Development and Experimental Validation of a Viscosity Meter for Newtonian and Non-Newtonian Fluids

Raúl O. Rojas ¹, Juan C. Quijano ¹, Claudia P. Tafera Ruiz² and Alex F. Estupiñán L.²

¹Universidad Autónoma de Bucaramanga (UNAB), Programa de Ingeniería Biomédica, Departamento de Matemáticas y Ciencias Naturales, Santander, Colombia.
²Universidad de Investigación y Desarrollo (UDI), Departamento de Ciencias Básicas y Humanas, Santander, Colombia.

(Dated: August 14, 2020)

Abstract

The study of viscosity, in the area of fluid physics at a university level, is of great importance because of the various applications that are presented in the different fields of engineering. In this work an experimental method of implementation and validation is exposed, to be able to calculate the viscosity of some newtonian and non-newtonian fluids, in which the method of a sphere that descends through a fluid has been used, we implemented a viscometer of our own construction, with the help of the CassyLab sensor and software of Leybold Didactics, we show the results obtained by our measuring instrument, which is intended to highlight the versatility and precision of the measuring instrument prepared by us, in addition. In this research the authors want to motivate the physics laboratory teachers; to explore the use of these tools that allow you to check the topics seen in the theoretical classes. Finally, we present the hardworking results of the measurement of viscosity for different fluids, both newtonian and non-newtonian, for the latter we show the viscosity behavior as a function of temperature.

Keywords: Viscometer, Newtonian fluid, non-Newtonian fluid, descending sphere method and fluid mechanics.

1 Introduction

One of the great applications of the calculation of the viscosity of the fluids, is directed mainly to the area of electrochemical research, in which it is sought to relate the electrical conductivity with the viscosity of the fluid to be studied, one of the most studied fluids in this Last decade are vegetable oils [1, 2] and milk [3] for different temperatures. Among the most interesting findings, they showed that proteins and lactose affected the electrical conductivity of milk by modifying its viscosity, in most liquid foods the concentration of electrolytes is relatively low, with soy sauce and fish sauce [4].

Another field in which the viscosity of the fluids has a great application is civil engineering, which consists in determining the fluidity state of the asphalts at the temperatures used during their application [5, 6], for example: The viscosity is measured in the Saybolt-Furol viscosity test or in the kinematic viscosity test.

The viscosity of an asphalt cement at the temperatures used in mixing (normally 135 °C) is measured with capillary flow meters viscometers or Saybolt viscometers; The absolute viscosity, at high operating temperatures (60 °C), is usually measured with vacuum glass capillary viscometers [7,8].

We, too, can see the importance of viscosity in tribology, such as that science that is responsible for studying friction, which generates wear and lubrication in some materials, as occurs in some mechanical mechanisms such as teeth of a gear.

Where it should be taken into account that at higher contact velocities of these materials, a hydrodynamic (or elastohydrodynamic) lubrication film is formed in highly charged mechanisms where the surfaces in contact are deformed by the action of these forces.

At this stage the minimum wear values are achieved because the oil or grease that was designed for this friction regime acts. Showing that the higher the viscosity of the lubricant, we will have greater losses due to viscous friction, so lubricants with high viscosity oils are only recommended in slow-moving elements [9,10].

In this work, we present the results obtained from the experimental implementation, which was carried out for the measurement of the dynamic viscosity of Newtonian fluids such as sunflower oil, glycerine and non-Newtonian fluids such as yogurt, cornstarch and ketchup, for each of the above fluids varying the temperature.

In addition, we show the analytical development, using two different methods, to show the validity of
our experiment and the quality of the data taken in it.

2 Theoretical framework

The classic definition for viscosity, arises as internal friction force that brought in a fluid. Where it should be taken into account, that these viscous forces oppose the movement of a portion of the fluid in relation to another. Fluids that flow easily, such as water and gasoline, have lower viscosity than thick liquids such as honey or oil. The viscosity of all fluids are very dependent on temperature, increase for gases and decrease for liquids as the temperature rises. A viscous fluid tends to adhere to a solid surface that is in contact with it.

