CHAPTER I
INTRODUCTION
1.1 REVIEW OF EXPERIMENTAL TECHNIQUES FOR MEASUREMENT OF VISCOSITY.

The principal property characterising flow resistance is viscosity. It can be defined as the internal friction of a fluid. When the fluid passes between two parallel plates of unit area and unit distance apart, and the plates are moved in opposite directions at a given rate of shear, a certain force must be applied to overcome the shearing stress of the fluid. The ratio of shearing stress to the rate of shear is an expression of the viscosity.

For a Newtonian fluid this ratio is a constant and can be mathematically expressed as

\[ F = \eta A \frac{dv}{dx} \quad (1) \]

where \( \eta \) is a constant called the coefficient of viscosity, the physical dimensions of which are \( \text{ML}^{-1}\text{T}^{-1} \). In S.I units it has the unit pascal. second or \( \text{NSm}^{-2} \). In C.G.S. system it is measured in poise\(^1\).

The quotient of viscosity by density (\( \eta/d \)) assumes much importance and is called the kinematic viscosity \( ^2 \). It is usually abbreviated as \( \nu \) and has the dimensions \( \text{L}^2\text{T}^{-1} \). The reciprocal of the viscosity coefficient is known as the fluidity \( \phi \). The relationship between these quantities being

\[ \eta = \nu d = 1/\phi \]
There are several ways of making viscosity measurements, but there are relatively few that lend themselves to industrial practice where the measurement is to be used for purposes of control. The various visometers can be broadly classified as

A) Tube viscometers 3-14
B) Capillary type viscometers 15-37
C) Rotational type of viscometers 38-44
D) Miscellaneous Types of viscometers 45-61

A) TUBE VISCOMETERS

The development of absolute viscometers has taken a big leap with the early improvements to the poiseuills apparatus. In the viscometers developed by subsequent investigators the defects of poiseuills apparatus have been recognised and attempts have been made to eliminate them. These viscometers include Blotte's viscometer, Bruckner's viscometer, Thorpe and Rodger's viscometer, Stone's viscometer and Erk's viscometer.

The use of various forms of tube viscometers is so common in certain industries that some account of the instruments standardised must be included in any survey of viscometric practice. Three main commercial viscometers, namely, Redwood, Saybolt and Engler viscometers are discussed here.

The Redwood, Saybolt, and Engler viscometers may lay claim to the description under absolute viscometers, in that
their standardisation depends primarily on dimensions, the calibration which has been found necessary to ensure uniformity being in the nature of a retirement due to the impossibilities of specifying the dimensions to the precision required.

The principle underlying the design and use of each of these three viscometers is essentially the same. The liquid to be examined is poured into an opencup or tube mounted in a small bath which can be filled with water or oil to provide temperature control. In the middle of the base of the cup there is a carefully bored Jet which is provided with a simple form of valve. The level of the liquid in the cup is adjusted to a definite height, the Jet is opened and an observation is made of the time required for a stated volume to be discharged through the air into a measuring vessel placed below the Jet.

The Redwood No.I viscometer \(^9,10\) can be used for all oils, the time of flow for 50 ml of which, at the temperature of the test, does not exceed 2000 seconds. The oils of greater viscosity are to be tested in a Redwood No.II \(^11\) viscometer. The Redwood viscometers are unsuitable when the time of flow is less than 30 seconds. It is recommended that viscosity determination shall be made at one or more of the following temperatures: \(70^\circ F, 100^\circ F, 140^\circ F, 200^\circ F, 250^\circ F\). These types are mainly used in some industrial fields because of its popularity due to simplicity and inexpensive operation. The major areas of application of Redwood No.I and Redwood No.II is for measuring viscosity of petroleum products. Redwood No.I can
be used in the viscosity ranges of 1 to 500 centistokes, while the Redwood No.II can be used in the viscosity ranges of 500 to 5000 centistokes.

The Saybolt viscometer as laid down by the American Society of testing materials has the standard method of test for the viscosity of petroleum products and lubricants. Viscosity shall be determined by means of Saybolt Universal viscometer or Saybolt Furol viscometer. In general, Saybolt Universal viscometer shall be used for lubricants and the Saybolt Furol viscometer for fuel oils and other oils of similar viscosity. However, the Saybolt Universal viscometer shall not be used for times of flow less than 32 seconds. The viscosity measurement ranges from 400 to 4000 centistokes.

