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Analysis of Vegetable Oil's Rheological Parameters using AT-mega 328 Microcontroller

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ABSTRACT

This paper presents the microcontroller based measurement and analysis of kinematic viscosity of vegetable oils that reduces human effort and increases the accuracy of measurement. The developed system consists of AT mega 328 microcontroller, ultrasonic range detecting sensor, temperature sensor, heater, solid heater controller, keyboard and LCD to display the results. The instrument will keep the oil at any desired temperature and measure the time of 50cc of the sample collection so as to compute viscosity of the sample. Viscosities of rice bran oil and corn oil at temperatures ranging from 303-363K are calculated from the measurement of time taken to collect 50cc. Observations reveal that there is a decrease in viscosity with increase in temperature due to decrease in intermolecular forces. The experimental results obtained are compared with a standard instrument and the correlation coefficient is found to be accurate (R^2 = 0.998). The measured viscosity and its corresponding temperature are found to fit into the Arrhenius equation, Reynolds equation, Walther equation and Power law model using regression analysis.

Keywords: AT mega 328 microcontroller, temperature controller, ultrasonic range detector, viscosity.

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INTRODUCTION

Rheological assessment provides handy, behavioral and anticipative report for device flexibility [1]. Temperature is an essential parameter and frequently appears in Rheological equation in the study of flow of liquids. Viscosity measurement is crucial to the design and development of mass and heat transfer flow system [2]. Accurate knowledge about viscosity is also very important for the transport properties of oils [3]. The known viscosity helps in ease of handling, storage and to transfer the oils from one part of the world to the other [4]. Kinematic viscosity is an important possession of lubricating oil and it is calculated from the ratio of absolute viscosity to its density [5].The unit of kinematic viscosity is m^2/s. The flow rate (viscosity) of a fluid is highly persuaded by temperature, pressure, density, chemical properties such as iodine value, amount of saturated and unsaturated fatty acids and time of storage [5-7]. Several studies have been made in the computation of viscosity of fats and oils [8]. The effect of hydrogenation has been investigated on the viscosity and density of oils [9]. Recent researches also reveal the interrelationship between viscosity and dielectric properties such as loss tangent, relaxation time and breakdown strength [10]. Hence it is imperative to measure viscosity which is an important parameter in computing the various properties of fluids [11][12].

Embedded system is a special-purpose computer system designed with microcontroller, input devices, output devices and memories which could be used for dedicated functions, with real-time computing constraints. Microcontroller is a fast operating device; hence it is used in the designing of measurement and controlling system [13]. Depending upon the application point of view, engineers can design and optimize it by reducing the size and cost of the product, or by increasing the reliability and performance [14]. Flash memory chips or ROM (read-only memory) is used to store the software program and necessary data for the execution of the operation.

In the present work viscosity of edible oils at various temperatures is measured using an AT-mega 328 microcontroller. The performance of the instrument is studied and the computed viscosity is analyzed using

(a) Correlation analysis
(b) Regression analysis

MATERIALS AND METHODS

The block diagram of microcontroller based kinematic viscosity measurement setup to study the rheological behaviour of vegetable oils is shown in figure (1). The measurement system consists of a Redwood viscometer, a temperature sensor, a level detector, a solid-state power controller and an AT-mega 328 microcontroller. Block A represents the Redwood viscometer (Associated Instrument manufacturers India Pvt. Ltd., Delhi) which measures viscosity using the principle of laminar flow through a capillary tube. The standard viscosity measurement device chosen to calculate the kinematic viscosity of oil at various temperatures is the redwood viscometer (specification No.1) which has a flow time of about 30 to 2000 seconds. The redwood viscometer comprises of vertical cylindrical oil cup with an orifice in the centre of its base. The orifice can be closed by a ball. A hook pointing upward serves as a guide mark for filling the oil. The water bath, which encloses the cylindrical cup, maintains the temperature of the oil to be tested at constant