In order to better understand the definition of viscosity of a fluid, we place a rectangular section, on some surface free of an unconfined fluid. We hope that on this surface a shear stress is experienced or appears in the direction parallel to the surface of the fluid. In addition, a gradient of velocities will appear in the fluid as a result of said shear stress, the velocity of the sheet being equal to that of the particles in contact with it (adhesion condition), as can be seen in Figure 1.

\[ F_b + F_v = F_g \]
\[ m_s g + F_v = m g \]
\[ \rho_f g V + 6\pi \eta v = \rho_{obj} g V \]
\[ 6\pi \eta v = (\rho_{obj} - \rho_f) g V \]
\[ 6\pi \eta v = \Delta \rho g \frac{4}{3}\pi r^3 \] (1)

Solving for \( \eta \) we have the Equation (2):

\[ \eta = \frac{2\Delta \rho g r^2}{9v} \] (2)

\[ F_b \]
\[ F_v \]
\[ a = \frac{dv}{dt} \]
\[ mg \]

Figure 2: a.) Free body diagram for the sphere inside the fluid. b.) Schematic representation of the laminar flow disturbance present in the fluid, due to the presence of the sphere.

The previous formula applies in case of an infinitely extended fluid, but according to the experiment a correction factor is need to be added (See Equation (3)) [13,14].

\[ \eta = \frac{2\Delta \rho g r^2}{9v} \left( \frac{1}{1 + 2.4r/R} \right) \] (3)

Where \( R \) is the radius of the test tube. Stokes’ law is subject to a restriction in terms of its use and
involves considering a laminar flow. Laminar flow is defined as that condition, in which fluid particles move along the smooth paths in the sheet, in other words, is when an orderly and smooth movement of the particles that form the fluid occurs.

To predict the type of flow that a fluid will present in a cross-section pipe, the Reynolds number should be calculated. This dimensionless number is a ratio between inertial and frictional force, and takes different expressions depending on whether it is for a pipe with a non-circular transversal section, open channels or fluid flows around a body [15]. In our experiment, it is a sphere submerged in a fluid moving with velocity \( V \), in this case the Reynolds number can be calculated experimentally by the Equation (4) [16].

\[
Re = \frac{\rho f V r}{\mu}
\]

(4)

Where \( \rho_f \) is the fluid density, \( V \) the sphere velocity, \( r \) the sphere radius and \( \mu \) the viscosity calculated experimentally. If the calculated \( Re < 1 \) then the fluid will present a laminar flow and, if \( Re > 1 \) the flow is turbulent.

In order to know the viscous behavior of a fluid, it is necessary to determine the shear stress and the velocity gradient. The main equations to determine the shear stress are the following [17,18]:

- **Newton’s law**: \( \tau = \mu \left( \frac{dv}{dz} \right) \)  
  (5)

- **Power law**: \( \tau = k \left( \frac{dv}{dz} \right)^n \)  
  (6)

- **Bingham’s equation**: \( \tau = \tau_0 + \eta' \left( \frac{dv}{dz} \right) \)  
  (7)

- **Herschel–Bulkley’s model**: \( \tau = \tau_0 + k_H \left( \frac{dv}{dz} \right) \)  
  (8)

Where \( \tau \) is the shear stress, \( \eta \) viscosity, \( \left( \frac{dv}{dz} \right) \) the velocity gradient, \( k \) the consistency index, \( n \) is the flow behavior index, \( \tau_0 \) the creep threshold, \( \eta' \) plastic viscosity and \( k_H \) consistency index for Herschel-Bulkley’s fluids.

Depending on the effect of shear stress on the fluid, these can be classified as Newtonian and non-Newtonian fluids. Therefore, the mathematical model to be used to determine the shear stress depends on the type of fluid to be used.

Newtonian fluids are characterized because their rheological behavior can be described by Newton’s law (Equation (3)). This means that the shear stresses required to achieve a velocity are always linearly proportional, having a constant viscosity [20].

