B.TECH PROJECT REPORT

On

Design and Development of mini Viscometer

BY

Thamara Manohar(180003059)

DISCIPLINE OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

May 2022

Design and Development of mini Viscometer

A PROJECT REPORT

Submitted in partial fulfilment

of the requirements for the

award of the degree

of

BACHELOR OF TECHNOLOGY

in

MECHANICAL ENGINEERING

Submitted by:

Thamara Manohar(180003059)

Guided by:

Prof. Shanmugam Dhinakaran

INDIAN INSTITUTE OF TECHNOLOGY

INDORE May 2022

CANDIDATE'S DECLARATION

I hear by declare that the project entitled **"Design and Development of a mini Viscometer"** submitted in partial fulfilment for the award of the degree of bachelor of technology in mechanical engineering completed under the supervision of Prof. Shanmugam Dhinakaran, discipline of mechanical engineering, IIT Indore is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

Signature: T. Manohar

Date: 27/05/2022

Thamara Manohar

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the student is correct to the best of my knowledge.

Signature:

Date: May 27, 2022

Dr. Shanmugam Dhinakaran

Professor

Preface

This report on **“Design and Development of mini Viscometer "** is prepared under the guidance of Prof. Shanmugam Dhinakaran.

Through this report I have tried to give a detailed explanation on the design of a Arduino based falling sphere viscometer and try to cover every aspect of the new design. The developed device is tested on three liquids and compared with the Ostwald viscometer. The results are comparable with accuracy of 90 to 99.82%.

I have tried to the best of our abilities and knowledge to explain the content in a lucid manner. I have also added pictures of the product designs and graphs to make the report more illustrative.

Thamara Manohar
B.Tech. IV Year,
Discipline of Mechanical Engineering,
IIT Indore

Acknowledgements

I wish to thank **Prof. Shanmugam Dhinakaran** for his kind support and valuable guidance. It is his help and support, due to which I became able to complete the design and technical report. Without his support this report would not have been possible. I have learned so many new techniques and procedures to develop a device from him.

I would also like to thank our friends and family for believing in us and providing us for whatever needed.

Thamara Manohar
B.Tech. IV Year,
Discipline of Mechanical Engineering,
IIT Indore

Abstract

Researchers and students are using traditional falling ball viscometers, which require manual calculation of velocity and viscosity, resulting in erroneous measurements. There is lot of advancements in technology, specific improvisation needs to be made. The Arduino microcontroller is used to create a falling sphere viscometer. To measure the time taken, an IR sensor detects the ball travelling through a liquid of unknown viscosity; data processing and connection with the digital display are handled by an Arduino microcontroller.

The improved viscometer's results are validated using an Ostwald viscometer and available reference sources. The positive results suggest that the new Viscometer may be utilised in the laboratory to help students better understand the idea of viscosity. Experimentation carried out on three kinds of oils, they are coconut oil, cooking oil and engine oil. The results are, the viscosity of the coconut oil, cooking oil and engine oil are 35.328cp, 38.789cp and 54.464cp respectively.

Contents

List of Figures

List of Tables

Nomenclature

ϑ	Kinematic Viscosity
μ	Dynamic Viscosity
ρ	Density
τ	Shear stress
r_s	Radius of the sphere
m_f	Mass of the fluid
m_s	Mass of the sphere
g	acceleration due to gravity
V	Velocity of the sphere
ρ_S	Density of sphere
ρ_f	Density of fluid
t_f	experimentally obtained time by Ostwald viscometer
Re	Reynolds number
L_D	the maximum length so that the flow would be laminar
μ_1	absolute viscosity of unknown fluid
μ_2	absolute viscosity of known fluid

Chapter 1
Introduction

1.1 Viscosity

Fluid viscosity is a fundamental mechanical characteristic. The "Viscosity" refers to the resistance to flow of fluids. It comes into the discussion only when the fluid is in motion. A fluid's viscosity is a measure of the resistance to flow. When a fluid's layers move relative to one another, friction will be developed. Internal friction among fluid layers as they travel through one another while fluid movement causes flow resistance, which is precisely quantified. Viscosity is a measurement of a fluid's thick or resistance to materials travelling through it.

A fluid with a high viscosity opposes motion by producing a large amount of internal friction, which stops layers from moving past the other due to strong intermolecular forces. A fluid with a low viscosity, on the other side, flows easily because its molecular structure produces little friction when in motion. .

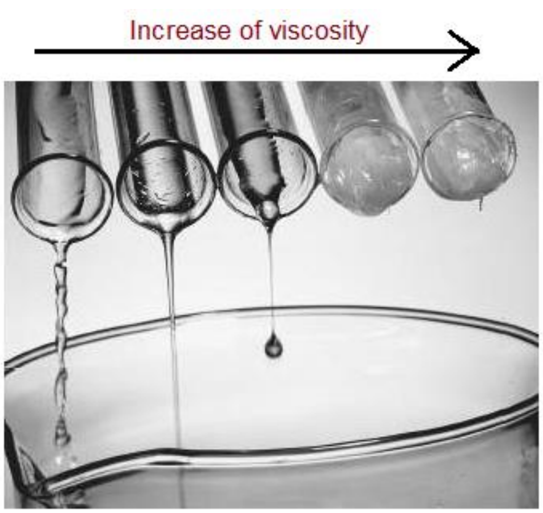

Figure 1. viscosity's influence on fluids

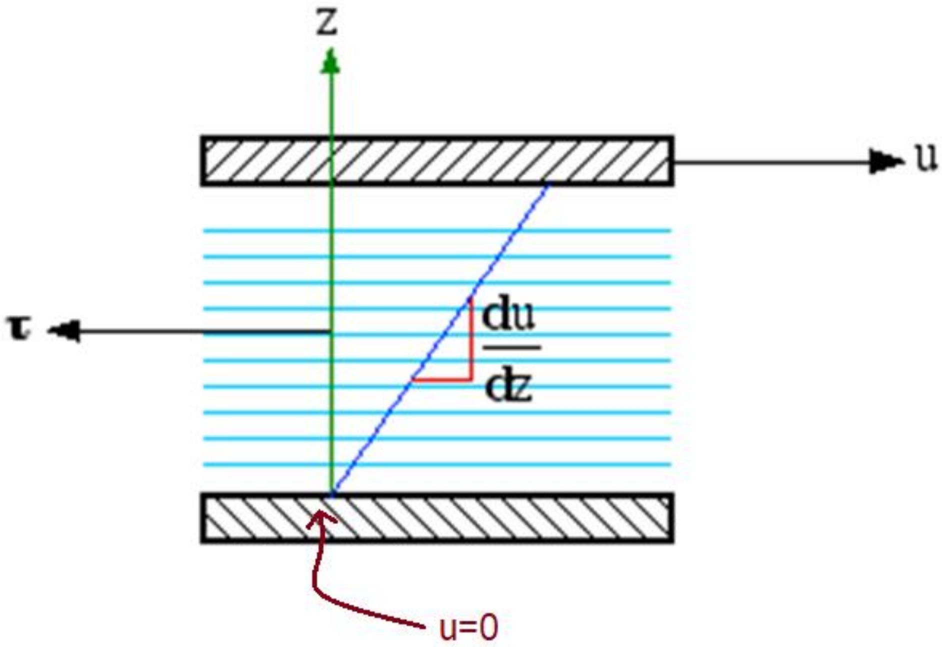

Figure 2. Schematic of flow of fluid placed in-between two infinite parallel plates

By seeing Figure 1 one can understand how viscosity influence the motion of fluid. In order to understand the viscosity mathematically, we need to know about no slip condition. Whenever fluid comes in contact with the solids surface, at the point of contact the relative velocity of fluid and solid is zero. This condition is called no slip condition. Consider the following imaginary experiment in which the fluid is sandwiched between two extremely large parallel plates as it is shown in Figure (2): The bottom plate has been fixed in place, whereas the upper plate is not fixed and can move about. Let say upper plate is moving with velocity u. Because of intermolecular attraction forces velocity gradient will be generated between the fluid layers. Because of this shear stress is generated. In case of solids because of shear force, strain would be generated, so shear stress is generated. But in fluids it's because of velocity gradient (also called as shear strain rate).

$$\tau \propto \frac{du}{dz} \tag{1}$$

The shear stress generated is directly proportional to the shear strain rate, and the proportionality constant is μ.

$$\tau = \mu \frac{du}{dz} \quad (2)$$

where τ is shear stress, $\frac{du}{dz}$ is velocity gradient and μ is coefficient of viscosity.