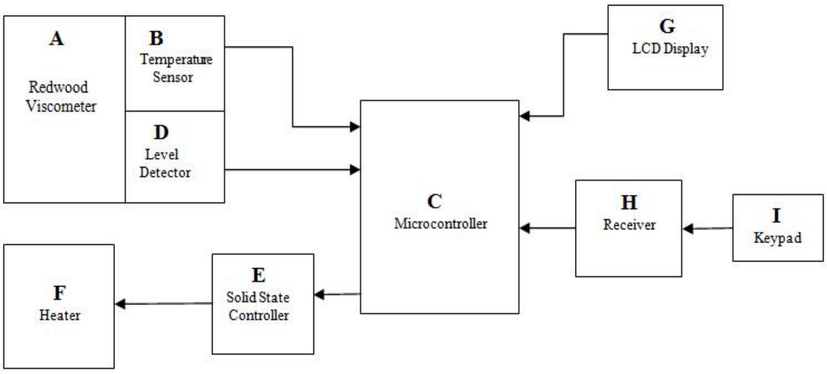

Figure (1): Block diagram of microcontroller based viscometer

temperature. The oil is heated by heating the water bath by means of a solid-state relay and microcontroller. The provision is made to place the temperature sensor in order to record the temperature of oil. The cylinder is 47.625mm in diameter and 88.90mm deep. The orifice is 1.70mm in diameter and 12mm in length. The high-performance Atmel 8-bit AVR RISC-based microcontroller (block C) combines a 32KB ISP flash memory with read-while-write capabilities, a 1KB EEPROM, a 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, a serial programmable USART, a byte-oriented 2-wire serial interface, an SPI serial port, and a 6-channel 10-bit A/D converter.

A keypad (Block H) is used to enter the experimental parameters such as temperature in sequence. A temperature sensor LM-35 (block B) is kept in the sample to measure the temperature. The solid-state power controller in block F controls the power of the electric heater (block G) which is used to heat the oil. The microcontroller reads the data (temperature) of the sample and controls the temperature of bath to the set temperature.

A stepper motor (Block D), which when rotated in clockwise and counter clockwise direction, controls the opening and shutting of the orifice, respectively, through a ball valve. The level detector in block E is an ultrasonic range detecting sensor, which gives the distance of the fluid from the top of the glass jar. The timer 0 in the microcontroller is used to measure the time for 50 cc of sample collection. Block I consists of an LCD display, interfaced with the microcontroller. The LCD displays the measured data and the result. Key board (Block I) is used to give commands and data to microcontroller.

Circuit Diagram

The Circuit diagram for the microcontroller based viscosity measurement setup is shown in figure (2). A bipolar stepper motor is interfaced with the microcontroller digital pins 0-3(pin no. 2-5) through an H-bridge, SN754410NE. The motor is rotated for about 20°, which enables the hook that lifts the ball valve, thus allowing the liquid to flow through the orifice. The solid-state power controller, built with MOC3040 (opto-coupler) and BT136

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(triac) is used to set the desired temperature. Pulse width modulation (PWM) generated by the microcontroller is used to control the temperature of the heater. The output from the digital pin 6 (pin no. 12) of microcontroller is connected to MOC3040 (opto-coupler) through the transistor Q, as shown in the figure. The opto-coupler isolates high voltage AC from the microcontroller. The Triac and the heater are connected to Line Voltage AC, as shown in the figure. The keypad is interfaced with digital pins 16-18 (pin no. 25-28) of the icrocontroller. The output of temperature sensor, LM-35, connected to digital pin 4(pin no. 6) is given to A/D input of the built-in ADC of AT-mega 328. Ultrasonic range detection sensor output is connected to digital pin 6 (pin no. 12) which triggers the sensor and digital pin 7 (pin no.13) which receives the reflected signal. The experimental parameters are fed into the system by the keyboard. HD44780U (an LCD) from Hitachi, interfaced with digital **Figure (2): Circuit**

