Analysis of fluid flow states in viscometers in ansys software

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Abstract. Viscometers have multiple major applications in various areas of engineering, as the fluid flow is inherently connected to the properties of fluid viscosity. This paper substantively examines the fluid flow state over a capillary viscometer to examine the stability of such flow under the effects of various geometries (variations in tube length and cylinder base shape) of capillary viscometer, using a simulation model improved by means of the application of finite element software in Ansys 16 to depict the flow in the capillary viscometer. In this work, experimental measures were utilised and implemented to evaluate various fluid properties and to observe the effects of the geometrical shapes of the viscometer on the flow properties (pressure, velocity, and temperature) and the effect of fluid type on the vortex and fluid circulation during flow.

1. Introduction
Viscosity is the essential factor for investigating and identifying the properties of liquids, as this fundamental characteristic represents the strength to stream or shear off due to internal resistance to flow and also determines the friction of fluids in terms of drag force. Temperature and pressure play significant roles in determining the value of viscosity, especially concerning state changes from and to liquid or gas, which respond in different ways to changes in temperature and pressure, which thus affect the viscosity in varying ways. In this study, the focus was thus on liquid viscosity in terms of changes with respect to temperature.

Viscosity can be expressed in two main forms:

a. Absolute or dynamic viscosity.

b. Kinematic viscosity.

The tangential force is part of dynamic viscosity, measured per unit area, referring to the force required to slide one layer (A) along a different layer (B) as depicted in figure 1 where the two layers are of a certain unit length.

Figure 1. Sample shear of the liquid film.
Figure 1 shows how the force $F$ for layers A and B decreases rapidly at $v_1$ and $v_2$, respectively. Subsequently, the stickiness of a liquid can be defined as the amount of resistance of the fluid to pouring, in the mathematical form [1] such that

Shear stress = $\eta$ (shear rate or strain)

dynamic viscosity represented by $\eta$

If $\sigma$ is shear stress and $e$ is strain rate, the term becomes

$$\sigma = \eta e$$

(1)

The strain rate can thus be stated as

$$e = \frac{1}{x} \frac{dx}{dt}$$

(2)

where $x$ is the length, while $t$ is the time, and $dt/dx$ is the velocity $v$. Thus, the effective viscosity can be established using

$$\eta = \frac{\sigma}{v}$$

(3)

The density of the liquid ($\rho$) can be defined as its kinematic viscosity, which is a function of pressure and temperature in the form

$$\nu = \frac{\eta}{\rho}$$

(4)

2. Viscometers

The measurement of viscosity is of importance to both academia and industry. Precise knowledge of viscosity in industrial settings is particularly important [2], and many authors have successfully applied techniques to measure the value of viscosity that has been verified using experimental data. Instruments used to measure liquid viscosity can be classified into several categories [3]:

1. Capillary viscometers
2. Orifice viscometers
3. Increased temperature as related to increased shear value viscometers
4. Circular viscometers
5. Vibrational viscometers
6. Falling ball viscometers
7. Ultrasonic viscometers

3. Ostwald Viscometer

The U-tube type that represents the most widely used gravity type viscometer is the Ostwald viscometer. The main parts are the two bulbs and the fixed-bore pipe, as shown in Figure 2 [4].

**Figure. 2** Ostwald viscometer.
4. Literature review
Stokes' law is the foundation of the field-field viscometer, where the fluid is fixed in a perpendicular glass tube and a sphere of known density and size is observed descending through the fluid.

Pinkevich [5] identified the favourable marks of a successful viscometer, with amplitude measured by the time taken for a sphere to pass two marks in a tube. For measuring viscosity in opaque liquids, they recommended a reverse flow viscometer.

Applying the relevant liquid information such as sphere density and fluid size Stokes’ law could be applied to determine the viscosity for the liquid.

Zeitfuchs (Modified Ostwald) [6]. This halved an inner resistance to flow viscosity as a gauge for resistance to flow or shear. This can also be described as a drag force and may be used for measuring the frictional holding of a liquid. A chain of cross-cut bearings of various diameters was used to obtain a more detailed computation. Experimentation with the liquids and technical approaches was applied to test the viscosity of liquids in a method such as petroleum.