Equation (2) is stated by Newton, it's called Newton law of viscosity. This expression defines viscosity.

1.2 Non-Newtonian and Newtonian Fluids

A Newtonian fluid has the same viscosity at all shear rates (shear stress is proportional to shear rate). The fluids which satisfies the equation (2) are called Newtonian fluids. The most commonly found fluids like water, oil belongs to Newtonian fluids. These fluids are termed Newtonian because they follow Sir Isaac Newton's original formula in his Laws. However, some fluids do not react in this manner. They're known as non-Newtonian fluids in general. Thixotropic fluids, a kind of non-Newtonian fluids, are of special relevance is used in oil analysis because their viscosity reduces as the shear rate increases. As the shear rate falls, the thixotropic fluid's viscosity rises. Set-time can enhance apparent viscosity in thixotropic fluids, such as grease.

1.3 Viscosity types

1.3.1 Dynamic Viscosity

The resistance to flow of a fluid is measured by dynamic viscosity. Water has a lesser viscosity than either honey or motor oil . Oil has a lower viscosity than either molasses or tar. Depending upon the application method, a resin's viscosity affects how well it fills the gaps or the voids in a mould.

μ (the Greek letter miu) that is stated in equation 2 is dynamic shear viscosity.

$$\mu = \frac{\tau}{\frac{du}{dz}} \quad (3)$$

It is defined as the shear stress generated per unit velocity gradient. It is depends upon the fluid and it is a property of a fluid.

The Pascal second (Pas) is the unit of dynamic viscosity.
Absolute viscosity is a term that is sometimes used to refer as Dynamic viscosity.

1.3.2 Kinematic Viscosity

Kinematic viscosity is defined as the fraction of absolute viscosity in cp divided by specific gravity of a fluid determined at the same temperature.

$$\vartheta = \frac{\mu}{\rho} \tag{4}$$

Where,
μ : Dynamic Viscosity
ϑ : kinematic viscosity
ρ : Density
In most cases, kinematic viscosity is measured in square millimetres per second.
The stokes (St), named after George Stokes, is the physical unit denoting kinematic viscosity. Centistokes (cS or cSt) are sometimes used to describe it. 1 stokes = 100 centistokes = 0.0001 $m^2 s^{-1}$.

1.4 Viscometer

The instrument which is used to measure viscosity is called Viscometer. A viscometer is also called a viscosimeter. Viscometer measures viscosity under only one flow condition. One flow condition means, for one particular shear rate. Viscometer measures viscosity of those liquids, whose viscosity does not vary with shear rate.
Viscosity of Newtonian fluids does change with shear rate. The viscosity of liquids is measured with a rheometer whose viscosities change with flow conditions. Generally non-Newtonian fluids viscosity vary with flow rates(shear rate). Non-Newtonian fluids (fluids with a variable viscosity) cannot be characterised by a single number. Shear stress and shear rate are correlated in a variety of ways in non-Newtonian fluids. The drag resistance induced by the relative motion of the fluid and a contact surface is utilised to calculate the viscosity. “To determine the viscosity of fluids, a variety of approaches are employed, each of which is based through on one of three phenomena: - A moving surface in contact with a fluid, fluid flow through a resistive component, and an object moving through a fluid. Temperature control is vital for

precise readings, especially in materials like lubricants, whose viscosity can quadruple with a 6°C temperature change."[6]

Types of viscometers

1) Capillary Viscometer
2) Rotational Viscometer
3) Falling sphere viscometer

1.4.1 Capillary viscometer

It works on phenomena, passing the fluid through the restriction. It depends on gravitational force for driving the fluid through restricted cross section. The Ostwald and ubbelohde variations are included in the capillary Viscometer. They consist of a U-shaped glass tube with two bulbs, and they are simple to operate (one higher and one lower).

The working of it is, liquid is suctioned into the upper bulb, then the fluid goes from the upper bulb to the normal through the capillary tube, and viscosity is determined by timing how long the fluid requires to pass through the tube. A known volume is indicated by two markers (one over and one in under the upper bulb). The kinematic viscosity is proportional to the time it takes for the liquid level to move between these points. A fluid with known properties can be used for calibration. A conversion factor is included with most commercial units.

<u>Advantages</u>:

- Viscometers measure exact viscosities for a wide range of fluids.
- Small and portable, simple to use, and affordable.
- The Viscometer can accommodate a wide range of capillary tubes.

<u>Disadvantages</u>:

- No one tube can handle all viscosities.
- Only translucent fluids can be utilised with the basic model.
- Cleaning the capillary tubes is difficult.

1.4.2 Rotational viscometer

Rotational viscometer devices extend the upper limit of the potential measuring range further than Gravity-based devices. They use a motor drive that is far more powerful than the earth's gravitational pull. As a result, they are well adapted to monitoring more viscous liquids. Dynamic viscosity is also known as shear viscosity, is the consequence of this process.

A conventional rotating viscometer consists of a cup as shown in Figure (3) that holds the sample and a so-called measurement bob that is inserted in the substance being tested. There are two concepts that apply depending on which part is driven:

• the principle of Searle :

The bob inside the fixed cup is driven by the motor. The bob's rotational speed is preset, so it require the some torque for rotating the bob. This torque must surpass the viscous forces of the substance being evaluated, and is thus a measure of liquid's viscosity.

• the principle of couette :

The sample-filled cup is rotated around the fixed measuring bob by the instrument's motor.

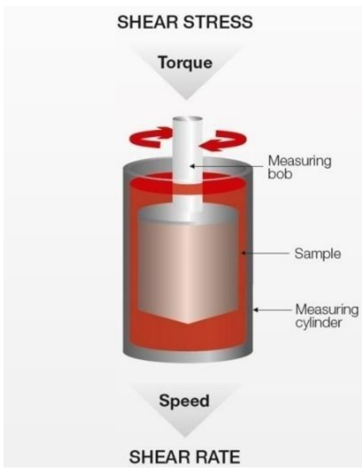

Figure 3. Schematic of working of Rotational viscometer

1.4.3 Falling sphere viscometer

The rolling or falling time of a ball is measured by a falling-ball viscometer, not the flow time of a liquid. The driving force is gravity.   A known-size ball is rolled or dropped through a closed cylindrical tube containing the sample liquid. The tube's inclination is determined by

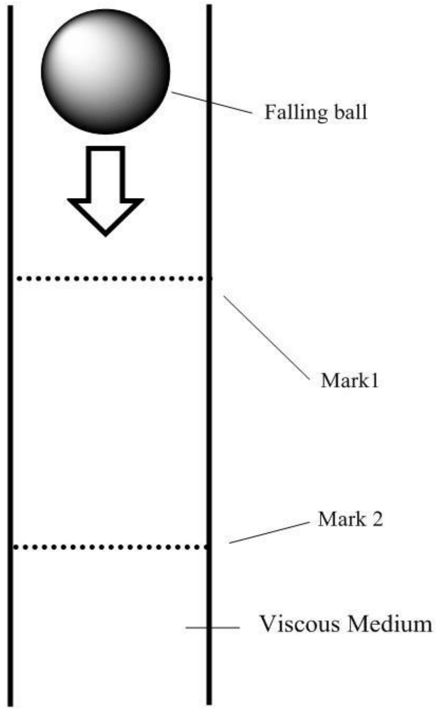

Figure 4. Schematic of falling sphere setup

Figure 5. Schematic of conventional falling ball viscometer with thermometer

predefined angle. The time it takes the ball to fall a specific distance within the fluid is directly proportional to the viscosity of the fluid.

The Stokes Law governs the measurement of the viscosity of a liquid using the falling ball viscometer. It is determined by the object's geometric shape. Pieces with geometric forms in the type of spheres have a k value of 6πr, according to George Stokes. The gravitational force (W), the buoyant force (F_a), and the viscous force (F_s), due to the fluid's viscosity, or the Stoke's force, all operate on the ball when it move in a stationary fluid. The forces that act on the sphere are as shown in:

as depicted in Figure 6. Firstly, gravity accelerates the ball. When the ball has travelled a sufficient distance, it will proceed at a constant speed.