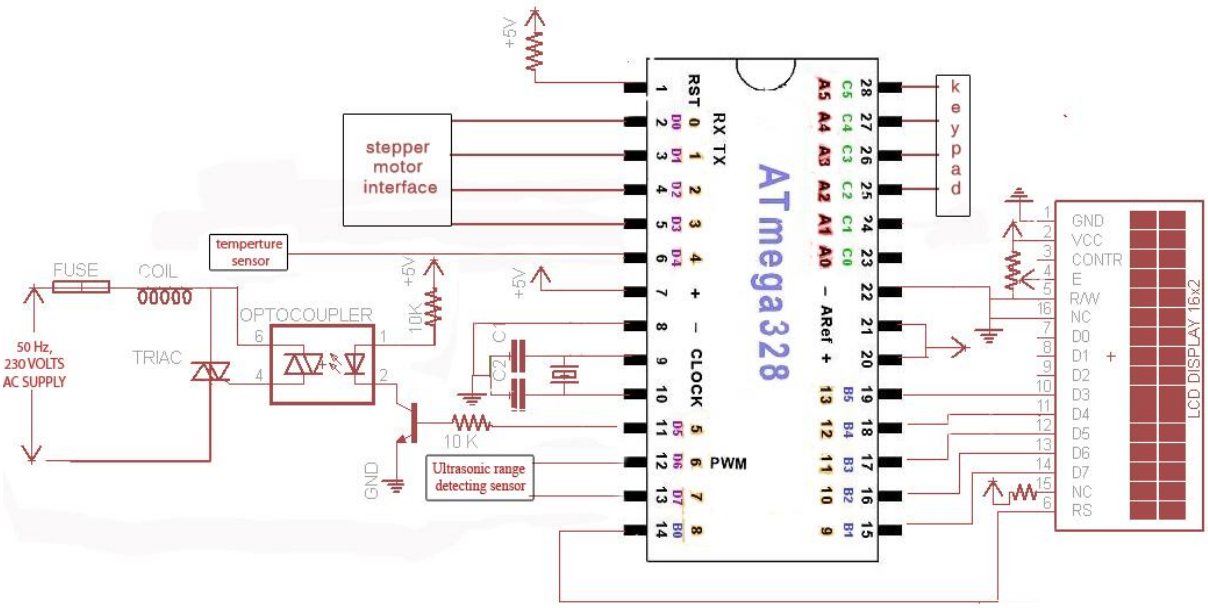

diagram for the microcontroller based viscosity measurement setup

pins 8,9,10,11,12,13of the microcontroller as shown, displays the measured data and the result.Software, established in C language is used to load the ports; to measure and control temperature; to start the timer when the level of the liquid reaches level of the liquid reaches 10 cc; to stop the timer when it reaches 60 cc; to compute the time and hence to compute the viscosity; to enter the data through the keypad and to display the temperature and the results (viscosity) in LCD. The ISR (Interrupt service subroutine) maintains the temperature of the sample at the desired temperature. The Flow chart of the program is shown in Figure (3).

EXPERIMENTAL

Vegetable oils like corn oil and rice bran oil are bought from the market and maintained fresh by keeping at low temperature before they are used for the study. The copper cylinder in viscometer is filled with oil. The temperature of the sample is given through the keypad to withhold the temperature of water bath. When the stepper motor lifts the ball valve, the oil in the copper cylinder of the viscometer drains through the orifice into the beaker, placed below. When the level of the oil reaches 10 cc, the ultrasonic range detecting sensor senses it and the microcontroller is programmed so as to start the timer. Again, the timer is stopped, when 60 cc level of oil is reached and the stepper motor is rotated in the reverse direction to stop the liquid flow by shutting the orifice with the ball valve. The time consumed for draining of 50cc is found out from the value in the timer and the Kinematic viscosity is calculated by the AT-mega 328 with the Eq. (1)

$$\eta = (A \times t - B/t) \times 10^{-4}\ m^2/s \ldots (1)$$

Where,

η = Kinematic viscosity of oil

A=0.26, B=172 (for t > 34s) are viscometer constants which depend upon the dimensions of the cylinder and the orifice, and t = time required to drain 50cc of oil. Viscosity of rice bran oil is measured for various temperatures ranging from 303 K to 363 K.

The Experiments are repeated three times to check the reproducibility of the instrument. The copper cup is cleansed using CCl_4 before the next observation.

