***Original Research Article***

# Development of Viscosity Measuring Device using Vibrational Technique


## ABSTRACT

The project centers on the development of viscosity measuring device using vibrational techniques. The instrument consists of a variable power supply, solenoids, spindle with a pendulum bob attached, switching circuit, current – voltage sensors, microcontroller (arduino mega 2560), analog–to–digital converter and Liquid Crystal Display (LCD ) unit. The developed system consists of a variable power supply used to increase the magnetic field strength in the solenoid that has a spindle attached to a pendulum bob. As the magnetic field strength varied, the pendulum moves up and down inside the liquid and it overcomes the internal friction within. The pendulum bob is thus set into periodic upward and downward motion. The pendulum bob movement was monitored by a microcontroller through a reflective optical sensor. Viscosity was measured through the calibration constant generated from a liquid of known viscosity, applied voltage, current generated from the solenoids and the dragging time. Gear oil, engine oil, palm oil, olive oil were the fluids investigated with the developed system for performance evaluation. Statistical analysis revealed a percentage error value of 2.87% and accuracy of 97.13% which shows a good agreement between the standard and what is available in literature. The instrument performed well and it is therefore suitable for the measurement of liquids' viscosities.


**Keywords: Magnetic field strength, Calibration constant, Solenoid, Microcontroller**

## INTRODUCTION

The concept of viscosity was postulated by Sir Isaac Newton as the resistance of a fluid (liquid or gas) to a change in shape, or movement of neighboring portions relative to another and denotes opposition to flow. Viscosity is also referred to as lack of slipperiness [14]. Using this concept, all fluids can be categorized by examining the relation between the applied shear stresses and the deformation rate of flow of a fluid [6].

Viscosity is the quantitative property of a fluid, be it liquid or gas, and can also be used in quality control [5]. A change in viscosity can indicate a fundamental change in a material under test [12]. Viscosity measurement and control has great importance in food industry and an accurate knowledge of viscosity is necessary for various industrial processes [9]. Accurate viscosity data and their variations with operating conditions are needed also for various research and engineering applications in any branch of the food industry, such as developing food processes and processing equipment, control of products, quality evaluation and an understanding of the structure of food and raw agricultural materials [1].

Also, the knowledge of viscosity is of primary importance to the fruit industry. For example, viscosity is an important property of juices in the production of heat-and mass-transfer coefficients and in the design of heat-and mass-transfer equipment for juice industry. It is also of great importance in automobile industry because the knowledge of viscosity in engine oils is used as a method of maintaining the performance of engines (Higashi and Tanaka, 2012).

So many researches have been conducted on viscometry but none of them has addressed variation of liquid samples. The theory of the vibrating wire viscometer was improved by Mostert *et al.,* in 1989. Their publication includes the equations necessary to calculate viscosity based on the mechanical motion of wire and the motion of the surrounding fluid. Kandil (2005), made some modifications by varying the material, radius, length of wire used in the measurement of gases and liquids viscosities. He achieved a better accuracy with an estimated uncertainty of about 2%.

Retsina *et al.*, (1987) used a rod of much larger diameter instead of a wire. His model was tested on water it also produced an accuracy of 0.1%. A vibrating wire viscometer requires a smaller sample fluid volume than the falling body and oscillating viscometers. Moreover, its construction is also very simple relative to the other methods, securing the reproducibility of results.

The technique of viscosity measurements made by Won-kyu *et al*., (1999) involved a small sample of material levitated and melted in a high vacuum using a high temperature electrostatic levitator. The resonant oscillation of the drop was induced by applying a low level ac electric field pulse at the drop of resonance frequency; the transient signals which followed the pulses were recorded and the viscosity signal was then extracted. This technique is useful for both molten metallic alloy and semiconductors. The system is mostly designed for high temperature liquid.

Benjamin *et al.*, (2013) developed a real – time viscosity measuring instrument requiring micro liter sample volume based on nano mechanical resonators. In their work, a nano mechanical cantilever vibration was driven by photo thermal excitation and detected by an optical beam deflection system using two laser beams of different wavelengths. The performance of the developed sensor was studied and the theory was validated over a viscosity range of 1-20mPa.s (milli Pascal second).

Cakmak *et al.*, (2013) developed a viscometer to measure blood plasma and serum viscosity with a micro cantilever based micro-electromechanical systems (MEMS) sensor. Real time of cantilever frequency is performed remotely using diffraction gratings fabricated at the top of the dynamic cantilevers. Only few cantilever deflectors were employed due to interferrometric sensitivity of the read out. The resonant frequency of the cantilever wass tracked in the Phase Locked Loop (PLL) control circuit. The viscosity of liquid samples was obtained through the measurement of the cantilevers frequency with respect to a reference measurement taken within a liquid of known viscosity. The measuring viscosity range of the equipment was between 0.86 centipoise and 3.02 centipoise which cover human blood plasma viscosity range, with a resolution better than 0.04 centipoise.

