

# **Palestine Polytechnic University**



**College of Engineering and Technology**

**Mechanical Engineering Department**

## **Saybolt Universal Viscometer**

**By:**

Mahmuod Mohammad Zuol

Mohammad Ibrahim Al-Shaer

Ibrahim Dawuod Hmied

**Supervisor:**

Eng. Majdi Zaloum

**Submitted to the College of Engineering  
In partial fulfillment of the requirements for the  
Bachelor degree in Mechatronics Engineering**

**Hebron-Palestine**

**December, 2018**

Palestine Polytechnic University  
Collage of Engineering  
Mechanical Engineering Department  
Hebron – Palestine

**Saybolt Universal Viscometer**

**By**

**Mahmoud Mohammad Zoul**

**Mohammad Ibrahim Al-Shaer**

**Ibrahim Dawuod Hmied**

Submitted to the College of Engineering  
In partial fulfillment of the requirements for the  
Bachelor degree in Mechatronics Engineering.

Supervisor Signature

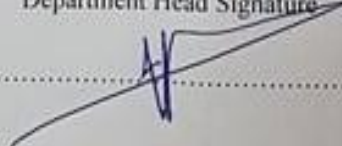
.....

Testing Committee Signature

.....  
.....

.....

Department Head Signature

.....

Dec. 2018

## *Dedication*

*To our wonderful parents*

*Who have raised us to be the persons who are today...*

*To our teachers for their advices...*

*To all students, and our friends...*

*To any person working hard, and*

*Looking for the new*

*In this world...*

*To our country Palestine...*

## *Acknowledgement*

*First, thanks and praise to god, for patronizing us to work on this project. And we would like to thank Palestine polytechnic university for the effort they had done in order to facilitate our work.*

*We would like to thank our supervisor Eng.majdi zalluom for this help and continuous encouragement to the team work, and anyone who help us.*

*Thanks for our wonderful parents, who have raised us to be the persons we are today. You have been with us every step of the way, through good times and bad. Thank you for all the unconditional love, guidance and support that you have always given us, helping us to succeed and installing in us confidence that we are capable of doing anything we put our mind to. Thank you for everything. Thank for our families for their continued support, encouragement and patience from the first step until the end, and their best wishes to us. To our teachers for their advices and to our friends.*

## Abstract

Saybolt Universal Viscometer is used to measure the viscosity of liquids by measuring the time required in second for 60 milliliters of the tested liquid between 40 °C and 100 °C, to pass through a standard orifice. Technology used in this project for eases the control during the test and gives the most efficient accuracy, as it will automatically open the gap of the orifice using a control valve that will open when the desired temperature is achieved in the orifice tube and calculate the required time to reach 60 ml, and then closes the gap. All of the parts are controlled by a Microcontroller unit which is programmed to analyze the inputs of the sensors, and uses the required time to reach 60 ml in the equation of viscosity then it shows the result on the screen.

جهاز قياس اللزوجة هو عبارة عن جهاز مستخدم لقياس لزوجة الموائع من خلال حساب الزمن المستغرق بالثواني لتعبئة 60 مل من العينة بعد مرورها من خلال الفوهة عند درجة حرارة 40 درجة مئوية و 100 درجة مئوية. التقنية المستخدمة في هذا المشروع تتيح سهولة التحكم أثناء الاختبار وتعطي الدقة الأكثر كفاءة ، حيث أنه سيتم تلقائياً فتح الفجوة باستخدام صمام التحكم الذي سوف يفتح عندما يتم تحقيق درجة الحرارة المطلوبة في الانبوب حيث يتم حساب الوقت المطلوب لتدفق 60 مل من العينة، ومن ثم يتم إغلاق الفوهة. يتم التحكم في جميع الأجزاء من قبل وحدة التحكم التي تم برمجتها أيضا لتحليل مدخلات أجهزة الاستشعار، ويتم استخدام الوقت المطلوب للوصول إلى 60 مل في معادلة اللزوجة ثم تظهر النتيجة على الشاشة .

<b>Table of Contents</b>	<b>Page</b>
<b>Cover Page</b> .....	<b>I</b>
<b>Project Title and Signature</b> .....	<b>II</b>
<b>Dedication</b> .....	<b>III</b>
<b>Acknowledgement</b> .....	<b>IV</b>
<b>Abstract</b> .....	<b>V</b>
<b>List of Figures</b> .....	<b>IX</b>
<b>List of Tables</b> .....	<b>X</b>
<b>Symbols</b> .....	<b>XI</b>

## **CHAPTER I: Introduction And Background**

<b>1.1 Overview</b> .....	<b>2</b>
<b>1.2 Main objectives of the project</b> .....	<b>3</b>
<b>1.3 Problem Definition</b> .....	<b>4</b>
<b>1.4 Literature Review</b> .....	<b>4</b>
<b>1.5 Project Management</b> .....	<b>5</b>

## **CHAPTER 2: Viscosity Of Liquids**

<b>2.1 Introduction to viscosity</b> .....	<b>8</b>
<b>2.2 Viscosity measurement</b> .....	<b>9</b>
<b>2.3 Newtonian vs. Non-Newtonian Fluids</b> .....	<b>10</b>
<b>2.4 Types of Viscosity</b> .....	<b>11</b>
2.4.1 Dynamic Viscosity .....	11
2.4.2 Kinematic Viscosity .....	11

## **CHAPTER 3:Building Saybolt Universal Viscometer**

<b>3.1 Definition of Saybolt universal Viscometer .....</b>	<b>14</b>
<b>3.2 apparatus of Saybolt Universal Viscometer .....</b>	<b>15</b>
3.2.1 Saybolt Universal Viscometer Case .....	16
3.2.2 Orifice or capillary tube .....	18
3.2.3 Thermistor .....	20
3.2.4 Filter .....	22
3.2.5 Flask .....	22
3.2.6 Level Sensor or Float .....	23
3.2.7 Heater .....	24
3.2.8 Arduino.....	25
3.2.9 Display Screen.....	26
3.2.10 Electrical Control Valve .....	27

## **CHAPTER 4:System Control Architecture for the Saybolt Universal Viscometer**

<b>4.1 Introduction.....</b>	<b>29</b>
<b>4.2 Flow Chart and Block Diagram of the Saybolt Universal Viscometer .....</b>	<b>29</b>
<b>4.3 System Control Architecture .....</b>	<b>32</b>
4.3.1 User Interface .....	32
4.3.4 Sensing Elements .....	34

## **CHAPTER 5:Design Of Electronic Circuits**

<b>5.1 Introduction.....</b>	<b>39</b>
<b>5.2 Power supply.....</b>	<b>39</b>
<b>5.3 Inputs .....</b>	<b>40</b>
<b>5.4 Outputs.....</b>	<b>43</b>

## **CHAPTER 6:Software Design**

<b>6.1 Introduction.....</b>	<b>46</b>
<b>6.2 Pin mapping.....</b>	<b>48</b>
6.2.1 20x4 LCD Display .....	49
6.2.2 Temperature sensor 1 .....	50
6.2.3 Temperature sensor 2 .....	55
6.2.4 Solenoid valve.....	56
6.2.5 Stopwatch.....	56
<b>6.3 Testing mode.....</b>	<b>56</b>

## **CHAPTER 7:Test Procedure & Results**

<b>7.1 Test Procedure .....</b>	<b>73</b>
<b>7.2 Test Results.....</b>	<b>80</b>
<b>References .....</b>	<b>83</b>



<b>List of Figures</b>	<b>Page</b>
Figure 1.1 Saybolt Universal Viscometer. ....	2
Figure 2.1 Effect Of Viscosity Difference On Fluids. ....	8
Figure 2.2 Behavior Of A Fluid Placed Between Two Parallel Plates. ....	9
Figure 3.1 Saybolt Universal Viscometer. ....	16
Figure 3.2 Saybolt Universal Viscometer Case. ....	16
Figure 3.3 Saybolt Universal Viscometer regions. ....	16
Figure 3.4 Orifice Tube.....	18
Figure 3.5 Dimensions of orifice tube. ....	18
Figure 3.6 Thermistor. ....	21
Figure 3.7 Filter. ....	22
Figure 3.8 Volumetric Flask. ....	23
Figure 3.9 Magnetic float level switch. ....	24
Figure 3.10 Heaters. ....	25
Figure 3.11 Arduino Board. ....	25
Figure 3.12 20x4 Lcd Display. ....	26
Figure 3.13 Schneider Magelis Touch Screen Panel. ....	26
Figure 3.14 Electrical Solenoid Valve .....	27
Figure 4.1 General Flow Chart For The Operation Saybolt Universal Viscometer. ...	30
Figure 4.2 Block Diagram Of The Saybolt Universal Viscometer. ....	31
Figure 4.3 Schneider Magelis Touch Screen Panel. ....	32
Figure 4.4: 20x4 LCD Display.....	33
Figure 4.5 Multistep Switch.....	33
Figure 4.6 Led Indicator .....	34
Figure 4.7: Closed Loop Pid Controller Block Diagram For The Project. ....	34
Figure 4.8 Level Indicator.....	37
Figure 5.1 220v Ac Powering Circuit. ....	40
Figure 5.2 Temperature Sensor Connection. ....	41
Figure 5.3 Multistep Switch Connection. ....	42
Figure 5.4 Level Indicator Connection. ....	43
Figure 5.5 Led's Indicator Connection.....	44
Figure 5.6 Electrical Control Valve Connection.....	44
Figure 6.1 Inputs And Outputs Of The System. ....	46
Figure 6.2 Pin Mapping Of Peripherals To The Arduino Uno. ....	48
Figure 6.3 Temperature Sensor 1.....	50
Figure 6.4 Temperature Sensor Mfile In Matlab. ....	51
Figure 6.5 Characteristic Curve For Ntc 103.....	52
Figure 6.6 Characteristic Equation For Ntc 103. ....	53
Figure 6.7 Temperature Sensor 2.....	54

Figure 6.8 Solenoid Valve .	55
Figure 6.9 Pid Temperature Controller.	55
Figure 7.1 Heating Chamber With Heating Oil .	73
Figure 7.2 Cleaning The Tube.	74
Figure 7.3 Filter The Prepared Sample.	74
Figure 7.4 Flask, And The Float.	75
Figure 7.5 Testing Temperature Mode.	75
Figure 7.6 Solenoid Valve.	76
Figure 7.7 The Float Inside The Flask.	77
Figure 7.8 Interface Of Read Time And Results For Water At 40 C.	77
Figure 7.9 Start Interface.	78

## List of Tables

Page

Table 1.1: Schedule Time-First Semester	5
Table 1.2: The Budget Of The Project	6
Table 4.1: Specification Of Ntc 103.	36
Table 6.1: Pin Out Connections for 20x4 LCD Display	49

## Symbols

$\mu$  Dynamic (shear) viscosity.

$\nu$  Kinematic viscosity.

$\tau$  Shear stress.

$u, v, \omega$  Speed, Velocity.

$p$  Pressure.

$L$  Length.

$D$  Diameter.

$F$  Force.

$T$  Time.

$A$  Area.

$R$  Resistance.

# **CHAPTER I: Introduction and background**

**1.1** Overview

**1.2** Main objectives of the project

**1.3** Problem Definition

**1.4** Literature Review

**1.5** Schedule Time

## 1.1 Overview

Viscosity is one of the most important properties of hydraulic fluids. It is a measure of a fluid's resistance to flow.

