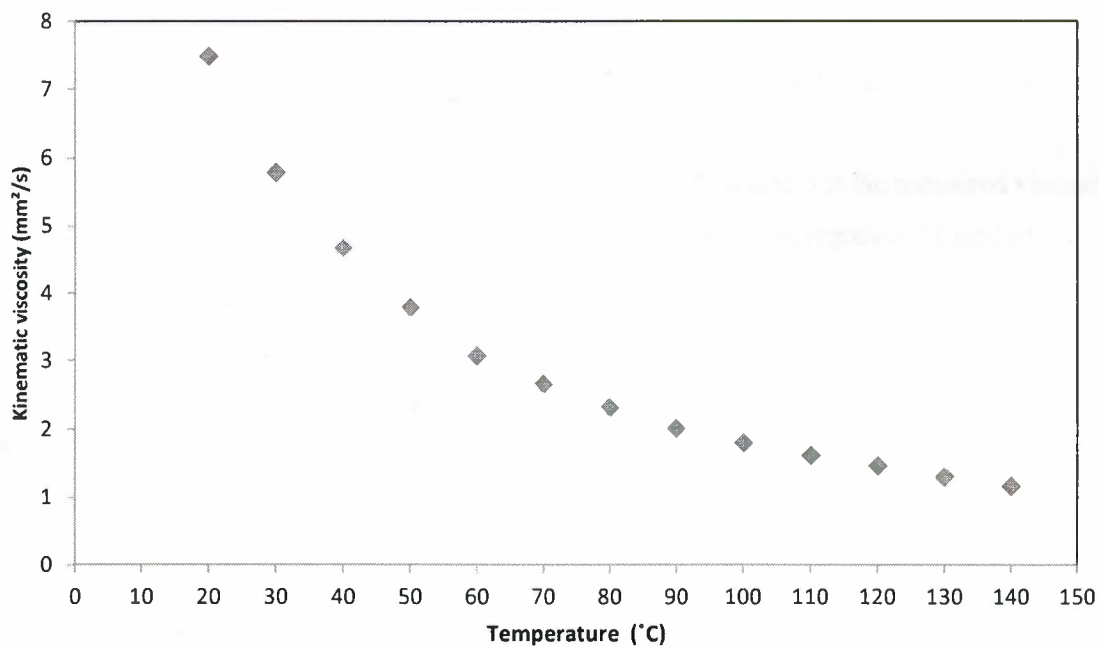


Figure 3.4 Kinematic viscosity of 75% waste frying methyl ester – 25% waste canola methyl ester (75 – WFME).

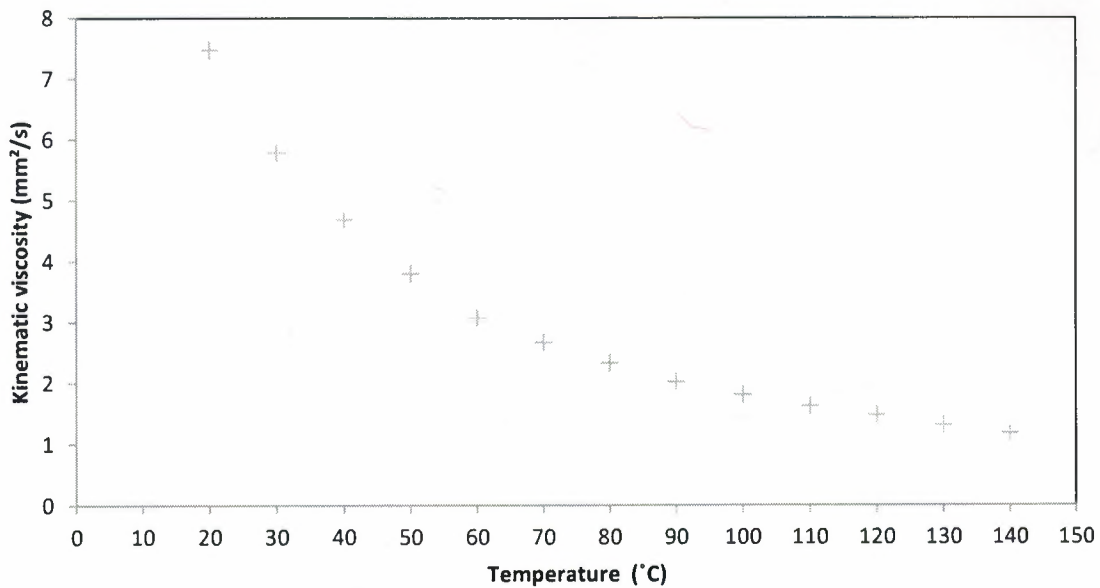


Figure 3.5 Kinematic viscosity of 25% waste frying methyl ester – 75% waste canola methyl ester (25- WFME).

Since our temperature range is below the boiling point of our samples, Equation 3.1 is used in analysis, validation and discussion of our data.

Assuming the prescribed behavior we plotted $\ln(v)$ versus $1/T$, where v is the measured viscosity and T is the absolute temperature in Kelvin. Figure 3.6-3.10 show the regression based of equation 3.1.

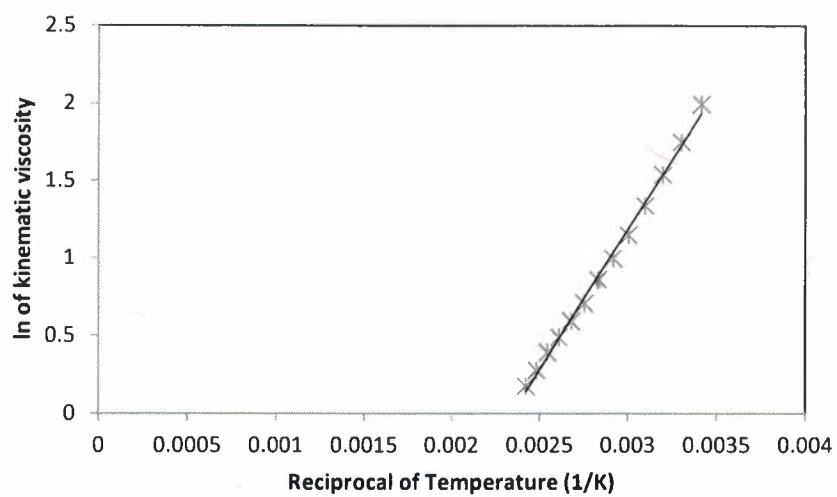


Figure 3.6 Empirical model for waste frying methyl ester (WFME).

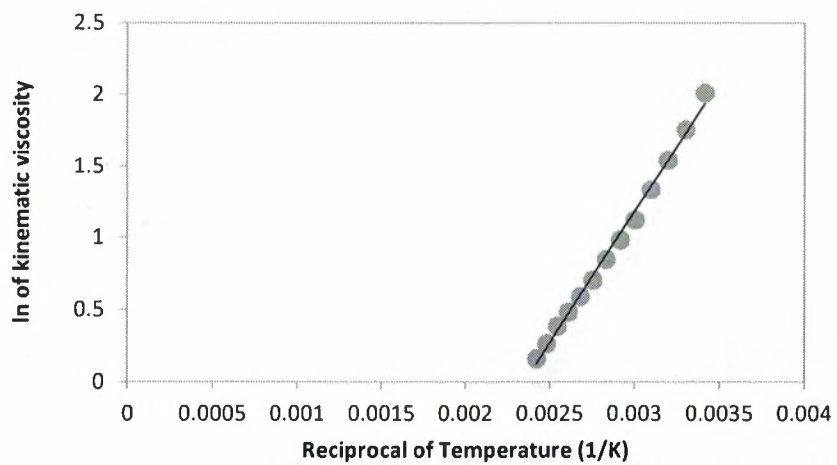


Figure 3.7 Empirical model for waste canola methyl ester (WCME).

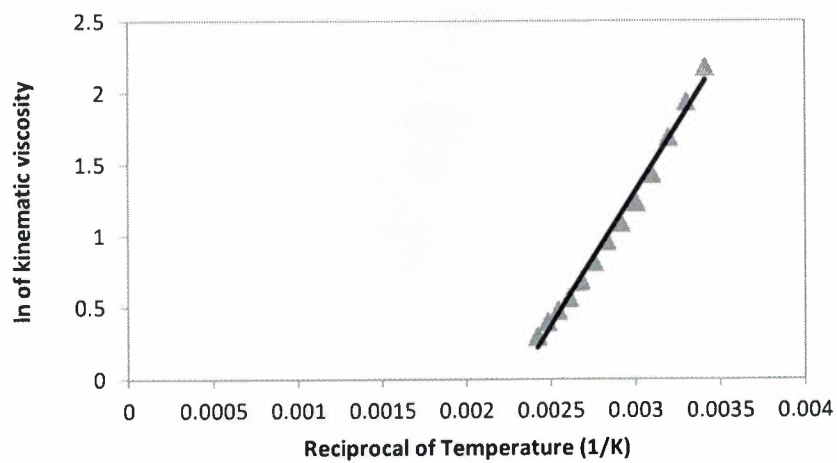


Figure 3.8 Empirical model for 50% waste frying methyl ester – 50% waste canola ester (50 –WFME).

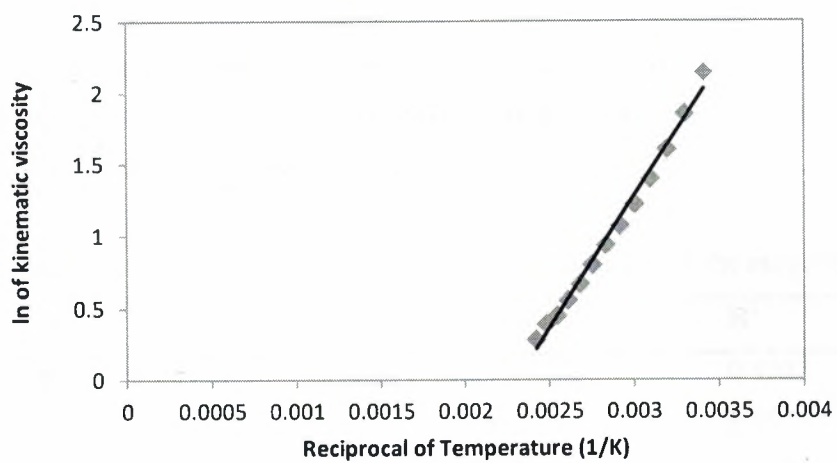


Figure 3.9 Empirical model for 75% waste frying methyl ester – 25% waste canola methyl ester (75 –WFME).

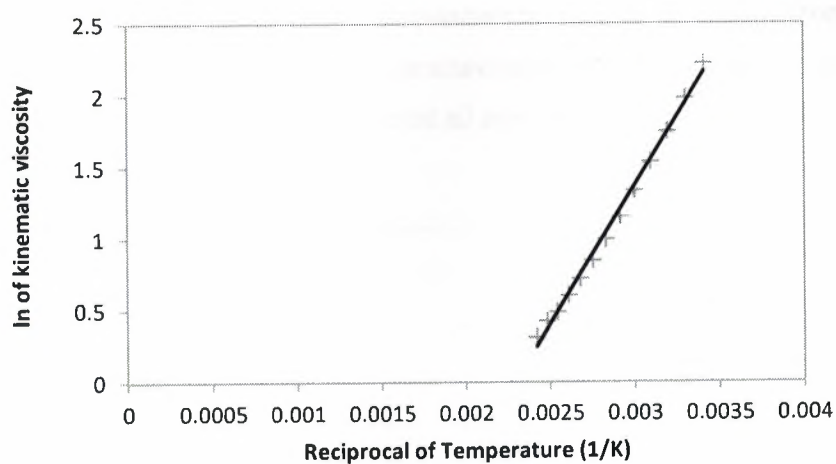


Figure 3.10 Empirical model for 25% waste frying methyl ester – 75% waste canola methyl ester (25 – WFME).

As a validation, in all cases, straight lines result with correlation coefficients are greater than 0.99 implying that all our correlations are scientifically alright. Table 3.2 gives the empirical equations for all tested samples between 293.15K – 413.15K, (20°C -140°C).

Table 3.2 Viscosity correlation constants for the five biodiesel fuel over the range of 20 -140°C.

Fuel type	A	B	R ²
WFME	1807.3	-4.2346	0.9967
WCME	1826.1	-4.294	0.9955
50-WFME	1881.7	-4.3343	0.9909
75-WFME	1822.5	-4.1925	0.9917
25-WFME	1934.6	-4.4396	0.9953

Figure 3.11 show that viscosity decreases as temperature increases as expected. From the figure we could see that for all samples tested, as temperature increases, the kinematic viscosity decreases. This is in line with other samples tested all over the world. It can be explained by kinetic molecular theory.

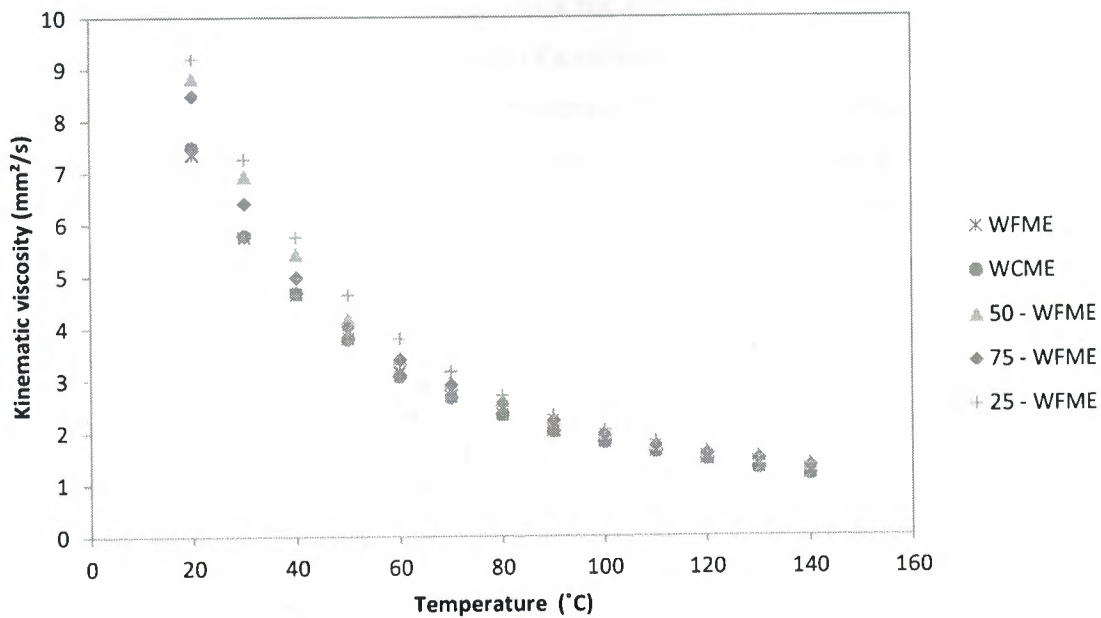


Figure 3.11 Viscosity – Temperature relationship for all samples.

Since viscosity is the resistance to flow of molecules to slide over one another, as temperature increases, the molecules gain heat energy which is transform molecularly into kinetic energy, enabling them to move more faster with reduction in flow resistance; viscosity. Figure 3.12 show this idea.

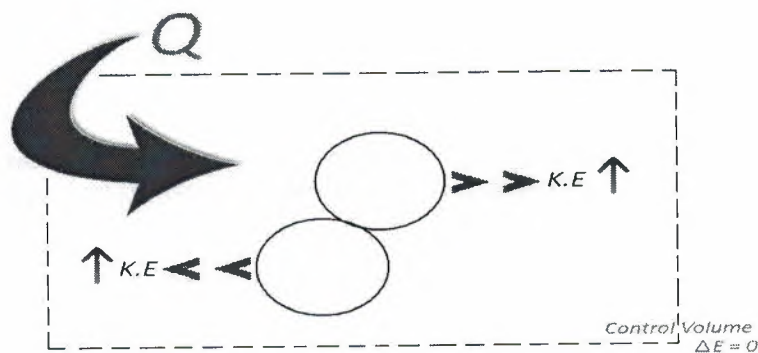


Figure 3.12 Energy balance of molecules.

Where Q is the heat energy transferred into the system, E is total energy of the system, and $K.E$ is kinetic energy of the molecules. Because of energy balance, conservation of energy, $\Delta E = 0$, then kinetic energy of the molecules have to increase as heat energy is being transferred into the system.

We can also explain this with theory of mechanics but in molecular concept. It is generally known that the size of the atoms or molecules of a substance increases when the temperature decreases and decreases when the temperature increase. Therefore as temperature of a molecule increases, the radius of the molecule decreases. Thereby, enabling the molecules to slide over each other more easily as it was stated in chapter 2, smaller molecule. The idea is, smaller radius increases contact area which increases the slide “the opposite of rolling resistance theory”.

We also examine the relationship between the viscosity of the sample and their relative mixing proportions. Figure 3.13 explain this in details.