On the other hand, non-Newtonian fluids cannot be described by Newton’s law. In this case, viscosity is no longer talked about, because the ratio between shear stress and velocity is not constant. That viscosity function as a function of velocity is known as apparent viscosity. Newtonian fluids are then characterized by different apparent viscosities at each shear velocity [18,20].

Non-Newtonian fluids are mainly classified as: independent of the time and, dependent of the time. In fluids independent of time the viscosity at any shear stress does not vary with the time, while in dependents ones it does. Among the time independent of the time fluids are the pseudoplastics, dilators and Bingham fluids. The time dependent will not be studied in this article therefore it will not be deepened in them [15].

The behavior of viscosity for pseudoplastics and dilators fluids can be modeled mathematically using the the Power Law (Equation (6)). On the other hand, if the exponent \( n \) of the equation is smaller than the unit \( (n < 1) \), it is called a pseudoplastic fluid, in the case where this exponent is larger than the unit \( (n > 1) \), it is called a dilating fluid [14]. The law of potency can also be used for Newtonian fluids, we have in this case the constant \( k \) is the viscosity and the value of \( n = 1 \) [13].

### 3 Experimental set-up

The set-up used for the experimental tests can be seen in Figure 3. This is made up of a graduated cylinder of 500 ml, a iron disk, a solid bronze sphere, and, two infrared sensors. The graduated cylinder has a mass of 458 g, volume of 500 ml and radius of 23.35 × 10^{-3} m. In order to prevent that the bronze sphere does not break the graduated cylinder in the fall, the iron disk is placed inside it. This disk has a mass of 68 g and a volume of 8.877 × 10^{-6} m^3. Once the iron disk is inside the graduated cylinder, this is filled with the fluid under study.

As newtonian fluids were used: glycerine and sunflower oil; as non-newtonian fluids were used: yogurt, ketchup, cornstarch and corn flour. The sensors were located at a height \( L \) of 0.017 m. Once the fluid is inside, at room temperature, the mass sphere is launched. The sphere has a mass of 74.5 g, volume of 8.877 × 10^{-6} m^3, radius of 12.66 × 10^{-3} m and a density of 2635.29 kg/m^3.

The velocity of the sphere will be calculated as the distance \( L \) routed by the sphere, divided by the
time that it takes to travel that distance (Equation \ref{eq:10}). The sensor will detect the passage of the sphere and record the time $\Delta t$. This time data collection was performed using the CASSY LAB-LD Didactic system software (as shown in Figure 3). For each fluid, the sphere was launched 10 times. For each launch, the time taken by the sphere to travel the distance $L$ was measured by the detectors. The time of all releases was averaged. With the average time the velocity was calculated (See Equation \ref{eq:10}).

$$v = \frac{L}{\Delta t} \quad \text{(9)}$$

4 Results

To carry out the analysis of the results obtained in this research, we wanted to start by analyzing the non-Newtonian fluids that we have worked on in this research, which were:

1. Yogurt.
2. corn flour.
3. Ketchup.
4. Cornstarch.

On the other hand, we also work with two Newtonian fluids, which are:

1. Sunflower oil.
2. Glycerine.

Taking into account this order of presentation of our results, we present below the results obtained for non-Newtonian yogurt fluid.

4.1 Yogurt results analysis

To begin with the analysis of the results obtained for this fluid, we have taken The average times obtained of the travel of the sphere in the distance $L$; at different temperatures are presented in the Table 1. With these times, the data of the fluid density, density and dimensions of the sphere were calculated, by replacing the viscosity in Equation \ref{eq:10} (See Table 1). It was found that when the temperature increases, the time decreases, which represents a lower shear stress at a higher temperature, that is, a lower viscosity of the fluid. This variation in viscosity with temperature proves that ketchup sauce is a non-Newtonian fluid.
Table 1: Experimental data on the viscosity of Yogurt for different temperatures.