Viscosity is normally determined by measuring the required time for a fixed volume of a fluid (at a given temperature) to flow through calibrated orifice. The instrument used to measure the viscosity of a liquid is known as a viscometer. The Saybolt viscometer, shown in figure 1.1, measures the required time, in seconds, for 60 milliliters of tested fluid between 40 °C and 100 °C to pass through a standard orifice. The time measured is used to express the fluid's viscosity, in Saybolt Universal Seconds or Saybolt Furol Seconds[1]. These Viscometers are used to measure kinematic viscosity.

The following figure illustrates the conceptual design of the project:-

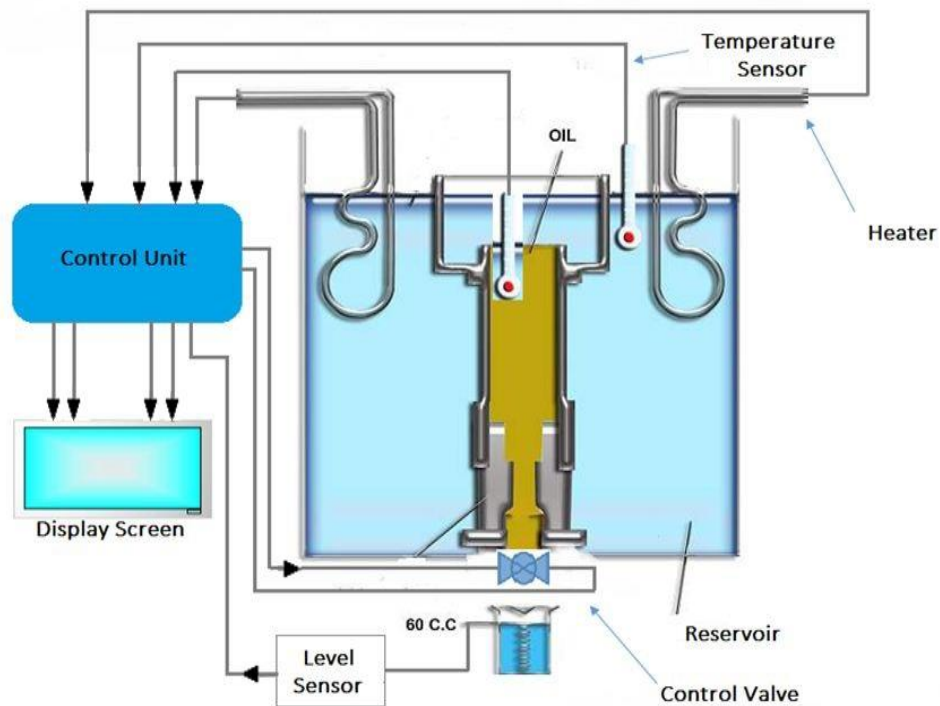


Figure 1.1 Saybolt Universal Viscometer.

In the previous figure the working principle of the project is illustrated as follows:-

At the beginning it is needed to justify the mode of the temperature that is needed to start the viscosity test with, whether it is 40 °C or 100 °C. Then the heaters are activated to heat the liquid path in order to heat the orifice where the liquid sample is going to be in it, to reach the desired temperature to conduct the experiment, where the temperature is being measured through the temperature sensor inside the orifice feeding it back to the control unit. Then the control unit sends a signal to activate the electrical control valve and at the same time a timer is needed to start counting the time where the liquid starts to flow to the receiving flask, and it continues to flow until it reaches the desired limit which is 60ml, then after the level sensor sends a signal to the control unit, where the control unit sends a signal to close the valve and at the same time the timer value is saved and used to substitute it in equation (1.1) or equation (1.2) depending on the value of time, finally the value of viscosity is displayed on the added screen to show it to the user.

**For  $t < 100$  s,**

$$v = 0.226t - 195/t \text{ Centistokes [2]} \quad (1.1)$$

**For  $t > 100$  s,**

$$v = 0.220t - 135/t \text{ Centistokes [2]} \quad (1.2)$$

## **1.2 Main Objectives of the Project**

As a part of the requirements of the project, a number of goals and objectives are established to measure the success of the project. The main goals of project are:

- 1) To measure kinematic viscosity for liquids, to satisfy if the viscosity for any liquid that correspond with standard table of viscosity.
- 2) To be used in experiments in fluid laboratory.
- 3) To be used in the industrial side, such as: petroleum industry.
- 4) To be used for researches, like the research about reducing the viscosity of heavy oils to facilitate pump through pipe lines.

### **1.3 Problem Definition**

The Saybolt Universal Viscometer cost is more than 5000\$ but it can be designed at much lower costs to be used in the laboratory of fluid in Palestine Polytechnic University, and also some of the relevant laboratories in this field.

### **1.4 Literature Review**

- 1- This project was previously designed, where it was not fully controlled. The project was developed and modified to become fully controlled by electrically and programmatically. Another test mode was used, which is 100 ° C which they did not use. The project is designed to allow the use of this mode as will be illustrated.
  
- 2- American Society for testing and materials "ASTM D88:Standard test method for Saybolt viscosity" 1968.

This paper was prepared by American Society for Testing and Materials (ASTM), is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. The organization do these document to create a scale and supported way to conduct this experiment to measure the viscosity. That is Standard Test Method for Saybolt Viscosity[3].

## 1.5 Project Management

### Time Table

Table 1.1: Schedule Time-First semester

Task\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selection of project idea	■	■	■													
Collecting Data			■	■	■											
Literature Review					■	■	■									
Writing and Documentation						■	■	■	■	■	■	■	■	■		
Revising Documentation														■	■	■



## Cost Table

Table 1.2: The budget of the project:-

Item\ Cost	Number of Items	Cost [\$]
Aduino Uno Microcontroller	1	35.2
Orifice	1	146.6
Level Sensor	1	5.8
NTC Temperature Sensor	2	20
Helical Liquid Heater	2	96
Electrical Control Valve	1	13
Touch Screen	1	100
Flask	1	3
Liquid Filter	1	7.8
Finishing Outer Case	1	250
Total		677.4

## **CHAPTER 2: Viscosity of Liquids**

2.1 Introduction to viscosity

2.2 Viscosity measurement

2.3 Newtonian vs. Non-Newtonian Fluids

2.4 Types of Viscosity

2.4.1 Dynamic Viscosity

2.4.2 Kinematic Viscosity

## 2.1 Introduction to Viscosity

Viscosity is an important mechanical property of fluids. Physical systems and applications as diverse as fluid flow in pipes, the flow of blood, lubrication of engine parts, to name just a few, the flow of all fluids depends on the viscosity where the flow varies according to the viscosity, also viscosity enters into the calculations of pressure losses through pipes, the determination of pump sizes, the calculation of fluid forces, so viscosity is defined as the internal friction of a fluid [4].

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid. As shown in the Fig (2.1), the fluid with large viscosity resists motion because its molecular structure gives it a lot of internal friction. A fluid with low viscosity flows easily because its molecular structure affect in very little friction when it is in motion.



Figure 2.1 Effect of viscosity difference on fluids.

To determine this additional property, consider a hypothetical experiment in which a material is placed between two very wide parallel plates as shown in Fig(2.2). The bottom plate is rigidly fixed, but the upper plate is free to move. If a solid, such as steel, were placed between the two plates and loaded with the force  $P$  as shown, the top plate would be displaced through some small distance,  $\delta a$  (assuming the solid was

mechanically attached to the plates). The vertical line  $AB$  would be rotated through the small angle,  $\delta\beta$ , to the new position  $AB'$ . We note that to resist the applied force  $P$ , a shearing stress,  $\tau$ , would be developed at the plate-material interface, and for equilibrium to occur,  $P=\tau A$  where  $A$  is effective upper plate area. It is well known that for elastic solids, such as steel, the small angular displacement,  $\delta\beta$  (called the shearing strain), is proportional to the shearing stress  $\tau$ , which is developed in the material.

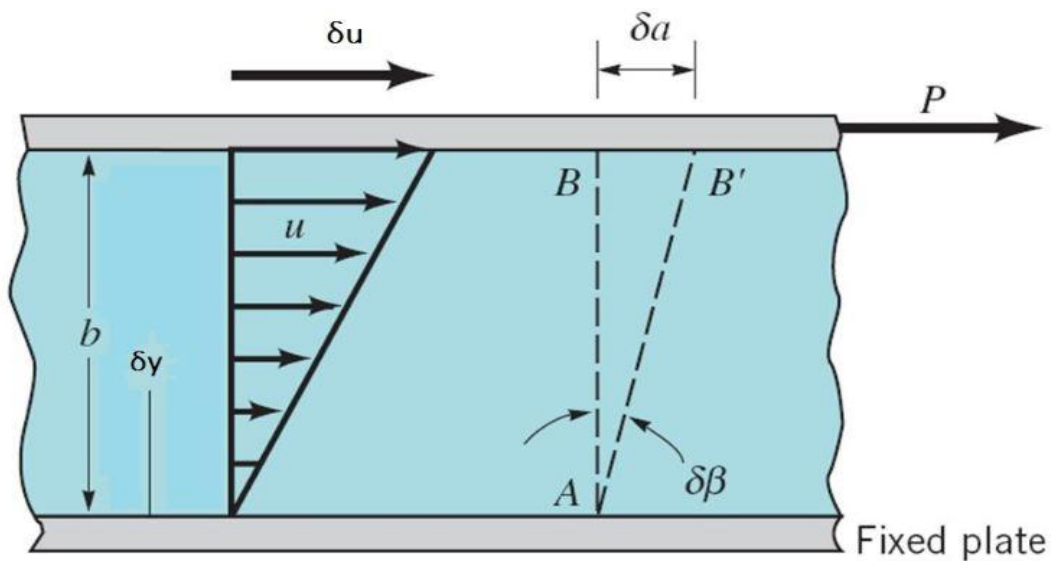


Figure 2.2 Behavior of a fluid placed between two parallel plates.

## 2.2 Viscosity Measurement

Viscosity is measured with various types of viscometers and rheometers. A rheometer is used for those fluids which cannot be defined by a single value of viscosity and therefore require more parameters to be set and measured than is the case for a viscometer. Close temperature control of the fluid is essential to accurate measurements, particularly in materials like lubricants, whose viscosity can double with a change of only 5 °C. For some fluids, viscosity is a constant over a wide range of shear rates (Newtonian fluids). The fluids without a constant viscosity (non-

Newtonian fluids) cannot be described by a single number. Non-Newtonian fluids exhibit a variety of different correlations between shear stress and shear rate[5].

One of the most common instruments for measuring kinematic viscosity is the capillary viscometer. In paint industries, viscosity is commonly measured with a Zahn cup, in which the efflux time is determined and given to customers. The efflux time can also be converted to kinematic viscosities (centistokes, cSt) through the conversion equations. Also used in paint, a Stormer viscometer uses load-based rotation in order to determine viscosity. The viscosity is reported in Krebs units (KU), which are unique to Stormer viscometers[6].

### **2.3 Newtonian vs. Non-Newtonian Fluids**

A Newtonian fluid can be described as a fluid that maintains constant viscosity across all shear rates (shear stress varies linearly with shear rate). These fluids are called Newtonian because they follow the original formula established by Sir Isaac Newton in his Law of Fluid Mechanics. Some fluids, however don't behave this way. In general, they are called non-Newtonian fluids. A group of non-Newtonian fluids referred to as thixotropic are of particular interest in used oil analysis because the viscosity of thixotropic fluid decreases as the shear rate increases. The viscosity of a thixotropic fluid increases as shear rate decreases. With thixotropic fluids, set-time can increase apparent viscosity as in the case of grease[7].

