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, two solenoids each with plungers, needle with a pendulum bob attached, switching circuit, current – voltage sensors, microcontroller, analog–to–digital converter and Liquid Crystal Display (LCD) unit. The developed system consists of a variable power supply used to create varying magnetic fields in the solenoids so that the plungers can attract and release the pendulum bob. As the magnetic field strength varies, the pendulum experiences force sufficient to overcome the internal friction within the liquid. The pendulum bob is thus set into periodic to and fro 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

1.0 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 [1]. 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 [2].

Viscosity is the quantitative property of a fluid, be it liquid or gas, and can also be used in quality control [3]. A change in viscosity can indicate a fundamental change in a material under test [4]. Viscosity measurement and control has great importance in food industry and an accurate knowledge of viscosity is necessary for various industrial processes [5]. 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 [6].

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.

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 the work of Mostert *et al* in 1989 [7]. Their publication includes the equations necessary to calculate viscosity based on the mechanical motion of wire and the motion of the surrounding fluid. In 2005, Kandil 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% [8].

A rod of much larger diameter instead of a wire was experimented by Retsina in 1987. His model was tested on water and it produced an accuracy of 0.1% [9]. 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.

Furthermore, the technique of viscosity measurement made by Won-kyu *et al.*, involved a small sample of material levitated and melted in a high vacuum using a high temperature electrostatic levitator [10]. The resonant oscillation of the drop was induced by applying a low level 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.

This work makes use of a vibrational system produced by varying magnetic field to drag a pendulum bob within the liquid sample under test. It measures the dragging time in relation with the applied voltage across the solenoid; and then compute the viscosity of the liquid sample as decribed below.

2.0 MATERIAL AND METHODS

Figure 1.0 shows the block diagram of the developed instrument for automatic measurement of liquid's viscosity. The instrument consist mainly of a vibrational unit, optical sensor, microcontroller unit, and a display unit. The vibrational unit is made up of two solenoids with plungers and a pendulum bob suspended vertically by a thin rod (needle) placed between the common ends of the two plungers as shown in figure 2. The variable power supply provides alternating magnetic fields in the two solenoids which causes the plungers to push and pull the needle which holds the pendulum bob. Hence the to-and fro movement of the pendulum bob was provided as the solenoids get energized and de-energized gradually. The optical sensing unit is made up of an optocoupler placed adjacent to the transparent liquid container for sensing the to and fro movement of the bob .The optocoupler is embedded with a Light Emitting Diode (LED) which offers the transmitting function and the phototransistor which serves as the receiver. The optocoupler utilized for this project was PS4009 and it was made to work in a switching mode. The optocoupler detects the to and fro movement of the bob as the bob intercepts the ray path between the sender (LED) and receiver (phototransistor) during oscillation. The period of oscillation is an analogue parameter while data acceptable by microcontroller must be in digital form. This period (time) is an example of 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 [11].

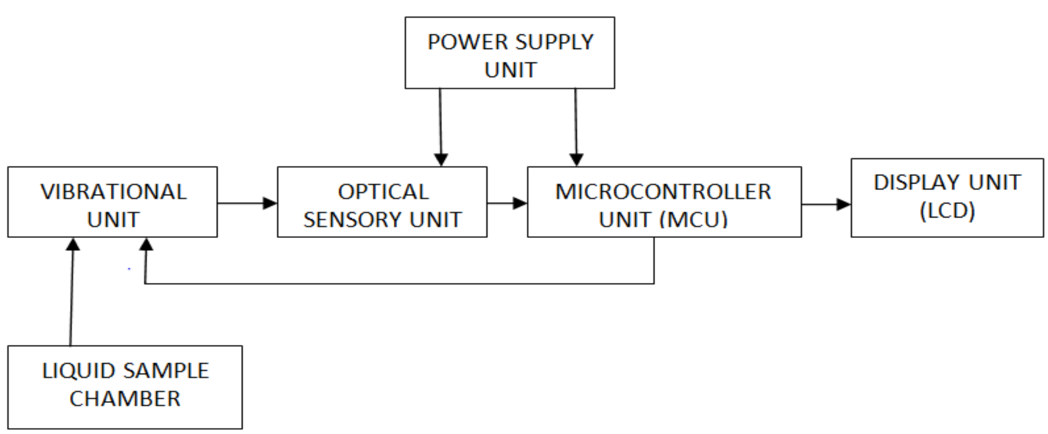

Figure 1: Block diagram of the developed viscometer

Figure 2: Image of the developed viscometer

The microcontroller also function as voltmeter and ammeter by measuring the applied voltage and current required to overcome the liquid's internal friction and set the bob into motion. The microcontroller unit consists of a programmable integrated circuit known as atmega 328P. A suitable micro-C code was written and embedded in the microcontroller so as coordinate the activity of the entire system, perform the necessary calculations and send output result to the display unit. The microcontroller was interfaced with a 2 by 16 Hitachi Liquid Crystal Display (LCD) so as to display the measured values of current, voltage, time and viscosity.