The Engler viscometer finds application mainly in the viscosity measurement of tar and other petroleum products. The range of measurement varies from 1 to 1500 centistokes.

B. CAPILLARY TYPE VISCOMETERS

If liquids of known viscosity are available for calibration purposes there is no advantage to be gained by the use of viscometers which have been specially designed to comply with the requirements indicated in the absolute measurements as necessary for the accurate determination of viscosity in absolute units.

On the contrary, the small diameters which have been shown to be essential for such instruments entail liability to
obstruction which can only be obtained by the most elaborate precautions. Further, the viscosity can be conveniently measured by the capillary viscometers described below and can be made more compact and more robust than those described as suitable for absolute measurements.

Capillary type viscometers can be either with an externally applied pressure or rely solely on the hydrostatic head of the liquid in the viscometer for the production of flow. However the measurement by externally applied pressure type claims the advantage for the fact that with a single instrument it is possible to make tests on liquids of very widely different viscosity without inordinately prolonging the time of flow of the more viscous fluids.

With gravity type of viscometers it is necessary, in order to calculate the relative viscosity, to determine the density of the liquid under examination with a percentage accuracy higher than the accuracy of measurement of time of flow. With the pressure type, the hydrostatic head of the liquid in the viscometer appears only as a correction term, and the density need not be known with any great precision.

The pressure type of viscometers also suffer from the disadvantages of 1) the necessity for the provision of a source of constant pressure and of a gas tight connection therefrom to the viscometer and to a manometer 2) the possibility of error either in the observation of manometric pressure or in the
application of the various corrections required to find the effective driving pressure.

Glass capillary viscometers have been widely used in determining the viscosity of many fluids. Most glass capillary viscometers are operated by the force of gravity. Because of the small driving force, this class of devices is useful for low viscosity liquids ranging from 0.4 to 16,000 centistokes. The viscometer can often be operated by application of external pressure in addition to the hydrostatic pressure. In this way the range of viscometers can be increased by as much as 40 times. Many non-newtonian fluids can be studied when external pressure is applied.

The principle of these instruments is derived from the viscometer originally used by Ostwald. Basically, the viscometer consists of reservoir bulbs and a capillary in U-tube arrangement. The original ostwald viscometer has been modified in many ways to minimise certain undesirable effects in viscosity measurements to increase the range of viscosity or to meet the specific requirements of certain test liquids. For instance, Cannon and Fenske modified the Ostwald viscometer so that the upper and lower bulbs lie on the same vertical axis, in order to reduce the error in the mean head caused by deviation of the viscometer from the vertical position.

For opaque fluids the viscometer was modified to have reverse flow so that movement of the miniscus can be clearly

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observed. Glass capillary viscometers have been widely used for determining viscosities of Newtonian liquids and gasses because of their excellent accuracy, relative cheapness, and simple operation.

Since non-newtonian properties are usually encountered in thick materials, measurements on such materials are often made applying external pressure to the viscometer. A summary of various types of glass capillary devices is given below:

CANNON-FENSKE VISCOMETER:

Two types of viscometers are used, one for transparant liquids and the other for opaque liquids. The one which is used for opaque liquids is often called as the reverse flow type. These viscometers can be used in the range of 0.4 to 1.6*10^4 centistokes.

UBBELOHDE VISCOMETER:

The major advantage of this viscometer over Cannon-Fenske viscometer is that it is not required to make corrections for temperature to the viscometer constant. In this the liquid is induced to flow only down the walls of the bulb below the capillary. This assures that the lower liquid level is automatically fixed and coincides with the lower end of the capillary, so that it is unnecessary to fill the viscometer with a definite volume of liquid. This can be used in the ranges 0.2-10^4 centistokes.
FITZ SIMONS VISCOMETER:

The unique feature of this viscometer is that filling, observing the efflux time, and cleaning can be done without removing the viscometer from a temperature bath. The operating range of this viscometer is $0.6-1.2 \times 10^3$ centistokes.

SIL VISCOMETER:

The SIL viscometer has the unique feature of an overflow gallery which is on the open arm. This feature permits precise automatic establishment of the corrected volume after the liquid under test has reached the desired temperature. This can be conveniently operated in the range $0.6-10^4$ centistokes.

