Precision Measurement of Viscosity and its Effect on the Quality of Many Industries

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Abstract

The measurement of viscosity is of a great importance in many industrial processes and scientific research. Viscosity is the physical property that determines the forces to be overcome when fluids are pumped or used between rubbing metal surfaces such as bearings and it controls the flow of liquids in spraying, painting and extraction.

Today the production of fluids is widely differentiated to meet market requirements in advanced and conventional technologies. Fluid properties must be, however, carefully weighed in order to determine their suitability of application as lubricant, damping sealing or hydraulic fluids in different working conditions and in aggressive environments. Testing methods and conditions can be established not only on the basis of the known correlation between required performance and laboratory measurement capability, but also, when some special lubricant properties are to be determined, on the base of specifications or recommendations issued by official bodies such as the International Standardization Organization (ISO), the Institute of Petroleum (IP), the American Society of Testing materials (ASTM) and the society of Automotive Engineers (SAE). The use of reference materials is often suggested for carrying out correctly several tests, in order to achieve
Keywords: kinematic, Viscosity**,** Dynamic viscosity, Uncertainty of Viscosity Determination, Viscosity Inter comparison, NIS Viscosity Determination capability.

Introduction

The National Institute for Standards (NIS) maintains the Egyptian national scale of viscosity. The scale is to be disseminated in same way to industry, researches and individual. Tractability to NIS viscosity standards can be obtained in two ways.

National Institute for Standard (NIS)

The traditional and most accurate method is by calibration a client's glass capillary viscometer against the laboratories working standard viscometers using oils as transfer liquids.

The alternative way is for the clients, to purchase NIS severance oils with viscosities certified at precisely stated temperatures [4]. These liquids may be requiring for instance, calibrating viscometers such as rotational and cupping viscometers, which are not of the simple glass capillaries viscometers.

From a practical point of view, viscosity determination is always required both in research activities and in industrial processes, whenever a fluid material is involved, as a valuable tool for studying, characterizing and checking; the tractability to a primary viscosity standard plays therefore an important role. At present, a number of easily available liquids, whose viscosity and density values are certified at stated temperatures, may be suggested for quick checking of devices used, for instance to calibrate and test different viscometers, such as the glass capillary, the cone and plate, the concentric cylinder and falling body types. Such liquids, employed as viscosity transfer standards, are supplied independently by certification authorities, including national standard laboratories, in several countries around the world.

The aim of this paper is to illustrate the importance and the physical meaning of viscosity and also to show the apparatuses used for setup the viscosity measurements.

This paper shows also the results different inter-compressions carried out in the viscosity field and the uncertainty calculations

1. Meaning of Viscosity

Viscosity is an expression of the resistance of fluid to flow; the higher the viscosity, the greater the resistance [1]. Viscosity is a material property, which is independent of geometry [2]. It is defined as the internal friction of a fluid, caused by molecular attraction, which makes it resist a tendency to flow.

2. Units Used in Viscosity

The Viscosity is the physical property of a fluid, that is, the fluid's resistance to flow. Usually, the viscosity is measured as kinematic viscosity. In the past the Stoke (St) was the unit of kinematic viscosity, in the SI system the

unit is m^2/s (mm^2/s). The dynamic viscosity is the kinematic viscosity multiplied by the density of the liquid. In CGS system the unit of dynamic viscosity is dyne.s/cm^2 or Poise, and in the SI system the unit is Ns / m^2 (Pa.s).

The viscosity scale, is based on the internationally accepted value of distilled water at 20°C (1,0035 mm^2/s). It is realized with the help of several capillary viscometers using a step-up procedure.

The number of viscometers depends on the range of viscosity and, usually, at every step, at least two viscometers with the same capillary are used.

3. Techniques used for viscosity determinations

As it is know, the Viscosity is an expression of the resistance of fluid to flow, so there are many methods and techniques for measuring the viscosity. For the kinematic viscosity the Glass Capillary Viscometers is used and for Dynamic viscosity the Rotational Viscometers can be used.

Choice of viscometer is important. For Newtonian fluid the rate ofshear is directly proportional to the shearing stress, one can use instruments that operate at a single rate of shear. These are called as 'one point' instrument. Implicit in use of a "one point" instrument is the prior knowledge that the flow characteristics of the material are Newtonian. Unfortunately, this is not always the case, and the system is being non-Newtonian, a "one point" determination is virtually useless in characterizing the flow properties of the system. It is therefore essential that, with non-Newtonian systems, the instrument used be able to operate at a variety of rates of shear. Therefore all viscometers can be used to determine the viscosity of Newtonian systems, only those with variable shear stress controls can be used for non-Newtonian materials.