The terminal speed is defined as the speed at which the weight of ball equals the buoyancy of the water plus the force of fluid friction, or the Stokes force.

From the Newton's Law of inertia, that is when the net force acting on the body is zero. The body which is in motion initially, will tend to move in constant velocity.

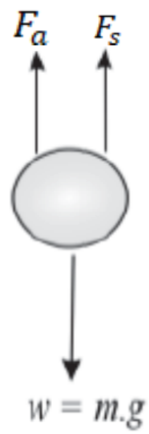

Figure 6. Schematic of forces acting on the sphere

$$\sum F_{net} = 0 \tag{5}$$

$$6\pi\mu r_s v + m_f g = m_s g \tag{6}$$

$$\mu = \frac{2{r_s}^2 g}{9v}(\rho_s - \rho_f) \tag{7}$$

Since the densities of the sphere and the sample fluid, as well as the velocity and radius of the sphere are known, if velocity of the sphere is measured ,viscosity can be measured.

Chapter 2
Literature Review

The work in Chul Huh et al. (2016) this paper focuses on designing a microfluidic viscometer to find the viscosity of blood in bedside testing using a falling sphere approach with some sensors. The method in this work includes a screening of patients. The work mainly focuses on decreasing the time of measurement and patient safety by collecting very few volumes of samples. The time required for measurement is just about 50sec. The components used in work include Lcd, photo-sensor, capillary tube, battery pack, and controller module. And the stand for placing the device at the required Angle during the measurement process based on the thickness of the sample. The Experimental process includes immobilizing the sphere and measuring aqueous solutions of chemicals, including DEG and TEG. The limitations or research gaps in the research manuscript focus on the single dataset from the medical centre. It can be elevated to multiple datasets from multiple locations or regions. The work successfully achieved the aim by showing the attributes of the design.[5]

The last few years have witnessed enormous growth in sensor technology. The things and experimental apparatus have become easier to use by using the sensors. The work done by Riady Siswoyo Jo et al. mainly focuses on incorporating the sensors in the Viscometer based on the falling sphere. The work aims to get high precision and decrease the relative error while measuring the viscosity.
The methods in this paper included the image acquisition, image processing, and detection algorithm in sphere sensing. In order to make the sensors work, they have used a code that is to be uploaded to the microcontroller. Overall, this review paper puts an emphasis on using algorithms and image sensors for
improving the performance and time saving while determining the viscosity of petroleum products using the technique of falling sphere. [9]

Yulkifli et al.(2017) analysed the digital Viscometer. The researchers used different kinds of the sensor to sense the ball. An expert validates the Viscometer system, and a valid criterion of 91.67 percent is attained. To find the distance between two objects ultrasonic sensor has been used. It successfully worked with the design of the Viscometer. The method in this paper included the segments of data processing using atmega microntroller and data acquisition using an ultra-sonic sensor for the present design. The samples used in this research work are few it can be escalated. Although the study is consistent with the output, the validation of the current results has not been specified. The time taken for the completion of the experiment is significantly less. The results show that the current design can be used in industries in order to find the viscosity of high viscous liquids. Yulkifli et al. utilized the technology advancement to improve the viscometer accuracy and experimentation time.[4]

Another study focused on minimizing the size of equipment in the laboratory, which works on the basis of the falling sphere method. It is done by Derrick JM et al.(2018) [3]

Some component of the older equipment is redesigned, and some are replaced with completely new apparatus. Particularly the use of sensors made the aim possible. Instead of only one tube, the current Viscometer consists of three tubes. one can perform experiments on three kinds of liquids at a time. The researchers also included a correction factor in measuring the velocity of the ball. The correction obtained is that the velocity of the sphere severely decreased because of the shear force of liquid and wall, so it is multiplied by factor 3. In another study, it is mentioned that while calculating the viscosity of fluid using the falling ball method, the correction has to be multiplied to use the Stokes formula. Faxen et al. worked on the correction factor.[2]

In another research work, it has mentioned that what difficulties would occur while doing experiment on falling ball viscometer. "They are 1) non-linear sighting (parallax error) in seeing the motion of the ball, 2) weariness of the observer's eye, and 3) inaccuracy in estimating the time required by the falling ball due to uneven synchronisation of spherical sightings and time recording. Because the recorded ball drop speed data is incorrect, the measured viscosity value is incorrect as well." (Surtono A et al.(2012). [7]

Generally capillary viscometers are used for Newtonian fluid's viscosity measurements. In this paper the work includes the design capillary viscometer for non-Newtonian fluid's viscosity measurement at very high shear rates. The samples used for the work are inks which are used for printing. The similarity in the capillary die of viscometer and the tube through which the sample fluid flows is big advantage in the experiment. It mentioned that capillary viscometer as standard. [8] Wang X et al.(2010)

The above researches has led to a better understanding of how a falling sphere viscometer works to find viscosity of different fluids and how we can improve the design of conventional viscometer by technology of sensors. But only a few investigations in the literature show the validation of their design. The researchers wang x et al. research on capillary viscometer gave better understanding on how the work and they can be used for both type of fluids, that Newtonian and non-Newtonian. The above studies suggested that the measuring accuracy of the falling sphere method will improve by utilising a sensor to monitor journey time. It is important on working the design of falling ball viscometer using sensor, not only that but also validation with standard viscometer like capillary.

Chapter 3
Objectives

3.1 Objective of the project

The main goals of the project are:

1. Design and Development of an Arduino based mini Viscometer.
2. To measure viscosity of liquids automatically.
3. To be utilised in fluid laboratory investigations.

3.2 Problem definition

In existing falling ball viscometers, a data inaccuracy in measurement and calculation can occur because the time is measured with a stopwatch and the viscosity is computed manually. In modern devices sensors are used in every aspect. So sensors can be utilized in measurement of viscosity.

Chapter 4
Construction of Arduino based falling sphere viscometer.

4.1 *Definition* of Arduino-based falling sphere viscometer

4.2 Apparatus of Arduino-based falling sphere viscometer

- 4.2.1 Base for supporting equipment
- 4.2.2 Acrylic cylindrical measuring tube
- 4.2.3 Sphere
- 4.2.4 Ball picker
- 4.2.5 Arduino uno
- 4.2.6 Ir sensors
- 4.2.7 Lcd display
- 4.2.8 I2c

4.3 Reference viscometer

- 4.3.1 Ostwald viscometer

4.1 Definition of falling sphere viscometer based on Arduino microcontroller

The design of the falling sphere viscometer is shown in figure. The crucial task of this

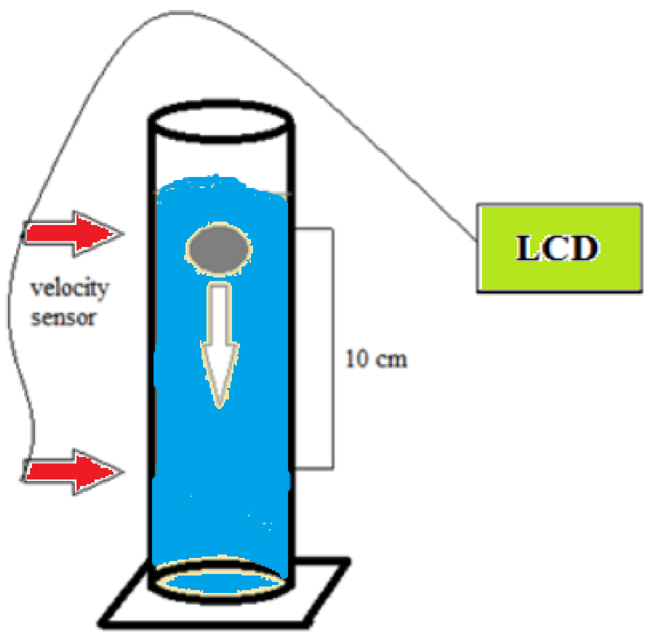

Figure 7. Schematic of design of new viscometer(cartoon)

kind of viscometer is finding the velocity of a sphere which would pass through a measuring cylinder filled with fluid whose viscosity to be determined. Since human eye can make error while taking readings of time using stopwatch, sensors can be used. The first sensor can be placed on the first mark or from where the stopwatch is started if it would be done manually. Similarly the second sensor can be placed at the second mark where the stopwatch would have been stopped if it is done manually. The sensor would detect the ball, when the ball crosses them. How this sensor work on sensing the ball is explained in later sections.