ATLANTIC VISCOMETER:

The main feature of this type of viscometer is that in this it does not have a U-tube arrangement as in the case of most of the glass capillary viscometers. In this, the capillary is connected to a large diameter tube so that the liquid can flow along the walls. This feature simplifies the construction of the viscometer considerably and can be operated in the range $0.6-10^5$ centistokes. This Atlantic viscometer is particularly well suited to use with applied air pressure.

ZEITFUCHS CROSS ARM VISCOMETER:

This comes under the reverse flow type and consequently suitable for both transparent and opaque liquids. A small volume of the sample is charged in a horizontal cross arm glass tube and the liquid flows down through the siphon and capillary
into the small efflux bulb. The capillary length-to-diameter ratio is large in these type of viscometers. This type of viscometer has a wider range of viscosity than other glass viscometers and can be operated in the range $0.6-10^5$ centistokes.

**BLOOD VISCOMETER:**

This viscometer consists of two capillaries one for the reference material and the other for a fluid to be measured. By mouth suction through a common header, the two liquids are drawn into capillaries at the same time. The scale of reference materials in read for a fixed length of capillary travelled by the test liquid. Obviously, the measurements are relative using water as a reference, the viscometer can measure upto 28 centipoises. The range can be extended by selecting other reference liquids.

A brief summary of some commercially available viscometers specially designed to operate over wide ranges of applied pressures is given below.

**MCER-HIGH-SHEAR-RATE CAPILLARY VISCOMETER:**

The Merz-colwell Extrusion Rheometer was originally developed at the Plastics Division of the Monsanto Chemical Company. In this viscometer, the piston movement causes the test material to flow through a precision-bore stainless steel capillary tube.

This instrument operates at pressures upto about 40,000 lb/in$^2$. At these pressures most fluids exhibit some
compressibility. For low viscosity fluids, a special piston having one or two O-rings may be needed to prevent back flow. A principal advantage of this instrument is that large (L/D) ratio capillaries can be used. This reduces the contribution of entrance effect, which normally can be neglected with this instrument. Viscosities in the range of about 1 to $5 \times 10^6$ poise can be measured with the instrument.

STANDARD OIL HIGH PRESSURE CAPILLARY VISCOMETER

This viscometer is a typical example of the cylinder-piston type of capillary viscometer using a hydraulic pressure system.

In this viscometer, the piston chamber is attached to the instrument by a union connection and the chamber can be easily removed from the system for filling or cleaning. Both ends of the chamber can be operated by threaded connections. Because of these features, loading and cleaning operations are relatively easy. There is no temperature control device in the instrument. The viscometer is designed only for tests at room temperature. If an accurate temperature control is desired, the cylinder should be thermostated.

This viscometer is not equipped with a safety device. For measurements of fluids of unknown properties, a pressure relief valve should be installed. This viscometer is not suited for slurries containing large solid particles. This can conveniently measure viscosities of the range $1-10^5$ poise.
MELT INDEXER:

This melt indexer is essentially a capillary viscometer of the extrusion type designed by E.I.Dupont de Nemours and Company. It was originally developed for determining the flow properties of polyethylene resins. The flow property is arbitrarily defined as the rate of extrusion of a thermoplastic through an orifice of a specified length and diameter under prescribed conditions of temperature and pressure. For polyethylene, this flow rate is called the melt index.

This apparatus is a dead weight piston cylinder plastometer and uses only one capillary and therefore measurements are limited. Unlike, the high pressure viscometers that have hydraulic systems in which measurements are dependent is less complicated. Its measurable viscosity range is about $50-10^5$ poise.

WESTOVER HIGH PRESSURE RHEOMETER$^{37}$:

This rheometer was first designed and constructed by R.F.Westover to study the capillary flow behaviour of polymer melts over a wide range of hydrostatic pressures. The instrument is particularly suitable for studying plastic melts at extremely high pressures upto 30,000 lb/in$^2$. It can also be used to study the effect of dissolved gasses on viscosity. This can be done by loading the instrument at a temperature slightly below the triggering temperature of the foaming agent.
BURREL-SEVERS EXTRUSION RHEOMETER:

The Burrel-Severs Rheometers are well designed instruments for various Rheological measurements. This Rheometer operates by pneumatic pressure applied by compressed air or nitrogen gas. These rheometers have large capillary length to diameter ratios. They are reported to be precise and accurate instruments. The cheapest model can also be operated by gravity.