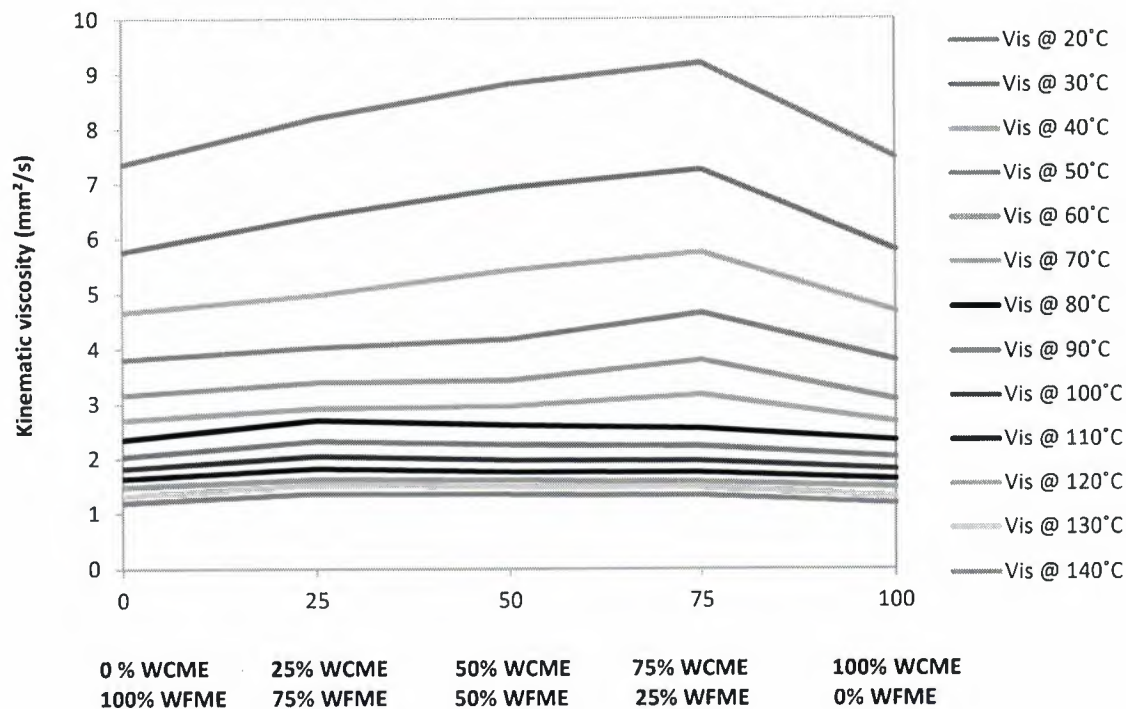


Figure 3.13 Viscosity – Composition relationship.

From figure 3.13 the kinematic viscosity of WCME is a little greater than the kinematic viscosity of WFME at same temperature and pressure. Since both of them are under the same condition with the same molecular structure (they are both biodiesel sample), it could be concluded that the variation in the viscosity is due to variation in “molecular size”. As discussed in chapter 2, it implies that WFME has a smaller radius compare to WCME.

Also, as the percentage of WCME increases, the viscosity increases until at 75% where it drops. It is easy to make a mistake by thinking that the viscosity of 50-WFME should be the average of the kinematic viscosity of WFME and WCME. On contrary, it increases. This is due to the fact that the smaller molecules of WCME are gradually filling up the intermolecular space between the WFME molecular structures. Figure 3.14 -3.16 show this in details.

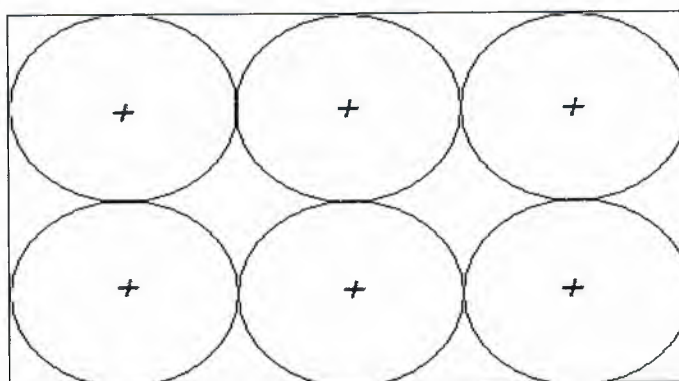


Figure 3.14 Approximated molecular structure of WCME.

Where the molecules represented by “+” are bigger, making them to slide slower

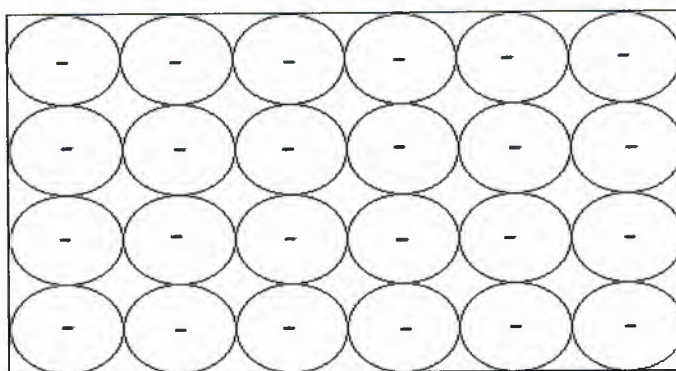


Figure 3.15 Approximated molecular structure of WFME.

Where the molecules represented by “-” are smaller, making them to slide more faster.

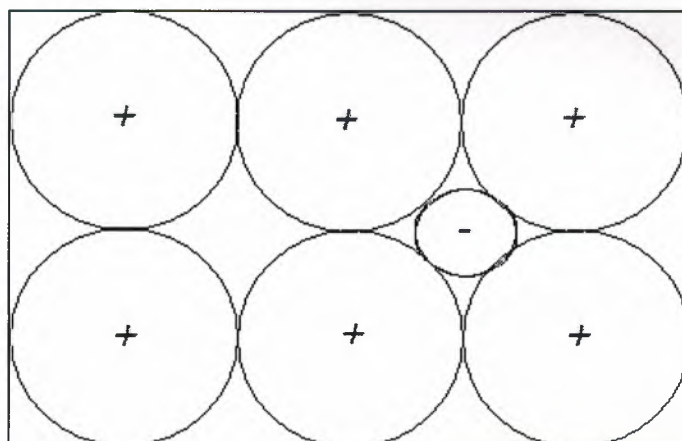


Figure 3.16 Approximated molecular structures of 25 – WFME.

Where the WCME molecule is gradually filling up the intermolecular space between the WFME molecules, making it much more difficult for the molecules to slide over one-another. This continues until the molecules of WCME become dominant, and then viscosity drops (at a noticeable percentage of 25- WFME and 75 – WCME).

At an elevated temperature the effect of temperature become more dominant and then all samples seems to have approximately same kinematic viscosity at a particular temperature.

We can also find computational empirical coefficients for the kinematic viscosity – composition relationships. This is done by forth order polynomial regression as shown in Figure 3.17.

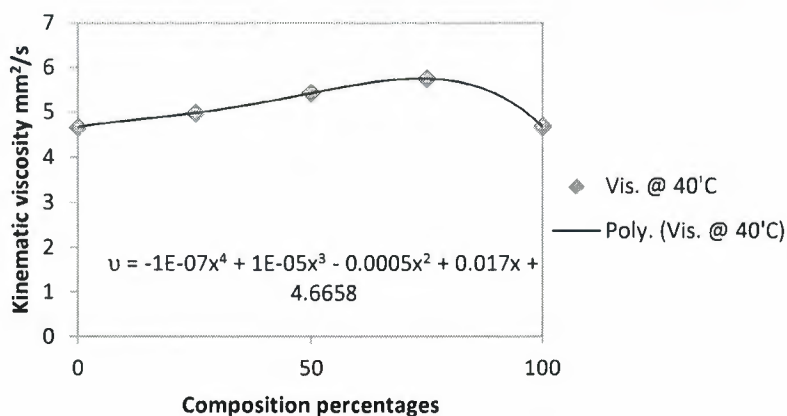


Figure 3.17 Polynomial regressions for composition percentages at 40°C.

In similar way, the regression is computed for temperature range between 20°C to 140°C in form of:

$$v = Ax^4 + Bx^3 + Cx^2 + Dx + E \quad 3.3$$

Where x is the desire WCME percentage in our mixture.

Table 3.3 Polynomial coefficients for kinematic viscosity – composition relationship.

Temperatures (°C)	A	B	C	D	E	R ²
20	-2E-07	3E-05	-0.0015	0.564	7.355	1
30	-2E-07	2E-05	-0.0011	0.0422	5.7583	1
40	-1E-07	1E-05	-0.0005	0.017	4.6658	1
50	-2E-07	4E-05	-0.0018	0.0346	3.8112	1
60	-2E-07	4E-05	-0.002	0.0397	3.1608	1
70	-1E-07	2E-05	-0.0012	0.0277	2.051	1
80	-7E-08	2E-05	-0.0012	0.0359	2.3533	1
90	-6E-08	1E-05	-0.001	0.0295	2.0332	1
100	-6E-08	1E-05	-0.0009	0.0252	1.814	1
110	-5E-08	1E-05	-0.0008	0.0216	1.6367	1
120	-2E-08	4E-06	-0.0004	0.0126	1.4822	1
130	-5E-08	1E-05	-0.0008	0.0215	1.3228	1
140	-3E-08	7E-06	-0.0005	0.0164	1.1904	1

R² = 1 means that all correlations are within an acceptable range. The data could be used to get the kinematic viscosity of biodiesel sample produce from varying mixture of waste frying oil and waste canola oil.

Table 3.4 shows the general result for kinematic viscosity at varying temperature.

Table 3.4 Kinematic viscosities of five biodiesel fuels in temperature range of (20°C – 140 °C)

Temperature (°C)	Kinematic Viscosity (mm ² /s)				
	WFME	WCME	75 - WFME	50 - WFME	25 - WFME
20	7.35502695	7.48472418	8.49465489	8.82023352	9.75
30	5.75829675	5.78697123	6.40497172	6.9325578	7.25884416
40	4.6657671	4.67827794	4.97882728	5.42115092	5.74857117
50	3.81119454	3.80076884	4.02787407	4.1833692	4.64675732
60	3.1608135	3.07853418	3.3952776	3.43319823	3.79955124
70	2.70514953	2.67289074	2.91733916	2.856791	3.16622421
80	2.353344	2.332709	2.553907	2.614311	2.705489
90	2.033174976	2.023108	2.226526	2.259513	2.322059
100	1.813971264	1.806903	1.955272	1.976977	2.04595
110	1.636679352	1.626112	1.745065	1.755703	1.82439
120	1.48216404	1.473239	1.571557	1.609613	1.626249
130	1.32279924	1.304664	1.481379	1.488804	1.527432
140	1.19035224	1.1775	1.329796	1.346647	1.362783

As discussed in chapter 2, the data in table 3.4 can be by used design engineers to optimize the performance in the fuel system and even to control the three T_s of combustion.

- Temperature
- Turbulence
- Time.

The temperature at each point in the fuel system is very important which is one of the major dependent factors of viscosity. In like manner, the turbulence is very important. the turbulence cannot be determined without the Reynolds's number, a determining parameter derived from viscosity. Also the time flow rate is important.

With respect to results in table 3.4, we can also check and compare the kinematic viscosity at 40°C to require standards. This is given in table 3.5.

Table 3.5 Standardization of kinematic viscosity of the five biodiesel samples.

Analysis	Method	ASTM D 6751		WFME	WCME	75-WFME	50-WFME	25-WFME
		Min.	Max.					
Viscosity @ 40°C (mm ² /s)	ASTM D 445	1.9	6.0	4.665767	4.678278	4.97882728	5.42115092	5.74857117

As discussed in chapter 2 also, the data in table 3.5 can be used by quality control engineers to check if they pass control test or not.

Complete experimental results and data are given in Appendix five.

CHAPTER 4

CONCLUSIONS

The ubbelohde viscometer was used to obtain the experimental data for kinematic viscosity of the five biodiesel samples tested and the following is be concluded.

- The entire sample passed the ASTM standard kinematic viscosity test.
- The viscosity of the biodiesel samples tested decrease logarithmically with increases in temperature, experimentally as predicted by Andrade equation.
- The viscosity of sample produced from mixture of oil varies from mixture of biodiesel sample mixture after production.
- The data can be use by design engineers for optimization of fuel performance during combustion in fuel system line.

The experiment is done with characterized limited error as discussed in Chapter 3. Source of limited errors may include.

- Parallax error.
- Reading and averaging error.
- Certainty error like non-uniform perfect distribution of temperature in the oil bath.
- Mechanical vibration of instruments.

Future works are also recommended. From the prospect of this work, the following future works are suggested.

- Effect of pressure on kinematic viscosity of biodiesel sample
- Investigation of the flash point of the biodiesel samples
- Investigation of combustion efficiency of the biodiesel sample
- Testing the biodiesel samples for detailed efficiency and performances.+

REFERENCES

- [1] Agrawal AK, "Biofuels (alcohols and biodiesel) application as fuels for internal combustion engines". *Prog Energy Combustion Sci* 2007;33:233-71
- [2] Escobar JC, Lora ES, Venturi OJ, Yanez EE, Castillo EF, Almazan O, "Biofuels: environment, technology and food security". *Renew Sustain Energy Rev* 2009;13:1275-87
- [3] Poonam Singh Nigam, Anoop Singh, "Production of liquid biofuels from renewable resources". *Progress in Energy and Combustion Science* 2011;37:52-68.
- [4] He Y, Wang S, Lai KK. Global economic activity and crude oil prices: a cointegration analysis. *Energy Econ*; 2010;. [Doi:10.1016/j.eneco.2009.12.005](https://doi.org/10.1016/j.eneco.2009.12.005).
- [5] Biodiesel Guidelines, World Fuel Charter Committee (Washington D.C.: Alliance of Automobile Manufacturers, 2009).
- [6] Changes in Diesel Fuel; The Service Technician Guide to Compression Ignition Quality; National Institute of Automotive Service Excellence: 2007.
- [7] Swern D, Bailey's Industrial Oil and Fat Products, Vol. I (John Wiley and Sons, New York), 1979.
- [8] R.E Tate, K.C. Watts, C.A.W. Allen, K.I. Wilkie, The viscosities of three biodiesel fuel at temperature up to 300°C. *Fuel* 2006;85:1010-1015.
- [9] K.G. Tushar, H.L.P Dasika, V.K.D Nidamarty, Y.R Kalipatnapu, *Viscosity of Liquids – Theory, Estimation, Experiment, and Data*. Springer 2007, Netherland.
- [10] Viscosity Lab, Loyola University of Chicago: Biodiesel Labs, <http://www.luc.edu/media/lucedu/biodiesel/pdfs/Biodiesel%20Curricula%20-%20Viscosity%20Lab.pdf> [accessed 04/01/2013].
- [11] H.J. Wilke, H. Kryk, J. Hartmann, D. Wagner, *Theory and Praxis of Capillary Viscometry – An Introduction-*, Schott, Germany.
- [12] ASTM D 446-07 : Standard Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers, Philadelphia 1995.
- [13] Marchetti, J.M., Miguel, V.U. and Errazu. A.F., 2007, Possible methods for biodiesel production. *Renew. Sust. Energy Rev.*, 11:1300-1311.

- [14] Demirbas A. Progress and recent trends in biodiesel fuels. *Energy Conservation Management* 2009;50:14-34.
- [15] Bajpai D, Tyagi Vk. Biodiesel: source, production, composition, properties and its benefits. *J Olio Sci* 2006;55:487-502.
- [16] Ma F, Hanna MA. Biodiesel production: A review. *Bioresour Technol* 1999;70:1-15.
- [17] Helwani Z, Othman MR, Aziz N, Fernando WJN, Kim J. Technologies for production of biodiesel focusing on green catalytic techniques: a review. *Fuel Process Technol* 2009;90:1502-14.
- [18] Govinda R. Timilsina, Ashish Shrestha, How much hope should we have for biofuels?. *Energy* 2011; 36:2055-2069.
- [19] Raymond A. Serway (1996). *Physics for Scientists & Engineers* (4th ed.). Saunders College Publishing. ISBN 0-03-005932-1
- [20] Victor Lyle Streeter, E. Benjamin Wylie, Keith W. Bedford *Fluid Mechanics*, McGraw-Hill, 1998 ISBN 0070625379.
- [21] Manual: Viscometers and their range of use. Scott, SI Analytics GmbH, 2012
- [22] <http://www.heidolph-instruments.com/fileadmin/pageflips/Magnetruhrer/en/index.html> [accessed 11/01/2013].
- [23] Wacker Silicone Fluids AK, Wacker – Chemie GmbH, Germany.
- [24] DIN 53012:2003-03: Viscosimetry - Capillary viscosimetry of newtonian liquids - Sources of errors and corrections, Berlin 2003
- [25] J. G. Kirkwood, F. P. Buff, and M. S. Green, The statistical mechanical theory of transport processes. III. The coefficients of shear and bulk viscosity of liquids, *J. Chem. Phys.* **17**(10), 988-994 (1949).
- [26] P. T. Cummings and D. J. Evans, Nonequilibrium molecular dynamics approaches to transport properties and non-Newtonian fluid, *Ind. Eng. Chem. Res.* **31**, 1237-1252 (1992).
- [27] Tat ME, Van Gerpen JH. *JAACS* 1999;76(12):1511-3

APPENDICES

APPENDIX A: MAIN FACTOR

Category	Value
12	
100	

Category	Value
12	
100	

APPENDIX 1.

DYNAMIC VISCOSITY CONVERSION FACTOR

Multiply by		To					
From	Poiseuille (Pa.s)	Poise (dyne.s/cm ² =g/cm.s)	Centipoise	kg/m.h	lb _r .s/ft ²	lb/ft.s	lb/ft.h
Poiseuille (Pa.s)	1	10	10 ³	3.63*10 ³	2.09*10 ⁻²	0.672	2.42*10 ³
Poise (dyne.s/cm ² =g/cm.s)	0.1	1	100	360	2.09*10 ⁻³	6.72*10 ⁻²	242
Centipoise	0.001	0.01	1	3.6	2.09*10 ⁻⁵	6.72*10 ⁻⁴	2.42
kg/m.h	2.78*10 ⁻⁴	2.78*10 ⁻³	2.78*10 ⁻¹	1			0.672
lb _r .s/ft ²	47.9	479	479*10 ⁴	1.72*10 ⁵	1		1.16*10 ⁵
lb/ft.s	1.49	14.9	1.49*10 ³	5.36*10 ³	3.11*10 ⁻²	1	3.63*10 ³
lb/ft.h	4.13*10 ⁻⁴	4.13*10 ⁻³	0.413	1.49	6.62*10 ⁻⁶	2.78*10 ⁻⁴	1

KINEMATIC VISCOSITY CONVERSION FACTORS

Multiply by		To				
From	Stoke	CentiStokes	m ² /s	m ² /h	ft ² /s	ft ² /h
Stoke	1	100	1.00*10 ⁻⁴	3.60*10 ⁻¹	1.076*10 ⁻³	3.875969
CentiStokes	0.01	1	1.00*10 ⁻⁶	3.60*10 ⁻³	1.08*10 ⁻⁵	0.03876
m ² /s	1.00*10 ⁴	1.00*10 ⁶	1	3.60*10 ³	1.08*10 ¹	3.88*10 ⁴
m ² /h	2.78	2.78*10 ²	2.78*10 ⁻⁴	1	2.99*10 ⁻³	1.08*10 ¹
ft ² /s	929.0	9.29*10 ⁴	9.29*10 ⁻²	3.34*10 ²	1	3.60*10 ³
ft ² /h	0.258	25.8	2.58*10 ⁻⁵	9.28*10 ⁻²	2.78*10 ⁻⁴	1

APPENDIX 2.

