Jurnal Serambi Engineering JSE
Volume IX, No.4, Oktober 2024 Hal 11295 - 11300
p-ISSN : 2528-3561
e-ISSN : 2541-1934

Calculation of Capillarity Constants in Ostwald Viscometer using The Water Viscosity Approach

Rahadyan Itsar Fadhilah, Ahmad Zaenal Arifin, Erwan Adi Saputro*

Department of Chemical Engineering, Faculty of Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Surabaya
***Corresponding author**: erwanadi.tk@upnjatim.ac.id

Received: October 14, 2024 Approved: October 19, 2024

Abstract
Each fluid possesses unique characteristics that distinguish it from others. One such characteristic is viscosity, with each fluid having its own viscosity coefficient. Viscosity can be considered as the internal movement within a fluid, influenced by strong intermolecular forces in the liquid. A commonly used device for determining fluid viscosity is a viscometer, which accurately and specifically measures viscosity according to predefined standards. The Ostwald viscometer is a widely used instrument, but it comes in different types, including the one-ball and two-ball Ostwald viscometers, each yielding different constants. This study aims to determine the constant coefficients of the one-ball and two-ball Ostwald viscometers, simplifying the determination of fluid viscosity through experimentation. The results indicate that the capillary constant of the first Ostwald viscometer is greater than that of the second. Specifically, the capillary constant for the first Ostwald viscometer is $C = 4{,}12343\ mm^2/s^2$, while for the second Ostwald viscometer, it is $C = 0{,}050355\ mm^2/s^2$.
Keywords: *fluid, viscosity, ostwald viscometer*

Abstrak
Setiap cairan memiliki karakteristik unik yang membedakannya dari yang lain. Salah satu karakteristik tersebut adalah viskositas, di mana setiap cairan memiliki koefisien viskositasnya sendiri. Viskositas dapat dianggap sebagai gerakan internal dalam cairan, yang dipengaruhi oleh kuatnya gaya antar molekul dalam cairan. Alat yang umum digunakan untuk menentukan viskositas cairan adalah viskometer, yang secara akurat dan spesifik mengukur viskositas sesuai dengan standar yang telah ditetapkan. Viskometer Ostwald merupakan alat yang banyak digunakan, tetapi hadir dalam berbagai jenis, termasuk viskometer Ostwald satu bola dan dua bola, yang masing-masing menghasilkan konstanta yang berbeda. Penelitian ini bertujuan untuk menentukan koefisien konstan dari viskometer Ostwald satu bola dan dua bola, yang mempermudah penentuan viskositas cairan melalui eksperimen. Hasil penelitian menunjukkan bahwa konstanta kapiler viskometer Ostwald pertama lebih besar dibandingkan dengan yang kedua. Secara spesifik, konstanta kapiler untuk viskometer Ostwald pertama adalah is $C = 4{,}12343\ mm^2/s^2$, sedangkan untuk viskometer Ostwald kedua adalah $C = 0{,}050355\ mm^2/s^2$.
Kata Kunci: *cairan, viskositas, viskometer ostwald*

1. Introduction

Fluids are substances capable of flowing, with liquids being one type of fluid. Liquids conform to the shape of any container in which they are placed. This property arises because they cannot withstand tangential forces at their surfaces. Each liquid possesses unique characteristics that distinguish it from others. Certain characteristics of a fluid are independent of its motion but rather depend on the inherent properties of the fluid itself. One such characteristic is viscosity, where each fluid possesses a unique coefficient of viscosity. Viscosity can be defined as the resistance to fluid flow, representing the friction between the fluid's molecules. A fluid that flows easily is described as having low viscosity, while a substance that flows with difficulty is said to have high viscosity (Samdara et al., 2008).

The viscosity of a fluid is an essential property for analyzing fluid behavior and motion within defined boundaries. Viscosity represents the fluid's resistance to shear or flow and serves as a measure of its adhesive, cohesive, or frictional properties. This resistance arises from the intermolecular friction encountered when fluid layers attempt to move past each other, thus making viscosity a measure of a substance's resistance to flow. In theory, the viscosity of a liquid decreases with an increase in temperature. This phenomenon is related to the molecular structure of the liquid. The molecules of the liquid are closely spaced, exhibiting strong cohesive forces between them, which hinder the relative motion between adjacent fluid layers associated with these intermolecular forces. As the temperature increases, these cohesive forces decrease, resulting in reduced resistance to motion (Young, 2002).