P.P.I. RHEOMETER:

This rheometer is a gas operated high pressure viscometer manufactured by pressure products industries, Hatboro, Pennsylvania. The operational procedure is similar to that for the Burrel-Severs Extrusion Rheometer. The instrument is mainly used for characterising flow properties of plastic melts and is designed for simplicity and flexibility of operation in routine tests rather than for accurate rheological measurements. With proper capillaries, the apparatus becomes an excellent working tool especially because of the convenience of its compactness and neat and clean operation.

C. ROTATIONAL TYPE VISCOMETERS:

Rotational viscometers are versatile laboratory instruments for measuring flow properties of many fluids. Many rheologists prefer this instrument because of the simplicity of the design and ease of manipulation. A brief review of some of the commercial rotational viscometers is given below:
The Rotovisco is by-far the most versatile viscometer found. The main advantages of this instrument is reduced heat losses from the measuring assembly at elevated temperatures and the convertibility of any laboratory recorder to receive the signal from the Rotovisco by means of a suitable helipot. The chief disadvantage being its relatively high moment of inertia which causes some difficulties in determining the yield value and prevents measurement of many transient effects. The measurable apparent viscosity of this instrument is in the range $5 \times 10^{-3}$ to $4 \times 10^7$ poise.

The Agfa rotational viscometer has a measuring range of $10^{-1}$ to $10^5$ poise at a temperature range of $-30^0$ to $+70^0C$. The chief advantage of this instrument is its high natural frequency that produces accurate readings in intervals as short as about 0.01 seconds. Another elegant research instrument well suited to fundamental research on homogeneous visco elastic fluids is the Rheogoniometer. Its design incorporates many of the most desirable features of a rotational viscometer such as rigid torque sensing member, very small time constant, combination of a steady state and dynamic measuring systems etc., This Rheogoniometer has an excellent temperature control with measurable apparent viscosity of $10^{-3}$ to $10^{-10}$ poise.

The Merrill-Brookfield viscometer, developed by Professor Edward W.Merrill of M.I.T. is a research tool elegant design which is specially meant for measurements of fluids under high rates of shear. The specific design of this viscometer for
non-Newtonian measurements is a most welcome addition to the field of commercially available rheological instruments. Its apparent viscosity range is $2.5 \times 10^{-1}$ to $10^3$ poise. Another commercial viscometer available for measuring properties of non-Newtonian fluids is Ferranti-Shirley Cone-Plate viscometer. Its measurable viscosity range is $2 \times 10^{-1}$ to $3.16 \times 10^4$ poise and has good temperature control up to $200^\circ C$.

The Brookfield Synchro-Lectric viscometer is one of the most widely used viscosity measuring units in this country. It is well adapted to many types of service and can make a measurement in almost any type of can, pot or bucket. Drage Rheometer is an improvised Brookfield synchro-Lectric viscometer and therefore is a contribution to rotational viscometry. This instrument is portable and handy to use. Drages Rheometer has viscosity range between $5 \times 10^{-2}$ to $3 \times 10^4$ poise while Brookfield viscometer has $10^{-2}$-6.4$ \times 10^5$ poise.

The Fann V-G meter based on the design of the Socony-Mobil Oil Company was specially designed to measure plastic viscosity and yield values of drilling muds in oil industry. This viscometer will measure apparent viscosities in the range of $1.0 \times 10^{-3}$ to $3 \times 10^2$ poises. Two other viscometers which come under the similar principle of operation of Fann V-G meter are Mac-Michael viscometer and the Precision-Interchemical viscometer whose measurable viscosities are respectively $10^{-1}$-2.1$ \times 10^4$ poise to $1-2.5 \times 10^3$ poise.
Two other viscometers which are essentially the same in design are C.W. Brabender visco-corder and visco-Amylo Graph. The visco-corder differs from the visco-Amylo-Graph in the means of controlling temperature. These instruments are capable of measuring viscosities in the range $10^{-1} - 3.5 \times 10^3$ poise.

The Hercules High-Shear viscometer is manufactured by Martinson Machine Company and is based on a design concept of the Hercules Powder Company. In this instrument, the basic disadvantage is that the temperature control is absent. It can measure viscosities in the range of $20 - 9 \times 10^3$ poise.