ASTM 446-07



Designation: D 446 – 07

An American National Standard

Designation: 71/2/95

Standard Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers¹

This standard is issued under the fixed designation D 446; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 These specifications cover operating instructions for glass capillary kinematic viscometers of all the types described in detail in Annex A1, Annex A2, and Annex A3 as follows:

Modified Ostwald viscometers, Annex A1
Suspended-level viscometers, Annex A2
Reverse-flow viscometers, Annex A3

1.2 The calibration of the viscometers is described in Section 6.

1.3 This standard covers some widely used viscometers suitable for use in accordance with Test Method D 445. Other viscometers of the glass capillary type which are capable of measuring kinematic viscosity within the limits of precision given in Test Method D 445 may be used.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 ASTM Standards:²

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D 2162 Practice for Basic Calibration of Master Viscometers and Viscosity Oil Standards

2.2 ISO Documents:³

ISO 3104 Petroleum Products—Transparent and Opaque Liquids—Determination of Kinematic Viscosity and Calculation of Dynamic Viscosity

ISO 3105 Glass Capillary Kinematic Viscometers—Specifications and Operating Instructions

ISO 5725 Basic Methods for the Determination of Repeatability and Reproducibility of a Standard Measurement Method

ISO 17025 General Requirements for the Competence of Testing and Calibration Laboratories

ISO Guide 25 General Requirements for the Calibration and Testing Laboratories

2.3 NIST Standards:⁴

NIST 1297 Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results

3. Materials and Manufacture

3.1 Fully annealed, low-expansion borosilicate glass shall be used for the construction of all viscometers. The size number, serial number, and manufacturer's designation shall be permanently marked on each viscometer. All timing marks shall be etched and filled with an opaque color, or otherwise made a permanent part of the viscometer. See detailed description of each type of viscometer in Annex A1, Annex A2, and Annex A3.

3.2 With the exception of the FitzSimons and Atlantic viscometers, all viscometers are designed to fit through a 51-mm hole in the lid of a constant-temperature bath having a liquid depth of at least 280 mm; and it is assumed that the surface of the liquid will be not more than 45 mm from the top of the bath lid. For certain constant-temperature baths, especially at low or high temperatures, it may be necessary to construct the viscometers with the uppermost tubes longer than shown to ensure adequate immersion in the constant-temperature bath. Viscometers so modified can be used to measure kinematic viscosity within the precision of the test method. The lengths of tubes and bulbs on the figures should be held within $\pm 10\%$ or ± 10 mm, whichever is less, such that the calibration constant of the viscometer does not vary by more than $\pm 15\%$ from the nominal value.

¹ These specifications and operating instructions are under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and are the direct responsibility of Subcommittee D02.07 on Flow Properties.

Current edition approved Jan. 1, 2007. Published January 2007. Originally approved in 1966 as D 2515 – 66. Redesignated D 446 in 1977. Last previous edition approved in 2006 as D 446 – 06.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

⁴ Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, <http://www.nist.gov>.

*A Summary of Changes section appears at the end of this standard.

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

4. Nomenclature for Figures

4.1 The figures in the annexes contain letters to designate specific parts of each viscometer. These letters are also used in the text of the standard when reference to the viscometers is given. The more frequently used letters on the figures in the annexes are as follows:

A	lower reservoir
B	suspended level bulb
C and J	timing bulbs
D	upper reservoir
E, F, and I	timing marks
G and H	filling marks
K	overflow tube
L	mounting tube
M	lower vent tube
N	upper vent tube
P	connecting tube
R	working capillary

5. Viscometer Holder and Alignment

5.1 All viscometers which have the upper meniscus directly above the lower meniscus (Cannon-Fenske routine in Annex A1 and all in Annex A2) shall be mounted in a constant temperature bath with tube L held within 1° of the vertical as observed with a plumb bob or other equally accurate inspection means. A number of commercially available holders are so designed that the tube L is held perpendicular to the lid of a constant-temperature bath; nevertheless, the viscometer should be tested with a plumb line in order to ensure that the tube L is in a vertical position.

5.1.1 Those viscometers whose upper meniscus is offset from directly above the lower meniscus (all others in Annex A1 and all in Annex A3) shall be mounted in a constant-temperature bath with tube L held within 0.3° of the vertical.

5.2 Round metal tops, designed to fit above a 51-mm hole in the lid of the bath, are frequently cemented on to the Zeitfuchs, Zeitfuchs cross-arm, and Lantz-Zeitfuchs viscometers which then are permanently mounted on the lid of the bath. Also a rectangular metal top, 25 mm × 59 mm, is often cemented on to the Zeitfuchs cross-arm and Zeitfuchs viscometers. Viscometers fitted with metal tops should also be set vertically in the constant-temperature bath with the aid of a plumb line.

5.3 In each figure, the numbers which follow the tube designation indicate the outside tube diameter in millimetres. It is important to maintain these diameters and the designated spacing to ensure that holders will be interchangeable.

6. Calibration of Viscometers

6.1 Procedures:

6.1.1 Calibrate the kinematic glass capillary viscometers covered by this standard using the procedures described in Annex A1, Annex A2, and Annex A3.

6.2 Reference Viscometers:

6.2.1 Select a clear petroleum oil, free from solid particles and possessing Newtonian flow characteristics, with a kinematic viscosity within the range of both the reference viscometer and the viscometer to be calibrated. The minimum flow time shall be greater than that specified in the appropriate table of the annex in both the reference viscometer and the viscometer which is to be calibrated in order that the kinetic energy correction (see 7.1 and 7.2) may be less than 0.2 %.

6.2.2 Select a calibrated viscometer of known viscometer constant C_1 . This viscometer may be a reference viscometer (driving head at least 400 mm) that has been calibrated by the step-up procedure using viscometers of successively larger capillary diameters, starting with distilled water as the basic kinematic viscosity standard or a routine viscometer of the same type that has been calibrated by comparison with a reference viscometer. See Test Method D 2162.

6.2.3 Mount the calibrated viscometer together with the viscometer to be calibrated in the same bath and determine the flow times of the oil in accordance with Test Method D 445.

6.2.3.1 The calibration of the reference viscometer should only be carried out by a reputable laboratory meeting the requirements of, for example, ISO Guide 25.

6.2.4 Calculate the viscometer constant C_1 as follows:

$$C_1 = (t_2 \times C_2) / t_1 \quad (1)$$

where:

C_1 = the constant of the viscometer being calibrated,

t_1 = the flow time to the nearest 0.1 s in the viscometer being calibrated,

C_2 = the constant of the calibrated viscometer, and

t_2 = the flow time to the nearest 0.1 s in the calibrated viscometer.

6.2.5 Repeat 6.2.1-6.2.3 with a second oil whose flow times are at least 50 % longer than the first oil. If the two values of C_1 differ by less than 0.2 % for those viscometers listed in Annex A1 and Annex A2 and less than 0.3 % for those viscometers listed in Annex A3, use the average. If the constants differ by more than this value, repeat the procedure taking care to examine all possible sources of errors.

6.2.5.1 The calibration constant, C , is dependent upon the gravitational acceleration at the place of calibration and this must, therefore, be supplied by the standardization laboratory together with the instrument constant. Where the acceleration of gravity, g , differs by more than 0.1 %, correct the calibration constant as follows:

$$C_2 = (g_2 / g_1) \times C_1 \quad (2)$$

where subscripts 1 and 2 indicate respectively the standardization laboratory and the testing laboratory.

6.3 Certified Viscosity Reference Standards:

6.3.1 Certified viscosity reference standards shall be certified by a laboratory that has been shown to meet the requirements of ISO 17025 by independent assessment. Certified viscosity reference standards shall be traceable to master viscometer procedures described in Practice D 2162.

6.3.1.1 The uncertainty of the certified viscosity reference standard shall be stated for each certified value ($k=2$, 95% confidence). See ISO 5725 or NIST 1297.

6.3.2 Select from Table 1 a certified viscosity reference standard with a kinematic viscosity at the calibration temperature within the kinematic viscosity range of the viscometer to be calibrated and a minimum flow time greater than that specified in the appropriate table of the annex. Determine the flow time to the nearest 0.1 s in accordance with Test Method D 445 and calculate the viscometer constant, C , as follows:

$$C = v / t \quad (3)$$

TABLE 1 Certified Viscosity Reference Standards

Designation	Approximate Kinematic Viscosity, mm ² /s					
	20°C	25°C	40°C	50°C	80°C	100°C
S3	4.6	4.0	2.9	...	...	1.2
S6	11	8.9	5.7	...	...	1.8
S20	44	34	18	...	...	3.9
S60	170	120	54	...	...	7.2
S200	640	450	180	...	...	17
S600	2400	1600	520	280	67	32
S2000	8700	5600	1700	...	...	75
S8000	37 000	23 000	6700	...	...	...
S30000	...	81 000	23 000	11 000	...	...

where:

ν = the kinematic viscosity, mm²/s, for the certified viscosity reference standard, and

t = the flow time, s.

6.3.3 Repeat with a second certified viscosity reference standard whose flow times are at least 50 % longer than the first certified viscosity reference standard. If the two values of C differ by less than 0.2 % for those viscometers listed in Annex A1 and Annex A2 and less than 0.3 % for those viscometers listed in Annex A3, use the average as the viscometer constant for the viscometer being calibrated. If the constants differ by more than this value, repeat the procedure taking care to examine all possible sources of errors.

6.4 Expression of Constant:

6.4.1 Report the constant to the nearest 0.1 % of the determined value. This generally means four significant figures from 1×10^N to 6.999×10^N and three significant figures from 7×10^N to 9.99×10^N .

7. Kinematic Viscosity Calculation

7.1 Basic Formula:

7.1.1 Kinematic viscosity, expressed in mm²/s, can be calculated from the viscometer dimensions as follows:

$$\nu = (10^6 \pi g D^4 H / 128 V L) - E/t^2 \quad (4)$$

where:

ν = the kinematic viscosity, mm²/s,

g = the acceleration due to gravity, m/s²,

D = the diameter of the capillary, m,

L = the length of the capillary, m,

H = the average distance between the upper and lower menisci, m,

V = the timed volume of liquids passing through the capillary, m³ (approximately the volume of the timing bulb),

E = the kinetic energy factor, mm²·s, and

t = the flow time, s.

7.1.2 If the viscometer is selected so that the minimum flow time shown in the tables of Annex A1, Annex A2, and Annex A3 are exceeded, the kinetic energy term, E/t^2 , becomes insignificant and Eq 4 may be simplified by grouping the non-variable terms into a constant, C , as follows:

$$\nu = C/t \quad (5)$$

7.2 Kinetic Energy Correction:

7.2.1 The viscometers described in the Annex A1, Annex A2, and Annex A3 are designed such that the kinetic energy

correction term, E/t^2 , is negligible if the flow time is more than 200 s. In the case of several sizes of viscometers for the measurement of low-kinematic viscosity liquids, a minimum flow time greater than 200 s is required in order that the kinetic energy correction term, E/t^2 , shall be negligible. The minimum flow times required are set out as footnotes to the appropriate tables of viscometer dimensions given in the Annex A1, Annex A2, and Annex A3.

7.2.2 For viscometers whose constants are 0.05 mm²/s² or less, a kinetic energy correction can be significant if the minimum 200 s flow is not observed. Where this is not possible, Eq 5 takes on the following form:

$$\text{kinematic viscosity, mm}^2/\text{s} = Ct - E/t^2 \quad (6)$$

where:

E = kinetic energy factor, mm²·s,

C = viscometer constant, mm²/s²,

t = flow time, s.

7.2.3 Although the kinetic energy factor, E , is not a constant, it may be approximated by means of the following equation:

$$E = 52.5 V^{3/2} / L (Cd)^{1/2} \quad (7)$$

where:

(using the units given in Figs. A1.1-A3.4)

V = volume of the timing bulb, mL,

L = capillary working length, mm,

d = capillary working diameter, mm,

C = viscometer constant, mm²/s².

NOTE 1—The kinetic energy factor for certain viscometer designs and flow time use can result in significant kinematic viscosity errors. Determine the effect of the kinetic energy factor for viscometers not described in this specification.

7.3 Maximum Flow Time:

7.3.1 The limit of 1000 s has been set arbitrarily for convenience as the recommended maximum flow time for the viscometers covered by this standard. Longer flow times may be used.

7.4 Surface Tension Correction:

7.4.1 If the two menisci have different average diameters during the flow time and if the surface tension of the sample differs substantially from the calibrating liquid, a surface tension correction is necessary. The changed C constant, C_2 , is given approximately as follows:

$$C_2 = C_1 [1 + (2/g h) (1/r_u - 1/r_l) (\gamma_1/\rho_1 - \gamma_2/\rho_2)] \quad (8)$$

where:

- g = the acceleration due to gravity, m/s^2 ,
- h = the average driving head, m ,
- r_u = the average radius of the upper meniscus, m ,
- r_l = the average radius of the lower meniscus, m ,
- γ = the surface tension, N/m , and
- ρ = the density, in kg/m^3 .

Subscripts 1 and 2 relate to values with the calibrating liquid and the test portion, respectively.

7.4.2 While this correction applies to all viscometers, a number of viscometers are designed to minimize the surface tension correction. The greatest correction normally encountered is with a viscometer calibrated with water and used for oils. Generally, viscometers are calibrated and used with hydrocarbons whose surface tensions are close enough for these corrections to be insignificant.

7.5 Effect of Temperature:

7.5.1 The viscometer constant, C , is independent of temperature for all those viscometers which have the volume of sample adjusted at bath temperature and in the case of all suspended-level viscometers.

7.5.2 The following viscometers, which have a fixed volume charged at ambient temperature, have a viscometer constant, C , which varies with temperature: Cannon-Fenske routine, Pinkevitch, Cannon-Manning semi-micro, Cannon-Fenske opaque.

7.5.3 The following equation can be used to calculate the viscometer constant at temperatures other than the calibration temperature for the Cannon-Fenske routine, Pinkevitch, and Cannon-Manning semi-micro viscometers:

$$C_2 = C_1[1 + (4000 V(\rho_2 - \rho_1)/\pi D^2 h \rho_2)] \quad (9)$$

where:

- C_1 = the constant of the viscometer when filled and calibrated at the same temperature,
- V = the volume of charge, mL ,
- D = the average diameter of the meniscus in the lower reservoir for the Cannon-Fenske routine, Pinkevitch, and Cannon-Manning semi-micro viscometers, and in the upper reservoir of the Cannon-Fenske opaque viscometer, mm ,
- h = the average driving head, mm ,
- ρ_1 = the density of the test liquid at the filling temperature, $\text{kg/m}^3 \times 10^{-3}$, and
- ρ_2 = the density of the test liquid at the test temperature, $\text{kg/m}^3 \times 10^{-3}$.

7.5.4 The temperature dependence of C for the Cannon-Fenske opaque (reverse-flow) viscometer is given as follows:

$$C_2 = C_1[1 - (4000 V(\rho_2 - \rho_1)/(\pi D^2 h \rho_2))] \quad (10)$$

8. Keywords

8.1 kinematic viscosity; viscometer; viscosity

ANNEXES

(Mandatory Information)

A1. MODIFIED OSTWALD VISCOMETERS

A1.1 General

A1.1.1 The following viscometers of the modified Ostwald type for transparent liquids follow the basic design of the Ostwald viscometer, but are modified to ensure a constant volume test portion in the viscometer as described in A1.1.2 and A1.1.3.

A1.1.2 These viscometers are used for the measurement of the kinematic viscosity of transparent Newtonian liquids up to 20 000 mm^2/s .

A1.1.3 For the modified Ostwald viscometers, detailed drawings, size designations, nominal constants, kinematic viscosity range, capillary diameter, and bulb volumes for each viscometer are shown in Figs. A1.1-A1.7.

A1.1.3.1 Constant volume at filling temperature:

- (1) Cannon-Fenske routine viscometer
- (2) Cannon-Manning semi-micro viscometer
- (3) Pinkevitch viscometer

A1.1.3.2 Constant volume at the test temperature:

- (1) Zeitfuchs viscometer⁵
- (2) SIL viscometer

(3) BS/U-tube viscometer

(4) BS/U-tube miniature viscometer

A1.2 Operating Instructions

A1.2.1 A standard operating procedure applicable to all glass capillary kinematic viscometers is contained in Test Method D 445. Operating instructions for the modified Ostwald viscometers are outlined in A1.2.2-A1.2.7 with emphasis on procedures that are specific to this group of viscometers.

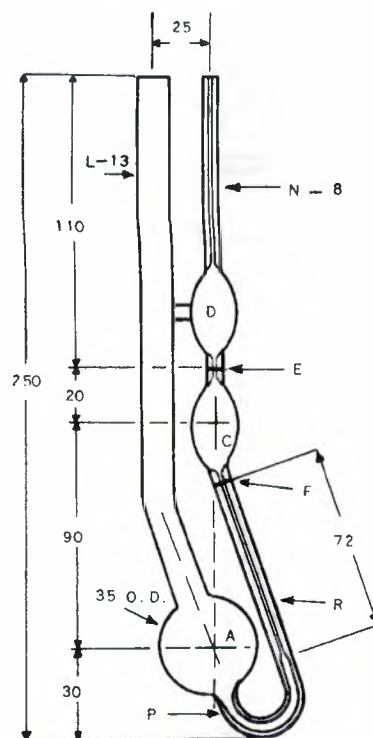
NOTE A1.1—ISO methods 3104 and 3105 correspond to Test Methods D 445 and D 446, respectively.

A1.2.2 Select a clean, dry calibrated viscometer which will give a flow-time greater than 200 s or the minimum shown in the table of dimensions, whichever is greater.