## 2.4 Types of Viscosity

### 2.4.1 Dynamic Viscosity

Dynamic viscosity is a measurement of a fluid's resistance to flow. Water is lower in viscosity than motor oil or honey. Oil is lower in viscosity than tar or molasses. Depending on the application method, viscosity determines how well a resin fills the cavities or voids in a mold [8].

The fact that the shear stress in the fluid is directly proportional to the velocity gradient can be stated mathematically[9] as

$$\tau = \mu \left| \frac{\delta u}{\delta y} \right|^n \quad (2.1)$$

Where:-

$\mu$ : constant of proportionality  $\mu$  (the Greek letter miu) is called Dynamic (shear) viscosity of the fluid.

$\tau$ : Shear stress.

The unit of dynamic viscosity is the Pascal second (Pa·s).

The term absolute viscosity is sometimes used.

### 2.4.2 Kinematic Viscosity

Kinematic viscosity is the time required for a fixed amount of fluid or oil to flow through a capillary tube under the force of gravity. Units of kinematic viscosity are stoke, centistoke (1/100 of a stoke), and Saybolt Universal Seconds (SUS). Saybolt Universal Seconds or Saybolt Universal Viscosity (SUV) is the time in seconds required for 60 milliliters of a fluid to flow through the orifice of a standard Saybolt universal viscometer at a given temperature under specified conditions, usually per

ASTM D88. Kinematic viscosity is also described as quotient of the absolute viscosity in centipoises divided by the specific gravity of a fluid where both are measured at the same temperature[10].

$$v = \frac{\mu}{\rho} \quad (2.2)$$

$\mu$ : Dynamic (shear) viscosity.

$v$ : Kinematic viscosity.

$\rho$ : Density.

The kinematic viscosity is usually expressed in square millimeters per second. USP The basic unit is the poise (according to USP). However, viscosities commonly encountered represent fractions of the poise, so that the centipoise (1 poise = 100 centipoises) proves to be the more convenient unit.

## **CHAPTER 3: Building Saybolt Universal Viscometer**

### 3.1 Definition of Saybolt Universal Viscometer

### 3.2 Apparatus of Saybolt Universal Viscometer

#### 3.2.1 Saybolt Universal Viscometer Case

#### 3.2.2 Orifice or Capillary tube

#### 3.2.3 Thermistor

##### 3.2.3.1 Temperature Sensor Types

#### 3.2.4 Filter

#### 3.2.5 Flask

#### 3.2.6 Level Sensor

#### 3.2.7 Heater

#### 3.2.8 Microcontroller

#### 3.2.9 Display Screen

##### 3.2.9.1 Display Screen Types

#### 3.2.10 Electrical Control Valve



### 3.1 Definition of Saybolt Universal Viscometer

A viscometer invented by Saybolt for measuring the viscosity of petroleum based liquids, typically consisting of an oil tube surrounded by a heated bath which controls the temperature of the liquid.

The Saybolt Universal Viscometer shown in figure 3.1 ,measures the time required , in seconds, for 60 milliliters to flow through a calibrated orifice or capillary tube(at a given temperature), the time measured is used to express the fluid's viscosity.

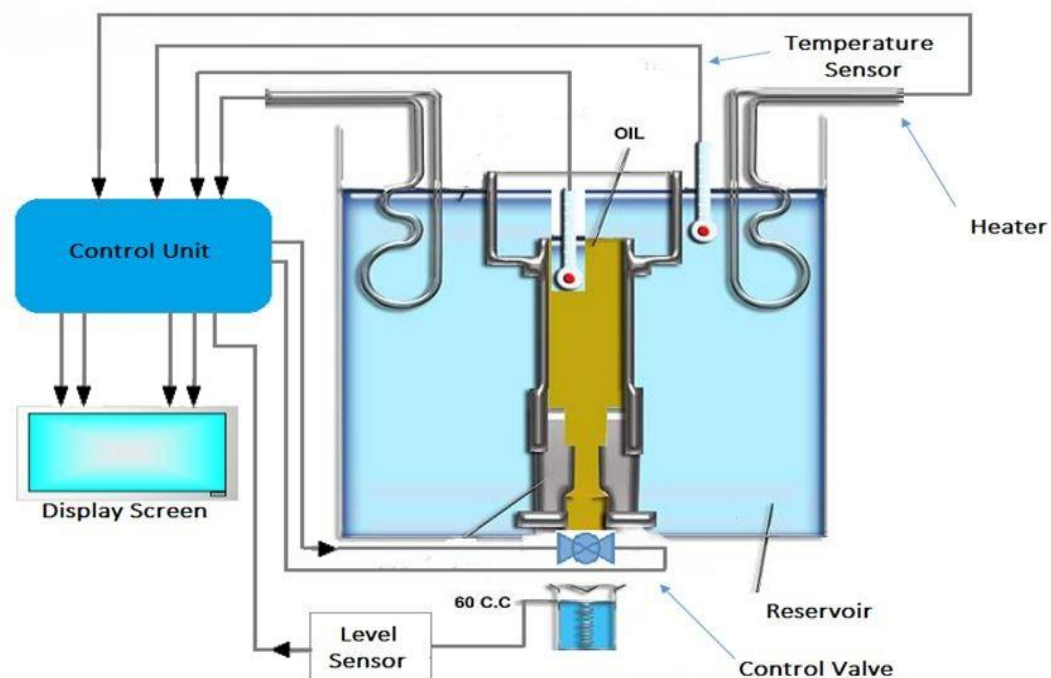


Figure 3.1 Saybolt Universal Viscometer.

### **3.2 Apparatus of Saybolt Universal Viscometer**

To build the Saybolt Universal viscometer we need several components and each of these components has a specific function, these components are:

- 1) Saybolt Universal Viscometer Case.
- 2) Orifice or Capillary tube.
- 3) Thermistor.
- 4) Filter.
- 5) Flask.
- 6) Level Sensor.
- 7) Heater.
- 8) Arduino.
- 9) Display Screen.
- 10) Electrical Control Valve.

### 3.2.1 Saybolt Universal Viscometer Case

Its box made from stainless steel, which contains most of the parts for this project. The structure of Saybolt Universal viscometer case will be design in cylindrical form like a tank as shown in figure 3.2 , also the heating chamber walls it will be built from two layers of steel and the insulation material will be between them.

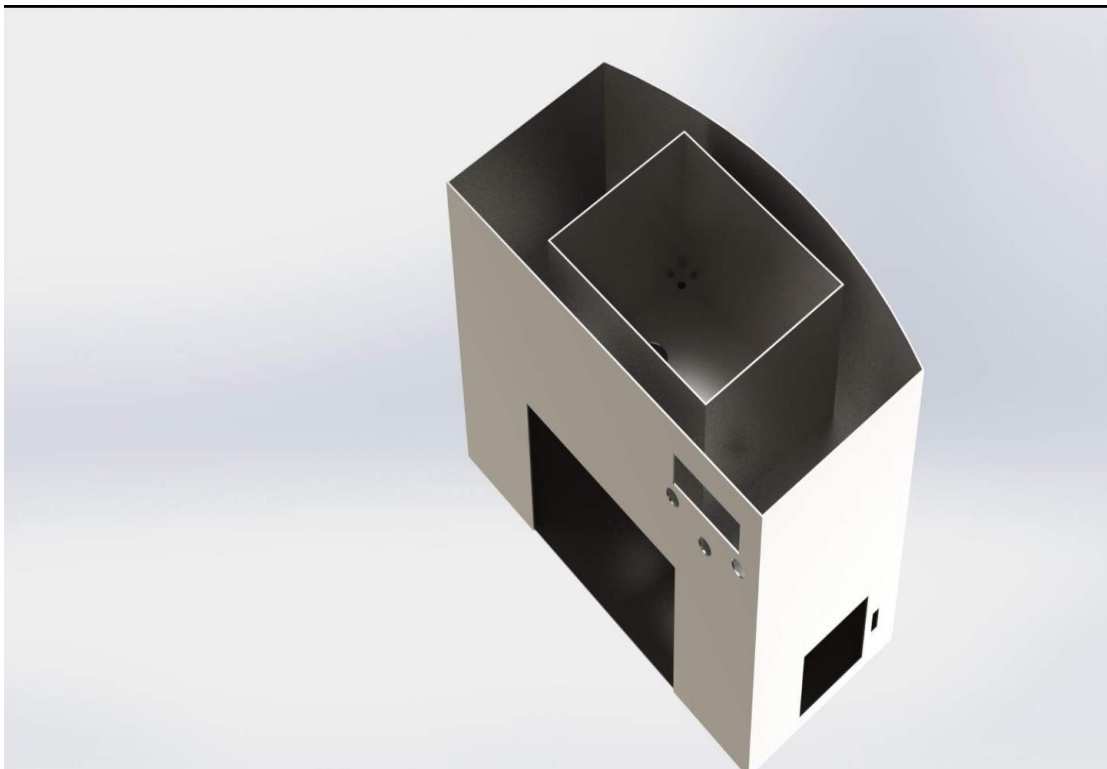


Figure 3.2 Saybolt Universal viscometer case.

The heat must stay inside the box in water region between plate 1 and plate 2 as shown in figure 3.3, so we will use insulation material between plate 2 and plate 3 to reduce the heat transfer from water to environment, to reach the main purpose which is maintaining the temperature of the water and reduce energy consumption from heater.

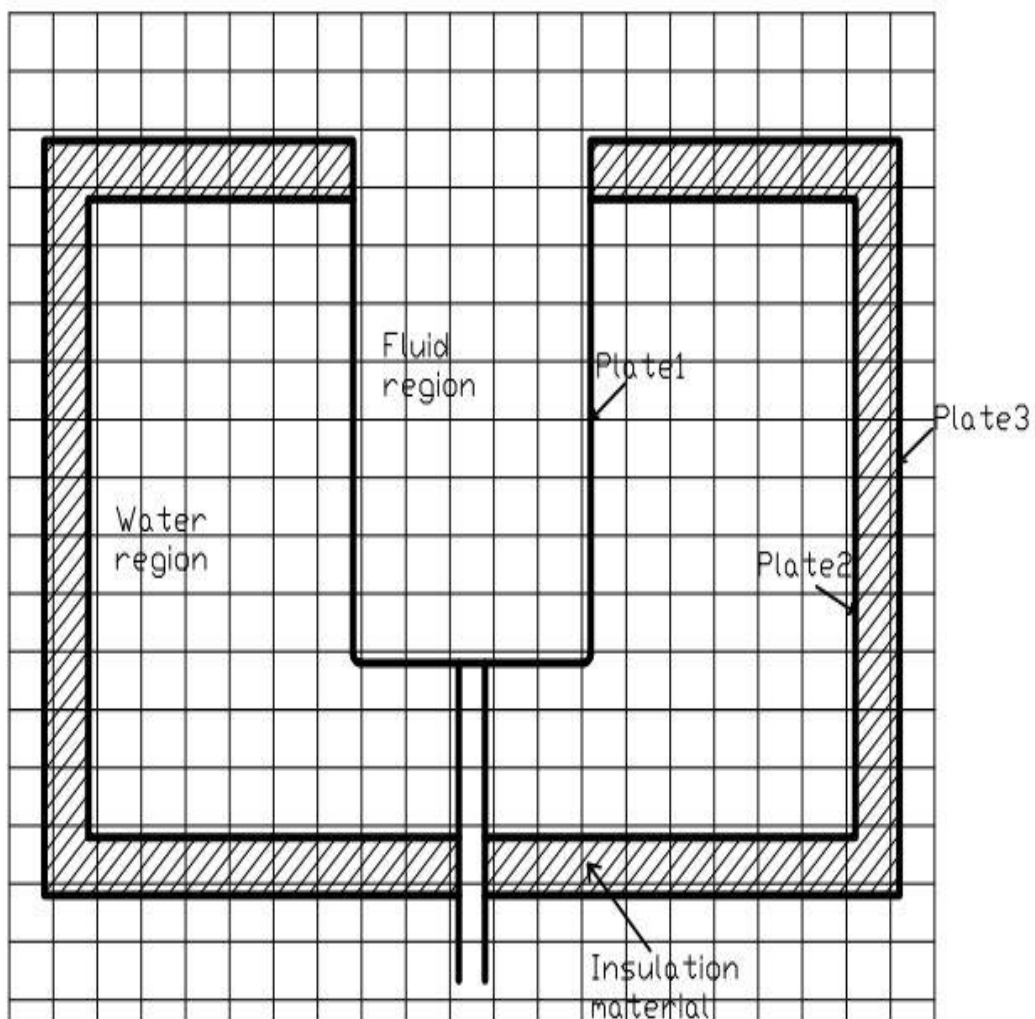


Figure 3.3 Saybolt Universal viscometer regions.