RESULTS AND DISCUSSION

Viscosity of corn oil and rice bran oil purchased from the market are measured using the designed instrument with respect to temperature are shown in table (1). Figure (4) shows the change in kinematic viscosity values of rice bran oil and corn oil for temperatures ranging from 303K to 363K. From the figure (4) it is found that an increase in temperature decreases the viscosity. It is a result of a higher thermal movement between the molecules, reducing intermolecular forces. Thus the flow among them is made easier which decreases the viscosity. Viscosity depends on the unsaturated fatty acid composition of oils and the viscosity decreases with increase in unsaturated composite. The variation of viscosity of the oils is also studied during cooling in the same range of temperature and the same variation is observed which proves that unsaturated compounds in oil is retained; no degradation has taken place and the oil exhibits Newtonian behavior [4] [15].

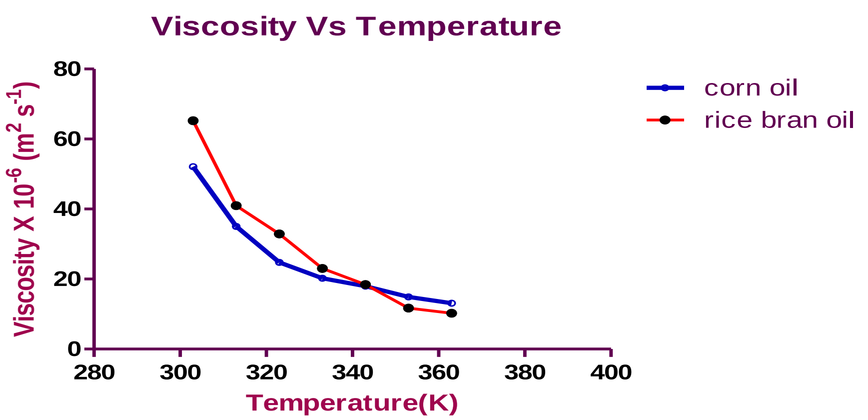

Figure (4):Variation of viscosity with temperature

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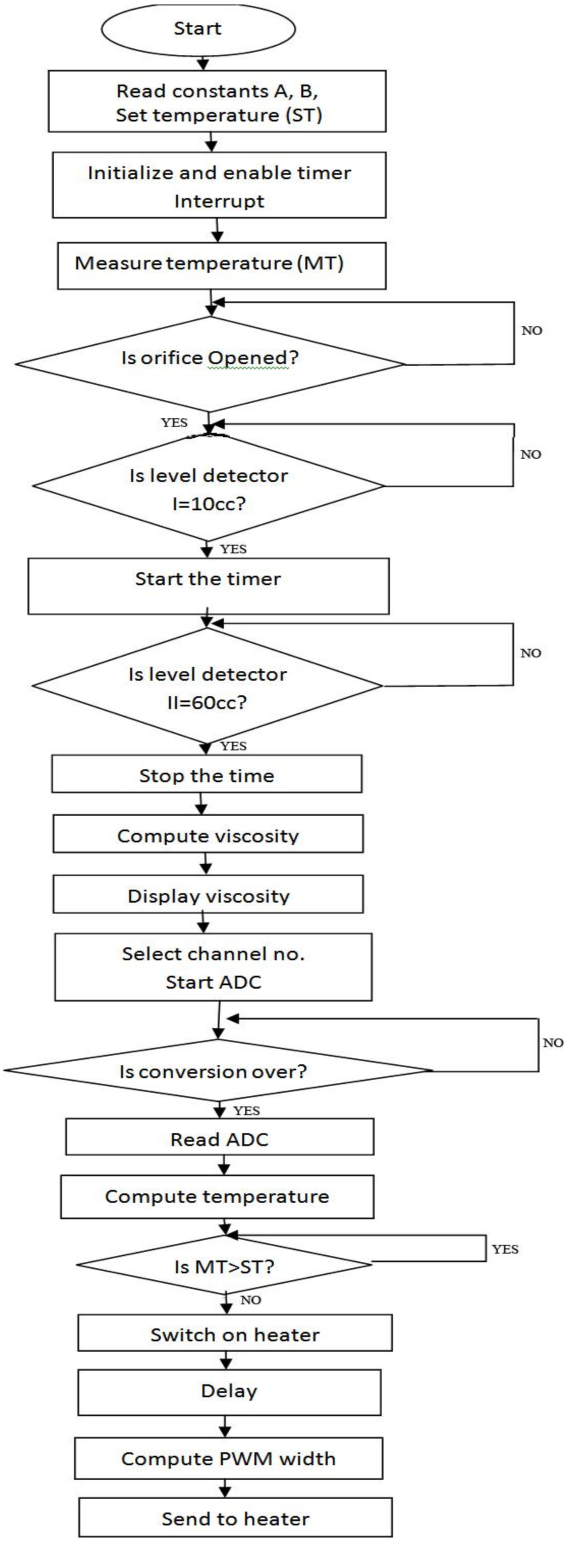