3-Facilities used at Thermal Metrology for Viscosity Detrmination.

The viscosity measurements are carried out using the system shown in Fig. (2) which is consists of the following components.

3-1 The Bath Used to Maintain Capillary Viscometer

A temperature controlled water bath was used for short capillary viscometers. The bath (model TEV-40) was manufactured by P.M.Tamson

N.V.Zoetemeterr Holand- Its inside vessel is rectangular which provides a better thermal distribution than round bath. The liquid volume of the bath is 40 liters. The bath has a glass window of 270 x 270 mm. Its top plate is made of stainless steel 2 mm thick and has seven holes each of 5 cm in diameter, provided with lids, for suspension of the viscometers. Temperature uniformity through the working space is attained by means of a wing stirrer causing good circulation of the liquid with the aid of baffle plates. This wing stirrer is situated over a hole in a system of stainless steel baffles around which the liquid is propelled. As a result of the low resistance and the large passage a very good circulation is obtained.

The heater used is made of chrome nickel spiral 220 V and 1500 watt, enclosed inside a quartz tube. An auxiliary heater of 500 watt installed in the bath has to be switched off as soon as the bath has reached the required temperature. The bath has a built in cooling spiral. The cold water passing through it is provided from a cooling unit connected to the spiral by a thick rubber hose. The maximum temperature variation in the bath is less than ± 0.01 ^{o}C.

3-2 The Cooled Unit

As the bath has a built in cooling spiral. the cooled water passing through it was provided from a cooling unit connected to the spiral by thick rubber hose. To obtain an even temperature in the bath it was necessary to have no areas where the temperature differs greatly from the rest. Cooling is necessary as the stirring gives off heat due to friction, which causes an increase in temperature of few degrees. A flow of cooling water is necessary to compensate for this increase in temperature. This has been achieved by the flow of the cooling liquid via the cooling spiral inside the bath. A JULABO refrigerated circulators employ a circulator head and a cooling machine with bath tank, and had been designed for heating and cooling of liquids in the bath tank. Besides the cooling aggregate, the main functional elements are the heater, circulation pump and control electronics. A proportional temperature control (PID characteristic) adopts the heat supplied to the thermal requirements of the bath. The working temperature stability is ±0.02^{0}C with bath dimensions of 230 x 420 x 600 mm and volume of 3-4.5 Liters.

3-3 Thermometers

Temperature was measured by means of standard platinum resistance thermometers connected in four-wire configuration and calibrated at NIS in accordance with ITS-90. Two standard platinum resistance thermometers, having an estimated uncertainty of ± 2 mk, calibrated according to ITS-90 in the range from triple point of water to the zinc point were used for bath characterization and temperature measurement.

Table (1): Identification of standard long stem NIS SPRT's used.

NIS SPRT Code	Type	Serial Number
NIS-2	Rosemount	232247
NIS-3	Rosemount	232234

It is known that one important source of error that arises in viscometry is that the element of a platinum resistance thermometer is sensitive to ambient light. The levels of ambient lighting are necessarily high and unless precautions are taken, errors exceeding 0.01 ^{o}C may readily occur. This difficulty was overcome by enclosing the thermometer stem completely in a thin – walled stainless steel tube with a closed end. By this way the absorbed ambient energy has a negligible influence.

3-4 Thermometer Bridge

The measurement of the resistance of the SPRT used was carried out by using the ASL model F700 resistance thermometer bridge. The bridge measures the ratio of two four terminal resistor, R_t and R_s it has a display range of 0.000000 to 3.999999 for R_T/R_S ratio, with a standard resistor of 100 ohms, the measured range of R_T is from 0 to 399.9999 ohms in 0.0001 ohm steps selected by the front panel thumb-wheel switches. An estimate of the next decimal place can be made from the out of balance meter display. An internal reference resistor R_S mounted in temperature-controlled oven is provided with value of 25.00057 ohm at 36 ^{o}C. An R_S Trim control is fitted so that the bridge can be calibrated against an external standard or adjusted to compensate for variations from the nominal value of R_O when used with resistance thermometers.