Once the first sensor detects the ball, it would send a signal to the Arduino microcontroller. It would start counting time, and once the ball passes through the second sensor, the signal will be received by Arduino then the counting would be stopped. Based on measured time and the gap/length between sensors, the microcontroller would calculate the velocity. The measured velocity is used to find the viscosity of the liquid.

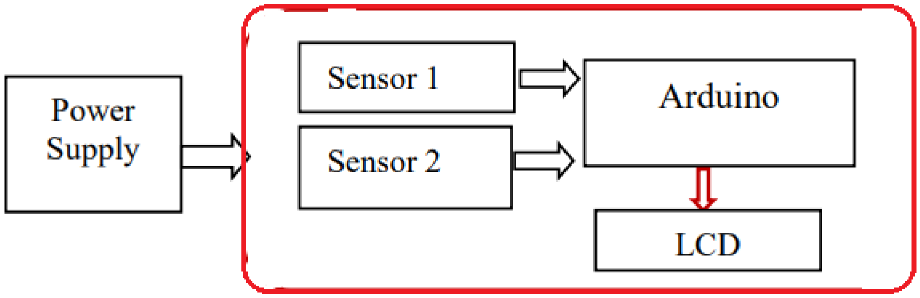

Figure 8. Block diagram of present design

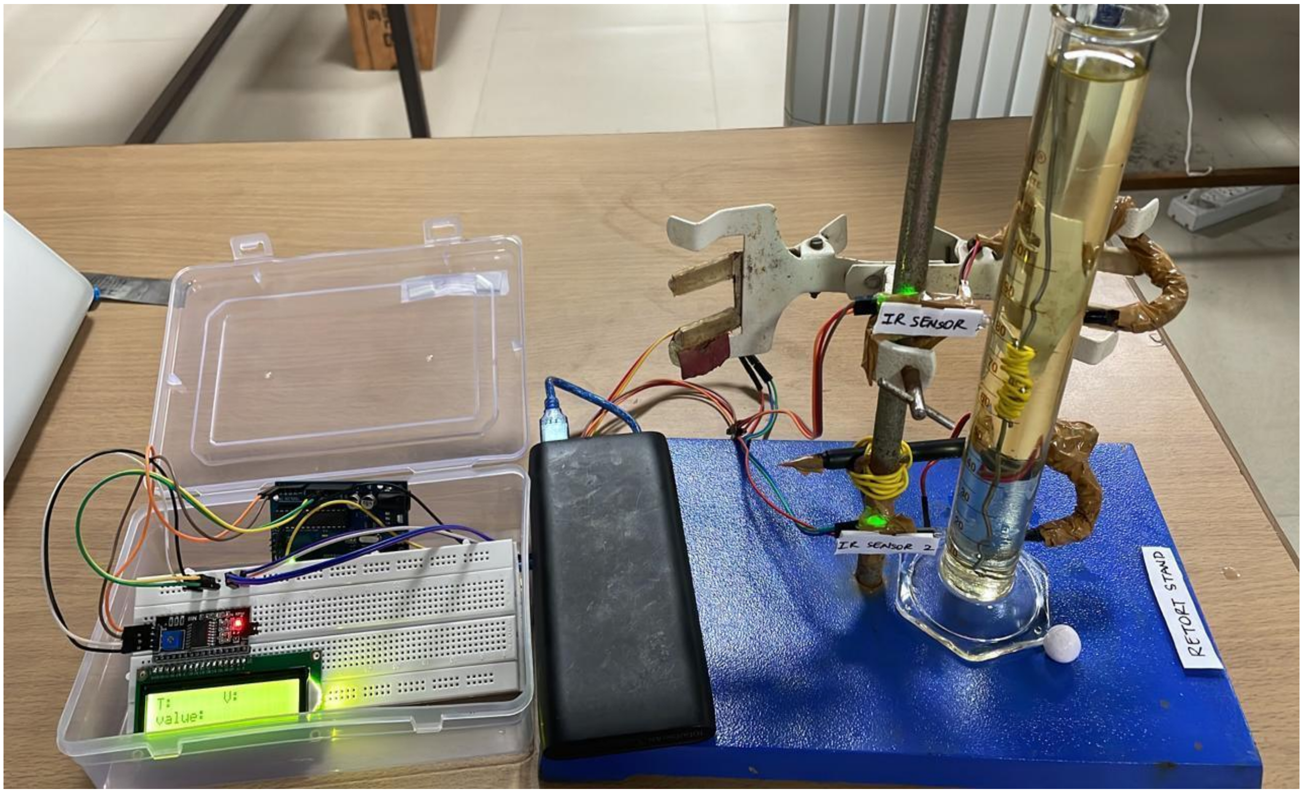

Figure 9. Schematic of Falling sphere viscometer based on Arduino

4.2 Apparatus of falling sphere viscometer

i. Base for supporting equipment
ii. Acrylic cylindrical measuring tube
iii. Sphere
iv. Ball picker
v. Arduino uno
vi. Ir sensors
vii. Lcd display
viii. I2c

4.2.1 Base for supporting equipment

Figure 10. schematic of clamp

Figure 11. Schematic of iron rod mounted on base

Figure 12. Retort Stand

Retort stand is a laboratory equipment which comprises of a metal pole supporting a clamp, a strong firm base which supports pole used to hold laboratory glassware like test tubes and other equipment in one place, so that while doing experiment they do not come apart.

In this experiment the stand is used for supporting acrylic cylinder filled with liquid sample, to carry two IR sensors, and to perform experiment with Ostwald viscometer.

4.2.2 Acrylic measuring cylinder

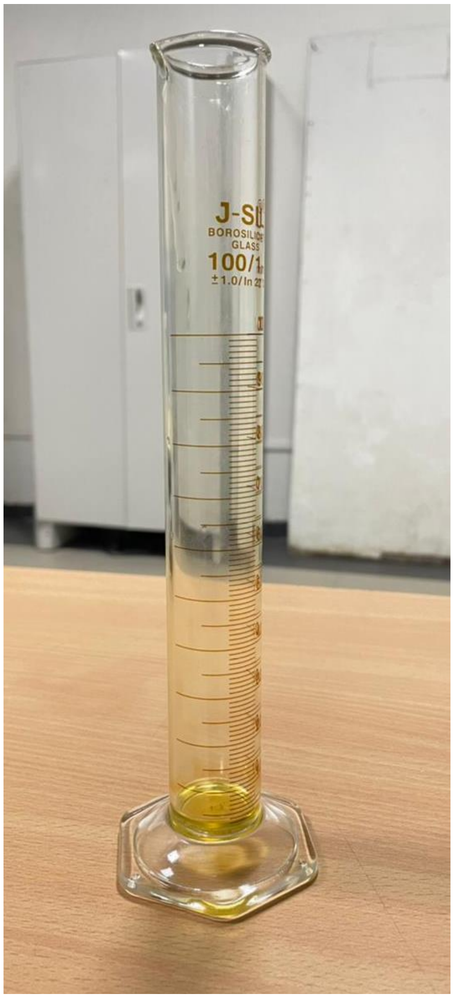

Figure 13. Acrylic Measuring Cylinder

The measuring cylinder as shown in figure .It is a cylindrical jar with specified dimensions.

It can measure 100ml of liquid. Its total volume is around 130cc. Its height is 26 cm and inner diameter of 27mm. It is made of transparent glass.

Glass made material is selected because ir rays can pass through it.

4.2.3 Sphere

It is a sphere made of glass and coated with white paint. As the white surface reflects the radiation that falls on it. So it can be easily detected by the IR sensors.

The specifications of the sphere is, its radius is 0.675m and weight is 4.5g and density is 3800kg/m3

Figure 14. Sphere

4.2.4 Ball picker

The ball is used to pick the sphere from the measuring cylinder after every experiment.

4.2.5 Arduino Uno

This is a diagram of an Arduino board, showing the typical components that go on it. The pins we're looking at are digital pins with numbers ranging from 0 to 13. These pins take digital input from the sensors and send it to some of the components as digital output.

This is a high-power LED. If this is on, the Aurdino is active. The major component is the Mega 328 chip, which controls all of the board's key functions.

There are six analogue pins numbered A0 to A5 on the board. On these pins, we can attach any analogue sensor.