The CENCO viscometer is basically an educational instrument useful for demonstrating rheological fundamentals. It has a poor temperature control and the apparent measurable viscosity is $10^{-2} - 6.45 \times 10^2$ poise. The CORN industries viscometer is manufactured by Gaertner Scientific Corporation for detecting the changes in physical properties of starch suspensions. It has a good temperature control.

D. MISCELLANEOUS TYPE OF VISCOMETER:

The flow behaviour of a fluid in a Rheological instrument is obtained in principle by solving the equation of motion for the given geometry with appropriate boundary conditions. In order to solve the equations an expression for stress in terms of the velocity gradient is required. For a particular rheological model, a useful relationship between
rheological parameters and measured quantities can sometimes be derived. Some miscellaneous type of viscometers are given in table 1.1.1.

Of all these types, capillary viscometer technique is one of the most popular methods for obtaining flow measurements. Glass capillary viscometers have been widely used for determining viscosities of Newtonian liquids because of their excellent accuracy, relative cheapness and simple operation. In view of this, we proposed to design a personal computer based glass capillary viscometer with suitable modifications.
<table>
<thead>
<tr>
<th>Name</th>
<th>Approximate measurable apparent viscosity (poise)</th>
<th>Features</th>
<th>Accessories and special attachments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Falling or Rolling ball type:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoepper</td>
<td>$10^{-4}-10^4$</td>
<td>Good accuracy and reproducibility</td>
<td>Set of balls, stopwatch, circulating thermostat.</td>
</tr>
<tr>
<td>Ruska</td>
<td>NA</td>
<td>High pressure upto 12,000 lb/in² and high temp. upto 350°F</td>
<td>Timer, Pyrometric controller, and six stainless steel balls.</td>
</tr>
<tr>
<td>Gerin</td>
<td>NA</td>
<td>Field testing of lubricating oils.</td>
<td>---</td>
</tr>
<tr>
<td>Visage</td>
<td>0.4-4.5</td>
<td>Field testing of oils</td>
<td>---</td>
</tr>
<tr>
<td><strong>Rising bubble type</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gardner</td>
<td>10-2000</td>
<td>Glass tubes with corks, simple test unit.</td>
<td>viscometer holder, stopwatch.</td>
</tr>
<tr>
<td>vertical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gardner</td>
<td>0.005-1060</td>
<td>A set of reference viscosity tubes, five series.</td>
<td>---</td>
</tr>
<tr>
<td>bubble</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM</td>
<td>4-1000</td>
<td>Simple glass tubes</td>
<td>Holder, stopwatch</td>
</tr>
<tr>
<td>timer</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>tubes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R.P.C</td>
<td>NA</td>
<td>Set of reference tubes</td>
<td>Holder, stopwatch</td>
</tr>
<tr>
<td>viscosity</td>
<td></td>
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<td></td>
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<tr>
<td>tubes</td>
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<tr>
<td><strong>Telescopic Shear and related units</strong></td>
<td></td>
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<tr>
<td>Gardner</td>
<td>NA</td>
<td>Simple weighted plunger</td>
<td>Stop watch</td>
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<tr>
<td>mobilo-</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>meter</td>
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<td></td>
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<tr>
<td>SIL</td>
<td>NA</td>
<td>Simple leaking cone with split bearing, water jacketed</td>
<td>Stop watch</td>
</tr>
<tr>
<td>Name</td>
<td>Approximate / measurable</td>
<td>Accessories and special attachments</td>
<td></td>
</tr>
<tr>
<td>------</td>
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<td>------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>Features</td>
<td>Penetro-meter</td>
<td>Cheap method for rheology of rigid goods.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sliding motion type</td>
</tr>
<tr>
<td>NPIRI band</td>
<td>10-3000</td>
<td>Mylar film-band, thermostated blocks, stop watch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Designed for ink characterization. 2 parallel plates with a plastic film passing between.</td>
<td></td>
</tr>
<tr>
<td>Sliding plate</td>
<td>100-10^{11}</td>
<td>Recorder and thermostated bath, stop watch.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Designed for asphalt characterization. Two parallel glass plates.</td>
<td></td>
</tr>
<tr>
<td>Vibrating reed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultraviscoson</td>
<td>0.5-10^{3}</td>
<td>Recorder and/or controller, temperature compensator.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vibrating reed with response-sensing unit; stands high pressures and temperature</td>
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</tr>
<tr>
<td>Mixture with dynamometer</td>
<td></td>
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</tr>
<tr>
<td>Plastograph plastigraph plastiser, or Farnograph</td>
<td>&gt;ca.20, large range</td>
<td>Practical measurement of softening caused by mixing or blending.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermostating or furnacing; wide range of mixture geometries, extrusion and working equipment.</td>
<td></td>
</tr>
<tr>
<td>Continuous industrial rotational type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hallikainen</td>
<td>500-5000</td>
<td>Strain gage as the force sensing element.</td>
<td></td>
</tr>
<tr>
<td>non rotating disk</td>
<td></td>
<td>Recorder and/or controller.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brookfield</td>
<td>0-500</td>
<td>Flapper- Nozzle arrangement, variable condenser, or potentiometer for reading spring deflection.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recorder and/or controller.</td>
<td></td>
</tr>
<tr>
<td>Capillary type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hallikainen</td>
<td>0-25</td>
<td>Pressure drop along tube converted to pneumatic signal.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recorder and/or controller.</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Approximate measurable apparent</td>
<td>Features</td>
<td>Accessories and special attachments</td>
</tr>
<tr>
<td>----------------------</td>
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</tr>
<tr>
<td>Viscosity (poise)</td>
<td></td>
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</tr>
</tbody>
</table>