Hassan *et al.,* (2013) fabricated a viscosity measuring instrument. A motor was used to rotate a disk having holes for infrared light to pass through and fall on a photodiode thus undergoing amplification. This signal was translated on the moving coil meter as a deflection with the motor speed kept constant. Variation of the motor speed changes the viscosity of the fluid during stirring and this altered the reading on the meter. The faster the revolution per minute of the disk, the lesser the deflection on the meter and vice-versa. The results of the test conducted on various sample fluids using data of fluid had an efficiency of 78.5%.

This work looks at the design a magnetic field induced vibrational system that will drag the pendulum bob in a liquid sample under test, determine the dragging time in relation with the applied voltage or current across the solenoid; and then calibrate and evaluate the vibrational viscosity system.

## MATERIALS AND METHODS

Figure 1.0 shows the block diagram of the developed instrument for an automatic measurement of liquid's viscosity. The instrument contains a vibrational unit which is made up of a solenoid and a pendulum bob. An optical image sensor called optocoupler is fixed adjacent to the transparent liquid container for image sensing. This helps to measure the to- and -fro timing (period) of the pendulum bob through the software code embedded in the microcontroller. The to-and fro movement of the solenoid used in this work was achieved through a variable power supply and relay operating in the switching mode. The microcontroller also function as voltmeter and ammeter which measures the applied voltage and current required to overcome the liquid resistance and set the bob into motion. The pendulum bob was hanged at the joint of the solenoid to enhance the to-and-fro movements. Two reflective optical sensors (optocouplers) were employed to measure the period of oscillation of the pendulum bob. The period measured were analogue parameters while data acceptable to the microcontroller must be in digital form. This period (time) is an example of a physical quantity existing in analogue form. To convert a continuously varying physical quantity into electrical signals, there is need for an Analog-to-Digital Converter (ADC) to translate the analog signals to digital numbers so that the signal can be recognised by microcontroller [10]. The microcontroller was interfaced with a LCD so as to display the measured values of current, voltage, time and viscosity.

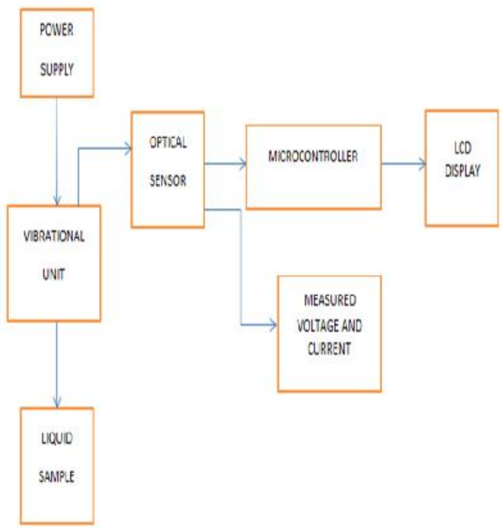


Figure 1.0: Functional block diagram of the automated liquid viscosity measuring instrument

**Experimental Setup**

Figure 2.0 shows the experimental setup of the developed instrument. This work made use of a linear type solenoid. The solenoid type utilized in this work was used because of the need for the plunger to go on and off as long as power is fed into the solenoid. The adjustable power supply was powered with an input voltage of 15 V and it gave a digital voltage that ranges from 1.2 V -15 V. The output of the voltage regulator (LM317) was fed into the relay coil to increase the magnetic field strength of the solenoids attached to the common and normally open points of the relay. When the solenoid attracting magnetic force overcomes the viscosity of the liquid, the pendulum bob moves to-and-fro. The reflective optocoupler positioned directly adjacent to the transparent liquid container senses the ON and OFF states of the solenoids as the pendulum moves respectively. The ON and OFF states of the solenoids were used to determine the to-and-fro time movement of the bob as shown in figure 2.0. Methods previously used by researchers required that viscosity be calculated manually from measured parameters like: distance (cm), time (s), current (A) and voltage (V). This present study however overcame this hurdle as viscosity values were deduced directly from the sample.

**Viscometer Calibration**

The developed instrument was calibrated using water as a standard liquid with known viscosity value as provided in literature. It is necessary to compute the calibration constant in order to ascertain the accuracy and efficiency of the developed system.

The calibration of the viscometer was done usi The c nd water as a sample.

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$$\eta = \eta \qquad 1.0$$

ng equation 1.0 ar

$$K = KIVt \qquad 1.1$$

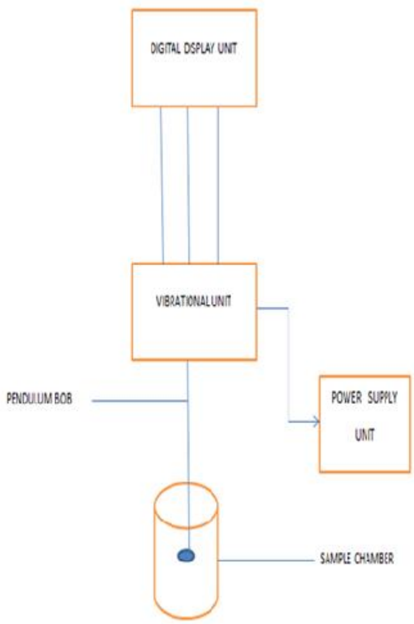


Figure 2.0: Experimental setup of the developed instrument for viscosity measurement.

where η is the viscosity, K is the calibration constant, I is the current, V is the voltage and t is the time taken for the bob to complete an oscillation in a liquid. The microcontroller was used to measure the current, voltage and time which made the computation of the calibration constant easier.