Then there are power pins, which can be used to power any of the components .The Arduino, as indicated in the picture, is a critical component of this project because it is employed in the process of controlling all jobs in the project and will connect all of the components to each other's parts.

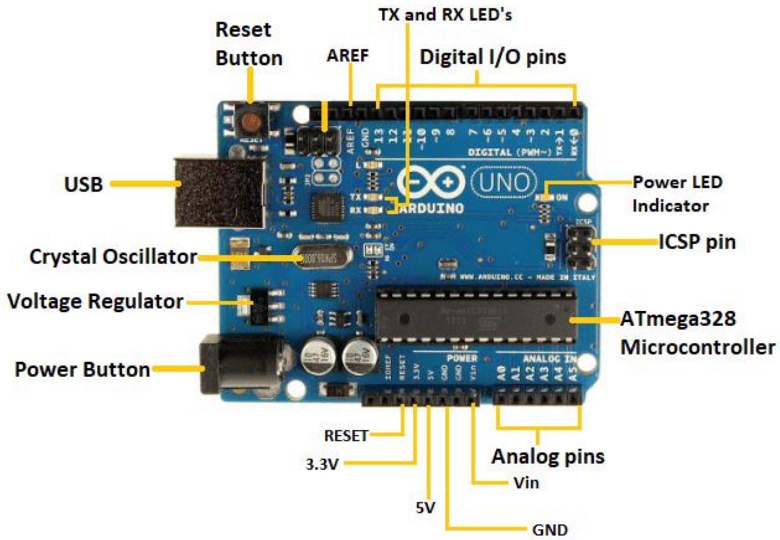

Figure 15. Schematic of Arduino Microcontroller Board, along with its parts

4.2.6 Ir sensors

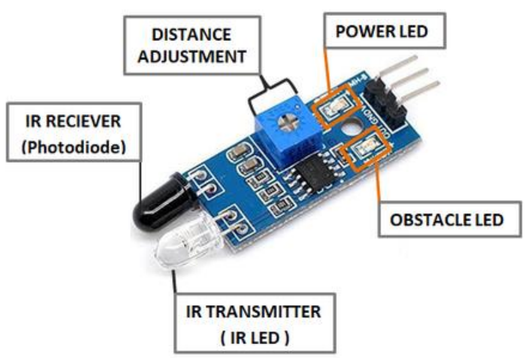

Figure 16. Schematic regular Ir Sensor, depicting along with its parts

The classification of infrared transmitters is based on their wavelength, power output, and response time. An IR sensor is made comprised of an IR LED and then an IR Photodiode, When used together, they're known as a PhotoCoupler or OptoCoupler.

IR LED or IR Transmitter :

“Infrared Transmitter (IR LED) is a light-emitting diode (LED) that emits infrared radiation. Although an IR LED appears to be a regular LED, the radiation it emits is invisible to the naked eye.”

Photodiode or IR Receiver :

The radiation from an IR transmitter is detected by infrared receivers or infrared sensors. Photodiodes and phototransistors are two types of infrared receivers. Infrared photodiodes differ from ordinary photodiodes in that they only sense infrared energy. An IR receiver or photodiode is depicted in the image below.

IR receivers are classified by wavelength, voltage, packaging, and other factors. The wavelength of the receiver should match that of the transmitter when utilised in an infrared transmitter-receiver combo.

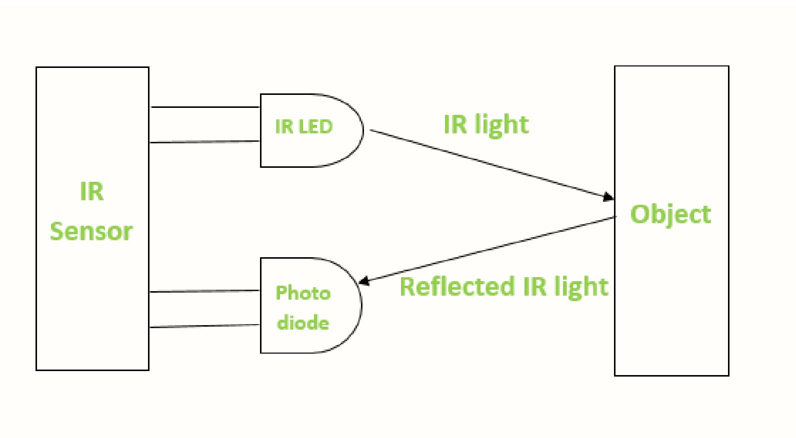

Figure 17. Schematic of working of IR sensor

The emitter is an infrared LED, while the detector is an infrared photodiode. An IR photodiode detects infrared light generated by an IR LED. The resistance and the output voltage of photodiodes change on relation to the amount of the IR light they receive. The IR sensor's basic functioning concept is as follows.

Some of the IR transmitted by the IR transmitter reaches the target and is reflected to a IR receiver. That intensity of IR receiver's acceptance determines the sensor's output.

Modification of IR sensor

If both transmitter and receiver are at the same side Then problem would occur. Since IR rays is reflected by every object even glass would reflect the IR rays on fallen on it. Then The sensor would detect the glass cylinder as obstacle and send the signal to Audino. Since the sensor should detect only the ball passing through the glass cylinder filled with liquid, it has to be modified.

IR rays can pass through glass and liquids. So the receiver can receive IR rays. When ball pass through the sensor it would obstruct the IR rays receiving by the sensor. The program would be written in opposite manner which is written for regular sensor. So now it would sense the ball. The following figure shows the usage of modified IR sensor.

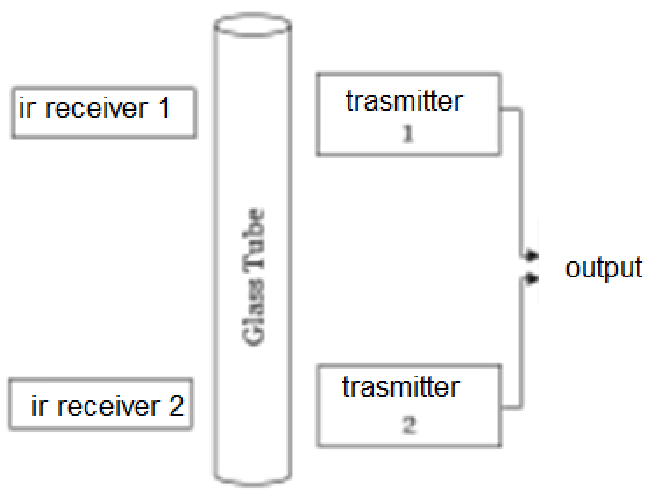

Figure 18. Schematic of modified IR sensor usage

4.2.7 Liquid crystal display

In this project, I need a screen to display the experimental results, which include viscosity, falling ball time required by the ball to travel the distance between sensors, and falling velocity.

1. Liquid crystal display LCD Screen

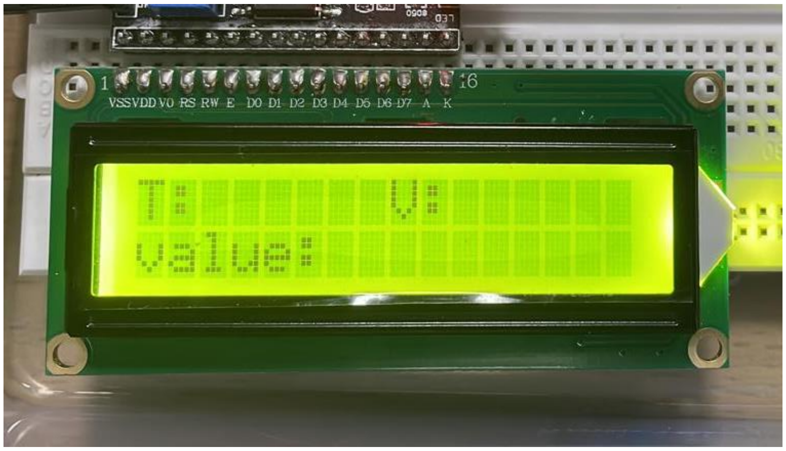

Figure 19. LCD display

4.2.7 I2c

The I2C serial interface module is shown in the diagram. Because it can be directly connected to the LCD, it is employed in this project to reduce the number of connections. It facilitates circuit design.