2.1 MODE OF OPERATION

Figure 3.0 shows operational chart of the developed instrument. This work made use of a linear type solenoid because of the need for the plunger to move in and out when variable is power fed into the solenoids from the microcontroller. A 15 V adjustable power supply was used to provide digital voltage ranging from 1.2 V to 15 V to power the MCU, transistors and optocoupler. The alternating output voltage from the MCU was amplified by transistors. The outputs of these transistors were connected to the commonly open and normal terminals of the relay so as to create varying magnetic field in the two solenoids one after the other. When the solenoid produces magnetic force which is just sufficient to overcome the viscosity of the liquid, the pendulum bob begins to move 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 oscillates.

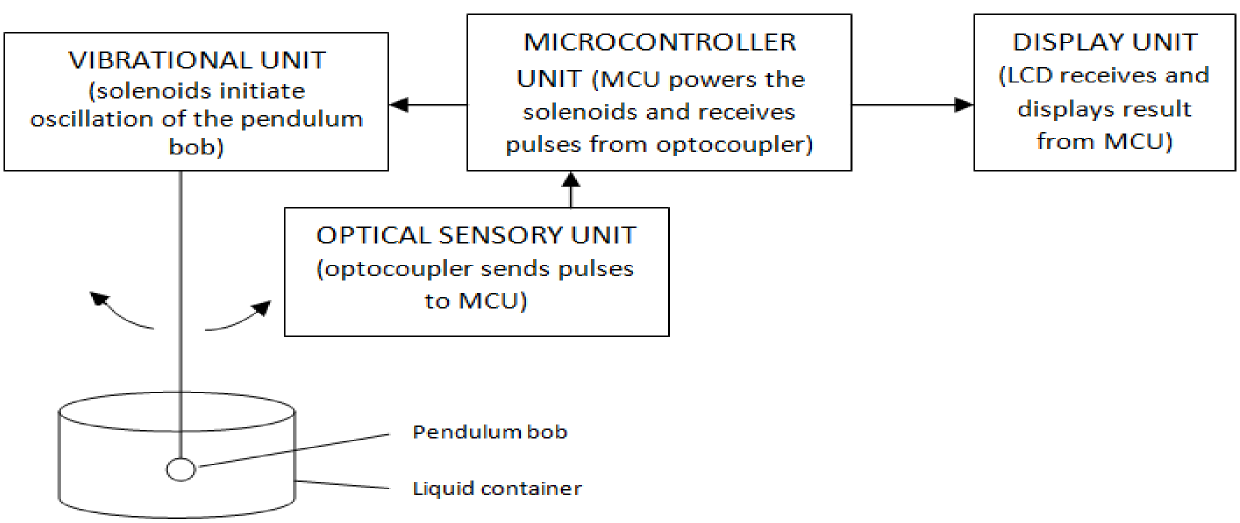

Figure 3: Operational chart of the developed viscometer

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 and displayed on the screen. Figure 4 shows the image of the designed circuit.