**Float type**

- **Fischer-porter 4-85**
  - Rotameter measuring viscosity via sensitive float controller.

- **Fischer-porter 0-1000**
  - Piston upheld by viscous drag, with plunger position controller to measure viscosity.

**Plunger type**

- **Norcross 0-10^4**
  - Piston raised by a lifting mechanism and end of piston travel sensed by a proximity switch.

**Falling needle type**

- **-- --**
  - Reduce the end correction factor.

**Vibrational Sphere type**

- **-- 4x10^{-3}**
  - Maximum error < 5% for viscosity measurement
  - Frequency counter digital voltmeter

**Bob-in-Cup type**

- **-- --**
  - On line computer to calculate the net torque and reduce the surface effects at the fluid-air interface
  - Computer controller, Digital voltmeter, and constant temperature source

**Differential type**

- **-- --**
  - Capable of measuring differences in viscosities as small as 4%
  - Two rotating cylinder viscometers

**Buret type**

- **-- --**
  - Provides a ready means of comparing instrumental and physical variables.
The viscosity behaviour of binary liquid solutions commonly starts from the concept of an "ideal" solution, with a view to considering particular systems as departing more or less from the ideal behaviour. There seem to have been few studies on the effects of variations in type and degree of interaction between unlike molecules on the viscosities of binary liquid mixtures. Positive deviations from a rectilinear dependence on mole or volume fraction, and maxima, may occur if strong specific interaction causes complex formation. Negative deviations occur where dispersion forces are primarily responsible for interaction but they may also occur where components are known to interact more strongly.

Fort and Moore measured viscosities of fourteen binary liquid systems at different molar concentrations at 25°C and calculated excess viscosities. The expression for excess viscosity $\eta^E$ is given by

$$\eta^E = \eta - x_1\eta_1 - x_2\eta_2$$

Where $\eta$ is the viscosity of the mixture and the subscripts (1) and (2) refer to the components. $\eta^E$ may be used to represent deviations from a rectilinear dependence of $\eta$ on mole fraction. Grunberg and Nissan suggested the following equation:
where \( d \) is a constant proportional to \( W/RT \) and \( W \) is the interchange energy. Values of \( d \) would seem to provide a better measure. Their variation with composition is not large except where strong specific interactions might be expected to vary with composition. At any given composition the variation of \( d \) with strength of interaction is similar to that of excess viscosity. Excess viscosity is negative for systems in which dispersion forces are dominant. It is less negative and then increasingly positive as the strength of interaction increases correspondingly.