### 3.2.2 Orifice or Capillary Tube

The Orifice tube as shown in figure 3.4. It's a tube with standard dimensions. Calibrated brass oil cup with stainless steel flowing orifice, polished and calibrated flow through this tube to flask. [15]



Figure 3.4 Orifice tube.

Each orifice and cup assembly should be calibrated using the ASTM viscosity standards to obtain the correct calibration constant. [15]

Three types of orifice are available:

- 1) Universal.
- 2) Furol
- 3) Asphalt.

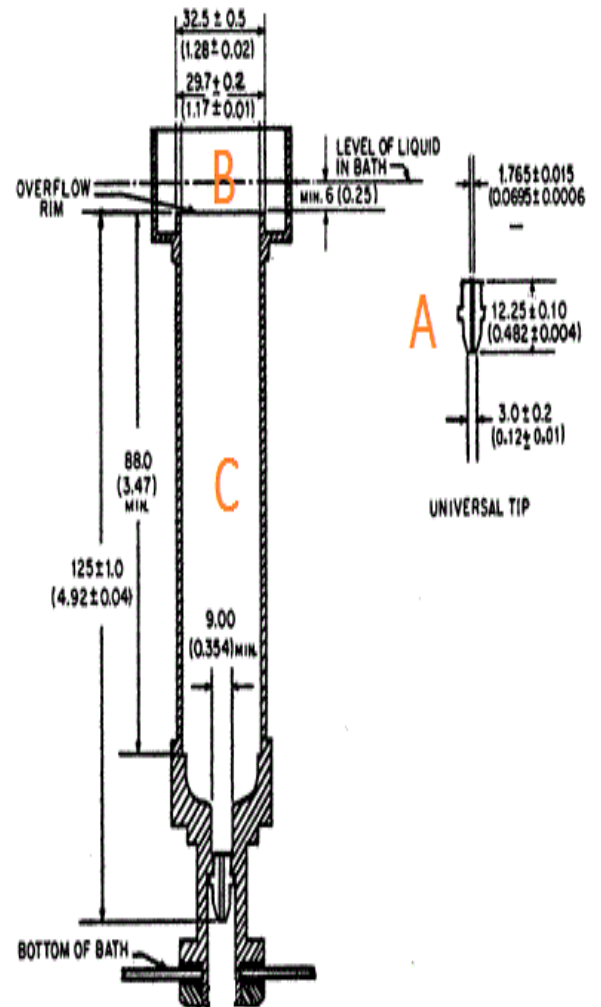
The used orifice in this project will be the universal type.

The dimensions of orifice should be measured with respect to the ASTM standard to get the perfect results as in the standard table of viscosity, dimensions of the orifice tube is shown in the figure 3.5 below:

Region A: this region is the orifice tube, where the liquid sample will cross through this orifice to the flask.

Region B: in this region the filter will be placed to purification the liquid before entering the tube.

Region C: this region contains the liquid sample to be tested.



Note-All Dimensions are in inches.

Figure 3.5 Dimensions of orifice tube.

### **3.2.3 Thermistor**

To obtain high accuracy the temperature of the liquid sample should be controlled since the saybolt universal viscometer measure the viscosity at a specific temperature, so we need temperature sensor to measure the temperature especially in the container that contains the liquid sample which is called a thermocouple.

The challenge is that the thermocouple must be selected with the precision required to maintain the temperature required according to the standard of the saybolt universal viscometer criteria.

Thus, a thermocouple or thermistor must be selected with high accuracy since it will be used as a feedback to the controller which will be designed prevents errors in the temperature and can compensate for changing environment factors, so detection circuit should be more intelligent.

On the other hand, the sensor must be designed to be able to withstand the sudden rise in temperature were the temperature has two modes and in one of them the temperature will reach 100 °C.

#### **3.2.3.1 Temperature Sensor Types:**

There are three commonly used temperature sensor types illustrated as follows:-

##### 1) Negative Temperature Coefficient (NTC) thermistor:-

A thermistor is a thermally sensitive resistor that exhibits a large, predictable, and precise change in resistance correlated to variations in temperature. An NTC thermistor provides a very high resistance at low temperatures. As temperature increases, the resistance drops quickly. Because an NTC thermistor experiences such a large change in resistance per °C, small changes in temperature are reflected very fast and with high accuracy (0.05 to 1.5 °C). Because of its exponential nature, the output of an NTC thermistor requires linearization. The effective operating range is - 50 to 250 °C for gas encapsulated thermistors or 150°C for standard[11].

## 2) Resistance Temperature Detector (RTD)

An RTD, also known as a resistance thermometer, measures temperature by correlating the resistance of the RTD element with temperature. An RTD consists of a film or, for greater accuracy, a wire wrapped around a ceramic or glass core. The most accurate RTDs are made using platinum but lower cost RTDs can be made from nickel or copper. However, nickel and copper are not as stable or repeatable. Platinum RTDs offer a fairly linear output that is highly accurate (0.1 to 1 °C) across -200 to 600 °C[12].

## 3) Thermocouple

This temperature sensor type consists of two wires of different metals connected at two points. The varying voltage between these two points reflects proportional changes in temperature. Thermocouples are non-linear, requiring conversion when used for temperature control and compensation, typically accomplished using a lookup table. Accuracy is low, from 0.5 to 5 °C. However, they operate across the widest temperature range from -200 to 1750 °C.

Since the NTC thermistor has the highest accuracy (0.05 to 1.5 °C) and it can operate with temperature above 100 °C and it has operating range from -50 to 250 °C, also its cost is not high, so in this project we can use it.

The NTC as shown in figure 3.6, is a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end, which produce a small voltage at a given temperature.



Figure 3.6 Thermistor.



### 3.2.4 Filter

The filter as shown in figure 3.7, it's used to clean the sample of the liquid from impurities to get pure liquid as much as possible.

Typical commercial pneumatic filters will remove particles as small as 5 micrometers from the air. The filters used to get pure liquid as much as possible also to protect the orifice or capillary tube from the errors in the calibration that would be caused by these contaminants. These contaminants include lubricant particles, dirt particles, small water droplets or aerosols.

The filter should be placed at the top of the container that contains the liquid sample.



Figure 3.7 Filter.

### 3.2.5 Flask

It's calibrated to contain a precise volume at a particular temperature. Volumetric flasks are used for precise dilutions and preparation of standard solutions. These flasks are usually pear-shaped, with a flat bottom, and made of glass or plastic. The flask's mouth is either furnished with a plastic snap/screw cap or glass stopper. The

neck of volumetric flasks is elongated and narrow with an etched ring graduation marking. The marking indicates the volume of liquid contained when filled up to that point. Volumetric flasks are of various sizes, containing from 1 to 20 000 mL of liquid and in this project we will use a volumetric flask with size of 60ml.

The flask as shown in the figure 3.8, it's a volumetric flask used to receive the liquid falling from the container, in order to measuring the required volume of the sample which is equal to 60ml.



Figure 3.8 Volumetric flask.

### **3.2.6 Level Sensor or Float**

The level sensor is an important part of the project. When the temperature inside the orifice reaches the desired value, the electrical control valve will be opened then the liquid will begin to flow to the receiving flask.

The main function of the level sensor is to detect the volume of the sample when it reach 60 milliliters since it will send a command to the microcontroller to make the electrical control valve closed.

The level indicator can be used which is magnetic float level switch for liquids series use a hermetically sealed reed contact actuated by a magnet in the float. As the float rises and falls, the magnetic field causes the switch inside the stem to open or close. As shown in figure 3.9, the level indicator sensor detects the level of the liquid in the flask, that will use to detect if the liquid in the flask reach 60ml or not.



Figure 3.9 Magnet float level indicator.

### **3.2.7 Heater**

Liquid heating is a thermodynamic process that uses an energy source(heater) to heat it above its initial temperature.

In this project the results must be accurate according to the standard table of viscosity, so the temperature must be provided according to the standardization of saybolt universal viscometer.

This project needs robust heater to ensure the heat transfer from the heating liquid to all parts of the liquid sample inside the orifice.

The heater as shown in figure 3.10 should be selected so that it is able to provide the required temperature according to the standards of saybolt universal viscometer, since the viscosity will be measured in two modes, one of them is at 40 °C and the other is at 100°C.



Figure 3.10 Heaters.

### 3.2.8 Arduino

In this project, Arduino as shown in figure 3.11 is a very important part because it is used in the process of control of all tasks in the project where it will connect all the parts to each other, for example through which will control the heat by programming and writing the difference equation of the PID controller which will be designed in this project, also display the results on the screen where it will be programmed by Arduino and etc.



Figure 3.11 Arduino Board.

### 3.2.9 Display Screen

In this project we need to display the results, viscosity, temperature values, the time required for the flow of 60 ml and some other values, so this project needs a screen to display those values.

#### 3.2.9.1 Display Screen Types

- 1) Liquid Crystal Display LCD Screen.

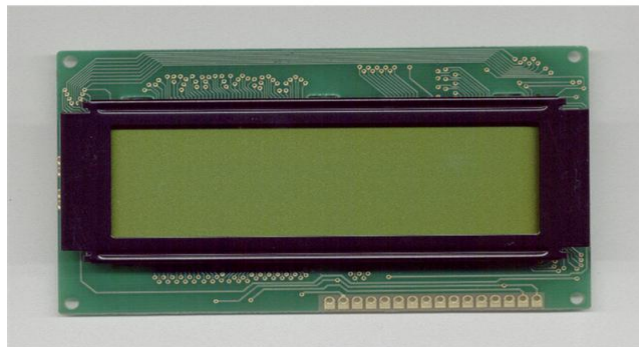


Figure 3.12 20x4 LCD Display.

- 2) HMI Touch Screen.



Figure 3.13 Schneider Magelis touch screen panel.