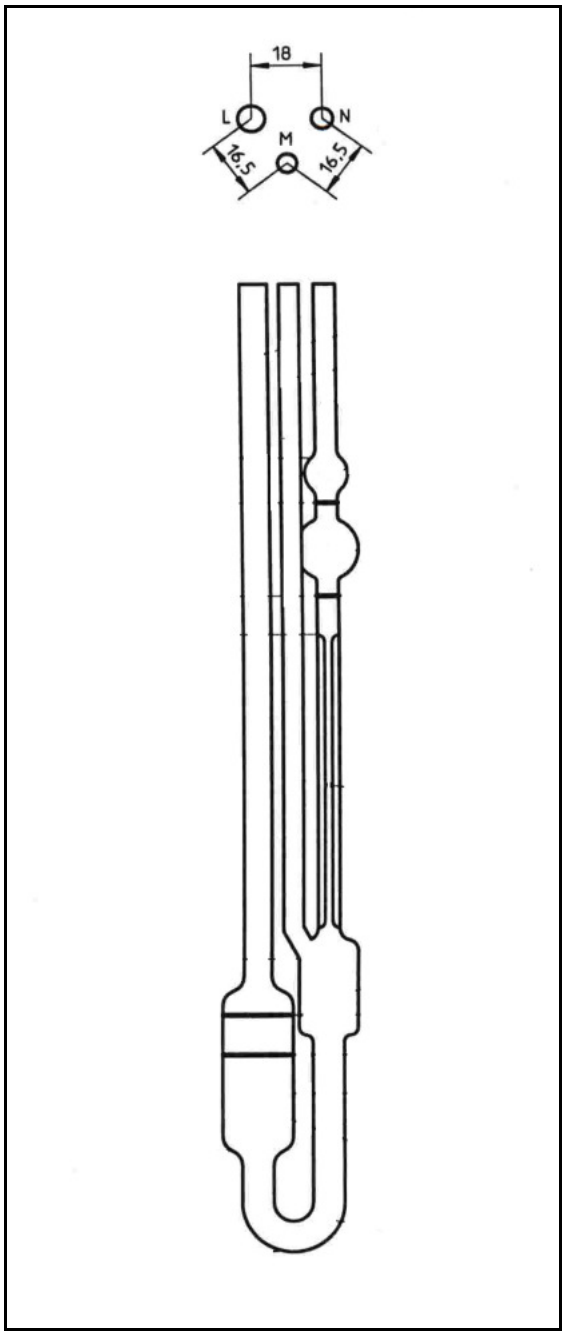
3-5 Stopwatches

A manually operated electronic stopwatch with resolution of 0.01 sec was used. It is calibrated frequently at the NIS Time and Frequency Department. The uncertainty of its calibration is $\pm 2.5 \times 10^{-6}$ sec.

3-6 Ubbelohde Viscometers Used in This Study

The capillary viscometers used are made of borosilicate glass. The capillaries are manufactured with a tolerance on internal diameter of as little as ± 0.01 mm. This makes the viscometers very reliable and extremely accurate.

Ubbelohde viscometers figure (2-4) are used, as they are extremely accurate and yet very simple to use. This is because of the suspended level at the lower end of the capillary. The radius of the bulb surface on which the suspended level forms has been calculated so that the surface tensile stress in the suspended level and the surface tensile stress on the meniscus in the measuring bowl balance each other out. The suspended level ensures that the mean pressure head remains constant at all times even though the volume varies.



Glass viscometers have therefore been chosen for the realization of the NIS viscosity scale; these are of Ubbelohde Pattern because of the following:-

1- their high accuracy

2- their measurement stability

3- their ease of handling

Figure (1) Ubbelohde viscometer.

Figure (2): System used for measurements.

(1) SPRT (2) The bath (3) Ubbelohde viscometer.

(4) Cooled unit (5) RTD (6) Thermometer bridge

4. Method of viscosity calculation

The kinematic viscosity of a Newtonian liquid is calculated from the experimental data obtained by the glass capillary viscometers by using the given equation [3] which includes the correction for the air bouncy

$$\nu = (Ct - Kt^{-2})(1 + c_b + Xc_s) \quad (1)$$

where

ν is the kinematic viscosity values of the oil used

C is the instrumental constant.

K is a constant called kinetic energy factor.

t is the time for reproducible volume of the liquid to flow under gravity, through the capillary.

with:

$$c_b = (\frac{\rho_a}{\rho_w} - \frac{\rho_a}{\rho_l}) \quad (2)$$

where:

ρ_a is the density of air at the measured temperature,

ρ_w is the density of water at the measured temperature,

ρ_l is the density of the used liquid at the measured temperature.

and

$$c_s = X\left(\frac{\sigma_l}{\rho_l} - \frac{\sigma_w}{\rho_w}\right) \qquad (3)$$

Where:

σ_l is the surface tension of the reference liquid,

σ_w is the surface tension of the water,

X is a factor, which is depending on the viscometer used.