| T [K] | Average time [s] | Viscosity [Pa·s] |
|-------|------------------|------------------|
| 293.05 | 0.0694            | 1.1317           |
| 295.05 | 0.0683            | 1.1131           |
| 298.35 | 0.0666            | 1.0855           |
| 304.15 | 0.0653            | 1.0651           |
| 311.75 | 0.0648            | 1.0349           |
| 315.15 | 0.0635            |                  |

The results of the yogurt viscosity at different temperatures are presented in the Figure 4a. Equation 10 was used to calculated the viscosity at each temperature, in this case the density of the yogurt used was $1052.6894 \text{ kg/m}^3$ [11]. Because yogurt is a non-Newtonian fluid, a exponential adjustment was fitted, obtaining a good approximation with an $R^2$ of 0.929. The model obtained corresponds to the Arrhenius’s equation (See Equation (11)), In which a dependence of the viscosity of the fluid with temperature can be observed, in which a notable decrease in viscosity can be evidenced as the temperature increases, in view of the shape of this figure (See Figure 4a), indicating that the fluid is pseudoplastic.

$$\eta(T) = \eta_0 \cdot e^{\frac{E}{RT}}, \quad (11)$$

where $\eta$ is the viscosity of fluid, $\eta_0$ is a pre-exponential factor, $E$ is the activation energy, $R$ is the ideal gases universal constant and $T$ is the absolute temperature of fluid.

In this way, comparing Equation (14) with Equation (15), it can be seen that making the graph of ln $\eta$ as a function of $1/T$, where moreover making a linear adjustment (See Figure 5), the value of the activation energy $E$ of the fluid can be obtained experimentally.

Figure 4: Viscosity as a function of temperature for non-Newtonian fluids. a.) Yogurt. b.) Corn flour. c.) Ketchup. d.) Cornstarch.

Figure 5: Linear fitting of viscosity as a function of temperature for non-Newtonian fluids. a.) Yogurt. b.) Corn flour. c.) Ketchup. d.) Cornstarch.

From the linearization used in Equation (14) to power the linear fit, shown in Figure 5b, the value of the activation energy $E$ can be calculated, in the case of yogurt, as can be seen in the equations from (16) to (17).

$$\frac{E}{R} = m, \quad (16)$$
$$E = m \cdot R. \quad (17)$$

Where $m$ is the slope of Figure 5b, which corresponds to a numerical value of $m = 330.399 \text{ K}$, with this value; and using the value of the universal constant of ideal gases given by the unit literature in the I.S system, we have $R = 8.314 \text{ J/(K \cdot mol)}$, we obtain the result of the activation energy $E$, shown in equations (18-19).

$$E = \frac{mR}{m} = R,$$
$$E = 8.314 \text{ J/(K \cdot mol)}.$$
In this way we can see that with a Pearson regression factor $R^2 = 0.9723$ approximately, we can say that this model fits the experimental data obtained quite well (See Figure 4). This behavior is to be expected according to the literature. Where it can be noted that as the temperature value increases, the viscosity value decreasing, reflected in an increase in the falling velocity of the sphere inside the fluid (See Figure 4). In Figure 4, you can also see a recent behavior; on the curve of viscosity as a function of temperature, which indicates that the fluid is pseudoplastic modeled by Equation 11.

On the other hand, fitting the data to a linear model (See Figure 5), the activation energy $E$ of corn flour can be calculated, using the linearization of Equation 14 and Equation 15, with these Two equations, the result shown in Equation 20 of the energy $E$ is obtained for corn flour.

$$E = 9290.684 \cdot 8.314, \quad (20)$$

In this way we can see that with a Pearson regression factor $R^2 = 0.9723$ approximately, we can say that this model fits the experimental data obtained quite well (See Figure 4). This behavior is to be expected according to the literature. Where it can be noted that as the temperature value increases, the viscosity value decreasing, reflected in an increase in the falling velocity of the sphere inside the fluid (See Figure 4). In Figure 4, you can also see a recent behavior; on the curve of viscosity as a function of temperature, which indicates that the fluid is pseudoplastic modeled by Equation 11.