### 3.2.10 Electrical Control Valve

The electrical control valve as shown in figure 3.14. It's an important part of the project where the sample liquid must be trapped in the orifice until it reaches the desired temperature according to the temperature mode used. After reaching the required temperature, the temperature sensor will send a command to the microcontroller, which in turn opens the electrical control valve and it remains open until flows the required volume of the sample, after that the level sensor send a command to microcontroller to make it closed.



Figure 3.14 Electrical Solenoid Valve

It is important to note that the electric control valve must be selected with a diameter greater than the diameter of the orifice so that the results are accurate according to the standard table of viscosity also must be fully open and fully closed.

# **CHAPTER 4: System Control Architecture for The Saybolt Universal Viscometer**

4.1 Introduction

4.2 Flow Chart and Block Diagram of the Saybolt Universal Viscometer

4.3 System Control Architecture

4.3.1 User Interface

4.3.2 PID Controller

4.3.3 Sensing Elements

## **4.1 Introduction**

In this chapter the block diagram for all components of the Saybolt Universal Viscometer will be discussed, to integrate all components with each other, this will include the mechanical device that will be used, the sensors, the interface device and the controlling unit.

## **4.2 Flow Chart and Block Diagram of the Saybolt Universal Viscometer**

The flow chart in figure 4.1 shows in general the steps and sequence of operations of the Saybolt Universal Viscometer. When the start, two options are available the 40 C and 100 C.

When Choosing 40 C mode, the temperature will be defined as we selected, then the heaters will be starting to reach the specified temperature, the heaters will run as long as the sample temperature it is less than the specified temperature.

Then the orifice tube will open, and the stop watch will start timing, when the liquid reach 60ml in the flask the stop watch will stop and the orifice tube closed by the electrical control valve. The same procedure will be operate when choosing 100 C, but the orifice tube will open at 100 C, and the watch will start at this temperature.



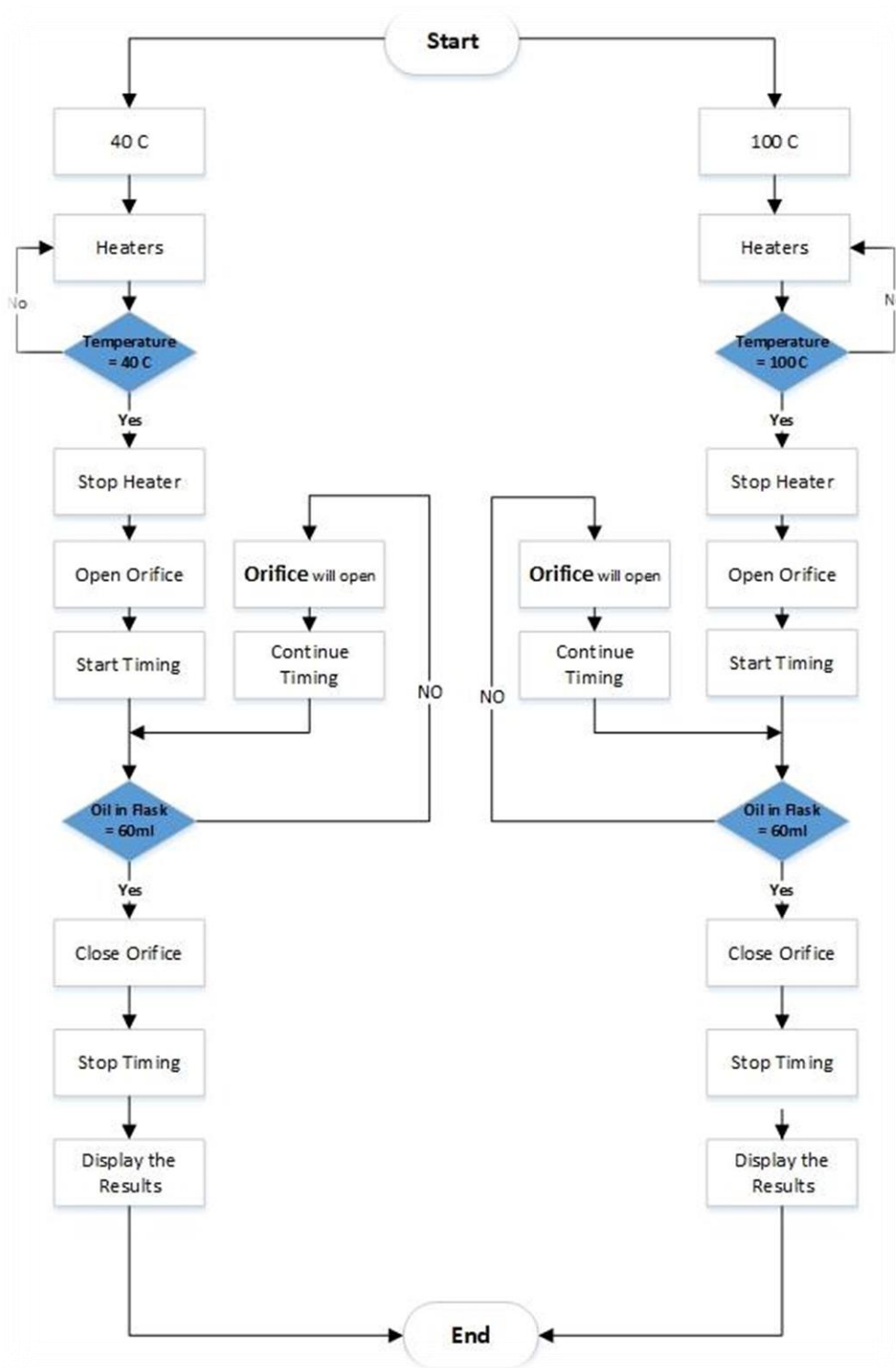


Figure 4.1 General flow chart for the operation Saybolt Universal Viscometer.

Whenever the orifice tube is open the stop watch will be set to increment the time in the controller, the system will check whether the sample in the flask have reach the 60 ml by using level indicator. The orifice tube will be kept open until reaching 60 ml, which causes the system to close the orifice tube, and the result display on the LCD, then the system will be idle.

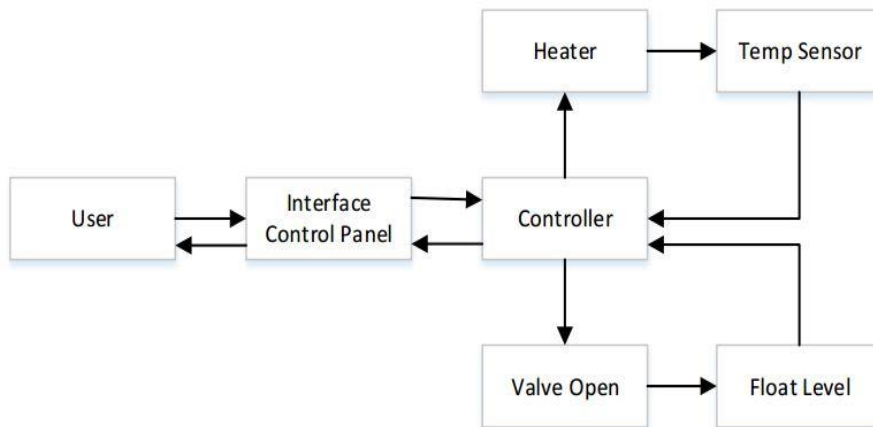


Figure 4.2 Block diagram of the Saybolt Universal viscometer.

As mentioned in the block diagram in figure 4.2 the user will have the ability to contact the control panel directly by the user interface, which will give the orders to the system where the controller starts reading the commands of the user and then it start the process. The controller must give signals to activate heaters which will increase the water temperature, other signals are sent to the electrical control valve. The controller will receive signals from the temperature sensor, and the level indicator.

## 4.3 System Control Architecture

In the system control architecture the parts of the Saybolt Universal Viscometer will be explained and described each part by itself.

### 4.3.1 User Interface

For the user interface two options are available to do, the first choice is the electric touch screen that can establish a serial communication with microcontroller that is relatively expensive, the other option is the multistep switch that can chose a temperature operation and to start and stop the system, and LCD to display the results on it.

- Schneider Electric Touch Screen Panel:



Figure 4.3 Schneider Magelis touch screen panel.

The Schneider touch screen provides two monochrome versions that are available with three colore backlighting for high visibility and status indication. The display features 16 levels of grey, numerous character fonts, and the vijeo designer extensive object library, which all help to provide best in class, high-quality graphic animations.

Vijeo Designer supports 38 alphabets and enables the HMI to manage up to 15 languages simultaneously. And Ease of maintenance:-

- 1) No batteries required, backlit by LEDs.
- 2) Removable power connector.
- 3) USB memory stick for application downloads.

- **20x4 LCD Display:**

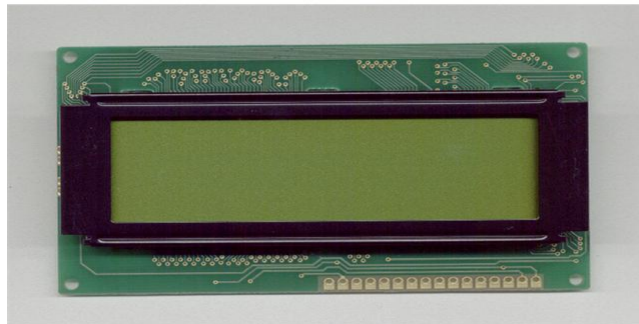


Figure 4.4 20x4 LCD Display.

This is an industry standard HD44780 based controlled 4 lines X 20 characters LCD display with WHITE characters on BLUE background and backlight. It is a parallel interface so you will need 7 General-purpose input/output (GPIO) pins for 4-bit mode or 11 GPIO pins for 8-bit mode to interface to this LCD screen.

- **Multistep Switch**

Is an electromechanical device which allows an input connected to one of a number of possible output connections, and in this apparatus a multistep switch with two outputs is used as shows in figure 4.5. The two options outputs 40 C and 100 C .



Figure 4.5 Multistep Switch.

- **LED Power Indicator**

Low energy consumption low maintenance and small size of LED has led to uses as status indicators and displays on a variety of equipment and installations. In this apparatus two LED indicators are used to display which operation selected, as shown in figure 4.6.



Figure 4.6 LED indicator

### 4.3.2 PID Controller

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems, a PID is the most commonly used feedback controller. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs [13].

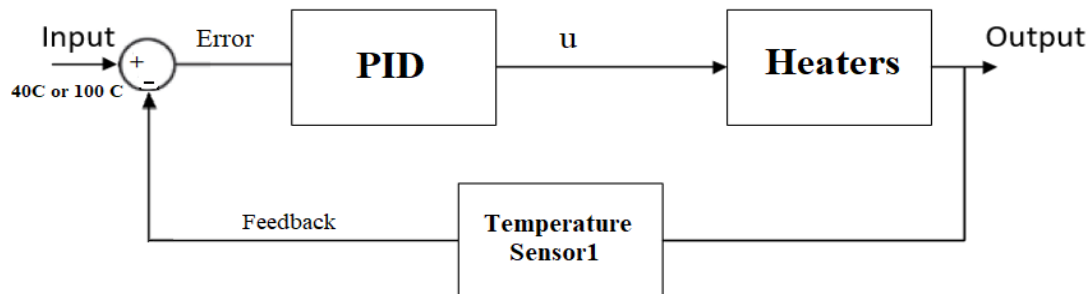


Figure 4.7: Closed Loop PID controller block diagram for the project.