X was determined by measuring the flow time of two liquids having approximately the same efflux time (i.e. water and n-Nonan at 20°C). So that X can be expressed as:

$$X = \frac{\left[\left(\frac{V_l}{Ct_l - \frac{K}{t_l^2}}\right) - 1 - \left(\frac{\rho_a}{\rho_w} - \frac{\rho_a}{\rho_l}\right)\right]}{\left(\frac{\sigma_l}{\rho_l} - \frac{\sigma_w}{\rho_w}\right)} \qquad (4)$$

5. The uncertainty of Viscosity measurements

Under actual operation condition the calculated uncertainty for determined viscosity value were deduced from both A and B components of all the quantities involved in the measurements on the basis of an international agreed recommendation (ISO, Guide to the Expression of Uncertainty in MeasurementJAG4 WGS, ISO (1995)).

For determination of the uncertainty[5].of the measurements we have used the propagation low for uncorrelated quantities,

$$u^2{}_c(y) = \sum_{i=1}^{n}\left[\frac{\partial f}{\partial x_i}\right]^2 u^2(x_i) \qquad (5)$$

Where:

$u(x_i)$ is the uncertainty of all input quantities.

From equation (1) the uncertainty of the viscosity u_v is :

$$u(v) = \sqrt{\left(\frac{\partial v}{\partial c}\right)^2 u_t^2 + \left(\frac{\partial v}{\partial t}\right)^2 u_c^2 + \left(\frac{\partial v}{\partial k}\right)^2 u_t^2 + \left(\frac{\partial v}{\partial t}\right)^2 u_k^2} \qquad (6)$$

Where u_t is the uncertainty in time measurements and u_C is the standard uncertainty of the viscometer constant

Rewriting equation (6) for the instrumental constant as:

$$C = \frac{v}{t} + \frac{K}{t^3} \qquad (7)$$

the uncertainty of the constant C (u_c) for uncorrelated quantities is obtained by:

$$u_c = \sqrt{\left(\frac{\partial c}{\partial v}\right)^2 u_t^2 + \left(\frac{\partial c}{\partial t}\right)^2 u_v^2 + \left(\frac{\partial c}{\partial k}\right)^2 u_t^2 + \left(\frac{\partial c}{\partial t}\right)^2 u_k^2} \qquad (8)$$

the kinetic energy factor K from equation 1 is:

$$K = Ct^3 - vt^2 \qquad (9)$$

and its uncertainty u_k for uncorrelated quantities is obtained as:

$$u_K = \sqrt{\left(\frac{\partial k}{\partial c}\right)^2 u_t^2 + \left(\frac{\partial k}{\partial t}\right)^2 u_c^2 + \left(\frac{\partial k}{\partial v}\right)^2 u_t^2 + \left(\frac{\partial k}{\partial t}\right)^2 u_k^2} \qquad (10)$$

The expanded uncertainty budget in the form of 95% confidence level was calculated according to the ISO/TAG. Guide[4]

6.Committee Consultancy for measurements of Viscosity Key Intercomparison

Since 1998, when NIS established the viscosity scale based exclusively on freshly distilled water, several comparisons have been made with other advanced laboratories. There are two rather different ways in which such comparison may be made. The first way is for each laboratory in turn to calibrate the same viscometer, or group of viscometers, relative to its own scale, and then to intercompare the values of the viscometer constants so obtained after correcting to common value for the acceleration due to gravity. The second way is for each laboratory to measure the viscosity of a sample of stable oil at an agreed temperature and then compare the results obtained.

The second way have been used to compare the NIS scale with Physikalisch-Technische Bundesanstalt Braunschweig (PTB) and Consiglio Nazionale delle Ricerche-lstituto di Metrologia "G. Colonnetti" (IMGC) scales. The first comparison was made in 1999. The second comparison was made with IMGC scale NIS exchange samples whose viscosities were measured. The third comparison was also made with IMGC, which is a part of this paper. The results show an agreement within 0.37% between NIS and IMGC scales, which is within the uncertainty of measurements.

The aim of the intercomparison was

- to check the viscosity scale at low viscosities (close to the viscosity of water), in particular with respect to kinetic energy correction and surface tension correction (standard liquid A)
- to check the step–up procedure from water to 40000 mm²/s (standard liquid C)
- to check the viscosity measurements at temperatures up to 100°C (standard liquid B).