A1.2.3 Charge the viscometer in the manner dictated by the design of the instrument, the operation being in conformity with that employed when the unit was calibrated. If the sample is thought or known to contain fibers or solid particles, filter through a 75- μm screen either prior to or during charging.

NOTE A1.2—To minimize the potential of particles passing through the filter from aggregating, it is recommended that the time lapse between filtering and charging be kept to a minimum.

⁵ Zeitfuchs is a tradename of Cannon Instrument Co., P. O. Box 16, State College, PA 16804-0016.



NOTE 1—All dimensions are in millimetres.

NOTE 2—For size 25 only, the capillary *N* extends straight through bulbs *D* and *C* to about 10 mm below bulb *C*; the timing mark *F* encircles this capillary.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, mm ² /s	Inside Diameter of Tube <i>R</i> , mm (±2 %)	Inside Diameter of Tubes <i>N</i> , <i>E</i> , and <i>P</i> , mm	Bulb Volume, mL (±5 %)	
					<i>D</i>	<i>C</i>
25	0.002	0.5 ^A to 2	0.30	2.6 to 3.0	3.1	1.6
50	0.004	0.8 to 4	0.44	2.6 to 3.0	3.1	3.1
75	0.008	1.6 to 8	0.54	2.6 to 3.2	3.1	3.1
100	0.015	3 to 15	0.63	2.8 to 3.6	3.1	3.1
150	0.035	7 to 35	0.78	2.8 to 3.6	3.1	3.1
200	0.1	20 to 100	1.01	2.8 to 3.6	3.1	3.1
300	0.25	50 to 250	1.27	2.8 to 3.6	3.1	3.1
350	0.5	100 to 500	1.52	3.0 to 3.8	3.1	3.1
400	1.2	240 to 1200	1.92	3.0 to 3.8	3.1	3.1
450	2.5	500 to 2500	2.35	3.5 to 4.2	3.1	3.1
500	8	1600 to 8000	3.20	3.7 to 4.2	3.1	3.1
600	20	4000 to 20 000	4.20	4.4 to 5.0	4.3	3.1

^A 250-s minimum flow time; 200-s minimum flow time for all other units.

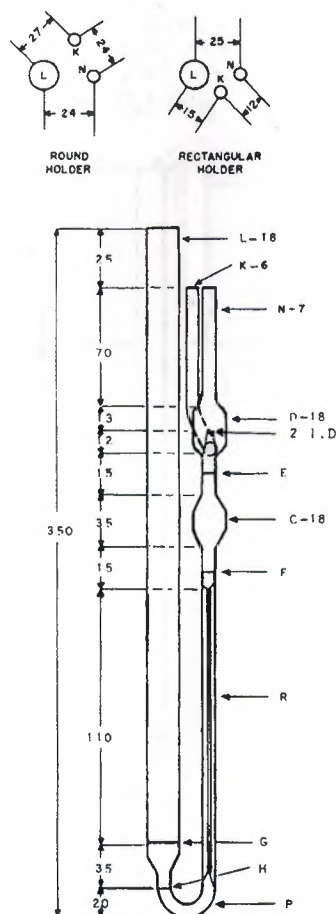
FIG. A1.1 Cannon-Fenske Routine Viscometer for Transparent Liquids

A1.2.3.1 To charge the Cannon-Fenske routine, Cannon-Manning semi-micro, and Pinkevitch viscometers, invert the viscometer and apply suction to tube *L* (the Pinkevitch viscometer has a side arm *O* to which vacuum is applied, with the finger on tube *L* being used to control the liquid flow) with tube *N* immersed in the liquid sample. Draw the sample to timing mark *F* for the Cannon-Fenske routine and Pinkevitch viscometers and to filling mark *G* for the Cannon-Manning semi-micro viscometer. Mount the viscometer upright in the constant-temperature bath keeping tube *L* vertical.

A1.2.3.2 Mount the Zeitfuchs viscometer in the constant-temperature bath, keeping tube *L* vertical. Pour sample through tube *L* to fill mark *G*. Allow 15 min for the sample to attain bath temperature and become free of air bubbles. Attach the

vacuum line with stopcock and trap to tube *K*. Slowly draw the sample into timing bulb *C* by partially opening the stopcock in the vacuum line and partially closing tube *N* with the finger. Allow the excess liquid to flow into bulb *D* and through tube *K* into the trap in the vacuum line. When the liquid in tube *L* reaches a point 2 mm to 5 mm above filling mark *H*, hold it at this point by alternately closing the opening tube *N* to the atmosphere with the finger for the time in the Table A1.1 shown as follows to permit the sample to drain from the walls of tube *L*.

(1) Adjust the working volume by drawing the meniscus at the bottom of the column of the liquid exactly to filling mark *H*, making sure that the sample completely fills the viscometer between mark *H* and the tip of the overflow in bulb *D*; after this



NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Inside Diameter of Tubes P, E, and F, mm	Volume, Bulb C, mL (±5 %)
1	0.003	0.6 to 3	0.42	3.8 to 4.2	3.0
2	0.01	2 to 10	0.59	3.8 to 4.2	4.0
3	0.03	6 to 30	0.78	3.8 to 4.2	4.0
4	0.1	20 to 100	1.16	3.8 to 4.2	5.0
5	0.3	60 to 300	1.54	3.8 to 4.2	5.0
6	1.0	200 to 1000	2.08	3.8 to 4.2	5.0
7	3.0	600 to 3000	2.76	3.8 to 4.2	5.0

^A 200-s minimum flow time for all units.

FIG. A1.2 Zeitfuchs Viscometer for Transparent Liquids

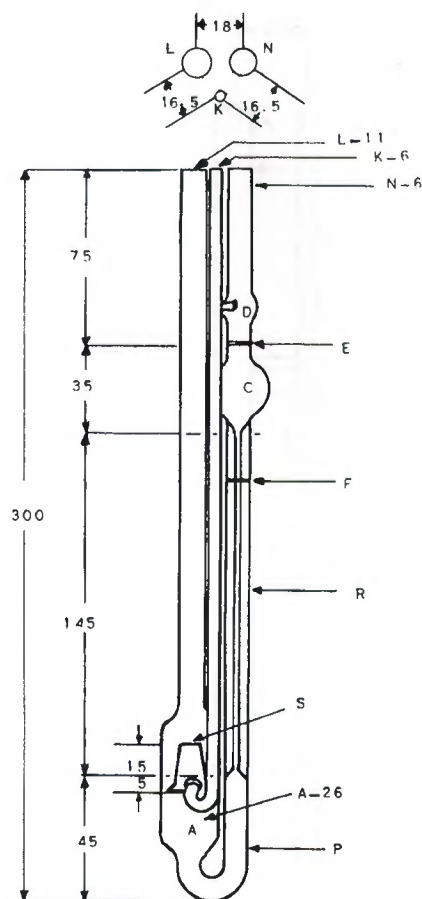
final adjustment of the working volume, remove the finger and close or remove the connection to the vacuum source. The final adjustment may be more conveniently made by disconnecting the vacuum and applying pressure to the mounting tube L by use of a rubber bulb.

A1.2.3.3 Charge the SIL viscometer by tilting it about 30° from the vertical, with bulb A below capillary R. Introduce enough of the sample into tube L for bulb A to fill completely and overflow into the gallery. Return the viscometer to the vertical position and mount it in the constant-temperature bath so that tube L is vertical. The quantity of sample charged should be such that the level in the lower reservoir is 3 mm to 14 mm above opening S. The sample will rise in capillary R

somewhat higher than opening S. After the temperature equilibrium has been reached, remove any excess sample from the gallery by suction applied to tube K.

A1.2.3.4 Mount the BS/U-tube or BS/U/M miniature viscometer in the constant-temperature bath keeping the tube L vertical. Using a long pipette to minimize any wetting of tube L above filling mark G, fill bulb A with a slight excess of the sample. After allowing the sample to attain the bath temperature, adjust the volume of the sample to bring the liquid level within 0.2 mm of filling mark G by withdrawing the sample with a pipette.

A1.2.4 Allow the charged viscometer to remain in the bath long enough to reach the test temperature. Because this time



NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Inside Diameter of Tubes E and P, mm	Volume, Bulb C, mL (±5 %)
0C	0.003	0.6 to 3	0.41	4.5 to 5.5	3.0
1	0.01	2.0 to 10	0.61	4.5 to 5.5	4.0
1C	0.03	6 to 30	0.79	4.5 to 5.5	4.0
2	0.1	20 to 100	1.14	4.5 to 5.5	5.0
2C	0.3	60 to 300	1.50	4.5 to 5.5	5.0
3	1.0	200 to 1000	2.03	4.5 to 5.5	5.0
3C	3.0	600 to 3000	2.68	4.5 to 5.5	5.0
4	10.0	2000 to 10 000	3.61	4.5 to 5.5	5.0

^A 200-s minimum flow time for all units.

FIG. A1.3 SIL Viscometer for Transparent Liquids

will vary for different instruments, for different temperatures, and for different kinematic viscosities, establish a safe equilibrium time by trial (30 min should be sufficient except for the highest kinematic viscosities). One bath is often used to accommodate several viscometers. Never add or withdraw a viscometer while any other viscometer is in use for measuring a flow time.

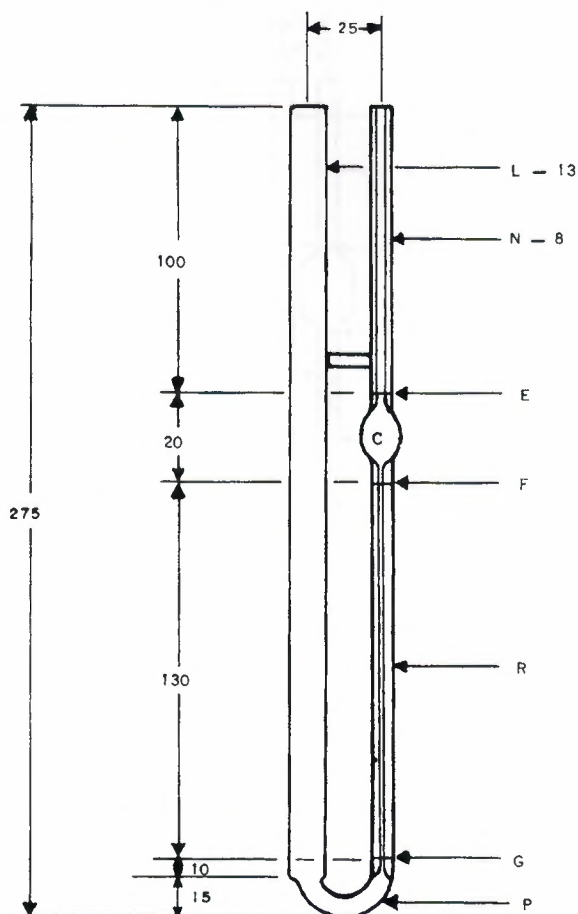
A1.2.5 Use vacuum (or pressure if the sample contains volatile constituents) to draw the sample through bulb C to about 5 mm above upper timing mark E. Release the vacuum, and allow the sample to flow by gravity.

A1.2.6 Measure, to the nearest 0.1 s, the time required for the leading edge of the meniscus to pass from timing mark E

to timing mark F. If this flow time is less than the minimum flow time specified for the viscometer, select a viscometer with a smaller diameter capillary and repeat steps A1.2.3-A1.2.6.

A1.2.7 Repeat steps A1.2.5 to A1.2.6 making a duplicate measurement of flow time. If the two measurements agree within the determinability given in Test Method D 445 for the product being measured, use the average for calculating kinematic viscosity.

A1.2.8 Clean the viscometer thoroughly by several rinsings with an appropriate solvent completely miscible with the sample, followed by rinsing with a completely volatile solvent. Dry the viscometer by passing a slow stream of filtered, dry air through the viscometer for 2 min, or until the last trace of



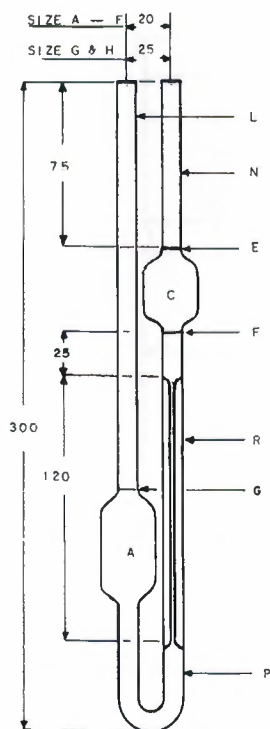
NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Inside Diameter of Tubes		Volume, Bulb C, mL (±5 %)
				N and F, mm	P, mm	
25	0.002	0.4 to 2.0	0.22 ± 0.01	1.0 to 1.2	0.4 to 0.7	0.31
50	0.004	0.8 to 4	0.26 ± 0.01	1.0 to 1.2	0.5 to 0.8	0.31
75	0.008	1.6 to 8	0.31 ± 0.01	1.1 to 1.3	0.6 to 0.8	0.31
100	0.015	3 to 15	0.36 ± 0.02	1.2 to 1.4	0.7 to 0.9	0.31
150	0.035	7 to 35	0.47 ± 0.02	1.2 to 1.4	0.8 to 1.0	0.31
200	0.1	20 to 100	0.61 ± 0.02	1.4 to 1.7	0.9 to 1.2	0.31
300	0.25	50 to 250	0.76 ± 0.02	1.5 to 1.8	1.2 to 1.6	0.31
350	0.5	100 to 500	0.90 ± 0.03	1.8 to 2.2	1.5 to 1.8	0.31
400	1.2	240 to 1200	1.13 ± 0.03	2.0 to 2.4	1.6 to 2.0	0.31
450	2.5	500 to 2500	1.40 ± 0.04	2.2 to 2.6	2.0 to 2.5	0.31
500	8	1600 to 8000	1.85 ± 0.05	2.4 to 2.8	2.5 to 2.8	0.31
600	20	4000 to 20 000	2.35 ± 0.05	3.0 to 3.4	2.7 to 3.0	0.31

^A 200-s minimum flow time for all units.

FIG. A1.4 Cannon-Manning Semi-Micro Viscometer for Transparent Liquids

solvent is removed. The use of alkaline cleaning solutions is not recommended as changes in the viscometer calibration may occur.



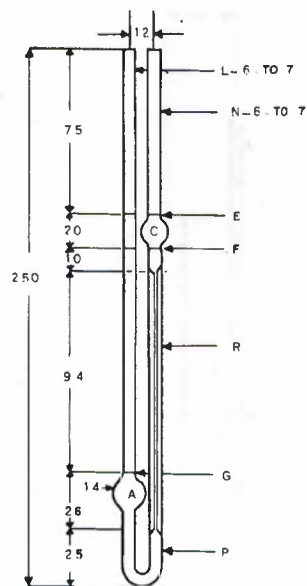
NOTE—All dimensions are in millimetres.

Size No.	Nominal Viscometer Constant, (mm ² /s)/s	Kinematic Viscosity Range, mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Outside Diameter of Tubes ^A		Volume Bulb C, mL (±5 %)	Vertical Distance F to G, mm	Outside Diameter of Bulbs A and C, mm
				L and P, mm	N, mm			
A	0.003	0.9 ^B to 3	0.50	8 to 9	6 to 7	5.0	91 ± 4	21 to 23
B	0.01	2.0 to 10	0.71	8 to 9	6 to 7	5.0	87 ± 4	21 to 23
C	0.03	6 to 30	0.88	8 to 9	6 to 7	5.0	83 ± 4	21 to 23
D	0.1	20 to 100	1.40	9 to 10	7 to 8	10.0	78 ± 4	25 to 27
E	0.3	60 to 300	2.00	9 to 10	7 to 8	10.0	73 ± 4	25 to 27
F	1.0	200 to 1000	2.50	9 to 10	7 to 8	10.0	70 ± 4	25 to 27
G	3.0	600 to 3000	4.00	10 to 11	9 to 10	20.0	60 ± 3	32 to 35
H	10.0	2000 to 10 000	6.10	10 to 11	9 to 10	20.0	50 ± 3	32 to 35

^A Use 1 to 1.25 mm wall tubing for N, P, and L.

^B 300 s minimum flow time; 200 s minimum flow time for all other sizes.

FIG. A1.5 BS/U-Tube Viscometer for Transparent Liquids



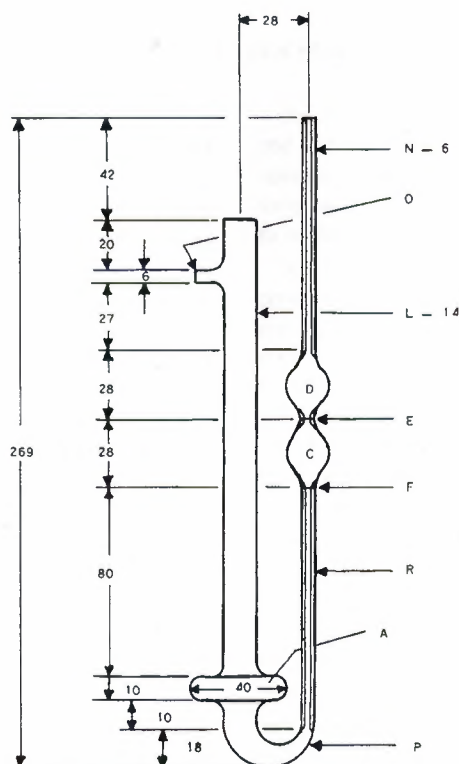
NOTE—All dimensions are in millimetres.

Size No.	Nominal Viscometer Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Outside Diameter of Tubes L, N, and P ^B , mm	Volume Bulb C, mL (±5 %)
M1	0.001	0.2 to 1	0.20	6 to 7	0.50
M2	0.005	1 to 5	0.30	6 to 7	0.50
M3	0.015	3 to 15	0.40	6 to 7	0.50
M4	0.04	8 to 40	0.50	6 to 7	0.50
M5	0.1	20 to 100	0.65	6 to 7	0.50

^A 200 s minimum flow time for all sizes.

^B Use 1 to 1.25 mm wall tubing for N, P, and L.

FIG. A1.6 BS/U/M Miniature Viscometer for Transparent Liquids



NOTE—All dimensions are in millimetres.