The PID controller compares the measured process value with a reference setpoint value. The difference or error,  $e$ , is then processed to calculate a new process input. This input will try to adjust the measured process value back to the desired setpoint. The alternative to a closed loop control scheme such as the PID controller is an open loop controller. Open loop control (no feedback) is in many cases not satisfactory, and is often impossible due to the system properties. By adding feedback from the system output, performance can be improved [14].

In this project a PID controller is desired to be added to make sure that no undesired error occur in the reading of the temperature, and to support the output with a high accuracy in the two modes whether it was 40C or 100C and to make the results fit with the standard table of viscosity as much as possible, the temperature must be controlled very well.

### **4.3.3 Sensing Elements**

#### **4.3.3.1 Thermistor (NTC)**

A negative temperature coefficient (NTC) thermistors are temperature-sensing elements made of two terminal solid state electronic component that has been sintered in order to display large changes in resistance in proportion to small changes in temperature. This resistance can be measured by using a small and measured direct current, or dc, passed through the thermistor in order to measure the voltage drop produced. Thermistors are an incredibly accurate category of temperature sensors. This apparatus has two NTC 103 thermistors in this apparatus the first one in the water region with PID controller, and the second in the testing sample region.

Table 4.1 : Specification of NTC 103.

NTC 103 F 343 F			TEMP. (°C)
RESISTANCE (kΩ)			
min.	center	max.	
179.593	186.796	194.269	-40
138.240	143.405	148.748	-35
107.162	110.881	114.717	-30
83.648	86.334	89.098	-25
65.737	67.683	69.680	-20
52.003	53.416	54.862	-15
41.403	42.431	43.479	-10
33.171	33.918	34.678	-5
26.737	27.280	27.830	0
21.678	22.071	22.469	5
17.677	17.960	18.246	10
14.494	14.697	14.901	15
11.947	12.091	12.235	20
9.900	10.000	10.100	25
8.213	8.312	8.410	30
6.848	6.942	7.037	35
5.737	5.326	5.916	40
4.828	4.911	4.996	45
4.081	4.159	4.237	50
3.465	3.536	3.609	55
2.954	3.019	3.086	60
2.528	2.588	2.650	65
2.172	2.227	2.284	70
1.873	1.924	1.975	75
1.622	1.668	1.715	80
1.409	1.451	1.494	85
1.228	1.266	1.305	90
1.073	1.108	1.144	95
0.942	0.973	1.006	100
0.828	0.858	0.888	105
0.731	0.758	0.785	110
0.647	0.671	0.697	115
0.574	0.597	0.620	120

#### 4.3.3.2 Level Indicator (Float level switch)

Its highly needed to use the level sensor in this project for its importance in indicating the level of the liquid that is needed to be tested, where level indicator sensor detects the level of the liquid in the flask that will be used to detect if the liquid in the flask reach to 60 ml or not, and such an action cannot be accomplished without this sensor.



Figure 4.8 Level indicator



# **Chapter 5: Design of Electronic Circuits**

## 5.1 Introduction

## 5.2 Power supply

### 5.2.1 220 volt AC Power Supply

## 5.3 Inputs

### 5.3.1 Temperature Sensor

### 5.3.2 Multistep Switch

### 5.3.3 Level Indicator

## 5.4 Outputs

### 5.4.1 Heater

### 5.4.2 LED's indicator

### 5.4.3 Electrical Control Valve

## **5.1 Introduction**

An electronic circuit is composed of individual electronic components, such as resistors, transistors, capacitors, inductors and diodes, connected by conductive wires or traces through which electric current can flow. The combination of components and wires allows various simple and complex operations to be performed: signals can be amplified, computations can be performed, and data can be moved from one place to another. Circuits in the project are constructed of discrete components connected by individual pieces of wire. In this chapter the electric parts and circuit are discussed to explain the necessary resistance needed for the circuit protection and explaining the circuit of each function such as LED indicators, temperature sensors, electrical control valve, level indicator, and power supply, these functions are divided into two groups: the inputs and outputs as discussed in the previous chapter.

## **5.2 Power supply**

A power supply is a device that supplies electric power to an electrical load, a regulated power supply is one that controls the output voltage or current to a specific value; the controlled value is held nearly constant despite variations in either load current or the voltage supplied by the power supply's energy source. Three types of power source are needed to power up the apparatus, 220v AC to power up the electrical heater and the electrical control valve, 5v DC to power up LED indicators, and to power up the control circuits such as the microcontroller.

### 5.2.1 220 volt AC Power Supply

There are two parts that need to be powered up with a 220 AC power source, with, figure 5.1 shows the connection circuit of the heater.

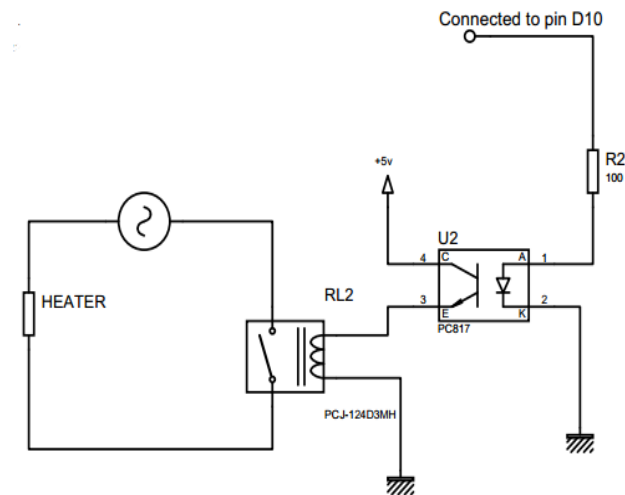


Figure 5.1 220 AC powering circuit.

As the figure above shows the AC parts are connected directly to the power source and are controlled using solid state relay (SSR) that is connected to the optocoupler which is connected to the ARDUINO which is powered with a PWM output (pin 10).

### 5.3 Inputs

This section discusses the inputs of the project that are two temperature sensors, multistep switch (two input), and level switch.

### 5.3.1 Temperature Sensor

Temperature sensor will use as a voltage divider element with  $2K\Omega$  resistance, the output from the NTC thermistor is the voltage through the  $2K\Omega$  resistance, figure 5.2 shows the connection circuit of temperature sensor.

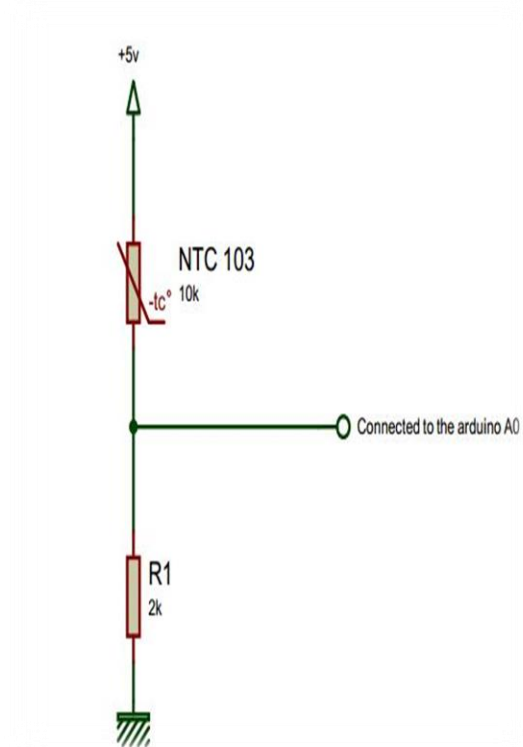


Figure 5.2 Temperature sensor connection.

### 5.3.2 Multistep Switch

The Multistep switch is activated by physical contact, and must give a value 0v if opened and 5v if close to do, so the following circuit is derived so ARDUINO can receive a logic order of 0 or 1.

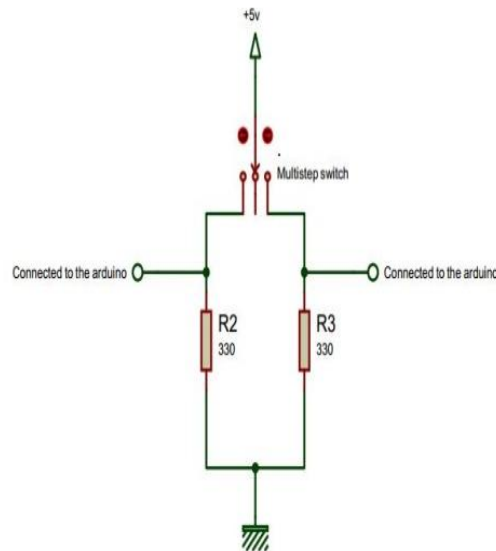


Fig 5.3 Multistep switch connection.

The resistor R2 and R3 are used to protect the microcontroller where the maximum current that can pass through the arduino is 25mA; the following equation shows the required resistance.

$$R = \frac{V}{I} = \frac{5v}{0.025A} = 200\Omega$$

The minimum resistance is 200Ω to give 25mA, in the project resistance of 330Ω is used where the current is 15mA which still can active the ARDUINO and less risk can be achieved to guarantee a more durability for the ARDUINO.

### 5.3.3 Level Indicator

The level indicator switch is activated by magnetic field, and the same connection circuit for multistep switch it's for level indicator, but the level indicator is a normally close switch, figure 5.4 shows the connection circuit of this part.

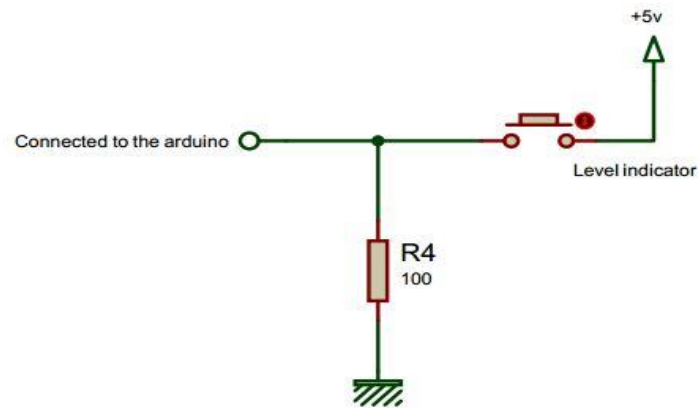


Figure 5.4 Level indicator connection.

## 5.4 Outputs

The control and activation of the outputs of the machine are discussed in this section, which are the electrical linear heater, two LED indicators, and electrical control valve.

### 5.4.1 Heater

As mentioned before the heater operate under a 220v AC voltage, and the output voltage of the ARDUINO is 5v DC which is not enough to power up the Heater; Figure 5.1 shows the connection circuit for heaters.

### 5.4.2 LED's indicator

The LED indicator is activated by command from ARDUINO, when choosing the right operation for both LED indicators. The LED's can working under 5v DC, so the connection circuit will be directly from ARDUINO as shown in figure 5.5.

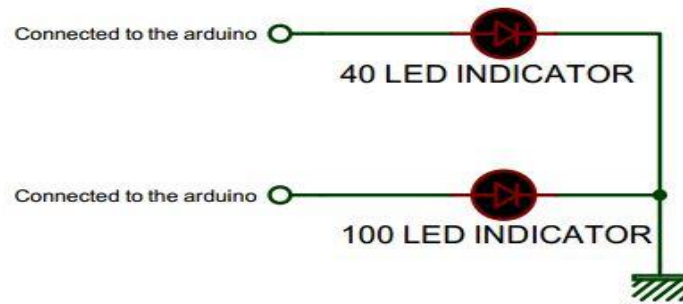


Figure 5.5 LED's indicator connection.