NIS was participate in the Committee Consultancy for measurements of Viscosity Key comparison by four Newtonian liquids with nominal kinematic viscosities of 10 mm²/s at 20°C, 1300 mm²/s at 20°C, 400 mm²/s at 40°C, and 40000 mm²/s at 20°C were used to determine the degrees of equivalence between the individual NMIs and the key Comparison Reference Value (KCRV). The relative standard uncertainty of the KCRV extends from 0,05% at 400 mm²/s to 0,15% at 40 mm²/s and 100°C.

The measurement of viscosity in the rang from 10 mm^2/s to 40000 mm^2/s is very important for NIS for calibration the different types of viscometers

The uncertainty of National Institute for Standards (NIS) measurements was found to be 1.58×10^{-3} for liquid A (with reference value 9.6519mm^2/s), 32.60×10^{-3} for liquid B (with reference value 1285.57 mm^2/s), 20.90×10^{-3} for liquid B2 (with reference value 394.075 mm^2/s) and 6.13×10^{-3} for liquid C (with reference value 36587.5 mm^2/s).

7.Results obtained by NIS.

Table (1) gives the results obtained by NIS for the reference oils, and the uncertainty given in this table has been calculated

Table (2) : Results given by NIS

Liquids	v (mm²/s)	u	D (mm²/s)	$U(D_i)$ (mm²/s)
A	9,6824	$1{,}58\times10^{-3}$	3.0×10^{-2}	3.1×10^{-2}
B1	1294,27	$32{,}60\times10^{-3}$	8,7	84.4
B2	394,768	$20{,}90\times10^{-3}$	0,7	16.5
C	37303,4	$6{,}13\times10^{-3}$	$7{,}2\times10^{2}$	4.6×10^{2}

Where :

v is the kinematic viscosity,

u the relative standard measurement uncertainty stated by NIS

D is the difference between NIS and reference value

The results of the intercomparison as shown in figures (3,4,5,6) give the difference $(v_i - v_R)$ between the reference value and the results of laboratories v_i.

In case of NIS the difference $(v_i - v_R)$ lies within the accepted range if we take into consideration the uncertainty $U(D_i)$ which is expressed in the form of95% confidence level