An ideal fluid (non-viscous fluid) possesses no viscosity, which would otherwise hinder the movement of fluid layers as they slide over each other. Highly viscous fluids like honey require greater force, while less viscous fluids (with low viscosity), such as water, demand less force. Moreover, a fluid's viscosity varies with temperature. As the temperature of a liquid rises, its viscosity decreases. For instance, heating frying oil causes initially thick oil to become thinner. Conversely, lower tempera-tures lead to increased fluid viscosity (Putri, 2024).

The viscometer serves as a tool for measuring the viscosity of a fluid. Commonly utilized viscometers include the falling ball viscometer, tube/capillary/Ostwald viscometer, and rotational systems. Among these, the Ostwald viscometer stands out as one of the most prevalent. Notably, the Ost-wald viscometer requires a smaller sample size compared to its counterparts (Putra, 2013). Its principle involves measuring the time taken for the fluid to traverse between two predetermined points within a vertical capillary tube (Shanti et al., 2014). However, it’s worth noting that the original Ostwald viscometer exists in different variations, including those with 1 ball and 2 balls, each yielding distinct constant coefficients. Hence, this study aims to ascertain the constant coefficients of both the Ostwald viscometer with 1 ball and 2 balls, with the goal of simplifying the determination of fluid viscosity.

2. Material and Methods

The research was conducted by examining the constant coefficients on viscometers 1 and 2. The fluid used in this study was water, serving as a reference for determining the constant coefficients of the viscometer.

Viscosity is a measurement that denotes the thickness of a liquid or fluid. The term “viscosity” originates from the word “viscous.” Viscosity can be regarded as the internal movement within a fluid. Strong molecular attraction forces within the liquid result in high viscosity. Thickness, or viscosity, is a property of a liquid closely associated with its resistance to flow. To obtain the viscosity value, an Ostwald viscometer is used. The Ostwald viscometer is an instrument designed to determine viscosity by measuring the flow time of a liquid through the viscometer (Irawati, 2018).

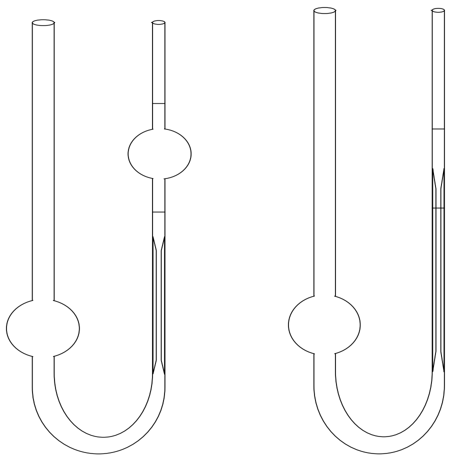

Fig. 1: Ostwald Viscometer 1 bulb and 2 bulb

The Ostwald viscometer operates on the principle of a capillary tube viscometer. Its operation involves measuring the time required for a fluid to flow from the upper boundary to the lower boundary within the viscometer. First, the fluid to be measured is introduced into the left tube until chamber A is half-filled. Next, the fluid is drawn from the right tube until it passes through chamber B and reaches the start line. Allow the fluid to flow naturally. When it reaches the start line, start the timer. Stop the timer and record the time when the fluid reaches the stop line. Repeat the experiment three times to ensure accurate results. Perform the same procedure with the two-ball viscometer (Fadilah et al., 2022). The degree of viscosity of a fluid is expressed by its viscosity coefficient. This coefficient is defined as the resistance to fluid flow. The viscosity coefficient can be determined using the Poiseuille equation:

$$\eta = \frac{\pi p r^4}{8 v l} \quad (1)$$

The variable *t* represents the time taken for a fluid of volume *V* to flow through a capillary tube with length *l* and radius *r*. The pressure *p* reflects the pressure difference between the two ends of the viscometer tube, assumed to be proportional to the weight of the liquid, while η denotes the viscosity of the fluid (Sulistyaningsih, 2021). The conventional unit for viscosity is the Poise (P), where 1 Poise equals 1/10 Ns/m². Typically, the viscosity of a fluid can be determined using two methods, one of which involves employing an Ostwald viscometer. Achieving precise viscosity measurements, as described by Equation (1), can prove challenging due to the precise determination of *r* and *l* being difficult. Measurement errors, particularly in *r*, have a significant impact as this value is raised to the fourth power. To mitigate such errors in practical applications, a reference fluid is employed, with distilled water (aquadest) being commonly used. When measuring two different fluids using the same instrument, a relationship is established:

$$\frac{\eta_1}{\eta_2} = \frac{\eta p_1 r^4 t_1}{8 v l} x \frac{8 v l}{\eta p_2 r^4 t_2} = \frac{p_1 t_1}{p_2 t_2} \quad (2)$$