Viscosity of aqueous Ammonium Nitrate solutions was determined by Kuppusami and Suryanarayana\(^67\) at 25°C and 35°C. Densities and Viscosities of Tiethylamine in Methanol, Ethanol and 1-Propanol were calculated by Kumar et al,\(^68\) at 25°C. From experimental data molar volume and their excess values along with excess viscosity and excess molar Gibbs free energy for the activation of flow have been computed and presented as functions of composition. The parameter \( d \) of the Grunberg and Nissan expression has also been calculated. The molar volume \( V \) of a mixture is defined as

\[
V = \frac{\bar{N}}{P} \quad (3)
\]

where \( \bar{N} = X_1 M_1 + (1-X_1) M_2 \quad (4) \)
M₁ and X₁ being the molecular weight and the mole fraction of the first component respectively and M₂ and (1-X₁) the molecular weight and the mole fraction of the second component, respectively. Excess molar Gibbs free energy for activation of flow Gₑ can be calculated from equation

\[ Gₑ = RT \left[ (\ln n)V - X₁ (\ln n₁)V₁ - (1-X₁) (\ln n₂)V₂ \right] \rightarrow (5) \]

The viscosity of mixtures of water with a number of organic liquids studied by Robert Stairs⁶² and of some mixtures of two organics has been analysed in terms of its deviation from ideality. Peter Thompson et al.,⁶⁹ calculated viscosities of solutions of electrolytes and Non-electrolytes in Ethylene Carbonate at 40°C. Hind et al.⁷⁰ proposed the relationship

\[ n = X₁^n₁ + 2X₁X₂n₁₂ + X₂^n₂ \rightarrow \ 
\]

Where n₁₂ is a term arising from interaction between components. Tamara and co-workers⁷¹,⁷² expressed the following equation for the viscosities of binary mixtures in terms of the volume fractions

\[ n = X₁V₁n₁ + 2(X₁X₂V₁V₂)^{1/2}n₁₂ + X₂V₂n₂ \rightarrow \ 
\]

where V₁ and V₂ are volume fractions, statistical mechanical basis of equation (8) is given by Bearman and Jones.⁷³

Viscosities of water between 0 and 60°C and of selected aqueous Sucrose solutions at 25°C were determined by James et al.,⁷⁴ using a Flared Capillary Viscometer. For Capillary
Viscometers the relationship between the coefficient of viscosity, \( n \) and density, \( p \), of the liquid involved and the observed flow time \( t \) is given by the expression

\[
\frac{n}{p} = ct - \frac{b}{tn} \tag{8}
\]

where \( c \) and \( b \) are constants for a particular viscometer and \( n \) varies from unity for conventional capillaries to four for the most extensively flared type. The \( b/tn \) term is associated with the kinetic energy correction. For the continuous-flare case, however, \( b \) is close to zero and equation (8) reduces to

\[
\frac{n}{p} = ct \tag{9}
\]

The precision of water viscosities at various temperatures obtained is 0.1% or better.

In chemical industry, a knowledge of the thermodynamic and physical properties of multicomponent systems is essential for design calculations involving separations, heat transfer, mass transfer and fluid flow. For many systems, there exists only a small amount of experimental data and no reliable methods for estimating the desired property for a particular composition of a multicomponent system. William Acree and Gary Bertrand\textsuperscript{75} calculated viscosity of multicomponent systems from data for binary systems at 25°C. Viscosities of NaI in water-N,N-Dimethylformamide mixtures were studied by Taniewska-Osinska et al\textsuperscript{76} in the temperature range 5-45°C. Densities and viscosities measured by Muhammed Rauf et al,\textsuperscript{77} at five different
temperatures, in the temperature range 15-55°C with a regular interval of 10°C and plotted graphs between molar volume vs. Mole fraction. The estimated error of measurement in viscosities was $1 \times 10^{-4}$ cp.

Subha and Brahmaji Rao have undertaken studies on binary mixtures containing Alkanoic Acids. The parameter $d'$ of Grunberg and Nissan has also been calculated. It is recognised that for a better understanding of solute-solvent interactions, Water-Alcohol mixtures have proved to be the most interesting due to unique structural relationship of Alcohols with pure Water. Thermodynamic studies of Amino Acids in aqueous Alcohol mixtures are not many and often a particular property has been determined only at one or at a few selected volume ratios and temperatures. Viscosities of some Amino Acids in Methanol-Water mixtures were studied by Sandhu and Urmil Kashyap at 298.15, 308.15 and 318.15K.

Rattan et al. estimated free volume, excess molar Gibb's free energy and excess viscosity from the viscosity data of mixtures of Cumene in Methanol, at 25°C and 35°C. An Ubbelohde Viscometer with accuracy 0.001 cp is used. Density, viscosity of six binary mixtures determined by Aminabhavi et al. at 293.15K. From this data they calculated thermodynamic and hydrodynamic excess quantities.