### 5.4.3 Electrical Control Valve

The electrical control valve operate under a 220 Volt AC, and the output voltage of the microcontroller is 5v DC which is not enough to power up the electrical control valve; as shown in the figure 5.6, the connection circuit for the electrical control valve.

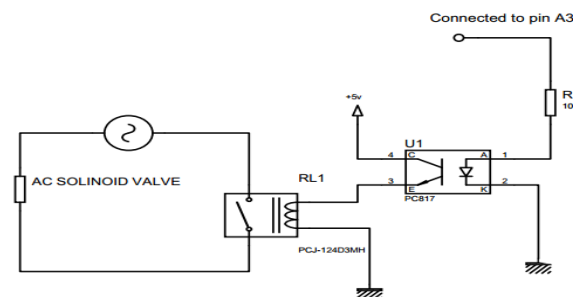


Figure 5.6 Electrical control valve connection.

As the figure above shows the AC parts are connected directly to the power source and are controlled using solid state relay (SSR) that is connected to the optocoupler which is connected to the ARDUINO digital pin.

# CHAPTER 6: Software Design

## 6.1 Introduction

## 6.2 Pin mapping

### 6.2.1 20x4 LCD Display

### 6.2.2 Temperature sensor 1

### 6.2.3 Temperature sensor 2

### 6.2.4 Solenoid valve

### 6.2.5 Stopwatch

## 6.4 PID controller

## 6.5 Testing mode



## 6.1 Introduction

To complete the desired procedures of the apparatus, rules must be done to lead the operation; these rules can be implemented using a microcontroller, and to make it work according to the rules; the rules must be translated to a language that can be understood by the used controller which is in this case Arduino Uno, the Arduino Uno is programmed in C language with arduino genuine for Arduino software.

In any system there must be outputs and inputs to interface with the mechanical structure, in this project the outputs and inputs are illustrated in figure 6.1.

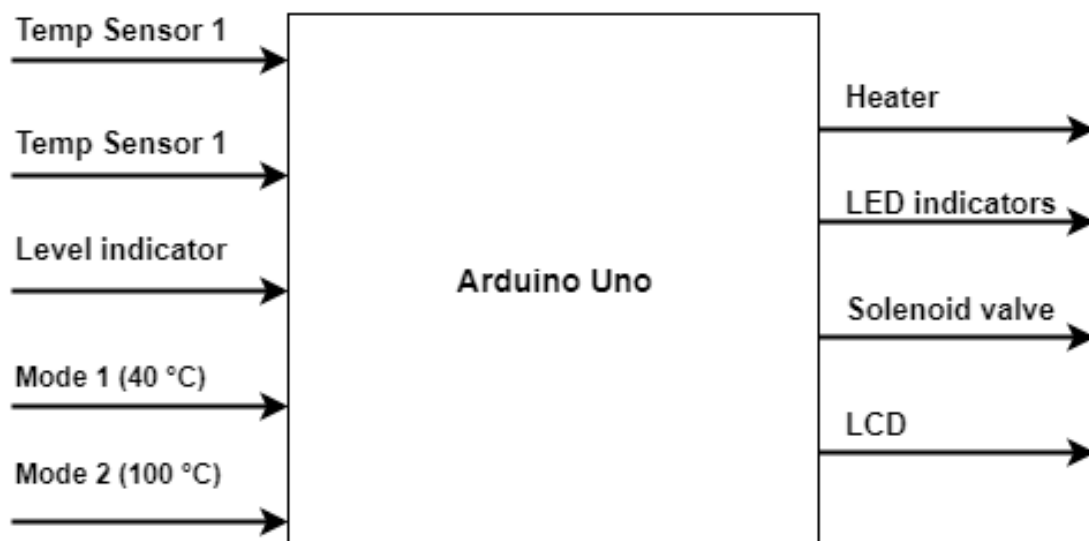


Figure 6.1 Inputs and outputs of the system.

According to the figure above these are the inputs and outputs of the system:

- **Inputs**

- 1- Temperature sensor 1: Detects the temperature of the heating oil region.
- 2- Temperature sensor 2: Detects the temperature of the testing sample region (inside the Orifice tube). With PID controller to keep the temperature constant.
- 3- Level indicator: Detects the level of the sample.
- 4- Mode 1: The first operation option, the apparatus will start at 40 C.
- 5- Mode2: The second operation option, the apparatus will start at 100 C.

- **Outputs**

- 1- Heater: Used to increase the temperature of the heating oil region.
- 2- Led indicators: Used to indicate which operation selected.
- 3- Solenoid valve: Used to open and close Orifice tube mechanism.
- 4- LCD: Is the display screen.

## 6.2 Pin mapping

To interface with the outputs as denoted the address of each part must be known and named in the software, the following figure 6.2 shows the wiring of the peripherals and there pin number , where the circuit designed using proteus software .

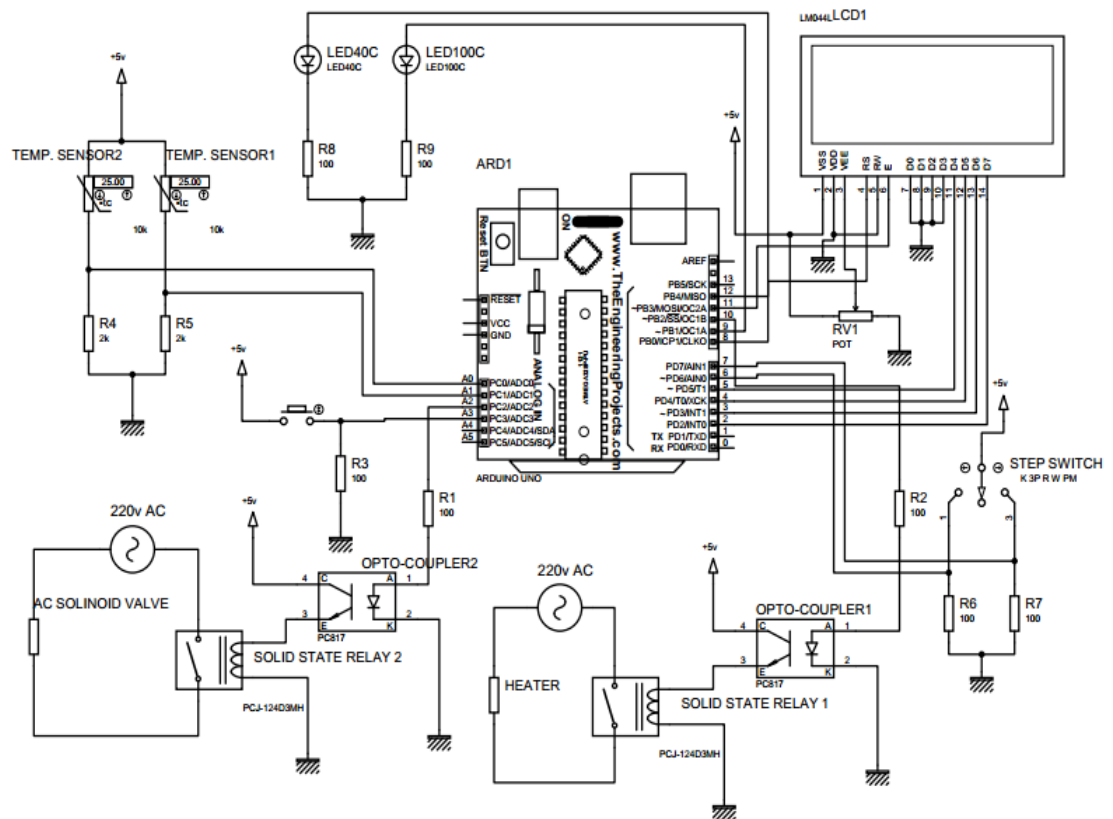
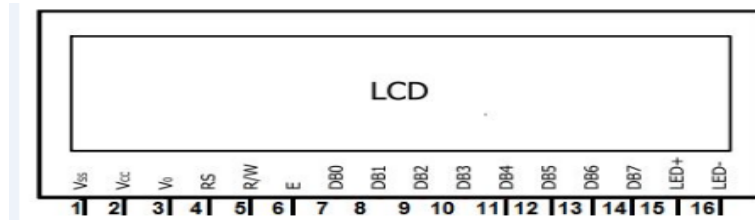


Figure 6.2 Pin mapping of peripherals to the Arduino Uno.

## 6.2.1 20x4 LCD Display



Pin no.	Symbol	External connection	Function
1	V <sub>SS</sub>	Power supply	Signal ground for LCM (GND)
2	V <sub>DD</sub>		Power supply for logic (+5V) for LCM
3	V <sub>0</sub>		Contrast adjust
4	RS	MPU	Register select signal
5	R/W	MPU	Read/write select signal
6	E	MPU	Operation (data read/write) enable signal
7~10	DB0~DB3	MPU	Four low order bi-directional three-state data bus lines. Used for data transfer between the MPU and the LCM. These four are not used during 4-bit operation.
11~14	DB4~DB7	MPU	Four high order bi-directional three-state data bus lines. Used for data transfer between the MPU
15	LED+	LED BKL power Supply	Power supply for BKL (Anode)
16	LED-		Power supply for BKL (GND)

Table 6.1 Pin out Connections for 20x4 LCD Display.

The following variables (LCD module connections) must be defined:

DB0 \_ Unused.

DB5 \_ Digital Pin 4.

DB1 \_ Unused.

DB6 \_ Digital Pin 3.

DB2 \_ Unused.

DB7 \_ Digital Pin 2.

DB3 \_ Unused.

RS \_ Digital Pin 12.

DB4 \_ Digital Pin 5.

E \_ Digital Pin 11.

## 6.2.2 Temperature sensor 1

As described in the previous chapter this sensor (NTC 103) placed in heating oil region, as shown in figure 6.3. The first analog input pin A0 will be an input for temperature sensor 1 (`analogRead(A0)`).



Figure 6.3 Temperature sensor 1.

By using MATLAB software we can get the characteristic equation for NTC 103 from Specification data as shown in table 4.1 in previous chapter 4. And the Electronic Circuit for NTC 103 was discussed in previous chapter, NTC 103 will use as a voltage divider element with  $2K\Omega$  resistance. Figure 5.2 shows the connection circuit of the NTC.

First step it's save workspace variables and their values in MATLAB.

```

Temperaturesensor.m x +
1 % Mfile for temperature sensor NTC 103
2 %Temperature (celsius)
3 A=[-40;-35;-30;-25;-20;-15;-10;-5;0;5;10;15;20;25;30;35;40
4 45;50;55;60;65;70;75;80;85;90;95;100;105;110;115;120];
5
6 %NTC resistance value (Kohm)
7 B=[186.7960;143.3050;110.8810;86.3340;67.6830;53.4160
8 42.4130;33.9180;27.2800;22.0710;17.9600;14.6970;12.0910
9 10.0000;8.3120;6.9420;5.3260;4.9110;4.1590;3.5360;3.0190
10 2.5880;2.2270;1.9240;1.6680;1.4510;1.2660;1.1080;0.9730
11 0.8580;0.7580;0.6710;0.5970];
12
13 %Voltage Divider Value(Volt)
14 C=[0.0523;0.0680;0.0875;0.1118;0.1418;0.1783;0.2225;0.2751
15 0.3375;0.4107;0.4954;0.5923;0.7020;0.8246;0.9599;1.1074
16 1.3526;1.4341;1.6099;1.7919;1.9774;2.1641;2.3501;2.5327
17 3.8349];
18 %ADC value
19 D=[10.7135;13.9207;17.9202;22.9014;29.0333;36.5113;45.5619
20 56.3452;69.1301;84.1055;101.4497;121.3052;143.7793
21 168.8852;196.5976;226.8027;277.0032;293.6974;329.7033
22 366.9751;404.9660;443.2172;481.2946;518.6971;555.1469
23 590.3094;624.0049;655.9844;686.0244;713.8722;739.9927
24 764.3235;786.3142];
25 %plot the characteristic curve
26 plot(D,A)

```

Figure 6.4 Temperature sensor Mfile in MATLAB.