Size No.	Nominal Viscometer Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Bulb Volume, mL (±5 %)	
				D	C
0	0.0017	0.6 ^A to 1.7	0.40	3.7	3.7
1	0.0085	1.7 to 8.5	0.60	3.7	3.7
2	0.027	5.4 to 27	0.80	3.7	3.7
3	0.065	13 to 65	1.00	3.7	3.7
4	0.14	28 to 140	1.20	3.7	3.7
5	0.35	70 to 350	1.50	3.7	3.7
6	1.0	200 to 1000	2.00	3.7	3.7
7	2.6	520 to 2600	2.50	3.7	3.7
8	5.3	1060 to 5300	3.00	3.7	3.7
9	9.9	1980 to 9900	3.50	3.7	3.7
10	17	3400 to 17 000	4.00	3.7	3.7

^A 350 s minimum flow time: 200 s minimum flow time for all other sizes.

FIG. A1.7 Pinkevitch Viscometer for Transparent Liquids

TABLE A1.1 Drainage Time for Various Kinematic Viscosity Ranges in the Zeitfuchs Viscometer

Kinematic Viscosity of Sample, mm ² /s	Drainage Time, s
Under 10	10 to 20
10 to 100	40 to 60
100 to 1000	100 to 120
Over 1000	180 to 200

A2. SUSPENDED LEVEL VISCOMETERS FOR TRANSPARENT LIQUIDS

A2.1 General

A2.1.1 The suspended level viscometers include the BS/IP/SL, BS/IP/SL(S), BS/IP/MSL, Ubbelohde, FitzSimons, Atlantic, Cannon-Ubbelohde, and Cannon-Ubbelohde semi-micro designs. The distinctive feature of suspended-level viscometers is that the liquid is suspended in the capillary which it fills completely. This suspension ensures a uniform driving head of liquid independent of the quantity of sample charged into the viscometer, making the viscometer constant independent of temperature. By making the diameter of the lower meniscus approximately equal to the average diameter of the upper meniscus, the surface tension correction is greatly reduced. Suspended-level viscometers are used for the measurement of the kinematic viscosities of transparent, Newtonian liquids up to 100 000 mm²/s.

A2.1.2 For the suspended-level viscometers, detailed drawings, size designations, nominal viscometer constants, kinematic viscosity range, capillary diameter and bulb volumes for each viscometer are shown on Figs. A2.1-A2.7.

A2.2 Operating Instructions

A2.2.1 A standard operating procedure, applicable to all glass capillary kinematic viscometers, is contained in Test Method D 445. Operating instructions for the suspended-level types are outlined in A2.2.2-A2.2.7 with emphasis on procedures that are specific to this group of viscometers.

NOTE A2.1—ISO methods 3104 and 3105 correspond to Test Methods D 445 and D 446, respectively.

A2.2.2 Select a clean, dry calibrated viscometer which will give a flow time greater than 200 s or the minimum shown in the table of dimensions, whichever is greater.

A2.2.3 Charge the sample into the viscometer in the manner dictated by the design of the instrument, this operation being in conformity with that employed when the instrument was calibrated. If the sample is thought or known to contain fibers or solid particles, filter through a 75- μ m screen either prior to or during charging (see Note A1.1).

A2.2.3.1 Charge the Ubbelohde and Cannon-Ubbelohde viscometers by tilting the instrument about 30° from the vertical and pouring sufficient sample through the L into bulb A so that when the viscometer is returned to the vertical the meniscus is between fill marks G and H, and tube P completely fills without entrapping air. Mount the viscometer in the constant-temperature bath keeping tube L vertical. To facilitate charging very viscous liquids, the viscometer may be inverted with tube L placed in the sample. Apply vacuum to tube N, closing tube M by a finger or rubber stopper; draw sufficient sample into tube L such that after wiping L clean and placing the viscometer in the constant-temperature bath, bulb A will fill as described above. The Cannon-Ubbelohde Semi-Micro design omits marks G and H since this viscometer is designed both for semi-micro and dilution use; pour sufficient sample through L into bulb A to ensure that capillary R and bulb C can be filled as described in A2.2.6.

A2.2.3.2 Charge the BS/IP/SL, BS/IP/SL(S), BS/IP/MSL, and FitzSimons viscometers through tube L with sufficient sample to fill bulb A, but not bulb B. The viscometer may be mounted vertically in the constant-temperature bath either prior to or following charging of the sample into the viscometer.

A2.2.3.3 Permanently mount the Atlantic viscometer in the constant-temperature bath with the enlargement S resting on the top-split collar, and the lower end of capillary tube R, 25 mm from the bottom of the bath. Pour the sample into a clean 50-mL beaker. Charge the viscometer by positioning the beaker and sample under tube L so that it will be completely immersed in the sample. Slowly apply vacuum to tube N by turning the three-way stopcock O to vacuum. Draw the sample into the viscometer filling capillary R, timing bulb C, and partially filling upper bulb D. Close stopcock O, holding the sample in the viscometer. If only a small sample is available, a short length of rubber-tipped glass tubing can be placed in the beaker with the rubber against the bottom of capillary tube R, and the sample drawn up as above.

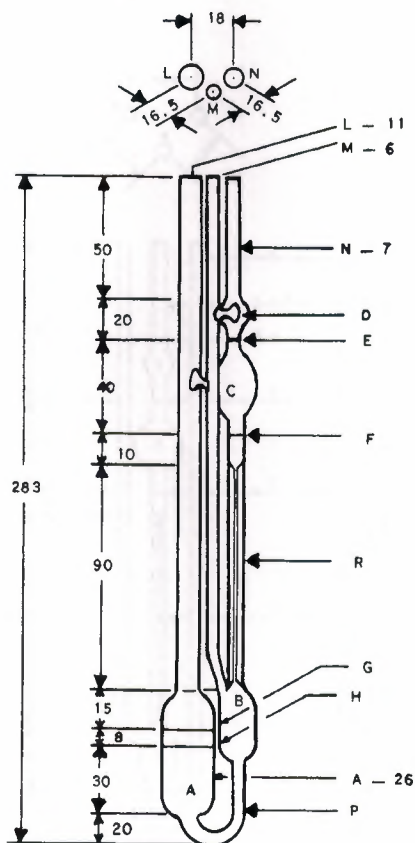
A2.2.4 Allow the charged viscometer to remain in the bath long enough to reach the test temperature. Because this time will vary for different instruments, for different temperatures and for different kinematic viscosities, establish a safe equilibrium time by trial (30 min should be sufficient except for the highest kinematic viscosities). One bath is often used to accommodate several viscometers. Never add or withdraw a viscometer while any other viscometer is in use for measuring a flow time.

A2.2.5 Except for the Atlantic viscometer which already has the sample in position, close tube M with the finger and use vacuum (or pressure, if the sample contains volatile constituents) to draw the sample slowly through bulb C to about 8 mm above upper timing mark E. Release vacuum from tube N and immediately place a finger from tube M to tube N, holding the meniscus above timing mark E until the lower meniscus has dropped below the end of capillary R in bulb B. Release finger and allow the sample to flow by gravity.

A2.2.6 Measure, to the nearest 0.1 s, the time required for the leading edge of the meniscus to pass from timing mark E to timing mark F. If this flow time is less than 200 s, select a smaller capillary viscometer and repeat A2.2.3-A2.2.6.

A2.2.7 Repeat steps A2.2.6 and A2.2.7 making a duplicate measurement of flow time. If the two measurements agree within the determinability given in Test Method D 445 for the product being measured, use the average for calculating kinematic viscosity.

A2.2.8 Clean viscometer thoroughly by several rinsings with an appropriate solvent completely miscible with the sample, followed by rinsing with a completely volatile solvent. Dry the viscometer by passing a slow stream of filtered, dry air through the viscometer for 2 min, or until the last trace of solvent is removed. The use of alkaline cleaning solutions is not recommended as changes in the viscometer calibration may occur.

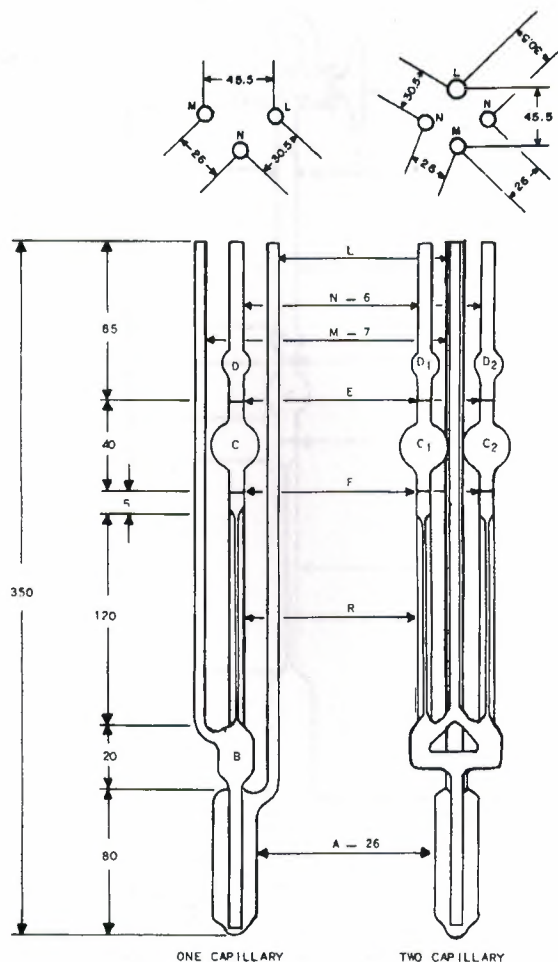


NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Volume, Bulb C, mL (±5 %)	Inside Diameter of Tube P, mL (±5 %)
0	0.001	0.3 ^A to 1	0.24	1.0	6.0
0C	0.003	0.6 to 3	0.36	2.0	6.0
0B	0.005	1 to 5	0.46	3.0	6.0
1	0.01	2 to 10	0.58	4.0	6.0
1C	0.03	6 to 30	0.78	4.0	6.0
1B	0.05	10 to 50	0.88	4.0	6.0
2	0.1	20 to 100	1.03	4.0	6.0
2C	0.3	60 to 300	1.36	4.0	6.0
2B	0.5	100 to 500	1.55	4.0	6.0
3	1.0	200 to 1 000	1.83	4.0	6.0
3C	3.0	600 to 3 000	2.43	4.0	6.0
3B	5.0	1 000 to 5 000	2.75	4.0	6.5
4	10	2 000 to 10 000	3.27	4.0	7.0
4C	30	6 000 to 30 000	4.32	4.0	8.0
4B	50	10 000 to 50 000	5.20	5.0	8.5
5	100	20 000 to 100 000	6.25	5.0	10.0

^A 300-s minimum flow time; 200-s minimum flow time for all other units.

FIG. A2.1 Ubbelohde Viscometer for Transparent Liquids

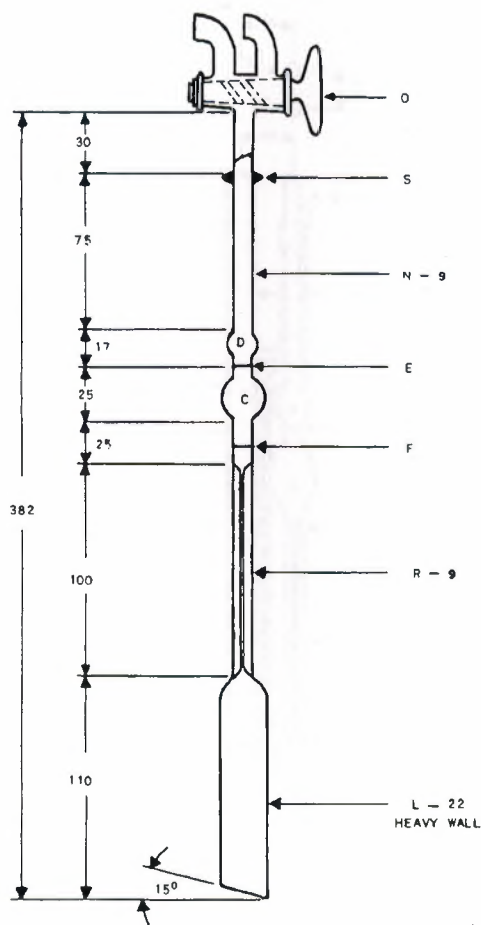


NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Volume, Bulb C, mL (±5 %)
1	0.003	0.6 to 3.0	0.43	3.0
2	0.01	2 to 10	0.60	3.7
3	0.035	7 to 35	0.81	3.7
4	0.10	20 to 100	1.05	3.7
5	0.25	50 to 250	1.32	3.7
6	1.20	240 to 1200	1.96	3.7

^A 200-s minimum flow time for all units.

FIG. A2.2 FitzSimons Viscometer for Transparent Liquids

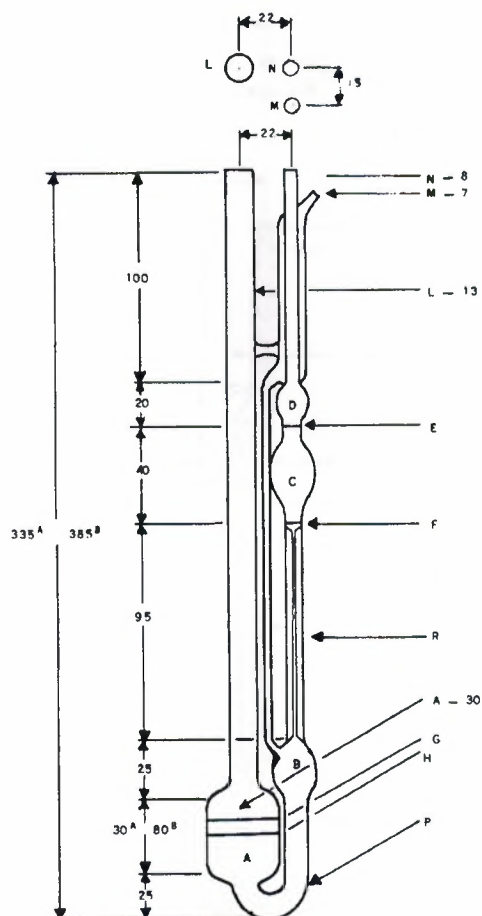


Note—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, mm ² /s	Inside Diameter of Tube R, mm (± 2 %)	Volume, Bulb C, mL (± 5 %)
0C	0.003	0.7 ^A to 3	0.42	3.2
0B	0.005	1 to 5	0.46	3.2
1	0.01	2 to 10	0.56	3.2
1C	0.03	6 to 30	0.74	3.2
1B	0.05	10 to 50	0.83	3.2
2	0.1	20 to 100	1.00	3.2
2C	0.3	60 to 300	1.31	3.2
2B	0.5	100 to 500	1.48	3.2
3	1.0	200 to 1000	1.77	3.2
3C	3.0	600 to 3000	2.33	3.2
3B	5.0	1000 to 5000	2.64	3.2

^A 250-s minimum flow time; 200-s minimum flow time for all other units.

FIG. A2.3 Atlantic Viscometer for Transparent Liquids

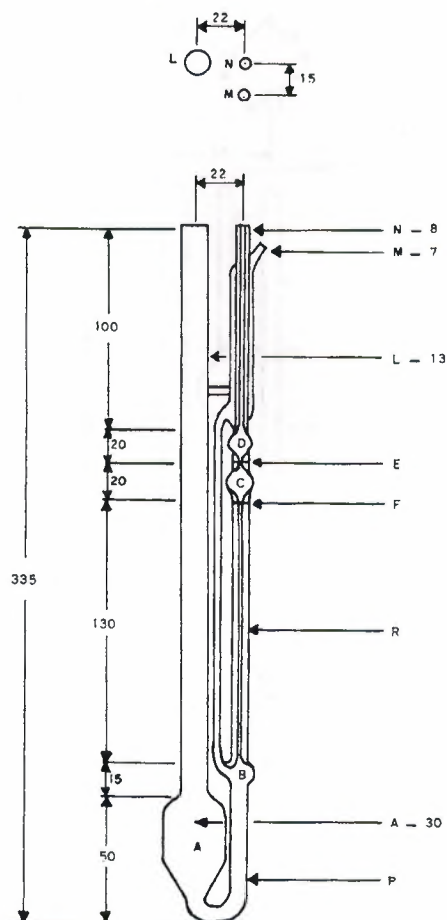


NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Volume, Bulb C, mL (±5 %)
25	0.002	0.5 ^A to 2	0.31	1.5
50	0.004	0.8 to 4.0	0.44	3.0
75	0.008	1.6 to 8.0	0.54	3.0
100	0.015	3 to 15	0.63	3.0
150	0.035	7 to 35	0.78	3.0
200	0.1	20 to 100	1.01	3.0
300	0.25	50 to 250	1.26	3.0
350	0.5	100 to 500	1.48	3.0
400	1.2	240 to 1200	1.88	3.0
450	2.5	500 to 2500	2.25	3.0
500	8	1600 to 8000	3.00	3.0
600	20	4000 to 20 000	3.75	3.0
650	45	9000 to 45 000	4.60	3.0
700	100	20 000 to 100 000	5.60	3.0

^A 250-s minimum flow time; 200-s minimum flow time for all other units.