Figure 3. Flow chart of the program.

Table (1): Variation of viscosity with temperature

	Temperature(K)	Vicosityx10-6(m2s-1)	
		Corn oil	Rice bran oil
1	303	52.086	65.237
2	313	35.013	40.978
3	323	24.7369	33.915
4	333	20.241	23.065
5	343	17.9768	19.434
6	353	14.927	11.68
7	363	13.123	10.219

Correlation analysis

The performance of the Microcontroller AT-mega 328 based viscosity measurement using Redwood Viscometer is investigated by correlating its results with the results obtained using Brookfield Viscometer; model LV DVII; Middleboro, MA, USA. Correlation analysis refers to the technique used in measuring the closeness of the relationship between the variables for the measured rice bran oil and corn oil with the readings from the standard instrument[2]. As the nearness of correlation coefficient R^2 value approaches 1, it indicates the accuracy of measured values. Perfect correlations are exhibited by all the values as shown in figure (5). The correlation analysis is performed using Graph pad prism 5 software. They fit into the linear range. The correlation coefficient quantifies strength of the linear association between two variables. The value of correlation coefficient (R^2) of corn oil and rice bran oil are 0.9979 and 0.9974, respectively. These values of R^2 show excellent correlations.

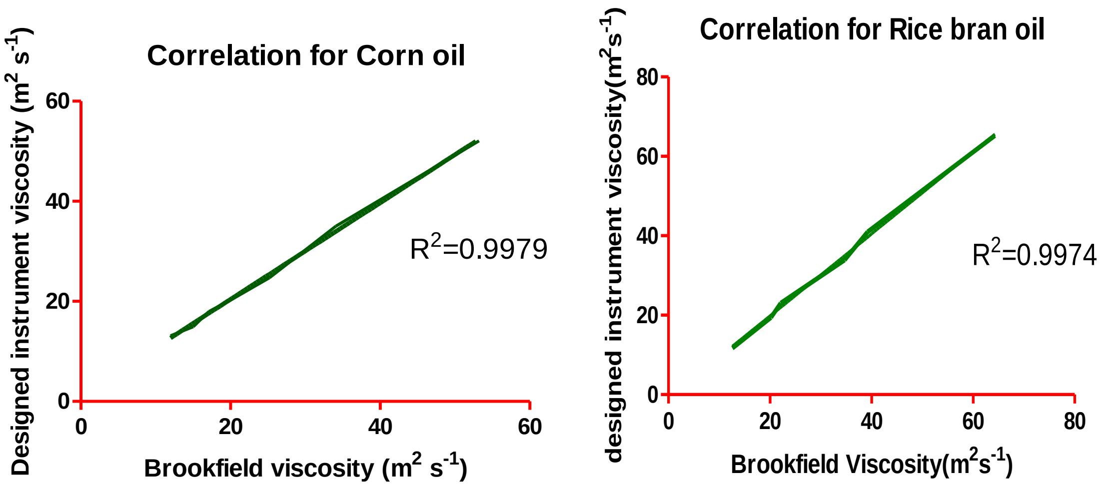

Figure (5): Correlation between Brookfield viscometer and designed instrument viscosity