Gabriel [7]. This researcher was interested in waves and the transformations forced by the paths out of different media. Stokes law was used to identify spirant and force drag exhaustion on a spherical body, and numerous Reynolds numbers for constant viscosity in liquid were thus determined.

5. Experimental Work.
A water bath was the main piece of experimental equipment, with rigid sides and apparatus for heating water. It was set to hold water at a steady state during the interval period [8]. In this state, no connection was made to the heater, as shown in figure 4(a) and (b) [9].

Figure 3 Creeping flow past a sphere.

Figure 4. a) water bath at 30 °C; b) Tube with scale in the water bath.
A Koehler conductivity device was used to measure the thermal conductivity of the ethanol and gasoline [10] and crude oil, shown in Figure 5.

![Koehler device](image)

**Figure (5) Koehler device**

Experimental values for the density, kinematic viscosity, and dynamic viscosity for the ethanol, gasoline, and crude oil at different temperatures are shown in Table 1.

| Table 1. Experimental values for the density, kinematic viscosity, and dynamic viscosity. |
|---|---|---|---|---|---|
| Sample | Size of viscometer | Constant mm²/s² | Temp °C | Density gm/cm³ | Time S | Kinematic Viscosity cm²/s | Dynamic viscosity gm/cm.s |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Ethanol | 200 | 0.09499 | 30 | 0.780 | 13 | 1.23487 | 0.963199 |
| | | | 32 | 0.770 | 12 | 1.13988 | 0.877708 |
| | | | 35 | 0.776 | 11.5 | 1.092385 | 0.847691 |
| | | | 37 | 0.774 | 10.9 | 1.035391 | 0.801393 |
| Gasoline | 350 | 0.45868 | 30 | 0.715 | 2.3 | 1.054964 | 0.754230 |
| | | | 32 | 0.710 | 2.1 | 0.963228 | 0.683891 |
| | | | 35 | 0.706 | 1.9 | 0.871492 | 0.615273 |
| | | | 37 | 0.703 | 1.0 | 0.458680 | 0.322452 |
| Crude oil | 450 | 2.4687 | 30 | 0.700 | 5.3 | 13.08411 | 9.158877 |
| | | | 32 | 0.698 | 4.5 | 11.10915 | 7.754187 |
| | | | 35 | 0.696 | 4.0 | 9.87480 | 6.872861 |
| | | | 37 | 0.694 | 3.5 | 8.64045 | 5.996472 |
Figure 6. Relationship between pressure and velocity in ethanol.

Figure 7. Relationship between pressure and velocity in crude oil.
6. Numerical Analysis
The procedure for developing the project in Ansys was as follows:
1. Fluid flow (fluent) was selected from the Ansys toolbox, as shown in Figure 8:

![Figure 8: Making Mesh](image)

2. On selecting Results, a new window opened. Using the Location command, (Plane1) was created using Method (YZ), with the Contour Range changed to local, to produce Figure 9:

A. Crude oil simulation:
   1. Simulation of crude oil without a chamber in the viscometer:

![Figure 9: Crude oil velocity in viscometer.](image)
2. Simulation of crude oil with triangle chamber:

![Figure 11 Crude oil velocity in viscometer.](image)

**Figure 10** Crude oil temperature in viscometer.
3. Simulation of crude oil with square chamber:
B. Ethanol simulation:
   1- Simulation of Ethanol without chamber in viscometer:

![Figure 14](image1)

**Figure 14** Crude oil pressure in the viscometer

![Figure 15](image2)

**Figure 15** Ethanol velocity in viscometer.
Figure 16 Ethanol pressure in viscometer.

2- Simulation of ethanol with triangle chamber:

Figure 17 Viscometer with triangle chamber
Figure 18 Ethanol velocity in the viscometer

Figure 19 Ethanol pressure in viscometer.
3- Square chamber:

Figure 20 Viscometer with square chamber

Figure 21 Ethanol velocity in the chamber
6. Discussion
A previous paper had introduced new correlations of ethanol properties depending on the least square method, using Excel such that the percentage of error in equations was reduced. This allowed the application of the equations to predict the density, conductivity, viscosity, and heat capacity of liquids at various temperatures with a high degree of accuracy. The relationship between density and conductivity with temperature is a linear equation. Figure 6 shows the relationship between pressure and velocity in Ethanol, which is inverse so that density decreases with increasing temperature. Change in density will be reflected in a change in temperature and vice-versa. When ethanol is heated, it expands, so the mass remains constant, while the volume increases, and density = mass/volume, explaining why, as the temperature increases, the density decreases. Conductivity depends predominantly on the molecular diffusion effect, and as the temperature increases, the randomness of molecular movements increases, obstructing the transport of heat through ethanol. Thus, the thermal conductivity of ethanol decreases with an increase in temperature. Figure 7 shows the relationship between pressure and velocity in crude oil, which is also inversely proportional.

Figure (9) represents the relationship between viscosity and temperature for crude oil. The viscosity of ethanol decreases when the temperature increases in an exponential curve due to the forces of cohesion between the molecules, which overshadow the transfer of molecular momentum between molecules, was due to the great affinity of the molecules. When ethanol is heated, the cohesion forces between the particles decrease, and consequently the attracting forces between them decrease, eventually reducing the viscosity of ethanol. Figure 15 represents the relationship between heat capacity and temperature in ethanol, which is a directly exponential relation. When ethanol is heated, the heat goes first into increasing the kinetic energies of the molecules, which can also store energy in vibration and rotation; these energies are quantized. Collisions often impart enough energy to allow rotation to occur, which then contributes to increasing the internal energy and raising the specific heat. This is an important result for accurate working in the laboratory, as it explains why such properties are very sensitive to temperature and why higher accuracy in working is required.
Sources of error in this work include measurement errors, device errors, and personal errors, highlighting the advantage of using a generalised equation to provide a rapid mathematical solution to calculate the properties affected by temperature. Another advantageous use of correlation is to determine solutions to problems that normally require laboratory work, which takes additional time and effort.

7. Conclusions:
1- The type of flow and its properties for each sample used in the experiment were obtained by simulation in ANSYS.
2- The appearance of the vortexes in the viscometer was observed in the simulation to match those in the samples.
3- Experimental determination of the kinematic and dynamic densities for three types of samples used in the experiment was achieved.

References
[1] Dinsdale A and Moore F 1962 Viscosity and its measurement (Chapman and Hall, London).
[2] Cannon M and Fenske M 1938 Viscosity measurement Ind. Eng. Chem. Analytical Edition. 10(6), 297-301.
[3] Cannon M and Fenske M 1938 Viscosity measurement Ind. Eng. Chem. Analytical Edition. 13(5), 299-300.
[4] Cannon M, Manning R and Bell J D 1960 Viscosity measurement the kinetic-energy correction and a new viscometer, Anal. Chem. 32, 355-358.
[5] Pinkevich Y 1945 New viscometer for the determination of the viscosity of petroleum products at low temperatures, Petroleum (London), 8, 214 215.
[6] Zeitfuchs E 1939 Modified Ostwald viscometer for routine control tests at petroleum refineries National Petroleum News 31(24), 262-3.
[7] Zeitfuchs E 1941 Speeds viscosity measurement in capillary-type viscometer, National Petroleum News, 33(16), R-121-124.
[8] Ruh E, Walke R and Dean E 1941 Viscometer Ind. Eng. Chem. Anal. Ed. 13(5), 346-349.
[9] Tourneau R and Matteson R 1935 Standard Methods for Testing Petroleum and Its Products IPT (Institution of Petroleum technologists London) 3rd ed 171-177.
[10] Mason W Hill M 1969 Measurement of the viscosity and shear elasticity of liquids by means of a torsionally vibrating crystal transactions of the ASME. In (Journal of Lubricating Technology Band) 1947, S. 359–370.