On the other hand, fitting the data to a linear model (See Figure 5), the activation energy $E$ of corn flour can be calculated, using the linearization of Equation 14 and Equation 15, with these Two equations, the result shown in Equation 20 of the energy $E$ is obtained for corn flour.

$$E = 9290.684 \cdot 8.314, \quad (20)$$

Continuing with the presentation of the results, obtained for corn flour, we can calculate the value of the Reynolds number (Re), given for each of the different temperatures, at which this experiment was carried out (See Equation 4). In Table 4, we show the value of the fluid viscosity (corn flour), as a function of the falling velocity $v$, for each of the tests carried out. The results of these experimental calculations are presented in Table 4.

$$E = 77.242 \cdot 8.314, \quad (21)$$

Continuing with the presentation of the results, obtained for corn flour, we can calculate the value of the Reynolds number (Re), given for each of the different temperatures, at which this experiment was carried out (See Equation 4). In Table 4, we show the value of the fluid viscosity (corn flour), as a function of the falling velocity $v$, for each of the tests carried out. The results of these experimental calculations are presented in Table 4.

Table 4: Experimental data from the calculation of the Reynolds number for corn flour as a function of the falling velocity of the sphere.

| Viscosity [Pa·s] | Velocity $v$ [m/s] | Re  |
|------------------|--------------------|-----|
| 7.7974           | 0.1350             | 0.1409 |
| 5.1954           | 0.2026             | 0.3175 |
| 4.7026           | 0.2239             | 0.3875 |
| 3.1000           | 0.3396             | 0.8918 |
| 2.5414           | 0.4143             | 1.3269 |

In this way (See Table 4), we can verify that the Reynolds number obtained is within the following range (0.1409 < $Re < 1.3269$), for which it can be assumed that the flow remains stationary and behaves as if it were formed by thin sheets, which interact only depending on the existing tangential stresses, so this flow is called laminar flow in which the Reynolds number value is $Re < 2300$. 
4.3 Ketchup results analysis

The average times obtained of the travel of the sphere in the distance \( L \) at different temperatures are presented in Table 5. With these times, the data of the fluid density, dimensions and density of the sphere were calculated by replacing the viscosity in Equation (10) (See Table 5). It was found that when the temperature increases, the time decreases, which represents a lower shear stress at a higher temperature, that is, a lower viscosity of the fluid. This variation in viscosity with temperature proves that ketchup sauce is a non-Newtonian fluid.

| \( T \) [K] | Average time [s] | Viscosity [Pa·s] |
|------------|-----------------|-----------------|
| 298        | 1.677           | 19.14           |
| 299        | 1.492           | 17.04           |
| 301        | 1.268           | 14.48           |
| 303        | 1.023           | 11.68           |
| 305        | 0.786           | 9.47            |
| 308        | 0.659           | 7.53            |

The results of the ketchup viscosity at different temperatures are presented in the Figure 4b. Equation (10) was used to calculate the viscosity at each temperature, in this case the density of the ketchup used was 1235 kg/m\(^3\) [11]. Because ketchup is a non-Newtonian fluid, a power adjustment was fitted, obtaining a good approximation with an \( R^2 \) of 0.999 (See Figure 4b). The model obtained corresponds to the exponential model (See Equation (11)), In Figure 4b, it is shown that the curve for the behavior of viscosity as a function of temperature is a decreasing exponential behavior as shown in Equation (11), in which it is evident that ketchup corresponds to a pseudoplastic fluid.

On the other hand, fitting the data to a linear model (See Figure 5a), the activation energy \( E \) of ketchup can be calculated, using the linearization of Equation (14) and Equation (15), with these Two equations, the result shown in Equation (23) of the energy \( E \) is obtained for ketchup.

\[
E = 8861.107 \cdot 8.314, \quad (22)
\]

\[
E = 73.671 \quad kJ/mol. \quad (23)
\]

On the other hand, the Reynolds number can be calculated as a function of the viscosity using the expression of the Equation (4). In the Table 6 shows the Reynolds number for each temperature and each velocity reached for the sphere in the ketchup fluid.