Regression Analysis

To check the measured data, the least square method of curve fitting is adopted and the data is fitted into the standard equations governing the rheological parameters of the oils. Curve fitting is a method of finding an equation of an approximating curve, which passes through as many points as possible. Among the available methods of curve fitting, the least square method gives a unique best fit and is highly recommended because it considers the sum of the squares of the residuals, thereby giving equal importance to both positive and negative residuals. The correlation coefficient (R^2) is the total of the squares of the deviation of the measured values from the fitted line [16] [17] [18]. It can be obtained using the following formulae:

$$R^2 = SSR/SST = 1 - (SSE/SST)$$

Where,

SSR=Regression Sum of the Squares= $\sum_{i=1}^{n}(\hat{Y}_i - \bar{Y})^2$
SSE = Sum of Squares of Residuals= $\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$
SST = Total Sum of the Squares= SSR + SSE

The equations chosen to fit the obtained data are

(a)Arrhenius equation
(b)Reynolds equation
(c) Power law Model
(d) Walther equation

Arrhenius Equation

Arrhenius equation Eq. (2) is an important and popular empirical equation which is also used to calculate the activation energy of the viscous flow of the liquids, apart from its viscosity.

$$\eta = A\exp|- E_a / RT| .... (2)$$

Where,

η =viscosity (m^2/s)
E_a =Activation energy (kJ kg^{-1})
R=Universal gas constant (8.314 kJ kg^{-1} mol^{-1} K^{-1})
T=Temperature (K) and
A=Constant (m^2/s).,

The measured values of viscosity are fitted into Arrhenius equation and the value of constant, R^2 is tabulated in table (2) with the graph in figure (6). The significant value of R^2 indicates best fit which speaks the accuracy of instrument. It is evident from the table the activation energy E_a for rice bran oil is greater than corn oil. The activation energy indicates the sensitivity of oils towards temperature, the oils that contain large measure of double bond compounds exhibits less activation energy. So it can be used to predict the amount of unsaturated fatty acids [19]. It is observed that both rice bran and corn oil have almost same activation energy that indicates the oil composites same and more quantity of unsaturated fatty acids.

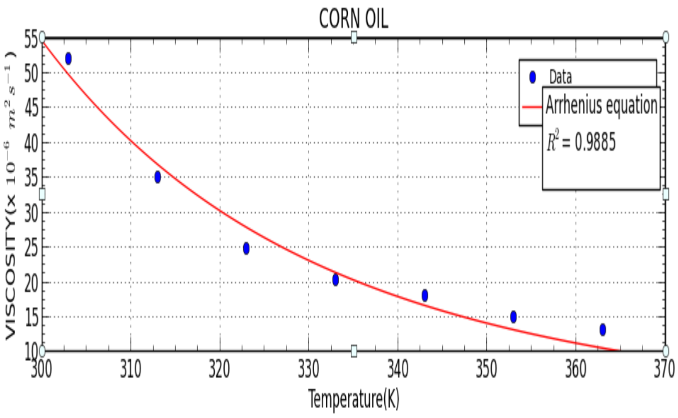

Figure (6): Regression with Arrhenius equation

Table (2): **Regression with Arrhenius equation, $\eta = A\exp|-E_a/RT|$**

Parameters	Corn oil	Rice bran oil
A	8.8730x10^-4	8.87141x10^-4
B	3.3887x10^3	3.3887x10^3
E_a(kJ kg^{-1})	28175.672	28175.978
R	0.9942	0.9942
r^2	0.9885	0.9885
Standard Error	2.28	2.28

Reynolds Equation

Osborne Reynolds in 1886 found the exponential equation to fit the available data of viscosity of oils varying with temperature [20].

$$\eta = R \exp |\alpha T| \quad \text{... (3)}$$

Where,

η =viscosity (m^2/s)
T= temperature (K)
R and α are constants.

The value of the constants found by fitting the data into Reynolds equation is given in table (3). This value of R^2 indicates reasonably good fit. The fitted curve is shown in figure (7).