Given that pressure is directly proportional to fluid density, it can be concluded that:

$$\frac{\eta_1}{\eta_2} = \frac{p_1 t_1}{p_2 t_2} \quad (3)$$

(Murdaka, 2015)

The ASTM D 445 Kinematic Viscosity test is among the various analyses carried out by Petroleum Laboratories. When conducting the ASTM D 445 Kinematic Viscosity test for petroleum products such as diesel and lubricants, the utilization of a viscometer tube is indispensable. This tube is employed to ascertain the viscosity of the fluid using a gravitational method (stoke). Centipoise is a unit commonly used to measure viscosity. The flowability measurement in pipes is greatly determined by the viscosity of fluids or gases. In secondary recovery processes, the viscosity of water plays a significant role. Additionally, the viscosity of natural gas affects the production of crude oil as well as gas. Predicting oil reserves and the amount of oil produced, particularly when production declines critically, is influenced by the viscosity of gas-saturated crude oil at specific reservoir pressures and temperatures. At these conditions, the viscosity of crude oil is lower due to the dissolved gas content at high pressures and temperatures (Abarua, 2022).

Viscosity is classified into two main types: dynamic (absolute) viscosity and kinematic viscosity. Dynamic viscosity can be defined as the ratio of the rate of deformation to shear stress, measured in units of N.s/m². Kinematic viscosity, on the other hand, is the relationship between dynamic viscosity and density, with units of m²/s or Stokes (St), where 10,000 Stokes equal 1 m²/s. Kinematic viscosity (v) is defined as the ratio of the dynamic viscosity coefficient (η) to the density of the liquid (ρ). The dimensions of the dynamic viscosity coefficient are grams per centimeter per second (g/(cm·s)) or mass per length per time (M/LT), while the dimensions for density are grams per cubic centimeter (g/cm³) or mass per length cubed (M/L³). Therefore, the dimensions for kinematic viscosity are η/ρ, as follows:

$$\frac{\eta}{\rho} = \frac{gram}{cm.t} x \frac{cm^3}{gram} \quad (4)$$

$$\frac{\eta}{\rho} = \frac{cm^3}{t} \quad (5)$$

(Saputri, 2021)

Kinematic viscosity is determined by measuring the flow of liquid within an Oswald Capillary Viscometer Tube under the influence of gravity

$$\frac{\eta_1}{\eta_2} = \frac{\eta \mathrm{P} r^4 t_1}{8 \mathrm{L} v} \quad (6)$$

Where *V* cm³ denotes the volume of the fluid with viscosity η flowing for *t* seconds through a capillary tube of radius *r* cm and length *L* cm, under a pressure of *P* dyne/cm². However, since the radius *r* and the length *l* of the capillary tube in the viscometer are difficult to measure accurately in the Poiseuille equation, it is more practical to determine viscosity using a reference fluid with a known viscosity (Rakhmawati et al., 2016).

$$\frac{\eta_1}{\eta_2} = \frac{\eta p_1 r^4 t_1}{8 v l} x \frac{8 v l}{\eta p_2 r^4 t_2} = \frac{p_1 t_1}{p_2 t_2} \quad (7)$$

$$\frac{\eta_1}{\eta_2} = \frac{p_1 t_1}{p_2 t_2} \quad (8)$$

$$\frac{\eta_1}{p_1 t_1} = \frac{\eta_2}{p_2 t_2} = C \quad (9)$$

Where C represents the capillary constant. This constant is usually labeled on the viscometer tube.

$$C = \frac{\eta}{\rho t} = \frac{gram}{cm.t} x \frac{cm^3}{gram} x \frac{1}{t} \quad (10)$$

$$C = \frac{cm^2}{t^2} = L^2/T^2 \quad (11)$$

To determine the kinematic viscosity (v), the formula is expressed as follows:

$$v = C\ x\ t \quad (12)$$

(Novandy, 2018)

By using comparisons, the amount of data required is reduced because the viscosity of water, used as a reference substance, is already known. The necessary data to be obtained is the flow time of water as the reference substance. Below are the known properties of water based on its temperature:

Table 1. Physical properties of Water (SI Units)

Temperature	Specific Weight	Density	Dynamic Viscosity	Kinematic Viscosity
T (°C)	**γ (KN/m^3)**	**ρ (KG/m^3)**	**μ (x 10^{-3}KG/M.S)**	**v (x 10^{-6}m^2/S)**
0	9.805	999.8	1.781	1.785
5	9.807	1000.0	1.518	1.519
10	9.804	999.7	1.307	1.306
15	9.798	999.1	1.139	1.139
20	9.789	998.2	1.002	1.003
25	9.777	997.0	0.890	0.893
30	9.764	995.7	0.798	0.800
40	9.730	992.2	0.653	0.658
50	9.689	988.0	0.547	0.553

To ensure accurate viscosity measurements, the reference water temperature must be precise (Crittenden, 2012). Since temperature variations affect water viscosity, a thermometer is crucial before measuring the water's flow time in the viscometer. The chosen water temperature is 25°C. According to **Table 1**, the water's viscosity at this temperature is 0.893 centipoise (cP) (Fadilah et al., 2022).

3. Results and Discussion

Based on equation 12, determining the capillary constant requires the kinematic viscosity data of water obtained from Table 1 and the flow time for each viscometer. The flow time of water was measured using an Ostwald viscometer, with five trials conducted at a temperature of 25°C. The average flow time of water from these measurements is as follows:

Table 2. Experimental data at a temperature of 25 °C

RUN	OSTWALD VISCOMETER 1 BALL	OSTWALD VISCOMETER 2 BALL
	T(S)	T(S)
1	0,21	17,67
2	0,22	17,85
3	0,20	17,72
4	0,22	17,64
5	0,23	17,79
Average	0,216	17,734

After determining the fluid flow time, the capillary constant can be calculated based on equation 12. According to Table 1, the viscosity of water at 25°C is 0.893 cSt. Based on Table 2, the flow time of water using the Ostwald viscometer with one ball is 0.216 seconds, and for the Ostwald viscometer with two balls, it is 17.734 seconds. Therefore, the capillary constant values can be calculated using equation 12 as follows.

$$v = C \times t \tag{13}$$

$$C = \frac{v}{t} \tag{14}$$

$$C = \frac{0{,}893\ cst}{0{,}216\ s} \tag{15}$$

$$C = 4{,}12343 \frac{mm^2}{s^2} \tag{16}$$

The capillary constant of the Ostwald viscometer 2 ball

$$v = C \times t \tag{17}$$

$$C = \frac{v}{t} \tag{18}$$

$$C = \frac{0{,}893\ cst}{17{,}734\ s} \tag{19}$$

$$C = 0{,}050355 \frac{mm^2}{s^2} \tag{20}$$

In Ostwald viscometer 1, the average kinematic viscosity time of water at a temperature of 25°C is measured to be 0.216 s. Using formula 14, the calculated capillary constant for the Ostwald viscometer is determined to be 4.12343 mm^2/s^2. Conversely, in Ostwald viscometer 2, the average kinematic viscosity time of water at a temperature of 25°C is found to be 17.734 s. Utilizing formula 18, the calculated capillary constant for the Ostwald viscometer is 0.050355 mm^2/s^2. The discrepancy in capillary constants is attributed to the differing lengths of the capillaries in Ostwald viscometer 1 and 2. The longer the flow time between points a and b in the capillary tube, the larger the capillary constant obtained.

Based on the results above, it can be concluded as follows:

Table 3. The main differences between the two types of viscometers

Feature	Ostwald Viscometer 1 Bulb	Ostwald Viscometer 2 Bulb
Number Of Balls	**One**	**Two**
Fluid viscosity	High	Low to medium
Accuracy	Low	High
Ease of cleaning	Easy	Hard

Based on **Table 3**, the Ostwald viscometer with a single ball is recommended for liquids with high viscosity, such as oil, due to its short flow time and higher efficiency for measuring thick liquids. Although the accuracy of the Ostwald single-ball viscometer is generally low, it provides accurate results for highly viscous liquids because the flow times for water and oil differ significantly, given oil's higher viscosity. On the other hand, the Ostwald viscometer with two balls is recommended for low-viscosity liquids, such as water, as it offers high accuracy for these types of fluids. This is because it has a longer flow time compared to the single-ball viscometer. Ease of cleaning is also a crucial factor in viscosity measurement, as a viscometer that is difficult to clean can hinder the process. Viscosity is a measure of a fluid's thickness, indicating the degree of internal friction within the fluid. The higher the viscosity, the more difficult it is for an object to move through the fluid, which can result in residue buildup and cleaning challanges (Budiarto, 2013).