The following results were obtained:

Current = 0.249 A

Voltage =12.022 V

Time (for to and fro) = 7.027 (ms)

K = 48.437 (mPa/VA)

The calculated calibration constant K was substituted into equation 1.0 and a suitable program was written and embedded into the microcontroller so as to compute the viscosity η of any liquid under investigation using equation 1.0.

**TESTING, RESULTS AND DISCUSSION**

Five different liquid samples of known viscosity values were tested using the designed instrument under the same condition. The results obtained were compared with their corresponding standard values as shown in Table 1.0. The samples are water, olive oil, engine oil, gear oil and palm oil. The samples were poured in the sample chamber. Varying voltage was supplied to the solenoid through a programmable power supply. The microcontroller performed the experimental measurement of period *t* during which the pendulum swings in the liquid sample, the supplied voltage *V* and current *I*, after which the measured parameters were used to simultaneously compute the viscosity of the samples. The system was allowed to dry before another sample measurement was taken. At the end of the measurements, the values obtained were compared with known literature values of [3].

Table 1.0: Standard and Measured viscosities of various liquids at ambient temperature

| Liquid | Time (m) | Voltage (V) | Current (A) | Literature Value (mPa.s) | Instrument Value (mPa.s) |
|---|---|---|---|---|---|
| Water | 7.028 | 12.03 | 0.25 | 1.0087 | 1.0237 |
| Olive Oil | 15.520 | 12.63 | 3.90 | 40.0000 | 37.0000 |
| Palm oil | 16.270 | 12.76 | 4.08 | 45.0000 | 41.0000 |
| Engine Oil | 60.780 | 13.83 | 9.32 | 390.0000 | 379.0000 |
| Gear Oil | 98.970 | 14.72 | 9.72 | 700.0000 | 686.0000 |

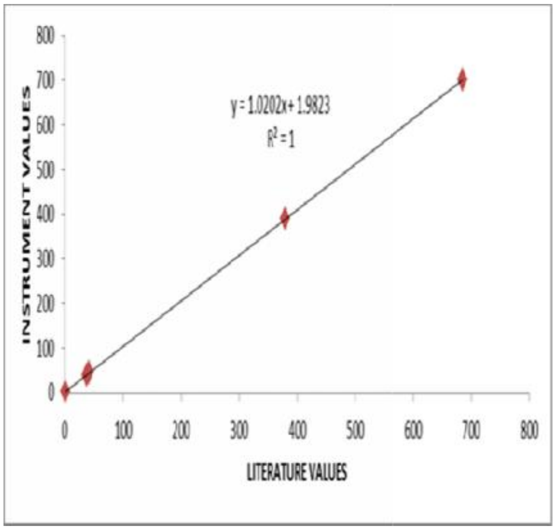


Figure 3.0: Plot between Measured viscosity values and literature values

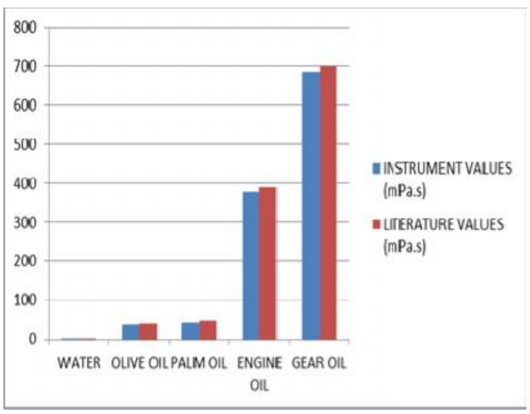


Figure 4.0:Bar chart between the measured viscosity values and literature values

Statistical analysis was carried out and a Mean Absolute Percent Error (MAPE) of 2.87 % was obtained between the experimental and theoretical values. The plots of the measured and the standard values shows that developed system provides linear and reliable output as shown in Figures 3.0 and 4.0.

The correlation factor ($R^2$) of 0.999978 obtained also show a reliably good agreement between the measured values with the standard data values. The instrument can be operated between $0^oC$ and 100°C.

## CONCLUSION

The Microcontroller-based vibrational viscometer has been developed to measure viscosity of liquids. The calibration constant of the instrument was 48.437mPa/VA which was calculated from liquid of known (water) viscosity. The viscosity obtained by the developed instrument compared favorably well with the standard. It was observed that the Mean absolute percentage error of the measurement was found to be 2.87% which translates to an accuracy of 97.13%. The instrument is highly reliable, user friendly, less expensive and portable.

Further investigation is still on-going using pendulum bob of various sizes to ascertain the effect of bob sizes on viscosity. Also, the speed of the pendulum bob is being investigated and measured. A wider output screen is being considered to accommodate a graphical user interface. A data logging section will also be incorporated to create a means of keeping the data in a more refined and modern way for future purposes.

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