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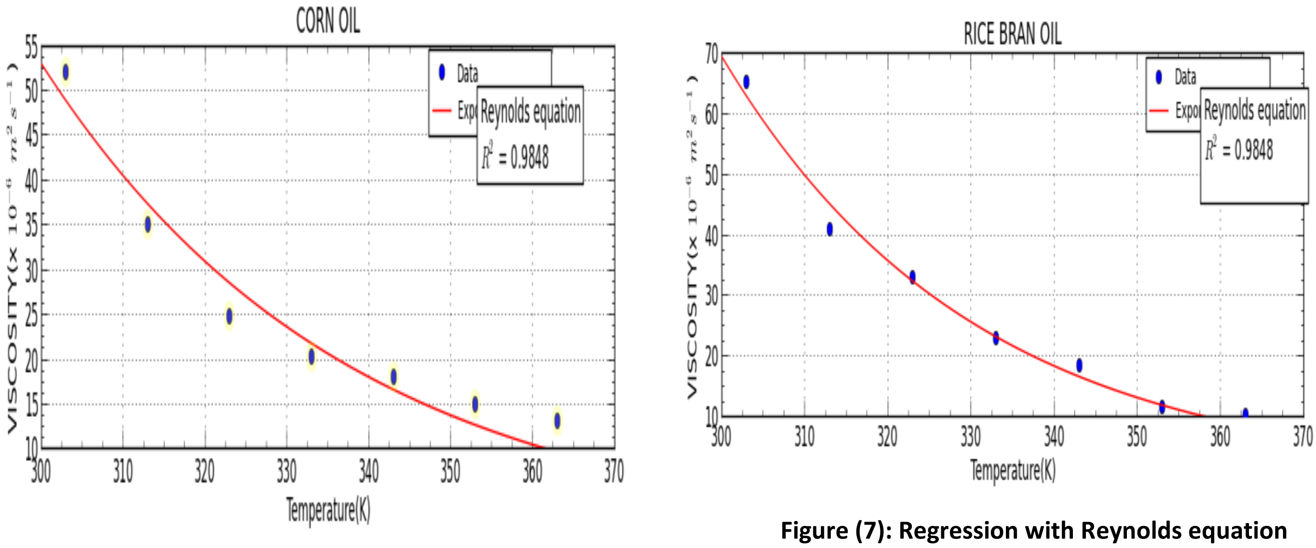


Figure (7): Regression with Reynolds equation

Table (3): Regression with Reynolds equation, η = R exp |αT|

Parameters	Corn oil	Rice bran oil
R	1.1992x10^6	1.1993x10^6
Α	0.0325	0.0325
R	0.9924	1.1993
r^2	0.9848	0.9848
Standard error	2.2	2.5291

Power law model

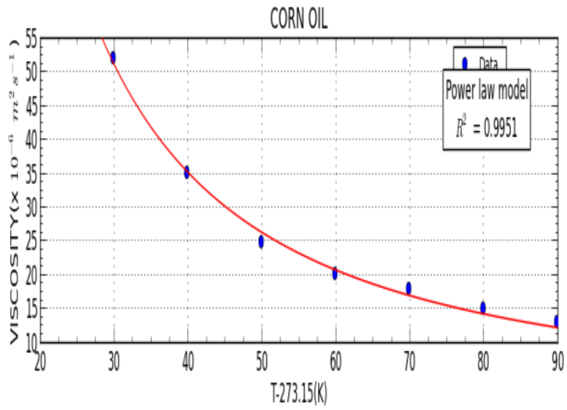
Another well-known equation used by researchers to compute viscosity as a function of temperature is as follows [6, 21].

$$\eta = k\,(T - T_{ref})^{n} \qquad \ldots (4)$$

Where,

η =viscosity (m^2/s)
T=Temperature (K)
T_{ref}=273.15K
k and n are constants.

The test results of the obtained values with power law model also indicate the best fit as shown in figure (8) and table (4).