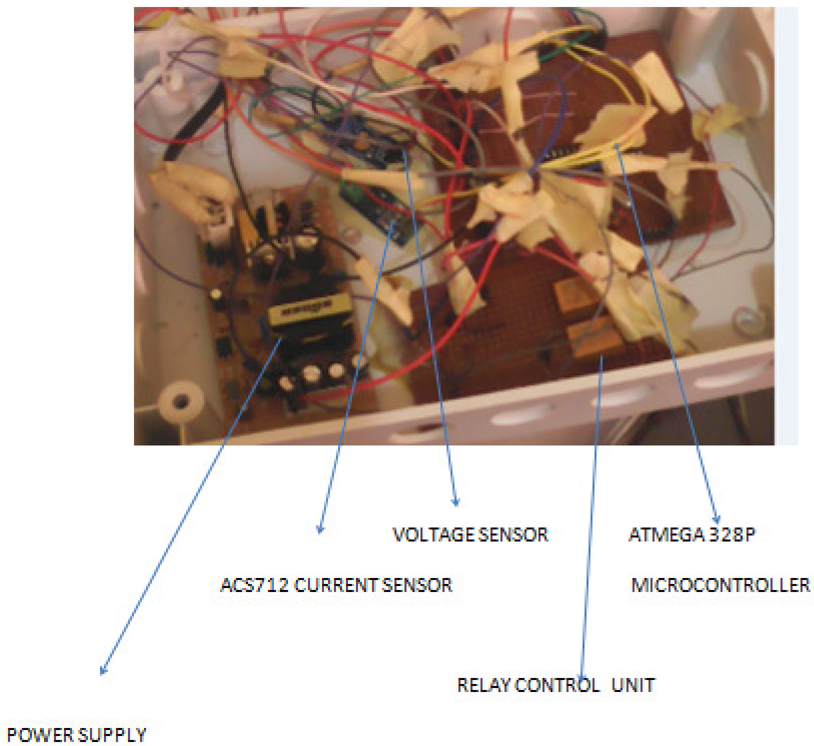

Figure 4: Image of the developed instrument showing the circuit components

2.2 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 K in order to ascertain the accuracy and efficiency of the developed system. The calibration of the viscometer was done using equation 1.1.

$$\eta = KIVt \qquad (1.0)$$

$$K = \frac{\eta}{IVt} \qquad (1.1)$$

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. Figure 5 shows the complete circuit diagram of the developed system.