4.4 Cornstarch results analysis

The average times obtained of the travel of the sphere in the distance \( L \) at different temperatures are presented in Table 7. With these times, the data of the fluid density, density and dimensions of the sphere were calculated by replacing the viscosity in Equation (10) (See Table 7). It was found that when the temperature increases, the time decreases, which represents a lower shear stress at a higher temperature, that is, a lower viscosity of the fluid. This variation in viscosity with temperature proves that cornstarch sauce is a non-Newtonian fluid.

| \( T \) [K] | Average time [s] | Viscosity [Pa·s] |
|------------|-----------------|-----------------|
| 299        | 1.1784          | 14.025          |
| 300        | 1.1784          | 14.025          |
| 303        | 1.019           | 12.127          |
| 305        | 0.8284          | 9.855           |
| 305        | 0.8277          | 9.850           |
| 306        | 0.8026          | 9.552           |

The results of the ketchup viscosity at different temperatures are presented in the Figure 4c. Equation (10) was used to calculate the viscosity at each temperature, in this case the density of the cornstarch used was 1207.31 kg/m\(^3\) [11]. Because cornstarch is a non-Newtonian fluid, a power adjustment was fitted, obtaining a good approximation with an \( R^2 \) of 0.9887 (See Figure 4c). The model obtained corresponds to the exponential model (See Equation (11)), In Figure 4c, it is shown that the curve for the behavior of viscosity as a function of temperature is a decreasing exponential behavior as shown in Equation (11), in which it is evident that cornstarch corresponds to a fluid that is pseudoplastic.

On the other hand, fitting the data to a linear model (See Figure 5c), the activation energy \( E \) of cornstarch can be calculated, using the linearization of Equation (14) and Equation (15), with these two
equations, the result shown in Equation (25) of the energy $E$ is obtained for cornstarch.

$$E = 5728.617 \cdot 8.314,$$

$$E = 47.627 \text{ kJ/mol.}$$

On the other hand, the Reynolds number can be calculated as a function of the viscosity using the expression of Equation (4). Table 8 shows the Reynolds number for each temperature and each velocity reached for the sphere in the cornstarch fluid.

Table 8: Experimental data from the calculation of the Reynolds number for cornstarch as a function of the falling velocity of the sphere.

| Viscosity [Pa·s] | Velocity $v$ [m/s] | Re   |
|------------------|--------------------|------|
| 14.025           | 0.0678             | 0.2729|
| 14.025           | 0.0679             | 0.2728|
| 12.127           | 0.0785             | 0.3650|
| 9.855            | 0.0965             | 0.5285|
| 9.850            | 0.0966             | 0.5858|
| 9.552            | 0.0996             | 0.5984|

4.5 Sunflower oil results and analysis

In the case of sunflower oil, where it has a Newtonian fluid behavior, in which with increasing temperature, the viscosity value will remain constant. It is for this reason that we only take the fall time of the sphere, for a single temperature, which in our case was 297 K. Using Equation (10), for an experimentally measured density value equal to 907.42 kg/m$^3$, a viscosity value was obtained for sunflower oil, equal to 41.22 $\times 10^{-3}$ Pa·s $^{[21][22]}$. Carrying out the respective comparison, with the theoretical value reported by the literature, we found a percentage error of 5.57%, in which a great closeness with the theoretical value could be evidenced; which is evidence that an experimental procedure could be successfully carried out, with the purpose of indirectly measuring the viscosity of sunflower oil; this being a Newtonian fluid.

4.6 Glycerine results and analysis

For the Newtonian fluid glycerine, 490.928 mL of glycerine were taken in the cylinder, this volume was weighed obtaining a mass of 1.115 kg. The density was calculated by dividing the mass of glycerine in the volume, obtaining an experimental density of 1177.374 kg/m$^3$. The distance traveled by the sphere was 0.1065 m and the average time was 0.1578 s. With these values the velocity was calculated obtaining 0.6748 m/s. These values were replaced in Equation (10) and the viscosity value was calculated, obtaining an experimental value of 1.4183 Pa·s. The reported viscosity value for commercial glycerine at a temperature of 298 K is 1.412 Pa·s $^{[23][24]}$, which indicates that the experimental value obtained in this study is very close to the reported theoretical value.