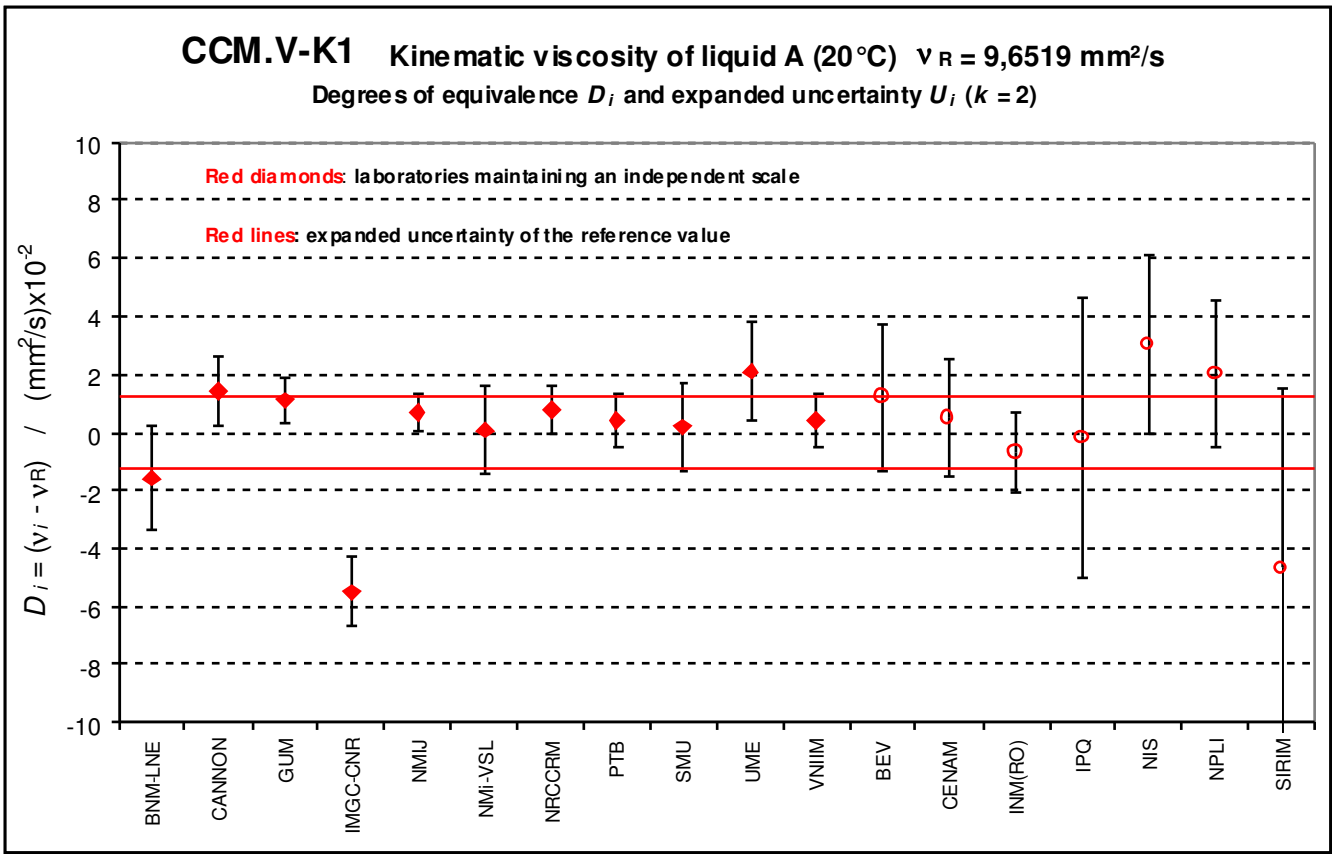


Figure (3) Liquid A @ 20°C

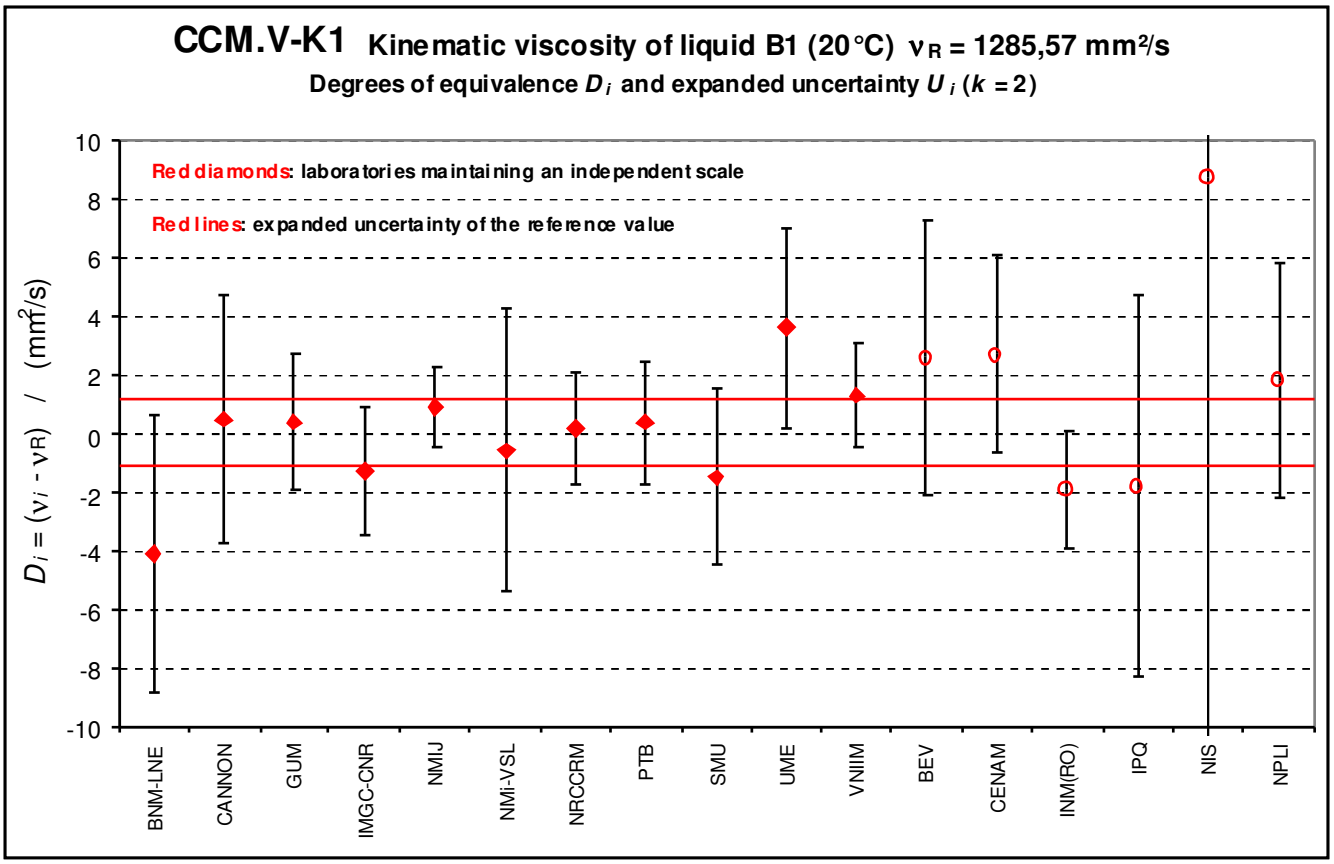


Figure (4) Liquid B1 @ 20°C

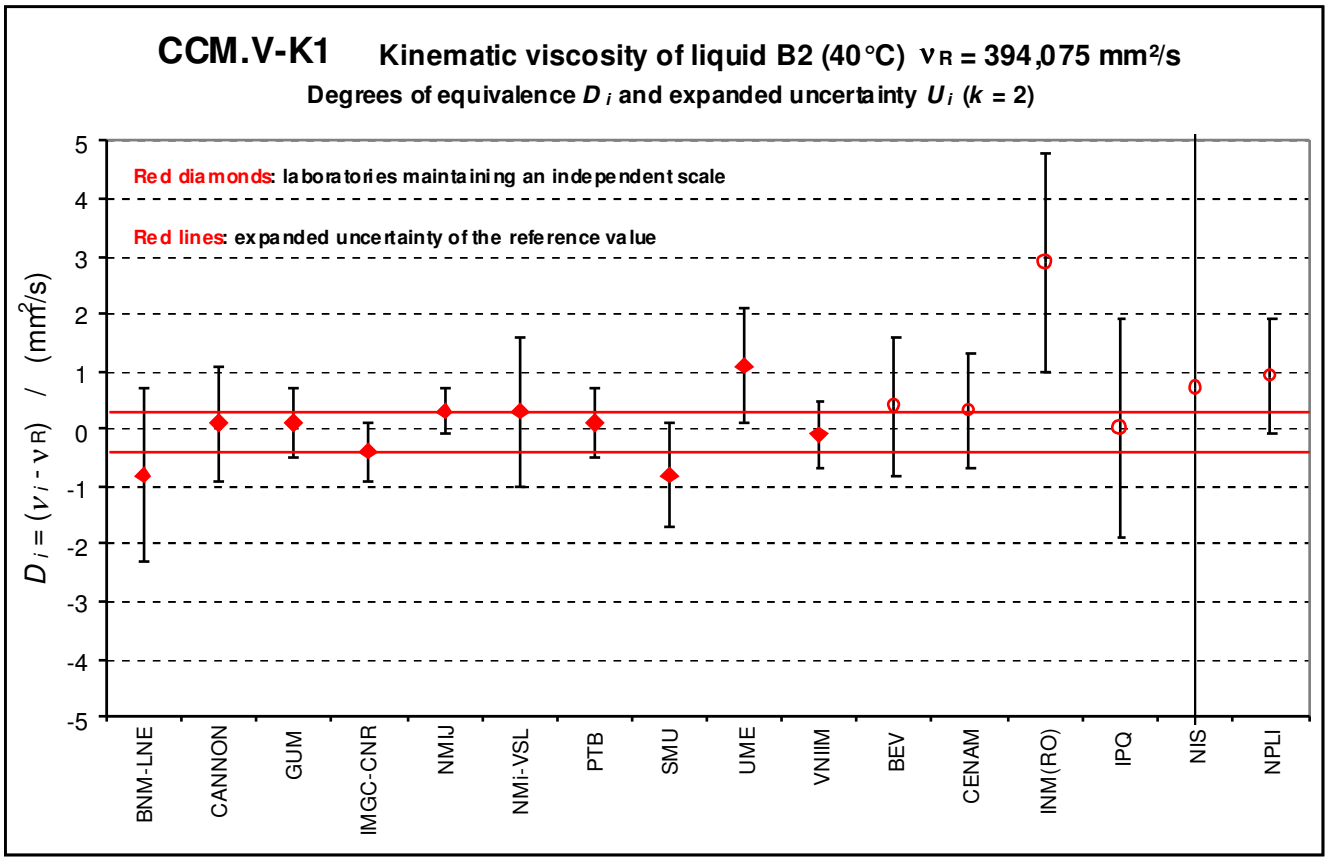


Figure (5) Liquid B2 @ 40°C

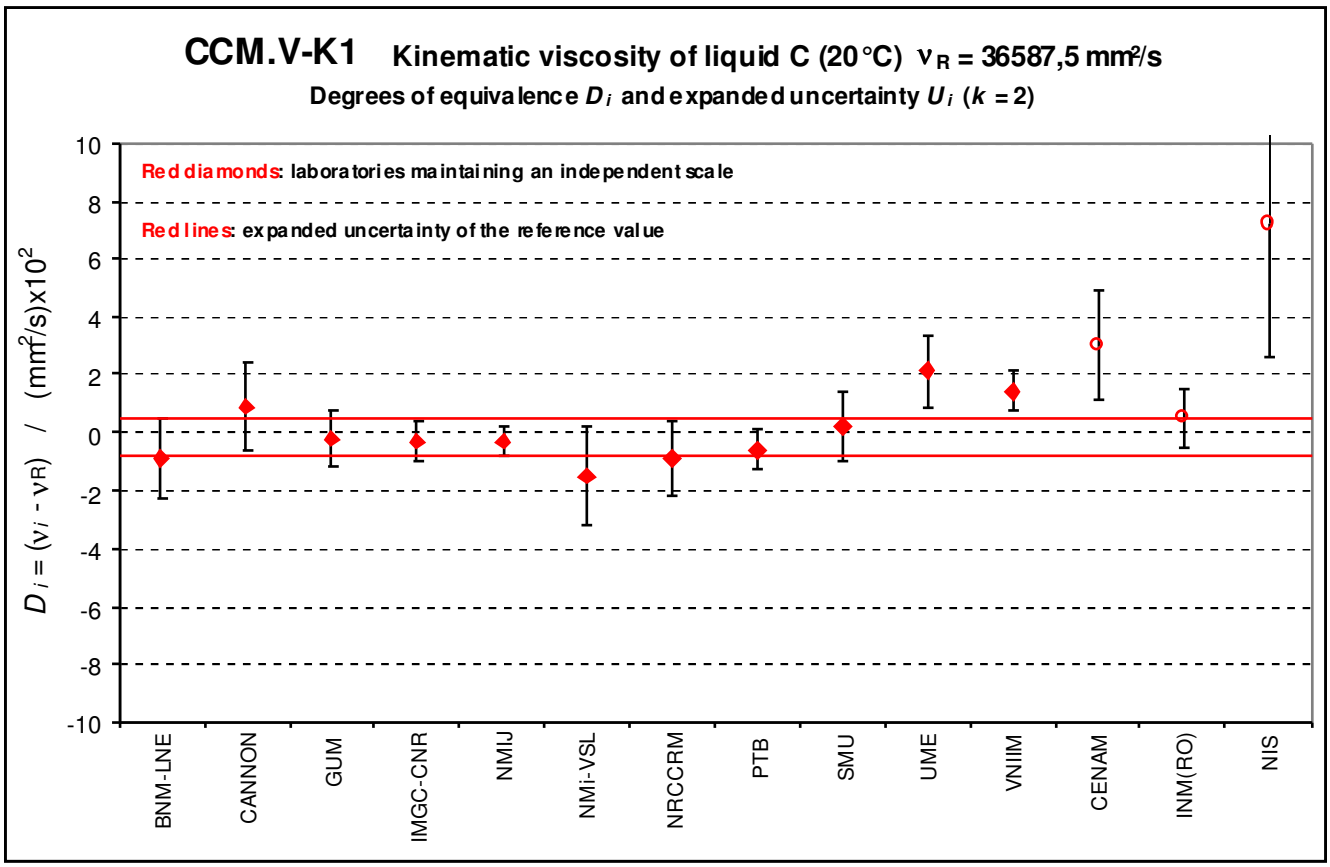


Figure (6) Liquid C @ 40°C

9. Conclusion

The paper gives a very good brief for viscosity measurements and what is meant by viscosity and its scientific meaning

The intercomparison of (NIS) scale with other scales enables mutual acceptance of accurate calibration system and tracability to international measurement metrology. This rationalize and harmonize the Egyptian national scale and assure international Tracability.

From the NIS measurements it is clear that the difference between the reference values and NIS values lies within the accepted rang taking into consideration the uncertainty $U(D_i)$ which is expressed in the form of 95% confidence level.

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