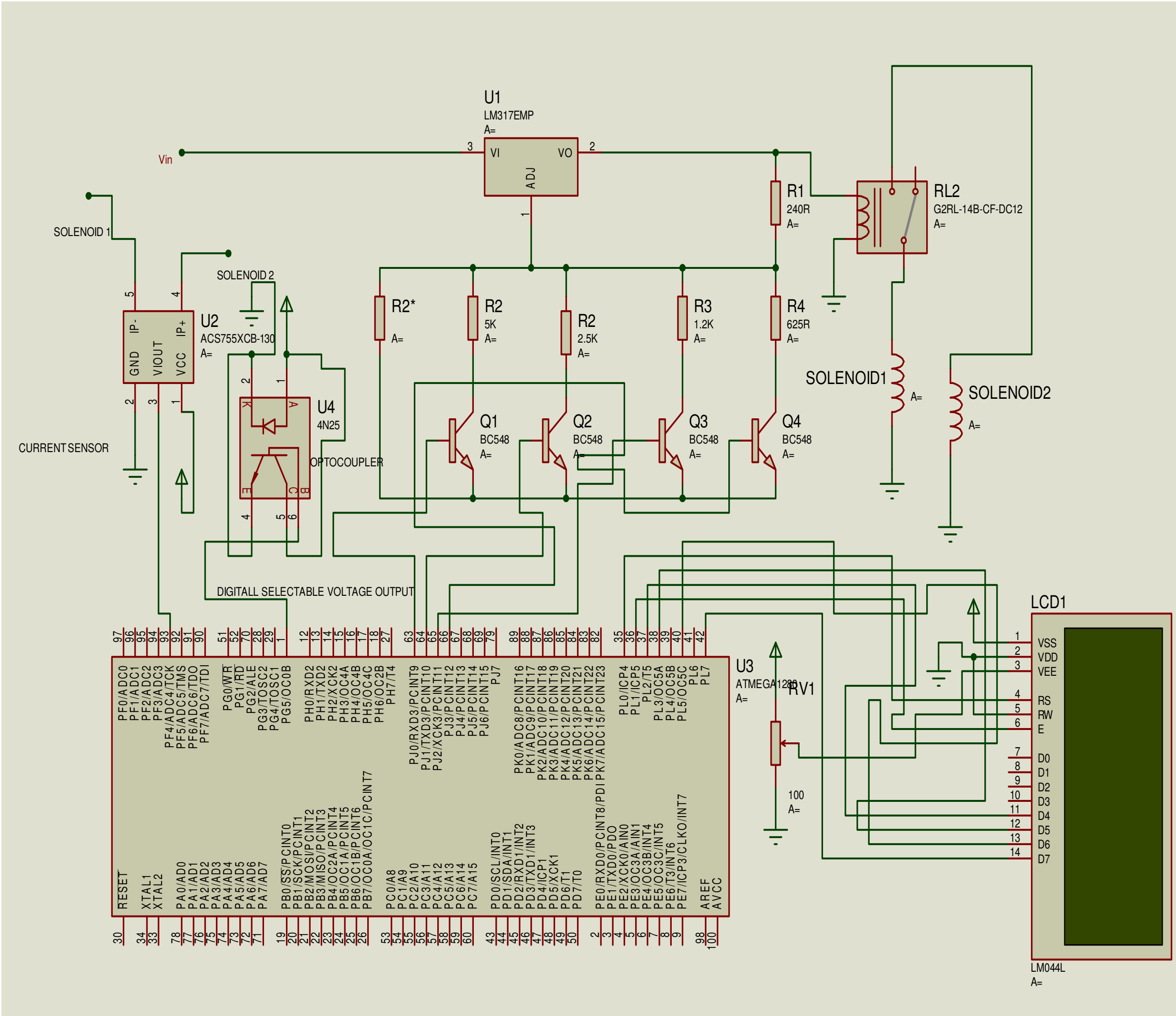

Figure 5: Circuit diagram of the developed viscometer

The following results were obtained when water was used as the standard liquid;

Current = *0.249 A*

Voltage =*12.022 V*

Time (for to and fro) = *7.0 ms*

Using equation 1.1, the calibration constant K is;

$$K = \frac{1.0087}{0.249 \times 12.022 \times 0.007}$$

$$K = 48.137\, mPa / VA$$

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 directly compute the viscosity η of any liquid under investigation using equation 1.0.

3.0 RESULTS AND DISCUSSION

Five different liquid samples of known viscosities 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 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 compute and display 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 [12].

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**

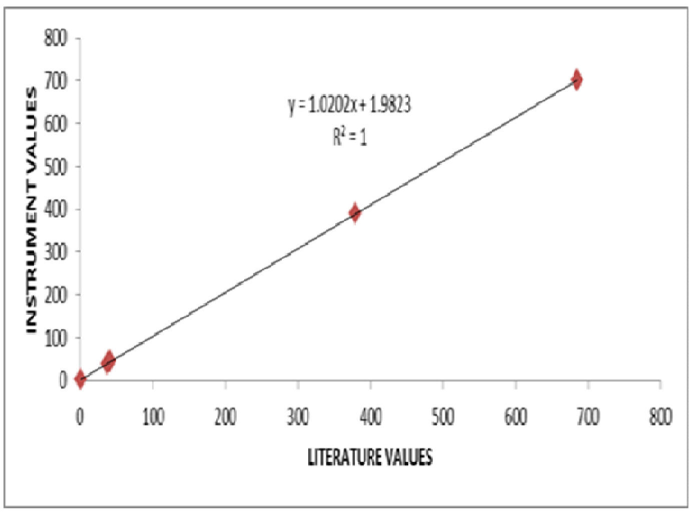

Figure 6.0: Plot between Measured viscosity values and literature values

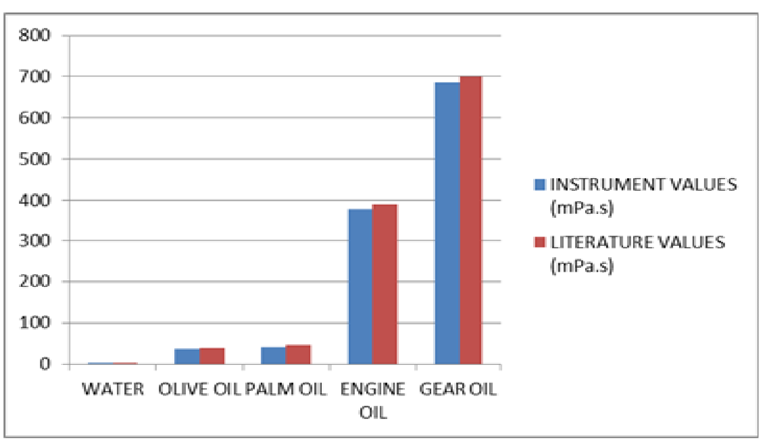

Figure 7.0:Bar chart between the measured viscosity values and literature values

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 6.0 and 7.0.

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°C and 100℃.

4. CONCLUSION

A cost effective locally made microcontroller-based vibrational viscometer has been developed to measure and display viscosity of liquids. The calibration constant of the instrument was 48.137 mPa/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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