4. Conclusion

It can be concluded that the capillary constant of the first Ostwald viscometer is greater than that of the second viscometer. Specifically, the capillary constant for the first Ostwald viscometer is $C = 4{,}12343\ mm^2/s^2$, whereas for the second Ostwald viscometer, it is $C = 0{,}050355\ mm^2/s^2$,the difference is influenced by the flow time in each Ostwald viscometer. Additionally, there is a distinction between the single-ball and double-ball Ostwald viscometers. This difference is based on the material used: if the material has high viscosity, it is recommended to use the single-ball Ostwald viscometer, while the double-ball Ostwald viscometer is recommended for materials with low viscosity.

5. Acknowledgment

Authors thank our colleagues from Universitas Pembangunan Nasional "Veteran" Jawa Timur who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

6. References

[1] Abarua, G.,*et al.* 2022. Analisa Perbandingan Fluida Pada Sumur X dan Sumur Z. *Jurnal SNTEM,* 2(1), 110 -115.

[2] Budiarto, H., & Adiwara. 2013. Pengaruh Konsentrasi Gliserin Terhadap Viskositas dari Pembuatan Pasta Gigi Cangkan Kerang Darah. *Jurnal Konversi,* 2 (2), 13 - 22.

[3] Crittenden, C., *et al.* 2012. *MWH's Water Treatment : Principles and Design*, New Jersey : John Wiley & Sons Inc.

[4] Fadilah, I., Sudarmawan, I., & Yusyama, A. 2022. Pengaruh Jarak Tempuh Sepeda Motor Terhadap Nilai Viskositas Pelumas SAE 10w-40 dengan Metode Ostwald. *Prosiding Seminar Nasional Teknik Mesin.*

[5] Irawati, A. 2018. Pembuatan dan Pengujian Viskositas dan Densitas Biodiesel dari Beberapa Jenis Minyak Jelantah. *Jurnal JFT*, 1(5), 82 - 89

[6] Murdaka, B., & Rizkiana, A. 2015. Studi Penentuan Viskositas Darah Ayam dengan Metode Aliran Fluida di Dalam Pipa Kapiler Berbasis Hukum Poisson. *Jurnal Fisika Indonesia*. 19 (57). 43 - 47

[7] Novandy, A. 2015. Metode Sederhana Penentuan Harga Baru Konstanta Kapilaritas Viskometer (C) Untuk Pengujian Viskositas Kinematik ASTM D 445. *Forum Teknologi*, 5(3), 33-37.

[8] Putra, A. S. 2013. *Disain dan Komputerisasi Viskometer Kapiler.* Jember: Universitas Jember.

[9] Putri, A. S., *et al.* 2024. Analisis Nilai Kecepatan Terhadap Viskositas Pada Fluida. *Jurnal Pendidikan Fisika.* 8(1). 89 - 96.

[10] Rakhmawati, I., Yanti., A., & Rahayu, S. 2016. *Buku Penuntun Praktikum Farmasi Fisika*. Jakarta: Universitas Esa Unggul.

[11] Samdara, R., Bahri, S., Muqorobin, A. 2008. Rancang Bangun Viskometer dengan Metode Rotasi Berbasis Komputer. *GRADIEN*, 4(2), 342-348

[12] Saputri, C. D. 2021. Pengukuran Viskositas Zat Cair Menggunakan Sensor Magnet dan Virtual Instrument LabView. *Jurnal Politeknik Negeri Cilacap.* 1(1). 1 - 9

[13] Sulistyaningsih, D., Mahmudah, I. R., & Sujarwanto, E. 2021. Penentuan Koefiisien Viskositas Air dengan Aliran Kapiler. *Jurnal Diffraction*, 1(1), 50-59

[14] Shanti, M. R. S.,*et al*. 2014. Pembuatan media pembelajaran pengukuran viskositas dengan menggunakan viskometer dua kumparan dan freewave 3. *Jurnal Pendidikan Fisika Indonesia*, 10(11), 28-35.

[15] Young, H. D. 2002. *Fisika untuk Universitas*. Jakarta : Erlangga.