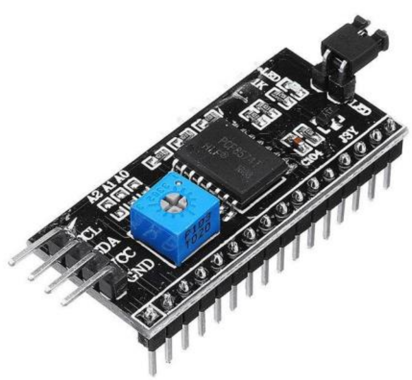

Figure 20. Schematic of I2C interface module

4.2.8 Battery pack/ power bank

The battery pack/ power bank is used to power the device.

4.3 Circuit diagram

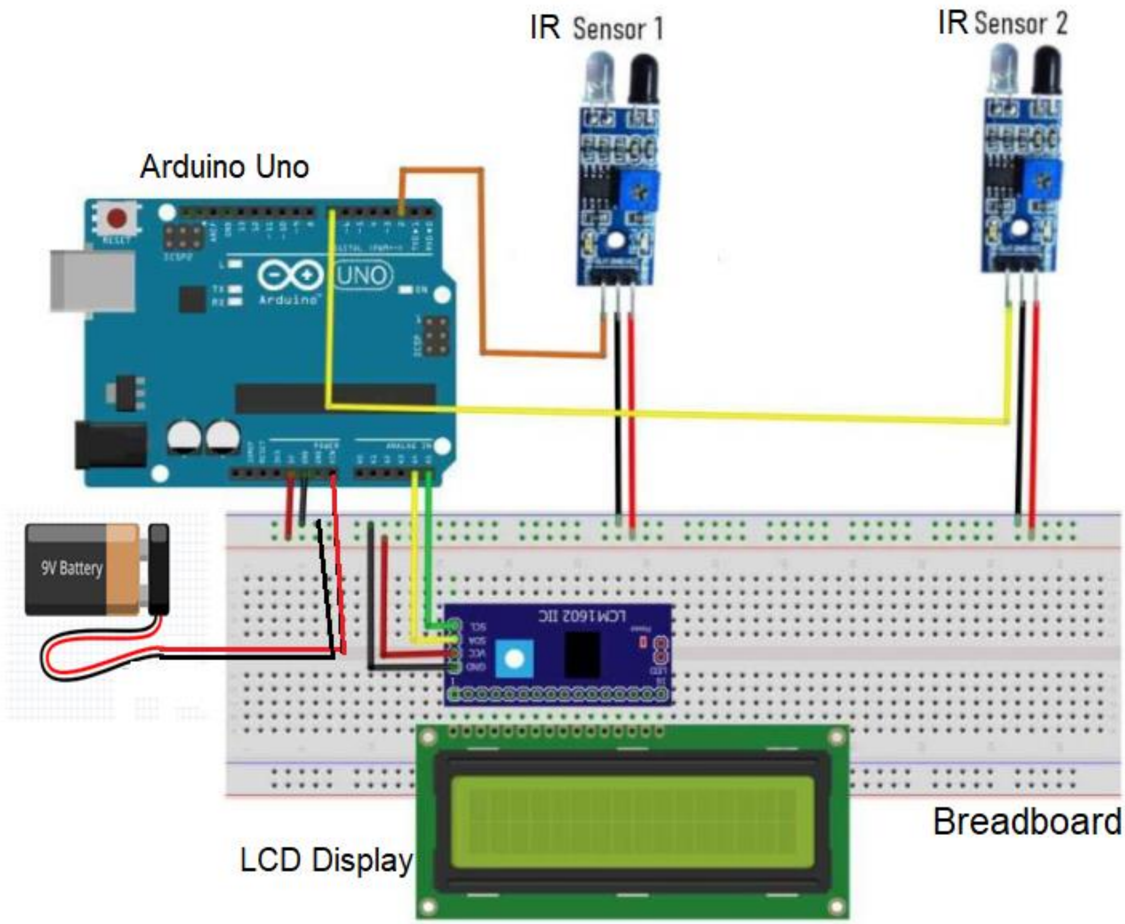

Figure 21. Schematic of circuit diagram used in the project

The circuit diagram shows all the connections in the current design. On the Arduino, Ports A4, A5, 5V and Gnd are used for I2c Liquid crystal display LCD Screen. Port 2, 7, 5V and Gnd are used to sensor (Figure 21). The output ports of two IR sensors are connected to port 2 and 7 respectively. On the breadboard positive and negative ports are used. The middle are used to connect I2c and LCD display.

4.4 Ostwald viscometer

Ostwald viscometer is one type of capillary viscometer. It is used to measure the viscosity of Newtonian fluids. It's working is same as capillary viscometre as discussed in the introduction.

The apparatus required to perform experiments with Ostwald viscometer.

1 Syringe : to suck the liquid
2 Rubber tube: to attach syringe and limb of Ostwald viscometer
3 Stopwatch : to measure time
4 Weighing machine : to weigh the liquid, in order to find the density.
5 Measuring cylindrical tube: to take specific amount of liquid for the expertation.

The parts of the Ostwald viscometer is shown in the figure. First the wider limbo to transfer liquids, there will be two bulbs in the Visco meter. The first one is marked as Bulb 1, then comes u-tube section, then capillary section, and then Bulb 2 with two marks they are Upper Mark A and Lower B. On the limb above upper mark rubber tube is attached to suck the fluid. After sucking the fluid, the liquid is allowed to free flow, based on the time required to cover two marks on bulb2 Viscosity is calculated.

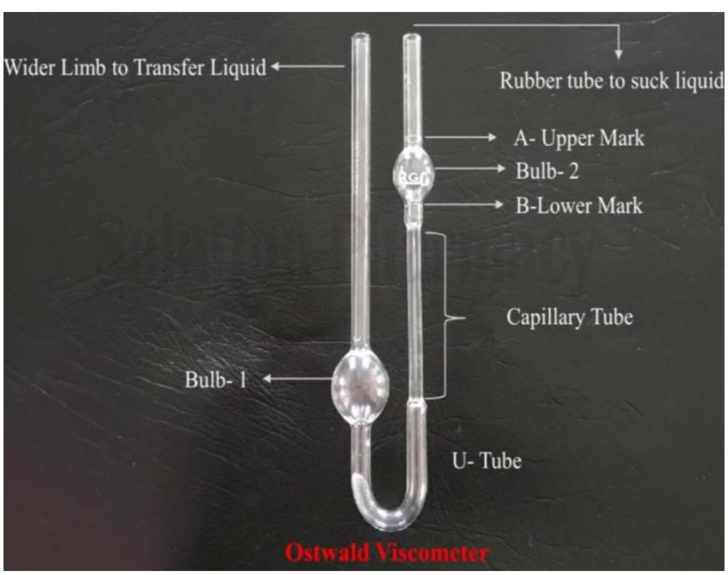

Figure 22. Schematic of Ostwald viscometer

(This page is intentionally left blank)

Chapter 5
Calculation and its programming

5.1 Falling sphere viscometer

The equation (2) is used to determine viscosity. This equation will only be accurate if the sphere reaches terminal velocity and drops in an infinity media with no inertial effects. Faxen et al. [2] gives the correction of the wall effect (W) for fall inside the hollow cylinder with radius R, as seen in equation (8). Equation (2) is modified to adjust for influences on the velocity of the ball comes into contact with container walls (W) as well as ends effect (E) while considering a travelling distance in a cylindrical pipe of height (h). The correction given in [3] is applied calculating velocity,equation(10). Finally equation (11) is used to find viscosity in present design.

$$W = 1 - 2.104\left(\frac{r_s}{R}\right) + 2.088\left(\frac{r_s}{R}\right)^3 - 0.948\left(\frac{r_s}{R}\right)^5 + \cdots \tag{8}$$

$$E = 1 + 3.3\left(\frac{r_s}{h}\right) + \cdots \tag{9}$$

$$v = (1 + 2.39\frac{D_S}{2R})(1 + 3.289\frac{D_S}{2h})v_m \tag{10}$$

$$\mu = \frac{W2{r_s}^2 g}{E9v}(\rho_s - \rho_f) \tag{11}$$

5.2 Ostwald viscometer

Allow a given amount of liquid to flow through the capillary and time how long it takes for the liquid level to travel from one mark to the next. The time taken is a measure of viscosity (since the velocity of flow depends on this viscosity value). Multiply the experimentally obtained time (t_f) by capillary constant (k_c) to get kinematic viscosity (ϑ). This constant must be calculated for each capillary by calibrating it, that is, measuring a known viscosity reference liquid.

$$\vartheta = k_c t_f \tag{12}$$

$$\frac{\mu_1}{\mu_2} = \frac{\rho_1 t_1}{\rho_2 t_2} \tag{13}$$

If the flow time drops below a certain threshold, the flow inside of the capillary would no longer be laminar. .$L_d = 0.05 R_e D$

5.3 Arduino Programming

The code is written to determine how long the ball takes to travel the distance between sensors.