FIG. A2.4 Cannon-Ubbelohde (A) and Cannon-Ubbelohde Dilution (B) Viscometers for Transparent Liquids

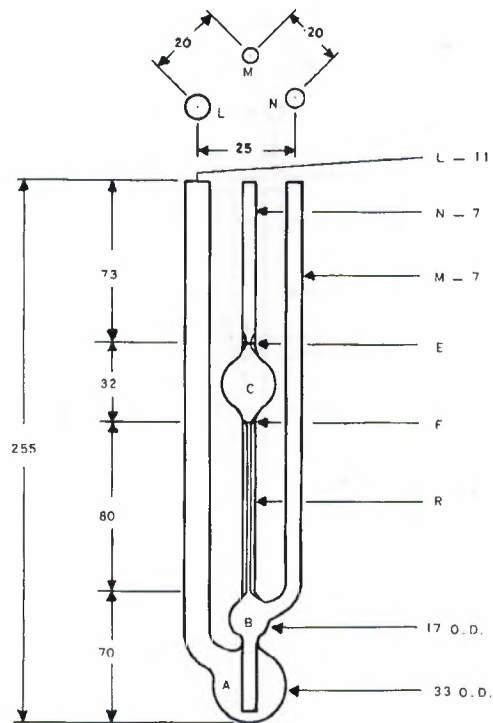


NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Volume, Bulb C, mL (±5 %)	Inside Diameter of Tubes N, E, F, and P, mm
25	0.002	0.4 to 2.0	0.22	0.30	1.2 to 1.4
50	0.004	0.8 to 4	0.25	0.30	1.2 to 1.4
75	0.008	1.6 to 8	0.30	0.30	1.2 to 1.4
100	0.015	3 to 15	0.36	0.30	1.2 to 1.4
150	0.035	7 to 35	0.47	0.30	1.2 to 1.4
200	0.1	20 to 100	0.61	0.30	1.4 to 1.7
300	0.25	50 to 250	0.76	0.30	1.5 to 1.8
350	0.5	100 to 500	0.90	0.30	1.8 to 2.2
400	1.2	240 to 1200	1.13	0.30	2.1 to 2.5
450	2.5	500 to 2500	1.40	0.30	2.4 to 2.8
500	8	1600 to 8000	1.85	0.30	2.7 to 3.1
600	20	4000 to 20 000	2.35	0.30	3.7 to 4.0

^A 200-s minimum flow time for all units.

FIG. A2.5 Cannon-Ubbelohde Semi-Micro Viscometer for Transparent Liquids



NOTE—All dimensions are in millimeters.

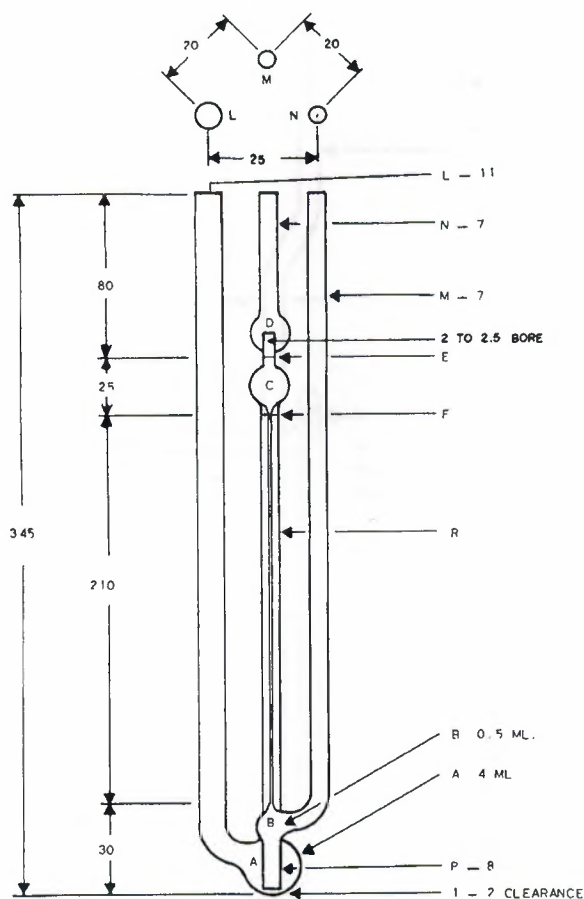
Size No.	Nominal Viscometer Constant, (mm ² /s)/s	Kinematic Viscosity Range, mm ² /s	Inside Diameter of Tube R, mm (±2%)	Volume Bulb C, mL (±5%)	Inside Diameter of Tube N, mm	Inside Diameter of Tube at E, mm
1	0.0008	1.05 ^A min	0.36	5.6	2.8 to 3.2	3
2	0.003	2.1 ^B to 3	0.49	5.6	2.8 to 3.2	3
3	0.01	3.8 ^C to 10	0.66	5.6	2.8 to 3.2	3
4	0.03	6 to 30	0.87	5.6	2.8 to 3.2	3
5	0.1	20 to 100	1.18	5.6	2.8 to 3.2	3
6	0.3	60 to 300	1.55	5.6	2.8 to 3.2	3
7	1.0	200 to 1000	2.10	5.6	3.7 to 4.3	4
8	3.0	600 to 3000	2.76	5.6	4.6 to 5.4	5
9	10.0	2000 to 10 000	3.80	5.6	4.6 to 5.4	5

^A 1320 s minimum flow time;

^B 600 s minimum flow time;

^C 380 s minimum flow time; 200 s minimum flow time for all other sizes.

FIG. A2.6 BS/IP/SL(S) Viscometer for Transparent Liquids



NOTE—All dimensions are in millimetres.

Size No.	Nominal Viscometer Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Volume Bulb C, mL (±5 %)	Inside Diameter of Tubes N and P, mm
1	0.003	0.6 to 3	0.35	1.2	4 to 6
2	0.01	2 to 10	0.45	1.2	4 to 6
3	0.03	6 to 30	0.62	1.2	4 to 6
4	0.1	20 to 100	0.81	1.2	4 to 6
5	0.3	60 to 300	1.10	1.2	4 to 6
6	1.0	200 to 1000	1.45	1.2	4 to 6
7	3.0	600 to 3000	1.98	1.2	4 to 6

^A 200 s minimum flow time for all sizes.

FIG. A2.7 BS/IP/MSL Viscometer for Transparent Liquids

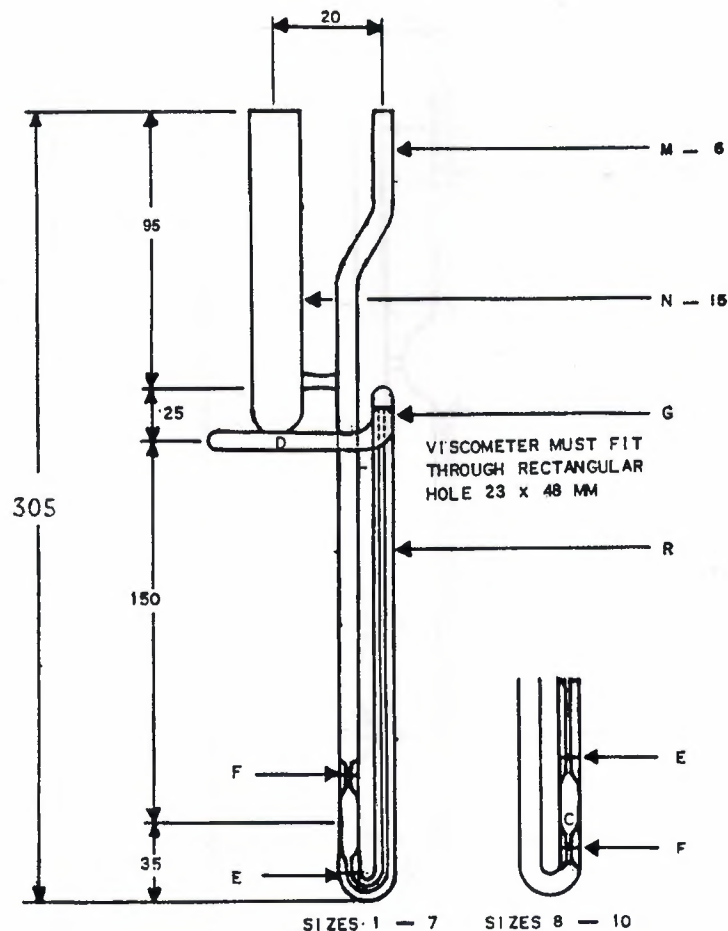
A3. REVERSE FLOW VISCOMETERS FOR TRANSPARENT AND OPAQUE LIQUIDS

A3.1 General

A3.1.1 The reverse-flow viscometers for transparent and opaque liquids include the Zeitfuchs cross-arm, Cannon-Fenske opaque, BS/IP/RF and Lantz-Zeitfuchs viscometers. Unlike the modified Ostwald and suspended-level viscometers, the sample of liquid flows into a timing bulb not previously wetted by sample, thus allowing the timing of liquids whose

thin films are opaque. Reverse-flow viscometers are used for the measurement of kinematic viscosities of opaque and transparent liquids up to 300 000 mm²/s.

A3.1.2 For the reverse-flow viscometers, detailed drawings, size designations, nominal viscometer constants, kinematic viscosity range, capillary diameter and bulb volumes for each viscometer are shown in Figs. A3.1-A3.4.



NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Length of Tube R, mm	Lower Bulb Volume, mL (±5 %)	Horizontal Tube Diameter, mm (±5 %)
1	0.003	0.6 to 3	0.27	210	0.3	3.9
2	0.01	2 to 10	0.35	210	0.3	3.9
3	0.03	6 to 30	0.46	210	0.3	3.9
4	0.10	20 to 100	0.64	210	0.3	3.9
5	0.3	60 to 300	0.84	210	0.3	3.9
6	1.0	200 to 1000	1.15	210	0.3	4.3
7	3.0	600 to 3000	1.42	210	0.3	4.3
8	10.0	2000 to 10 000	1.93	165	0.25	4.3
9	30.0	6000 to 30 000	2.52	165	0.25	4.3
10	100.0	20 000 to 100 000	3.06	165	0.25	4.3

^A 200-s minimum flow time for all units.

FIG. A3.1 Zeitfuchs Cross-Arm Viscometers for Transparent and Opaque Liquids

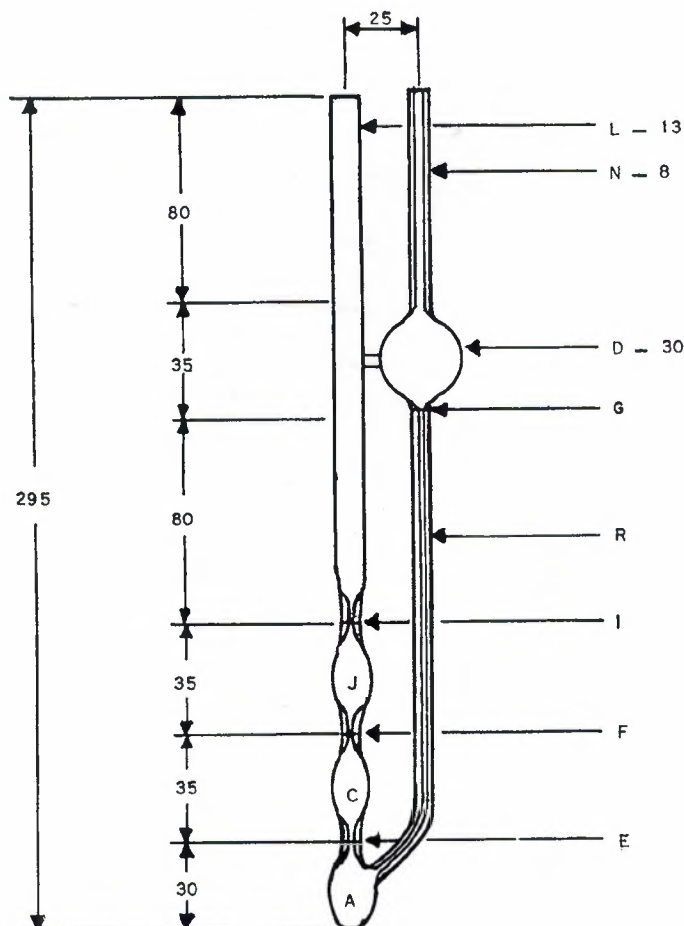
A3.2 Operation Instructions

A3.2.1 A standard operating procedure applicable to all glass capillary kinematic viscometers is contained in Test Method D 445. Operating instructions for the reverse-flow viscometers are outlined in A3.2.2-A3.2.7 with emphasis on procedures that are specific to a particular instrument or this group of instruments.

NOTE A3.1—ISO methods 3104 and 3105 correspond to Test Methods D 445 and D 446, respectively.

A3.2.2 Select a clean, dry calibrated viscometer which will give a flow time greater than 200 s and a kinetic energy correction of less than 0.2 %.

A3.2.3 Charge the viscometer in the manner dictated by the design of the instrument, this operation being in conformity with that employed when the unit was calibrated. If the sample is thought or known to contain fibers or solid particles, filter through a 75 µm screen either prior to or during charging. See Note A1.1.



NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Inside Diameter of Tube N, Tubes E, F, and I, mm (±5 %)	Volume, Bulbs A, C, and J, mL (±5 %)	Volume, Bulb D, mL (±5 %)
25	0.002	0.4 to 2	0.31	3.0	1.6	11
50	0.004	0.8 to 4	0.42	3.0	2.1	11
75	0.008	1.6 to 8	0.54	3.0	2.1	11
100	0.015	3 to 15	0.63	3.2	2.1	11
150	0.035	7 to 35	0.78	3.2	2.1	11
200	0.1	20 to 100	1.02	3.2	2.1	11
300	0.25	50 to 200	1.26	3.4	2.1	11
350	0.5	100 to 500	1.48	3.4	2.1	11
400	1.2	240 to 1 200	1.88	3.4	2.1	11
450	2.5	500 to 2500	2.20	3.7	2.1	11
500	8	1600 to 8000	3.10	4.0	2.1	11
600	20	4000 to 20 000	4.00	4.7	2.1	13

^A 200-s minimum flow time for all units.

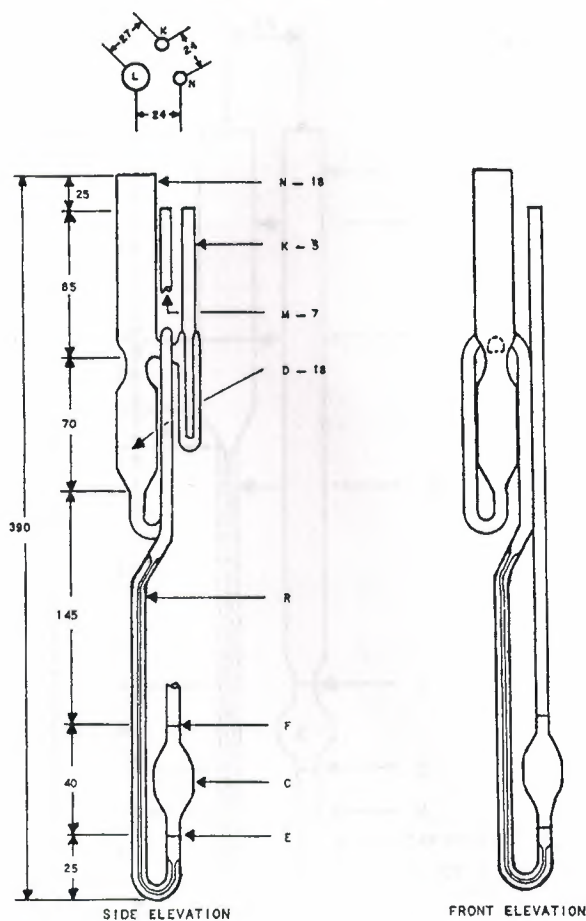
FIG. A3.2 Cannon-Fenske Opaque Viscometer for Transparent and Opaque Liquids

A3.2.3.1 To charge the Cannon-Fenske opaque viscometer, invert the viscometer and apply suction to the tube L, immersing tube N in the liquid sample. Draw liquid through tube N, filling bulb D to filling mark G. Wipe any excess sample off tube N and invert the viscometer to its normal position. Mount the viscometer in the constant temperature bath, keeping tube L vertical. Close tube N with a rubber stopper or a short length of rubber tube with a screw clamp.

A3.2.3.2 Mount the Zeitfuchs cross-arm viscometer in the constant-temperature bath, keeping tube N vertical. Introduce

the test specimen through tube N, taking care not to wet the sides of tube N, into the cross-arm D until the leading edge stands within 0.5 mm of fill mark G on the siphon tube. The volume of the test specimen is dependent on the location of the fill mark G. When the flow time of the lower meniscus is being measured between timing marks E and F (see A3.2.6), the upper meniscus shall be in the horizontal cross-arm D, thus making the location of fill mark G critical.

A3.2.3.3 Mount the Lantz-Zeitfuchs viscometer in the constant-temperature bath, keeping tube N vertical. Introduce



NOTE—All dimensions are in millimetres.

Size No.	Approximate Constant, (mm ² /s)/s	Kinematic Viscosity Range, ^A mm ² /s	Inside Diameter of Tube R, mm (±2 %)	Length of Tube R, mm	Volume, Bulb C, mL (±5 %)
5	0.3	60 to 300	1.65	490	2.7
6	1.0	200 to 1000	2.25	490	2.7
7	3.0	600 to 3000	3.00	490	2.7
8	10.0	2000 to 10 000	4.10	490	2.7
9	30.0	6000 to 30 000	5.20	490	2.7
10	100.0	20 000 to 100 000	5.20	490	0.85

^A 200-s minimum flow time for all units.

FIG. A3.3 Lantz-Zeitfuchs Viscometer for Transparent and Opaque Liquids

sufficient sample through tube N to completely fill bulb D, overflowing slightly into overflow tube K. If the sample is poured at a temperature above the test temperature, wait 15 min for the sample in the viscometer to attain bath temperature and add more sample to overflow slightly into tube K.

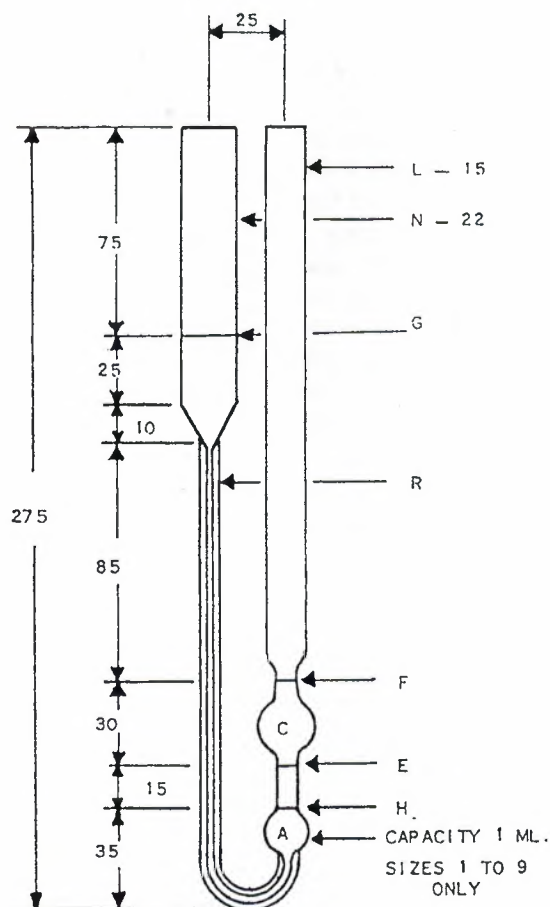
A3.2.3.4 Mount the BS/IP/RF viscometer in the constant-temperature bath keeping the straight portion of the capillary tube R vertical by using a plumb-line observed in two directions at right angles, or as stated in the certificate of calibration.