5 Acknowledgments

The authors: Alex Estupiñán and Claudia Tavera, would like to express their thanks, especially to the Universidad de Investigación y Desarrollo UDI, for all the human, material and financial support to carry out this research work. Also the authors: Raúl Rojas and Juan Quijano, they want to thank the Universidad Autónoma de Bucaramanga UNAB, for providing us with technical and financial support.

6 Conclusions

In this work was possible to implement an experimental protocol to perform the indirect measurement of the viscosity of Newtonian and non-Newtonian fluids. The results obtained in this research are shown with high precision and accuracy, and it is possible to catalog the behaviour of the different fluids.

It was demonstrated that our prototype can accurately measure the viscosity of both Newtonian and non-Newtonian fluids, in addition to working properly at different temperature conditions.

Additionally, due to the good adjustments presented in the graphs of $1/T$ Vs Ln of viscosity, it was possible to calculate the transition energy of the molecules, which are in accordance with the values presented in the literature. Likewise, experimental values of the Reynolds number could be obtained, with which it is possible to predict the behavior of the fluid. In this case, the fluids were in steady flow, which could be verified with the $Re$ values obtained.

References

[1] Amado, E., & Mora, L. (2006). Análisis de la variación de la viscosidad cinemática de un aceite vegetal en función de la temperatura. Bistua: Revista de la Facultad de Ciencias Básicas, 4(2), 54-56.

[2] Malkin, A. Y., & Khadzhiev, S. N. (2016). On the rheology of oil. Petroleum Chemistry, 56(7), 541-551.
[3] Sharifi, M., & Young, B. (2012). Milk total solids and fat content soft sensing via electrical resistance tomography and temperature measurement. Food and Bioproducts Processing, 90(4), 659-666.

[4] Walstra, P., Wouters, J. T. M., & Geurts, T. J. (2006). Milk components. Dairy science and technology, 2, 17-108.

[5] Griffin, R., Izatt, J., & Lettier, J. (1963, January). Application of Asphalt Viscosity to Paving Problems. In Symposium on Fundamental Viscosity of Bituminous Materials. ASTM International.

[6] Mertens, E. W. (1966). U.S. Patent No. 3,240,716. Washington, DC: U.S. Patent and Trademark Office.

[7] Korosi, A., & Fabuss, B. M. (1968). Viscosity of liquid water from 25 to 150 degree. measurements in pressurized glass capillary viscometer. Analytical Chemistry, 40(1), 157-162.

[8] Lundstrum, R., Goodwin, A. R., Hsu, K., Frels, M., Caudwell, D. R., Trusler, J. M., & Marsh, K. N. (2005). Measurement of the viscosity and density of two reference fluids, with nominal viscosities at T = 298 K and p = 0.1 MPa of (16 and 29) mPa, at temperatures between (298 and 393) K and pressures below 55 MPa. Journal of Chemical & Engineering Data, 50(4), 1377-1388.

[9] Stachowiak, G., & Batchelor, A. W. (2013). Engineering tribology. Butterworth-Heinemann.

[10] Quinchia, L. A., Delgado, M. A., Valencia, C., Franco, J. M., & Gallegos, C. (2009). Viscosity modification of high-oleic sunflower oil with polymeric additives for the design of new biolubricant formulations. Environmental science & technology, 43(6), 2060-2065.

[11] Segur, J. B., & Oberstar, H. E. (1951). Viscosity of glycerol and its aqueous solutions. Industrial & Engineering Chemistry, 43(9), 2117-2120.

[12] Marghitu, D. B. (2001). Mechanical engineer’s handbook. Elsevier.

[13] Mataix, C., Mecánica de fluidos y máquinas hidráulicas, second edition, Harla (1982).