The velocity is then calculated using the measured time. The equation(11) uses velosity to calculate viscosity. The Arduino circuit will automatically calculate the viscosity according to the time and distance input and show it on the LCD.

The part of the code for monitoring timetaken that is written on the Arduino IDE is presented in Figure (23) .

```
const int IR_Sensor1=2;
const int IR_Sensor2=7;
double startMillis;
double endMillis;
double falling_ball_time;
void loop() {
if(digitalRead(IR_Sensor1)==HIGH) //Check the sensor output
{
//lcd.clear();
startMillis = millis();
activate=0;
}
if(digitalRead(IR_Sensor2)==HIGH) //Check the sensor output
if (activate==0){
{
endMillis = millis();
falling_ball_time = (endMillis-startMillis)/1000;
lcd.setCursor(2, 0);
lcd.print(falling_ball_time);
activate=1;
}
}
}
```

Figure 23. Part of arduino programming

Chapter 6
Results and Discussion

The readings are taken by the reference viscometer(Ostwald viscometer) and the falling sphere viscometer simultaneously, and the values recorded are tabulated (Table 1, 2 and 3).

The table (2) contains the results of viscosity and density measurements of Ostwald and current design , and it contains the measured velocity and time of travelling of the ball. The viscosity values are also compared with available references.

Table 1. Readings from Ostwald viscometer

oil	Run no	time(min)	specific gravity	absolute viscosity(cp)
coconut oil	1	19.3	0.91	35.4
	2	18.26	0.91	33.5
	3	19	0.91	34.58
	Average			34.493
cooking oil	1	21	0.917	38.517
	2	21.4	0.917	39.73
	3	20.5	0.917	38.208
	Average			38.8183

Table 2. Readings of Soyabean oil from new Viscometer

Sample	SL no	distance (m)	Density,ρ (kg/m3) T=305K,P=1atm	Viscosity,μ(cp) T=305K,P=1atm		Relative error %	Accuracy %	Time (s)	Velocity (m/s)	References
				falling sphere	Ostwald (average)					
soyabean oil	1	0.18	917	40.03	38.819	3.11960	96.8803	0.444	1.238	At 297K,μ=60 cp; at 353k,12cp
	2	0.135	917	39.0696	38.819	0.64573	99.3542	0.33	1.216	
	3	0.115	917	38.7896	38.819	0.07556	99.9244	0.286	1.2	

Table 3. Readings of Coconut oil and Engine oil using new viscometer

Sample	Sl no	Distance	Density	Falling sphere viscosity	Ostwald viscosity	Relative error	Accuracy	time	velocity	References
coconut oil	1	0.13	910	38.043	34.493	10.292	89.707	0.31	1.25	At 297K, μ=55cp; at 311k, 30cp
	2	0.11	910	35.328	34.493	2.422	97.577	0.25	1.28	
	3	0.09	910	36.316	34.493	5.285	94.714	0.22	1.233	
Unknown Engine oil	1	0.16	860	58.305	NA	-	-	0.56	0.85	Not available
	2	0.11	860	54.464	NA	-	-	0.38	0.86	
	3	0.09	860	51.663	NA	-	-	0.30	0.88	

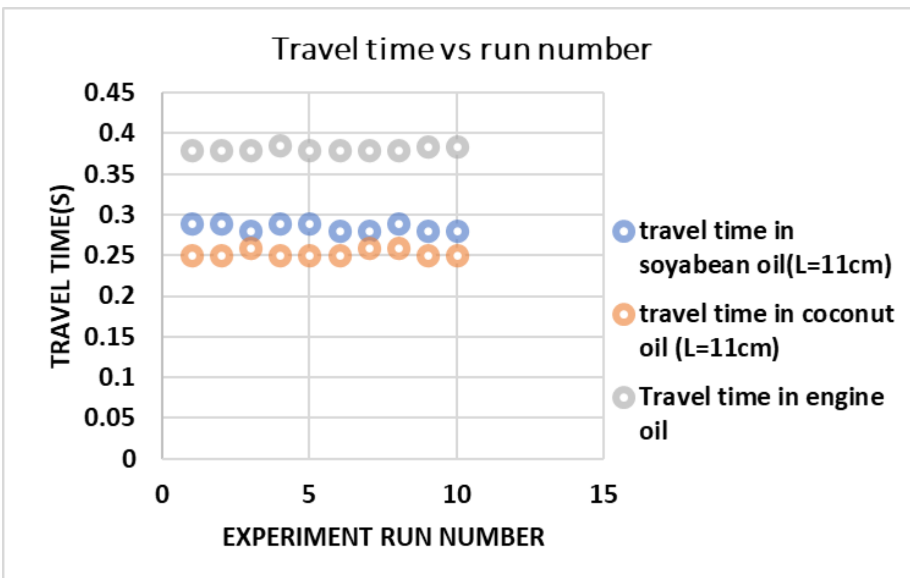

Figure 24. Graph drawn between Travel and Run number

Figure (24 and 25) shows the travelling time and the corresponding velocity of the sphere when the distance between the sensors is 0.11m. The date is potted for three oils that is soyabean oil, coconut oil and engine oil. The falling velocities calculated respectively to the traveling time is up to 1.4 m/s. Coconut oil has bigger velocity value than soyabean oil and it is highest among the three. Engine oil has the highest travelling time. The reproducibility of

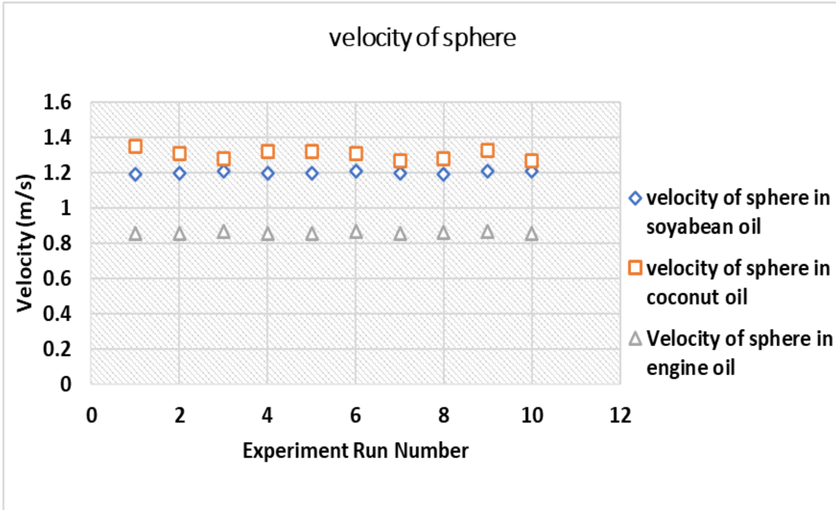

Figure 25. Corresponding velocities for measured time

the measurement data done by sensor is good . Reproducibility of the measurement is confirmed with the standard deviation 0.704. It can be shown that with the current architecture, measuring utilising a sensor to identify trip time improves measurement accuracy. The X-axis run number counts the set of the experimental data retrievals.