(1) Allow the viscometer to reach the bath temperature and then pour sufficient of the filtered test sample into the filling tube N to a point just below the filling mark G avoiding wetting the glass above G.

(2) Allow the liquid to flow through the capillary tube R, taking care that the liquid column remains unbroken, until it reaches a position about 5 mm below the filling mark H and arrest its flow at this point by closing the timing tube L with a rubber bung. It is desirable that the rubber bung is fitted with a glass tube and stopcock so that one can apply a controllable, very slight excess pressure to tube L.

(3) Add more liquid to the filling tube N to bring the oil surface to just below mark G. Allow the sample to reach the bath temperature and air bubbles to rise to the surface (at least 30 min is required).

(4) Gently manipulate the stopcock or bung closing the tube L until the level of the liquid is arrested at mark H. The uppermost ring of contact of the sample with the glass should



NOTE—All dimensions are in millimetres.

Size No.	Nominal viscometer constant (mm ² /s)/s	Kinematic viscosity range, ^A mm ² /s	Inside Diameter of tube R, mm (2 %)	Length of tube R, mm	Inside diameter at E, F, and H mm	Volume bulb C mL (±5 %)
1	0.003	0.6 to 3	0.51	185	3.0 to 3.3	4.0
2	0.01	2 to 10	0.71	185	3.0 to 3.3	4.0
3	0.03	6 to 30	0.93	185	3.0 to 3.3	4.0
4	0.1	20 to 100	1.26	185	3.0 to 3.3	4.0
5	0.3	60 to 300	1.64	185	3.0 to 3.3	4.0
6	1.0	200 to 1000	2.24	185	3.0 to 3.3	4.0
7	3.0	600 to 3000	2.93	185	3.3 to 3.6	4.0
8	10	2000 to 10 000	4.00	185	4.4 to 4.8	4.0
9	30	6000 to 30 000	5.5	185	6.0 to 6.7	4.0
10	100	20 000 to 100 000	7.70	210	7.70	4.0
11	300	60 000 to 300 000	10.00	210	10.00	4.0

^A 200 s minimum flow time for all units.

FIG. A3.4 BS/IP/RF U-Tube Reverse Flow Viscometers for Opaque Liquids

coincide with the bottom of mark H. Add sample to tube N until the uppermost ring of its contact with tube N coincides with the bottom of mark G.

A3.2.4 Allow the charged viscometer to remain in the bath long enough to reach the test temperature. Because this time will vary for different instruments, for different temperatures, and for different kinematic viscosities, establish a safe equilibrium time by trial (30 min should be sufficient except for the highest kinematic viscosities). One bath is often used to

accommodate several viscometers. Never add or withdraw a viscometer while any other viscometer is in use for measuring a flow time.

A3.2.5 For the Cannon-Fenske opaque and BS/IP/RF viscometers, remove the stopper in tubes N and L, respectively, and allow the sample to flow by gravity. For the Zeitfuchs cross-arm viscometer, apply slight vacuum to tube M (or pressure to tube N) to cause the meniscus to move over the siphon tube, and about 30 mm below the level of tube D in

capillary R; gravity flow is thus initiated. For the Lantz-Zeitfuchs viscometer, apply slight vacuum to tube M (or pressure tube N with tube K closed) until the lower meniscus is opposite the lower timing mark E; allow the sample to flow by gravity.

A3.2.6 Measure to the nearest 0.1 s the time required for the uppermost ring of contact of the sample with the glass to rise from the bottom of timing mark E to the bottom of timing mark F. The lower filling mark H, as shown in Fig. A3.4 (BS/IP/RF U-tube) if applicable, must not be confused with the lower timing mark E. Do not use timing marks F and I and bulb J (as shown in Fig. A3.2) for determining viscosity of the sample. If the flow time is less than the minimum specified for the viscometer, select a clean, dry viscometer with a smaller diameter capillary and repeat steps A3.2.2-A3.2.6.

A3.2.7 Using this viscometer after it has been thoroughly cleaned and dried, or a second clean and dry viscometer, repeat

steps A3.2.3-A3.2.6 making a duplicate determination of the kinematic viscosity. If the two determinations agree within the determinability given in Test Method D 445 for the product being measured, report the average of the calculated kinematic viscosities. Note that the precision of the viscometers in Annex A3 is slightly poorer than those in Annex A1 and Annex A2 (see 6.3.3).

A3.2.8 Clean the viscometer thoroughly by several rinsings with the appropriate solvent completely miscible with the sample, followed by a completely volatile solvent. Dry the viscometer by passing a slow stream of filtered, dry air through the viscometer for 2 min, or until the last trace of solvent is removed. The use of alkaline cleaning solutions is not recommended as changes in the viscometer calibration may occur.

REFERENCES

- (1) Cannon, M. R., and Fenske, M. R., "Viscosity Measurement," *Industrial and Engineering Chemistry*, Analytical Edition, ANCHA, Vol 10, 1938, p. 297.
- (2) Zeitfuchs, E. H., "An Accurate Viscometer for Refinery Control Laboratories," *Proceedings*, American Petroleum Institute, PDRAA, Vol 20 (III), 1939.
- (3) Ruh, E. L., Walker, R. N., and Dean, E. W., "The SIL Viscometer," *Industrial and Engineering Chemistry*, ANCHA, Vol 13, 1941, p. 346.
- (4) Ubbelohde, L., "The Suspended Level Viscometer," *Journal, Institute of Petroleum Technology* (London), JIPEA, Vol 22, 1936, p. 37.
- (5) FitzSimons, O., "A Rapid Precision Viscometer," *Industrial and Engineering Chemistry*, Analytical Edition, ANCHA, Vol 7, 1935.
- (6) Watt, J. J., and Headington, C. E., "New Viscometer Solves Old Problems," *Petroleum Refiner*, PEREA, October 1954.
- (7) Cannon, M. R., and Manning, R. E., "Viscosity Measurement," *Analytical Chemistry*, ANCHA, Vol 32, 1960, p. 355.
- (8) Cannon, M. R., and Fenske, M. R., "Viscosity Measurement—Opaque Liquids," *Industrial and Engineering Chemistry*, Analytical Edition, ANCHA, Vol 13, 1941, p. 299.
- (9) Zeitfuchs, E. H., "Kinematic Viscometer for Opaque and Very Viscous Liquids," *Oil and Gas Journal*, OIGJA, Vol 44, No. 36, 1946, p. 99.

SUMMARY OF CHANGES

Subcommittee D02.07 has identified the location of selected changes to this standard since the last issue (D 446-06) that may impact the use of this standard. (Approved Jan. 1, 2007.)

(1) Revised 6.3 and Table 1.

(2) Removed Footnote 4.

Subcommittee D02.07 has identified the location of selected changes to this standard since the last issue (D 446-04) that may impact the use of this standard. (Approved May 15, 2006.)

(1) Revised A3.2.6.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).

APPENDIX 3.

VISCOMETER MANUFACTURING CERTIFICATES

MANUFACTURER'S CERTIFICATE FOR CAPILLARY VISCOMETER

(Manufacturer's certificate M according to
DIN 55 350 Part 1A)

Subject: Ubbelohde viscometer with suspending
ball-level for the determination of the kinematic
viscosity according to ISO/DIS 3105
and ASTM D 2515/D 446

Manufacturer: SCHOTT-GERÄTE Mainz

Viscometer: Type and capillary no. 525 03 / 0c
Apparatus no. 101351

This viscometer is suitable to determine the kinematic
viscosity of newtonian liquids according to
ISO/DIS 3105, Annex B. The instrument constant K refers
to the timing marks during the visual survey of the
meniscus passage. It comes to

$$K = 0,002856 \text{ mm}^2/\text{s}^2$$

It was determined by using comparative measurements
with reference viscometers, of which the constants were
determined at the Physikalisch-Technischen Bundes-
anstalt, D-38116 Braunschweig

The instrument constant K is valid for liquids with a sur-
face tension of 20 to 30 mN/m and an acceleration of the
fall of 9.8125 m/s². For temperatures up to 100 °C it is
not required to pay attention to the heat expansion of the
viscometer. The kinematic viscosity ν within mm²/s of
liquids can be calculated using the instrument constant
in the equation

$$\nu = K \cdot t,$$

whereby t is the flow time in seconds which was cor-
rected, if necessary, according to
ISO/DIS 3105, Part 6.2

The relative uncertainty of the mentioned numerical val-
ue of K comes to 0.7 % at a confidence level of 95 %

It is required to check the instrument constant in regular
intervals. In particular any change to the viscometer, for
example when using liquids that corrode glass or a glass
blowing repair took place, makes a new determination of
the instrument constant necessary

CERTIFICAT DU FABRICANT DE TUBE VISCOSIMETRIQUE CAPILLAIRE

(Certificat du fabricant M selon DIN 55 350 Partie 1A)

Objet: viscosimètre selon Ubbelohde avec un ni-
veau sphérique pendent pour la détermi-
nation de la viscosité cinématique selon
ISO/DIS 3105 et ASTM D 2515/D 446

Fabricant: SCHOTT-GERÄTE Mainz

Viscosimètre: No. de type et de capillaire: 525 03 / 0c
No. d'appareil: 101351

Ce viscosimètre est approprié pour la détermination de
la viscosité cinématique de liquides newtoniens selon
ISO/DIS 3105, Annex B. La constante K de l'instrument
est valable pour des index rotatifs avec une saisie visuel-
le du passage du ménisque. Elle est de

Elle a été déterminée par des mesures de comparaison
avec des viscosimètres étalons dont les constantes ont
été déterminées auprès de la Physikalisch-Technischen
Bundesanstalt, D-38116 Braunschweig

La constante K de l'instrument est valable pour des li-
quides avec une tension de surface de 20 à 30 mN/m et
avec une accélération de la pesanteur de 9,8125 m/s².
Dans le cas de températures jusqu'à 100 °C, il n'est pas
nécessaire de tenir compte de la dilatation thermique du
viscosimètre. La viscosité cinématique ν en mm²/s de
liquides peut être calculée à l'aide de la constante de
l'instrument selon l'équation:

t est le temps d'écoulement en secondes qui a été cor-
rigé, si nécessaire, selon ISO/DIS 3105, Partie 6.2

L'incertitude relative de la valeur numérique de K indi-
quée est de 0.7 % dans le cas d'un niveau de confiance
de 95 %

Il est nécessaire de contrôler la constante de l'instrument
en intervalles réguliers. Une nouvelle détermination de la
constante de l'instrument devient absolument nécessaire
lors de toute modification du viscosimètre, par exemple,
en raison de l'utilisation de liquides qui attaquent le verre,
ou dans le cas de réparations par un souffleur de verre.

SCHOTT-GERÄTE GmbH, Mattenberg-Straße 10, D-55122 Mainz

This certificate was prepared mechanically and
is valid without signature.
The document may only be duplicated if no changes were

Ce certificat a été établi mécaniquement et
est valable sans signature.
Le document ne peut être reproduit que sans correction.

MANUFACTURER'S CERTIFICATE FOR CAPILLARY VISCOMETER

(Manufacturer's certificate M according to
DIN 55 350, Part 18)

Subject Ubbelohde viscometer with suspending
ball-level for the determination of the kine-
matic viscosity according to ISO/DIS 3105
and ASTM D 2515/D 446

Manufacturer SI Analytics GmbH, Mainz

Viscometer Type and capillary no. 525 10 / I
Apparatus no. 1049553

This viscometer is suitable to determine the kinematic
viscosity of newtonian liquids according to
ISO/DIS 3105, Annex B. The instrument constant K re-
fers to the timing marks during the visual survey of the
meniscus passage. It comes to

$$K = 0,009132 \text{ mm}^2/\text{s}^2.$$

It was determined by using comparative measurements
with reference viscometers, of which the constants were
determined at the Physikalisch-Technischen Bundesan-
stalt, D-38116 Braunschweig

The instrument constant K is valid for liquids with a sur-
face tension of 20 to 30 mN/m and an acceleration of the
fall of $9,8105 \text{ m/s}^2$. For temperatures up to 100°C it is
not required to pay attention to the heat expansion of the
viscometer. The kinematic viscosity ν within mm^2/s of
liquids can be calculated using the instrument constant
in the equation

$$\nu = K \cdot t,$$

whereby t is the flow time in seconds which was cor-
rected -if necessary- according to
ISO/DIS 3105, Part 6.2

The relative uncertainty of the mentioned numerical va-
lue of K comes to 0.7 % at a confidence level of 95 %

It is required to check the instrument constant in regular
intervals. In particular any change to the viscometer, for
example when using liquids that corrode glass or a glass
blowing repair took place, makes a new determination of
the instrument constant necessary

CERTIFICAT DU FABRICANT DE TUBE VISCOSIMETRIQUE CAPILLAIRE

(Certificat du fabricant M selon DIN 55 350, Partie 18)

Objet Viscosimètre selon Ubbelohde avec un ni-
veau sphérique pendant pour la détermi-
nation de la viscosité cinématique selon
ISO/DIS 3105 et ASTM D 2515/D 446

Fabricant SI Analytics GmbH, Mainz

Viscosimètre No. de type et de capillaire 525 10 / I
No. d'appareil 1049553

Ce viscosimètre est approprié pour la détermination de
la viscosité cinématique de liquides newtoniens selon
ISO/DIS 3105, Annex B. La constante K de l'instrument
est valable pour des index rotatifs avec une saisie visuel-
le du passage du ménisque. Elle est de

Elle a été déterminée par des mesures de comparaison
avec des viscosimètres étalons dont les constantes ont
été déterminées auprès de la Physikalisch-Technischen
Bundesanstalt, D-38116 Braunschweig

La constante K de l'instrument est valable pour des li-
quides avec une tension de surface de 20 à 30 mN/m et
avec une accélération de la pesanteur de $9,8105 \text{ m/s}^2$.
Dans le cas de températures jusqu'à 100°C , il n'est pas
nécessaire de tenir compte de la dilatation thermique du
viscosimètre. La viscosité cinématique ν en mm^2/s de
liquides peut être calculée à l'aide de la constante de
l'instrument selon l'équation

t est le temps d'écoulement en secondes qui a été cor-
rigé -si nécessaire- selon ISO/DIS 3105, Partie 6.2

L'incertitude relative de la valeur numérique de K indi-
quée est de 0,7 % dans le cas d'un niveau de confiance
de 95 %

Il est nécessaire de contrôler la constante de l'instrument
en intervalles réguliers. Une nouvelle détermination de la
constante de l'instrument devient absolument nécessaire
lors de toute modification du viscosimètre, par exemple
en raison de l'utilisation de liquides qui attaquent le verre,
ou dans le cas de réparations par un souffleur de verre

SI Analytics GmbH, Hattenbergstraße 10, D-55122 Mainz

This certificate was prepared mechanically and
is valid without signature.

The document may only be duplicated if no changes were

Ce certificat a été établi mécaniquement et
est valable sans signature

Le document ne peut être reproduit qu'avec correction

APPENDIX 4.