Excess viscosities and partial molar excess viscosities of binary mixtures of water with Tetrahydrofuran and Dioxane have been computed by Venkateswarlu et al.
Viscosity is one of the important tools for the determination of ion-solvent interactions which are the controlling forces in dilute solutions where ion-ion interactions are absent. Susanta Das and Dilip Kumar Hazra studied relative viscosities of Tetraalkylammonium Bromides in Dimethylsulphoxide-Water mixtures at 25, 35 and 45 °C. Nigam and Singh carried out Viscometric studies on the four binary systems, at 25, 30 and 35 °C. They evaluated the Grunberg and Nissan Parameter 'd'.
SECTION 1.3

ROLE OF MICROPROCESSORS/MICROCOMPUTERS IN INSTRUMENTATION

Microprocessors play an important role in the design of digital systems. This is a general purpose programmable logic device. They are found in a wide range of applications, such as process control, communication systems, digital instruments and consumer products. Microprocessor is used as a part of an intelligent instrument with the capabilities like keyboard and display, controlling, and arithmetic calculations.

There are many advantages for microprocessor based instruments. Interfacing the keyboard with a processor allows to enter the numbers using a numeric keypad rather than control knobs. The microprocessor based measurement offers CRT text read-out, updating measurement readings, scale factors, general calculations, waveform scaling, time-frequency conversion, scale factor calculation, controlling and coordinating modules within an instrument etc.,

Another useful feature is auto or self calibration. Self-calibration can also be extended to complete waveforms in waveforms processing instruments. These instruments have the provision to store and print the data. Processing and Analysis of data is another important feature of these instruments. There is a provision for real time measurements.
Another important advantage in using microprocessors is their self-test ability. A microprocessor with appropriate software can easily locate the failure at any part of the instrument and it can also give information regarding the various activities which are in progress.
Viscosity is one of the important properties of a fluid. The measurement of the viscosity of a liquid is of great importance in Medicine, Industry and in Research. Poiseuille's law was discovered in the course of an investigation, preliminary to an understanding of the circulation of the blood in body. It was not until two generations later that the law was shown to fail when applied to the flow of blood in fine capillaries. In connection with the clinical examination of blood Hess, using a capillary viscometer of his own design carried out a series of investigations.

Calculation of viscosity is necessary in the preparation of paints, printing inks, chocolates and detergents to ensure that consistency is right under various conditions used. There are many characteristics of a product or material that can indicate its quality, acceptance or performance in its intended use color, density, stability, composition, solids content and PH are examples of this type of "Product dimension".

Precise measurement of viscosity is very useful in understanding the rheology of liquids and solutions. Viscosity data of fluids help to predict their pourability, their performance in dipping or coating operations, the ease with which they may be handled processed or used. In the case of mixtures and solutions the excess viscosity data can be used to understand solute-solvent interactions.
It is also one of the important tools for the determination of ion-solvent interactions which are the controlling forces in dilute solutions where ion-ion interactions are absent. Information concerning molecular weight and shape of organic molecules can also be obtained from the determination of viscosity.

There are a number of different approaches to the continuous measurement of viscosity. The different types of viscometers available are broadly classified into Tube viscometers, Capillary viscometers, Rotational type viscometers and Miscellaneous type of viscometers.

Of all the above mentioned viscometers, glass capillary viscometers have been widely used for determining the viscosities of Newtonian liquids and gasses because of their excellent accuracy, relative cheapness and simple operation. In glass capillary viscometers extreme cleanliness of the instrument is essential for accurate measurement because of the small dimensions involved. This technique also requires further refinement. Hence computer based Glass Capillary viscometer is developed in the present study for measuring flow times accurately.

In the case of Glass Capillary viscometer, the time of flow of fluid between two reference marks is measured with human eye as detector and stop watch as time measuring device. However, it is difficult to maintain perfect synchronism between
eye and hand. This limits the accuracy in flow time measurements. Hence, in this work, the viscometer is modified by incorporating opto-electronic detection system and measuring the time of flow automatically with personal computer through proper interfacing. These modifications improve the accuracy and reliability of time of flow measurements. The design features, calibration and measurement procedure and results are presented. Instrument design is carried out such that it can be immersed in a liquid temperature control bath and viscosity measurements can be made at different temperatures.
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