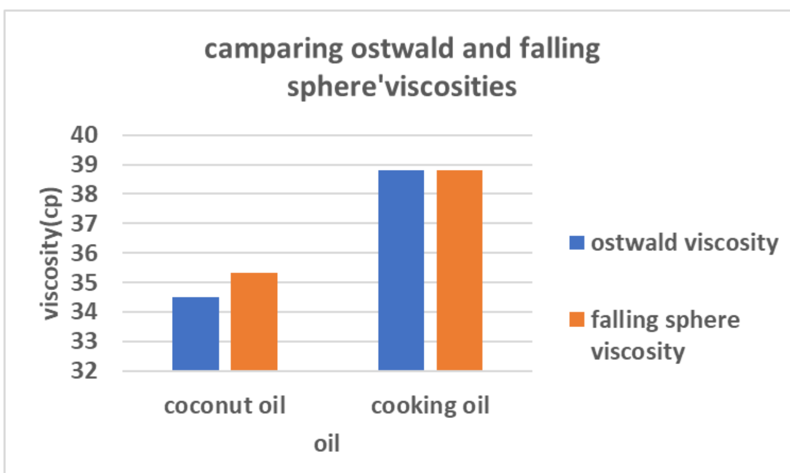

Figure 26. Graph comparing viscosities of Ostwald and Falling sphere viscometers

Figure.(26) shows the comparison of the viscosity value measured by current design and Ostwald viscometer. The variation in measured viscosity value is more in case of coconut oil compared to soyabean oil' viscosity. From this the observation is with the increase of viscosity value the variation is decreasing and accuracy is increasing. However the accuracy of current design still needs to be modified.

The viscosity measurement of engine oil hasn't been done with the Ostwald viscometer since the cleaning is difficult and experimentation is difficult. Capillary viscometer cannot be used for high viscosity fluids.

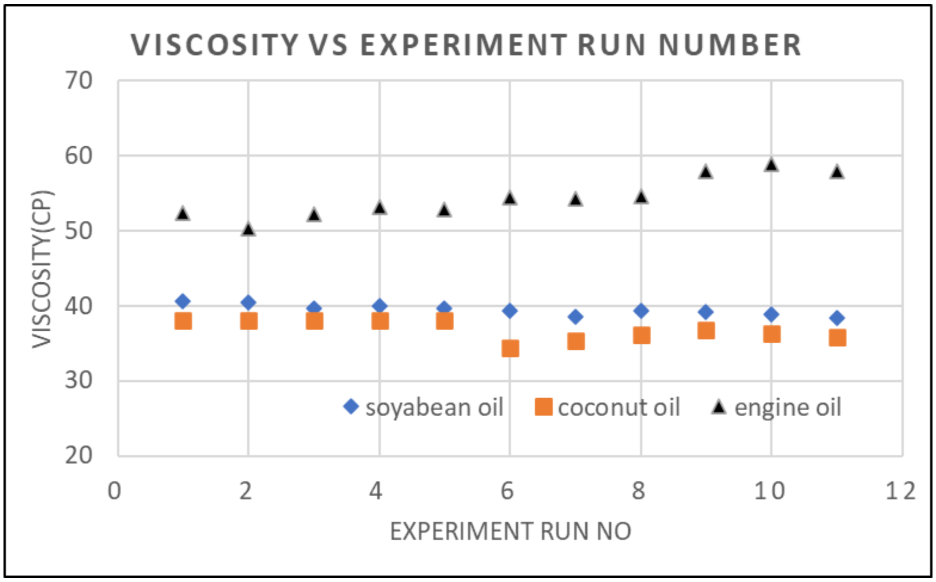

Figure 27. Graph plotted between Measured viscosity at different distance between sensors and Run no

Figure (27) shows the measured viscosity values of three fluids, by varying the distance between the sensors. After performing three measurements, one average value is noted. This is repeated for specific distance between the sensors. For experiment 1 to 4 the distance is 0.18m for soyabean oil, from 5 to 8 the distance is 0.135m, from 9, 10, 11 the distance is 0.09m. The detailed reading are given in the table no (2) note: the values given there, are average values.

Similarly for coconut oil, the distance between sensor taken are 0.13m (1 to 4),0.11m (5 to 8) and 0.09m (9 to 11). In the table the average values are presented with corresponding viscosity values.

For engine oil, the distance between sensors taken are 0.16m (1 to 4), 0.11m (5 to 8) and

0.09m (9 to 11).

From the figure it is observed that even though the distance between the sensors are varied the variation in viscosity values is very less(except for engine oil).

Chapter 7

7.1 Conclusion

To measure the dynamic viscosity of liquid at atmospheric pressure and temperature, a simple and inexpensive digital viscometer based on an infrared sensor and an Arduino micro controller through using falling sphere method was built and tested. Cooking oil, coconut oil and unknown engine oil has been measured and analysed. Also the results of present viscometer compared well with the results of the Ostwald viscometer. Experiments were conducted on three types of oils: coconut oil, cooking oil, and engine oil. The viscosity of coconut oil, cooking oil, and motor oil, respectively, is 35.328cp, 38.789cp, and 54.464cp.

The Arduino microcontroller served as a timer and viscosity calculator by taking velocity as input for the project. The IR sensor has been modified for use in this project.
Time taken by Ostwald viscometer to measure viscosity is 30min, while the present viscometer measure in 5min.

7.2 Scope of Future Work

In the present work for every different fluid, density value has to be changed in the programming while uploading to Arduino. It can be modified such that making the fluid's density as preset. Then just by selecting a fluid enough for experimentation, no need of measuring and changing the code again and again. This would significantly decrease the experimentation time. Another sensor can be added to find the distance between the pair of ir-sensors to act as distance finder. It will further increases the accuracy..

The current deviations from existing benchmarks show that with further refining, the current equipment may be able to take viscosity measurements with relative error of less than 5%.

(This page is intentionally left blank)

References

1. Aryanto D, Saptaningrum E, Wijayanto W. Design a Fluid Viscosimeter Fluid Method of Free Fall Ball Method Based on ATMEGA16 Microcontroller. JFA (Journal of Physics and Its Applications). 2012 Jun 14;8(2):120208-.
2. Yusibani E, Sasmita IR, Ardiah L, Yufita E, Surbakti MS. Design and testing of portable laser-based viscometer. InIOP Conference Series: Materials Science and Engineering 2020 Mar 1 (Vol. 796, No. 1, p. 012027). IOP Publishing.
3. Derrick JM, Golub M, Shrivastav VR, Zhang J. A Low-cost Affordable Viscometer Design for Experimental Fluid Viscosity Verification and Drag Coefficient Calculation. In2018 ASEE Annual Conference & Exposition 2018 Jun 23.
4. Kurniati R. Development of digital viscometer based on sensor technology and microcontroller. InJournal of Physics: Conference Series 2018 Jun 1 (Vol. 1040, No. 1, p. 012047). IOP Publishing.
5. Kim WJ, Kim S, Huh C, Kim BK, Kim YJ. A novel hand-held viscometer applicable for point-of-care. Sensors and Actuators B: Chemical. 2016 Oct 29;234:239-46.Approximate Viscosities of Some Common Liquids. michael-smith-engineers.co.uk
6. Suwardi, Haidul, Ayatullah E. Development of digital viscometer based on Arduino to determine the viscosity of liquid. InAIP Conference Proceedings 2021 Mar 2 (Vol. 2320, No. 1, p. 050036). AIP Publishing LLC.
7. Surtono A, Susanto E. aplikasi sensor fotodiada pada viscometer motode boa. Jurnal Sains MIPA Universitas Lampung. 2012 Jul 3;12(1).
8. Wang X, Carr WW, Bucknall DG, Morris JF. High-shear-rate capillary viscometer for inkjet inks. Review of Scientific Instruments. 2010 Jun 24;81(6):065106.
9. Jo RS, Jo HS, Chai A. Development of low-cost vision-based falling sphere viscometer. In2017 IEEE International Conference on Signal and Image Processing Applications (ICSIPA) 2017 Sep 12 (pp. 279-283). IEEE.
10. Chhabra RP, Richardson JF. Non-Newtonian flow and applied rheology: engineering applications. Butterworth-Heinemann; 2011 Apr 8.
11. Zuol M, Al-Shaer M, Hmied I. Saybolt Universal Viscometer.

12. Approximate Viscosities of Some Common Liquids, Michael smith engineers Ltd.
13. Boimau I, Mellu RN, Manuain MR. Design an Arduino-Based Practicum Viscometer Tool. Physics Probes. 2020;5(1):28-40.
14. Carvajal-Ahumada LA, Serrano-Olmedo JJ, Pazos-Alonso JE, García-Fox MA, Herrera-Sandoval OL. Designing and evaluating a low-cost micro-viscometer using a quartz crystal resonator (QCR) and an Arduino DUE microcontroller board. ORINOQUIA. 2017 Dec;21:45-55.
15. Fox and McDonald's Introduction to Fluid Mechanics (8th Edition) by Philip J. Pritchard - John Wiley-2