EXPERIMENTAL DATA

WASTE FRYING OIL				
Temperature = 20°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	806.06	0.009132	0.01	7.3608486
2	803.47	0.009132	0.01	7.33719672
3	806.01	0.009132	0.01	7.360392
4	806.15	0.009132	0.01	7.36167048
AV. VISCOSITY =				7.35502695
Temperature = 30°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	630.21	0.009132	0.03	5.75480376
2	632.75	0.009132	0.03	5.77799904
3	630.13	0.009132	0.03	5.7540732
4	629.28	0.009132	0.03	5.746311
AV. VISCOSITY =				5.75829675
Temperature = 40°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	511.47	0.009132	0.04	4.67037876
2	510.78	0.009132	0.04	4.66407768
3	511.29	0.009132	0.04	4.668735
4	510.32	0.009132	0.04	4.65987696
AV. VISCOSITY =				4.6657671
Temperature = 50°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	418.12	0.009132	0.05	3.81781524
2	417.31	0.009132	0.05	3.81041832
3	417.9	0.009132	0.05	3.8158062

4	416.25	0.009132	0.05	3.8007384
			AV. VISCOSITY =	3.81119454
Temperature = 60°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	347.12	0.009132	0.08	3.16916928
2	346.44	0.009132	0.08	3.16295952
3	346.01	0.009132	0.08	3.15903276
4	345.25	0.009132	0.08	3.15209244
			AV. VISCOSITY =	3.1608135
Temperature = 70°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	296.06	0.009132	0.11	2.7026154
2	296.25	0.009132	0.11	2.70435048
3	296.47	0.009132	0.11	2.70635952
4	296.56	0.009132	0.11	2.7071814
			AV. VISCOSITY =	2.7051267
Temperature = 75°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	278.25	0.009132	0.13	2.53979184
2	279.41	0.009132	0.13	2.55038496
3	280.63	0.009132	0.13	2.561526
4	280.1	0.009132	0.13	2.55668604
			AV. VISCOSITY =	2.55209721
Temperature = 80°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	824.7	0.002856	0	2.3553432
2	823.2	0.002856	0	2.3510592
3	824.1	0.002856	0	2.3536296
4	824	0.002856	0	2.353344
			AV. VISCOSITY =	2.353344

Temperature = 90°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	711.9	0.002856	0.004	2.033174976	
2	712.1	0.002856	0.004	2.033746176	
3	711.1	0.002856	0.004	2.030890176	
4	712.5	0.002856	0.004	2.034888576	
			AV. VISCOSITY =	2.033174976	
Temperature = 100°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	635.1	0.002856	0.006	1.813828464	
2	635.7	0.002856	0.006	1.815542064	
3	634.2	0.002856	0.006	1.811258064	
4	635.6	0.002856	0.006	1.815256464	
			AV. VISCOSITY =	1.813971264	
Temperature = 110°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	572.3	0.002856	0.008	1.634465952	
2	574.5	0.002856	0.008	1.640749152	
3	572.7	0.002856	0.008	1.635608352	
4	572.8	0.002856	0.008	1.635893952	
			AV. VISCOSITY =	1.636679352	
Temperature = 120°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	520.6	0.002856	0.01	1.48680504	
2	518.2	0.002856	0.01	1.47995064	
3	518.9	0.002856	0.01	1.48194984	
4	518.2	0.002856	0.01	1.47995064	
			AV. VISCOSITY =	1.48216404	
Temperature = 130°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	462.4	0.002856	0.01	1.32058584	
2	463	0.002856	0.01	1.32229944	
3	462.6	0.002856	0.01	1.32115704	

4	464.7	0.002856	0.01	1.32715464
			AV. VISCOSITY =	1.32279924
Temperature = 140°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	418.7	0.002856	0.01	1.19577864
2	415.8	0.002856	0.01	1.18749624
3	416.2	0.002856	0.01	1.18863864
4	416.5	0.002856	0.01	1.18949544
			AV. VISCOSITY =	1.19035224

		WASTE CANOLA OIL					
Temperature = 20°C							
	time "t" (sec)	Visc. Constant "K"		Correction factor "y'		Kin. Viscosity (mm²/s)	
1	820.13	0.009132		0.01		7.48933584	
2	819.96	0.009132		0.01		7.4877834	
3	818.06	0.009132		0.01		7.4704326	
4	820.35	0.009132		0.01		7.49134488	
				AV. VISCOSITY =		7.48472418	
Temperature = 30°C							
	time "t" (sec)	Visc. Constant "K"		Correction factor "y'		Kin. Viscosity (mm²/s)	
1	632.28	0.009132		0.03		5.773707	
2	633.47	0.009132		0.03		5.78457408	
3	635.46	0.009132		0.03		5.80274676	
4	633.72	0.009132		0.03		5.78685708	
				AV. VISCOSITY =		5.78697123	
Temperature = 40°C							
	time "t"	Visc. Constant "K"		Correction		Kin. Viscosity	

	(sec)		factor "y'	(mm ² /s)
1	514.59	0.009132	0.04	4.6988706
2	510.78	0.009132	0.04	4.66407768
3	510.22	0.009132	0.04	4.65896376
4	513.75	0.009132	0.04	4.69119972
			AV. VISCOSITY	4.67827794
			=	
Temperature = 50°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	417.72	0.009132	0.05	3.81416244
2	414.84	0.009132	0.05	3.78786228
3	416.47	0.009132	0.05	3.80274744
4	417.45	0.009132	0.05	3.8116968
			AV. VISCOSITY	3.80411724
			=	
Temperature = 60°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	336.6	0.009132	0.08	3.07310064
2	336.4	0.009132	0.08	3.07127424
3	338.44	0.009132	0.08	3.08990352
4	337.35	0.009132	0.08	3.07994964
			AV. VISCOSITY	3.07855701
			=	
Temperature = 70°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	292.75	0.009132	0.11	2.67238848
2	293.78	0.009132	0.11	2.68179444
3	292.6	0.009132	0.11	2.67101868
4	292.09	0.009132	0.11	2.66636136
			AV. VISCOSITY	2.67289074
			=	
Temperature = 75°C				
	time "t"	Visc. Constant "K"	Correction	Kin. Viscosity

	(sec)		factor "y'	(mm ² /s)
1	275.4	0.009132	0.13	2.51376564
2	275.28	0.009132	0.13	2.5126698
3	275.36	0.009132	0.13	2.51340036
4	276.01	0.009132	0.13	2.51933616
			AV. VISCOSITY	2.51479299
			=	
Temperature = 80°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	815.2	0.002856	0	2.3282112
2	818.2	0.002856	0	2.3367792
3	816.4	0.002856	0	2.3316384
4	817.3	0.002856	0	2.3342088
			AV. VISCOSITY	2.3327094
			=	
Temperature = 90°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	708.3	0.002856	0.004	2.022893376
2	706.9	0.002856	0.004	2.018894976
3	709.6	0.002856	0.004	2.026606176
4	708.7	0.002856	0.004	2.024035776
			AV. VISCOSITY	2.023107576
			=	
Temperature = 100°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	632.3	0.002856	0.006	1.805831664
2	632.5	0.002856	0.006	1.806402864
3	633.1	0.002856	0.006	1.808116464
4	632.8	0.002856	0.006	1.807259664
			AV. VISCOSITY	1.806902664
			=	
Temperature = 110°C				
	time "t"	Visc. Constant "K"	Correction	Kin. Viscosity

	(sec)		factor "y'	(mm ² /s)
1	569.7	0.002856	0.008	1.627040352
2	570.8	0.002856	0.008	1.630181952
3	568.6	0.002856	0.008	1.623898752
4	568.4	0.002856	0.008	1.623327552
			AV. VISCOSITY	1.626112152
			=	
Temperature = 120°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	515.7	0.002856	0.01	1.47281064
2	514.6	0.002856	0.01	1.46966904
3	516.5	0.002856	0.01	1.47509544
4	516.6	0.002856	0.01	1.47538104
			AV. VISCOSITY	1.47323904
			=	
Temperature = 130°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	458.4	0.002856	0.01	1.30916184
2	458.6	0.002856	0.01	1.30973304
3	459.6	0.002856	0.01	1.31258904
4	450.7	0.002856	0.01	1.28717064
			AV. VISCOSITY	1.30466364
			=	
Temperature = 140°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y'	Kin. Viscosity (mm ² /s)
1	412.7	0.002856	0.01	1.17864264
2	411.9	0.002856	0.01	1.17635784
3	411.7	0.002856	0.01	1.17578664
4	412.9	0.002856	0.01	1.17921384
			AV. VISCOSITY	1.17750024
			=	

WASTE FRYING OIL 50-50 WASTE CANOLA OIL								
Temperature = 20°C								
	time "t" (sec)	Visc. Constant "K"			Correction factor "y'		Kin. Viscosity (mm²/s)	
1	966.68	0.009132			0.01		8.82763044	
2	965.21	0.009132			0.01		8.8142064	
3	965.72	0.009132			0.01		8.81886372	
4							0	
					AV. VISCOSITY =		8.82023352	
Temperature = 30°C								
	time "t" (sec)	Visc. Constant "K"			Correction factor "y'		Kin. Viscosity (mm²/s)	
1	760.44	0.009132			0.02		6.94415544	
2	758.44	0.009132			0.02		6.92589144	
3	759.22	0.009132			0.02		6.9330144	
4	758.58	0.009132			0.02		6.92716992	
					AV. VISCOSITY =		6.9325578	
Temperature = 40°C								
	time "t" (sec)	Visc. Constant "K"			Correction factor "y'		Kin. Viscosity (mm²/s)	
1	593.75	0.009132			0.03		5.42185104	
2	593.37	0.009132			0.03		5.41838088	
3	593.9	0.009132			0.03		5.42322084	
4								
					AV. VISCOSITY =		5.42115092	
Temperature = 50°C								
	time"t" (sec)	Visc. Constant "K"			Correction factor "y'		Kin. Viscosity (mm²/s)	
1	457.16	0.009132			0.05		4.17432852	
2	457.4	0.009132			0.05		4.1765202	
3	459.75	0.009132			0.05		4.1979804	
4	458.29	0.009132			0.05		4.18464768	
					AV. VISCOSITY		4.1833692	

				=	
Temperature = 60°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	375.84	0.009132	0.07	3.43153164	
2	377.25	0.009132	0.07	3.44440776	
3	375.41	0.009132	0.07	3.42760488	
4	375.59	0.009132	0.07	3.42924864	
			AV. VISCOSITY =	3.43319823	
Temperature = 70°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	324.78	0.009132	0.09	2.96506908	
2	324.12	0.009132	0.09	2.95904196	
3	325.29	0.009132	0.09	2.9697264	
4					
			AV. VISCOSITY =	2.96461248	
Temperature = 75°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	284.69	0.009132	0.13	2.59860192	
2	286.18	0.009132	0.13	2.6122086	
3	285.2	0.009132	0.13	2.60325924	
4	284.88	0.009132	0.13	2.600337	
			AV. VISCOSITY =	2.60360169	
Temperature = 80°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	915.8	0.002856	0	2.6155248	
2	915.9	0.002856	0	2.6158104	
3	914.2	0.002856	0	2.6109552	
4	915.6	0.002856	0	2.6149536	
			AV. VISCOSITY	2.614311	

				=	
Temperature = 90°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	791	0.002856	0.004	2.259084576	
2	790.6	0.002856	0.004	2.257942176	
3	791.4	0.002856	0.004	2.260226976	
4	791.6	0.002856	0.004	2.260798176	
			AV. VISCOSITY =	2.259512976	
Temperature = 100°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	693.6	0.002856	0.006	1.980904464	
2	691.4	0.002856	0.006	1.974621264	
3	692.7	0.002856	0.006	1.978334064	
4	691.2	0.002856	0.006	1.974050064	
			AV. VISCOSITY =	1.976977464	
Temperature = 110°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	616.3	0.002856	0.008	1.760129952	
2	614.4	0.002856	0.008	1.754703552	
3	614.7	0.002856	0.008	1.755560352	
4	613.6	0.002856	0.008	1.752418752	
			AV. VISCOSITY =	1.755703152	
Temperature = 120°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	563.4	0.002856	0.01	1.60904184	
2	565.6	0.002856	0.01	1.61532504	
3	561.7	0.002856	0.01	1.60418664	
4	563.7	0.002856	0.01	1.60989864	
			AV. VISCOSITY =	1.60961304	

Temperature = 130°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	521.7	0.002856	0.01	1.48994664
2	521.2	0.002856	0.01	1.48851864
3	521.6	0.002856	0.01	1.48966104
4	520.7	0.002856	0.01	1.48709064
			AV. VISCOSITY =	1.48880424
Temperature = 140°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	472.2	0.002856	0.01	1.34857464
2	471.7	0.002856	0.01	1.34714664
3	471.6	0.002856	0.01	1.34686104
4	470.6	0.002856	0.01	1.34400504
			AV. VISCOSITY =	1.34664684

WASTE FRYING OIL 75-25 WASTE CANOLA OIL				
Temperature = 20°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	929.38	0.009132	0.01	8.48700684
2	931.6	0.009132	0.01	8.50727988
3	929.88	0.009132	0.01	8.49157284
4	930.01	0.009132	0.01	8.49276
			AV. VISCOSITY =	8.49465489
Temperature = 30°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	700.19	0.009132	0.02	6.39395244
2	701.6	0.009132	0.02	6.40682856
3	702.4	0.009132	0.02	6.41413416
4				

				AV. VISCOSITY =	6.40497172
Temperature = 40°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	544.74	0.009132	0.03	4.97429172	
2	545	0.009132	0.03	4.97666604	
3	545.97	0.009132	0.03	4.98552408	
4					
				AV. VISCOSITY =	4.97882728
Temperature = 50°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	440.34	0.009132	0.05	4.02072828	
2	441.31	0.009132	0.05	4.02958632	
3	441.56	0.009132	0.05	4.03186932	
4	441.28	0.009132	0.05	4.02931236	
				AV. VISCOSITY =	4.02787407
Temperature = 60°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	371.65	0.009132	0.07	3.39326856	
2	372.26	0.009132	0.07	3.39883908	
3	371.68	0.009132	0.07	3.39354252	
4	371.89	0.009132	0.07	3.39546024	
				AV. VISCOSITY =	3.3952776
Temperature = 70°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	319.91	0.009132	0.09	2.92059624	
2	319.34	0.009132	0.09	2.915391	
3	319.41	0.009132	0.09	2.91603024	
4					

				AV. VISCOSITY =	2.91733916
Temperature = 75°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	290.03	0.009132	0.11	2.64754944	
2	288.38	0.009132	0.11	2.63248164	
3	290.21	0.009132	0.11	2.6491932	
4					
				AV. VISCOSITY =	2.64307476
Temperature = 80°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	894.1	0.002856	0	2.5535496	
2	894.5	0.002856	0	2.554692	
3	893.7	0.002856	0	2.5524072	
4	894.6	0.002856	0	2.5549776	
				AV. VISCOSITY =	2.5539066
Temperature = 90°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	780.7	0.002856	0.004	2.229667776	
2	779.2	0.002856	0.004	2.225383776	
3	779.7	0.002856	0.004	2.226811776	
4	778.8	0.002856	0.004	2.224241376	
				AV. VISCOSITY =	2.226526176
Temperature = 100°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	685	0.002856	0.006	1.956342864	
2	684.2	0.002856	0.006	1.954058064	
3	684.7	0.002856	0.006	1.955486064	
4	684.6	0.002856	0.006	1.955200464	
				AV. VISCOSITY =	1.955271864

				=	
Temperature = 110°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	610.5	0.002856	0.008	1.743565152	
2	611.6	0.002856	0.008	1.746706752	
3	611.8	0.002856	0.008	1.747277952	
4	610.2	0.002856	0.008	1.742708352	
			AV. VISCOSITY =	1.745064552	
Temperature = 120°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	550.3	0.002856	0.01	1.57162824	
2	550	0.002856	0.01	1.57077144	
3	550.7	0.002856	0.01	1.57277064	
4	550.1	0.002856	0.01	1.57105704	
			AV. VISCOSITY =	1.57155684	
Temperature = 130°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	518.6	0.002856	0.01	1.48109304	
2	519.6	0.002856	0.01	1.48394904	
3	519.1	0.002856	0.01	1.48252104	
4	517.5	0.002856	0.01	1.47795144	
			AV. VISCOSITY =	1.48137864	
Temperature = 140°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	465.4	0.002856	0.01	1.32915384	
2	465.6	0.002856	0.01	1.32972504	
3	465.7	0.002856	0.01	1.33001064	
4	465.8	0.002856	0.01	1.33029624	
			AV. VISCOSITY =	1.32979644	

WASTE FRYING OIL							
25-75 WASTE							
CANOLA OIL							
Temperature = 20°C							
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)			
1	1006.78	0.009132	0.01	9.19382364			
2	1007.22	0.009132	0.01	9.19784172			
3	1007.78	0.009132	0.01	9.20295564			
4							
				AV. VISCOSITY =		9.198207	
Temperature = 30°C							
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)			
1	795.22	0.009132	0.01	7.26185772			
2	793.66	0.009132	0.01	7.2476118			
3	795.43	0.009132	0.01	7.26377544			
4	795.25	0.009132	0.01	7.26213168			
				AV. VISCOSITY =		7.25884416	
Temperature = 40°C							
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)			
1	630.63	0.009132	0.03	5.7586392			
2	629.69	0.009132	0.03	5.75005512			
3	628.09	0.009132	0.03	5.73544392			
4	629.7	0.009132	0.03	5.75014644			
				AV. VISCOSITY =		5.74857117	
Temperature = 50°C							
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)			
1	508.85	0.009132	0.04	4.64645292			
2	509.06	0.009132	0.04	4.64837064			
3	508.74	0.009132	0.04	4.6454484			
4							
				AV. VISCOSITY =		4.64675732	
Temperature = 60°C							
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)			

1	416.07	0.009132		0.05	3.79909464
2	416.28	0.009132		0.05	3.80101236
3	416.01	0.009132		0.05	3.79854672
4					
				AV. VISCOSITY =	3.79955124
Temperature = 70°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	346.01	0.009132	0.08	3.15903276	
2	346.81	0.009132	0.08	3.16633836	
3	347.24	0.009132	0.08	3.17026512	
4	347.13	0.009132	0.08	3.1692606	
				AV. VISCOSITY =	3.16622421
Temperature = 75°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	317.29	0.009132	0.09	2.8966704	
2	318.27	0.009132	0.09	2.90561976	
3	318.12	0.009132	0.09	2.90424996	
4					
				AV. VISCOSITY =	2.90218004
Temperature = 80°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	947.9	0.002856	0	2.7072024	
2	947.2	0.002856	0	2.7052032	
3	946.3	0.002856	0	2.7026328	
4	947.8	0.002856	0	2.7069168	
				AV. VISCOSITY =	2.7054888
Temperature = 90°C					
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)	
1	814.3	0.002856	0.004	2.325629376	
2	812.5	0.002856	0.004	2.320488576	
3	812.8	0.002856	0.004	2.321345376	
4	812.6	0.002856	0.004	2.320774176	
				AV. VISCOSITY =	2.322059376

Temperature = 100°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	715.9	0.002856	0.006	2.044593264
2	717	0.002856	0.006	2.047734864
3	716.2	0.002856	0.006	2.045450064
4	716.4	0.002856	0.006	2.046021264
			AV. VISCOSITY =	2.045949864
Temperature = 110°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	639.7	0.002856	0.008	1.826960352
2	638.8	0.002856	0.008	1.824389952
3	638.5	0.002856	0.008	1.823533152
4	638.2	0.002856	0.008	1.822676352
			AV. VISCOSITY =	1.824389952
Temperature = 120°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	569	0.002856	0.01	1.62503544
2	569.3	0.002856	0.01	1.62589224
3	569.4	0.002856	0.01	1.62617784
4	570	0.002856	0.01	1.62789144
			AV. VISCOSITY =	1.62624924
Temperature = 130°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	535	0.002856	0.01	1.52793144
2	535.6	0.002856	0.01	1.52964504
3	535.4	0.002856	0.01	1.52907384
4	533.3	0.002856	0.01	1.52307624
			AV. VISCOSITY =	1.52743164
Temperature = 140°C				
	time "t" (sec)	Visc. Constant "K"	Correction factor "y"	Kin. Viscosity (mm ² /s)
1	478.9	0.002856	0.01	1.36770984
2	478.2	0.002856	0.01	1.36571064
3	475.4	0.002856	0.01	1.35771384

4	476.2	0.002856	0.01	1.35999864
			AV. VISCOSITY =	1.36278324