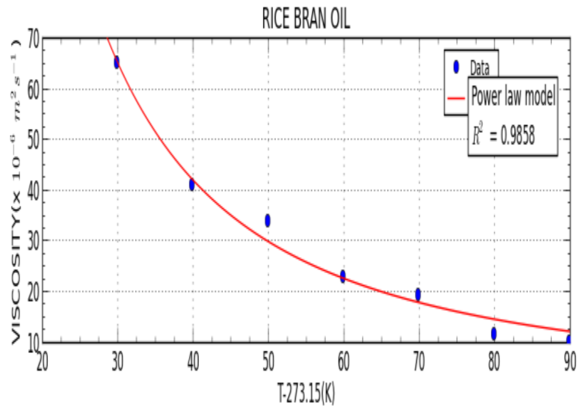


Figure (8): Regression with Power law model

Table (4): Regression with Power law model, η = k $(T-T_{ref})^n$

Parameters	Corn oil	Rice bran oil
k	4.2770x10^3	1.1554x10^4
N	-1.3015	-1.5223
R	0.9975	0.9929
r^2	0.9951	0.9858
Standard error	1.06	2.529151

Walther Equation

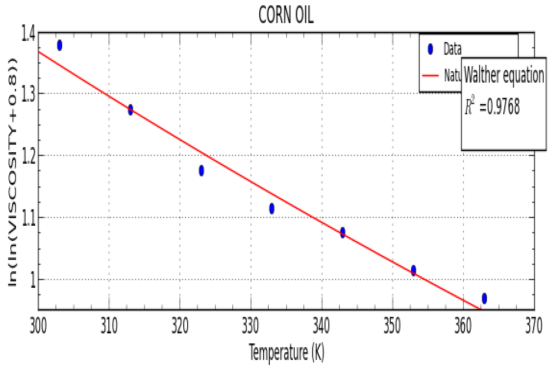
Walther introduced a new equation by correlating viscosity with temperature. He modified the equation in 1931 by correcting undefined double logarithm with an addition of 0.95 to viscosity. This equation was again modified by Geniesse and Delbridge by allowing viscosities down to 0.3 cSt [21, 22, 23], which is as follows:

$$\ln(\ln(\eta+0.8)) = a - b\log_e T \quad ...(5)$$

Where,

η =viscosity (m^2/s)
T-Temperature (K)
a and b are constants.

This equation has been adopted by ASTM international standards as a standard equation to compute viscosity at different temperatures. The value of R^2 as indicated in the table (5) is greater than 0.9 with the least error of 0.024. The graph is shown in figure (5-9). Thus, it is evident from the statistical analysis that the designed instrument is accurate to measure viscosity as a function of temperature.



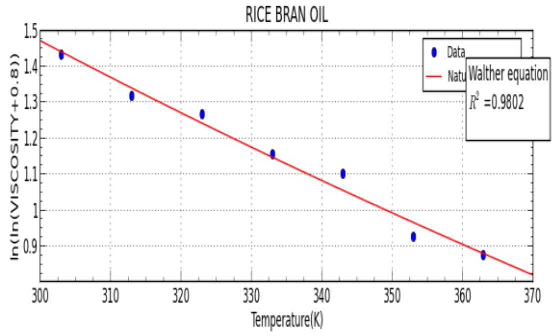


Figure (9): Regression with Walther equation

Table (5): Regression with Walther equation, ln (ln(η+0.8)) = a – b $\log_e T$

Parameters	Corn oil	Rice bran oil
a	1.3953x10^1	1.1917x10^1
B	2.2062	3.1037
R	0.9884	0.9901
r^2	0.9768	0.9802
Standard error	0.024202	0.024202

CONCLUSION

The AT mega 328 microcontroller based instrument system is designed and developed to measure kinematic viscosity of corn and rice bran oils at various temperatures. The oils exhibit Newtonian behavior on heating to the temperature range 303K to 363K. It is observed that the viscosity of oil decreases with increase in temperature due to the reduction of Vander waals forces, London forces etc., and the presence of large quantity of unsaturated fatty acids. The developed system is highly correlated with conventional viscometer and also the observed values are highly fitted with the standard equations. Hence this method consumes less time, reduces human effort to a greater extent, and it makes the process simple. The effective method employed in temperature monitoring and control system is tested and the error is found to be less than 1%. The system is highly accurate, simple, and cost effective.

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