Where

$$\text{Voltage divider value} = \frac{2K\Omega \text{ resistance} * \text{source voltage}}{2K\Omega \text{ resistance} + \text{NTC resistance}} \quad 6.1$$

$$\text{ADC value} = \frac{\text{voltage divider} * 1024}{5} \quad 6.2$$

Now by using plot command between matrix A and matrix D, it will get the characteristic curve for NTC 103.

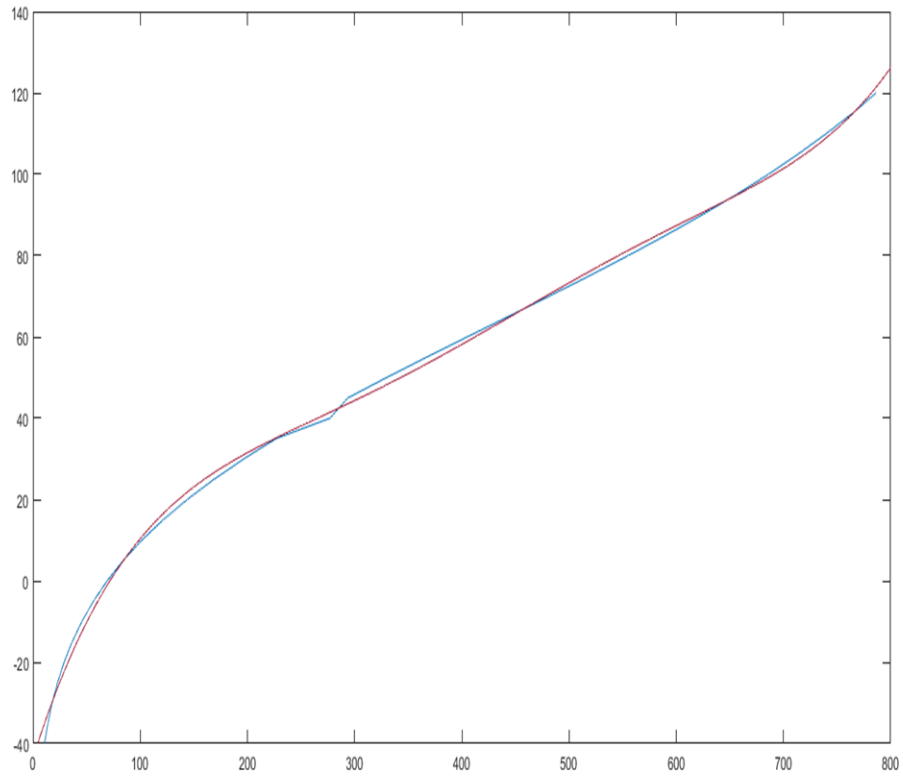


Figure 6.5 characteristic curve for NTC 103.

The final step it's to get the characteristic equation for NTC 103 to put it in the arduino program, by using basic fitting tool and select the fifth order polynomial equation.

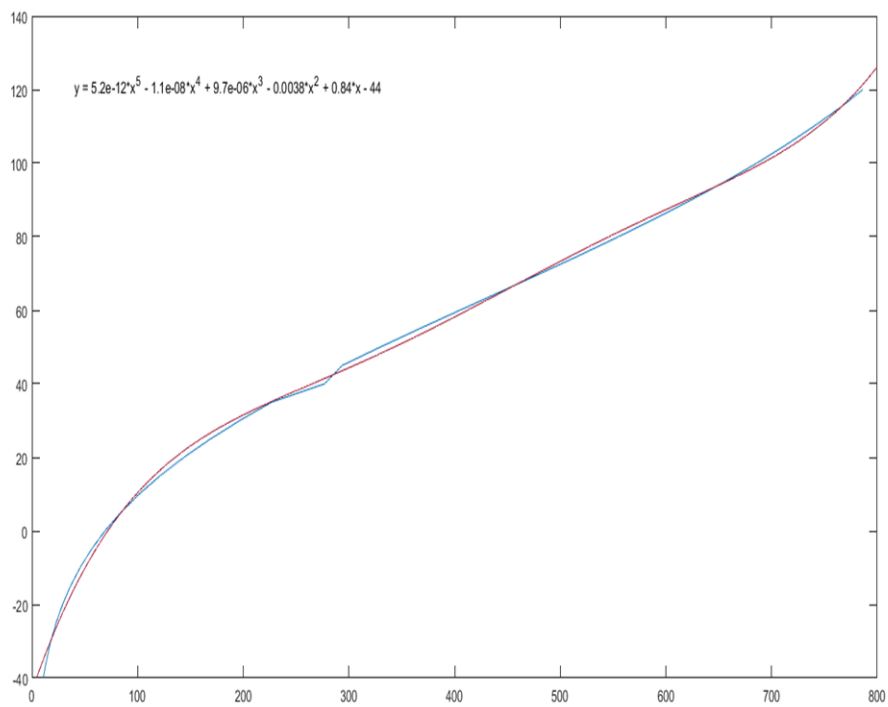


Figure 6.6 characteristic equation for NTC 103.



### 6.2.3 Temperature sensor 2

As described in previous chapter this sensor (NTC 103) placed in the testing sample region, as shown in figure 6.8, and this sensor will be a feedback from sample temperature. And will be programmed in the same way but with PID controller. The second analog pin A1 will be an input for temperature sensor 2 (`analogRead(A1)`).



Figure 6.7 Temperature sensor 2.

### 6.2.4 Solenoid Valve

The electrical control valve operate under a 220v AC voltage, and the output voltage of the microcontroller is 5v DC which is not enough to power up the electrical

control valve; as shown in the figure 5.6, the connection circuit for the electrical control valve.

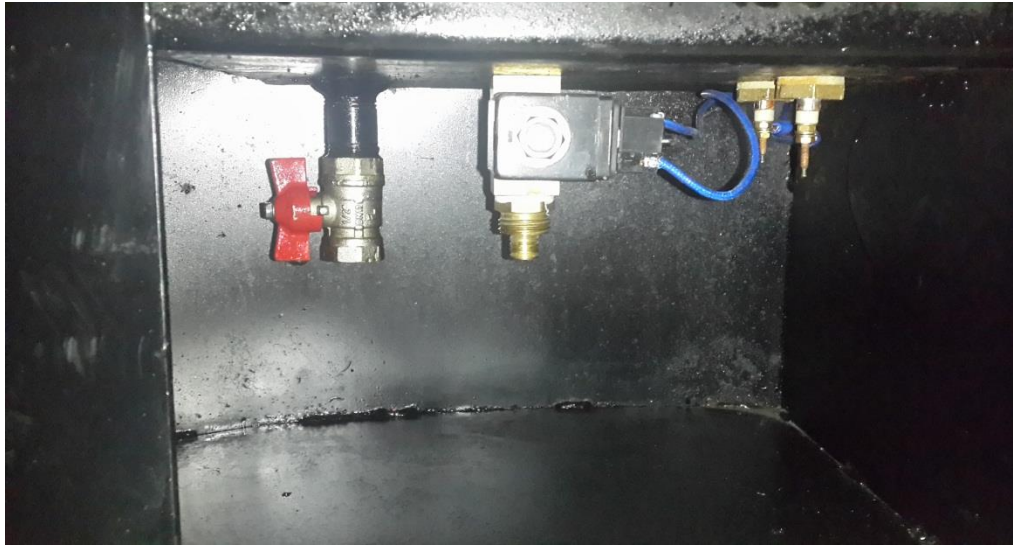


Figure 6.8 Solenoid Valve .

### 6.2.5 Stopwatch

A stopwatch designed to measure the amount of time elapsed from a particular time when it is activated (when the solenoid open the orifice tube), to the time when it deactivated (when the level indicator give a signal to arduino while the testing sample reach 60 ml in the flask).

### 6.4 PID controller

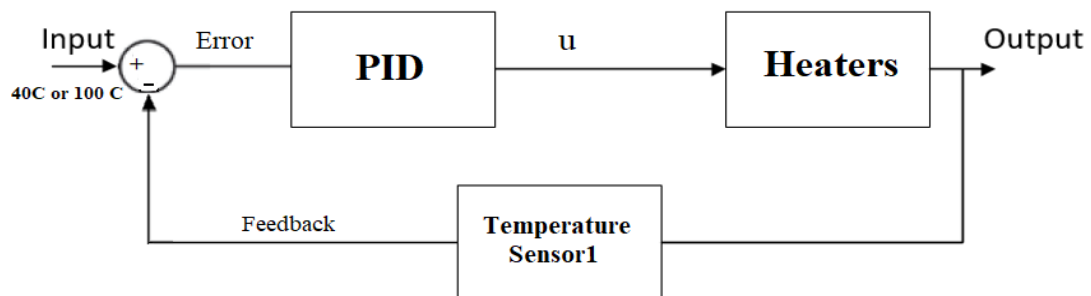


Figure 6.9 PID temperature controller.

As shown in figure 6.7, the output of a PID temperature controller, equal to the control input to heater.

The transfer function of a PID controller

$$T(S) = \frac{KdS^2 + KpS + Ki}{s} \quad 6.3$$

Where:

K: proportional gain.

Ki: Integral gain.

Kd: Derivative gain.

By using Tustin's method the transfer function of a PID controller can be written in Z-Domain as

$$D(Z) = kp + \frac{KiTs(z+1)}{2(z-1)} + \frac{2Kd(z-1)}{Ts(z+1)} \quad 6.4$$

The difference equation of the discrete (digital) PID controller is

$$u = \frac{(4Kd - 2KpTs + KiTs^2)e_{pp} + (2KiTs^2 - 8Kd)ep + (4Kd + 2KpTs + KiTs^2)e}{2Ts + upp} \quad 6.5$$

Where:

Ts: Sampling time.

e<sub>pp</sub>: Previous previous error.

e<sub>p</sub>: Previous error.

e: Current error.

u<sub>pp</sub>: Previous previous input.

u: Current input.

Use pulse-width modulation (PWM) to change the duty-cycle of square-wave pulses output by a PWM pin on the arduino hardware. PWM enables a digital output to provide a range of different voltage levels, similar to that of an analog output. The value sent to the block input determines the width of the square wave, called duty-cycle that the target hardware outputs on the specified PWM pin. The range of valid outputs is 0 to 255.

## 6.5 Testing mode

In this section the selection of the 40 °C or 100 °C test will be discussed, as well as how each function works, in this program there are many functions from arduino library were used.

```
/* Program start */

//including liblary for LCD
#include <LiquidCrystal.h>
#include<TimerOne.h>

double T, count;

double SetPoint=0;

double E,Ep,Epp,e,ep,epp;

double alpha, beta, gamma, kp, kd, ki;

double Output1,Output2, LastOutput1,LastOutput2;

double mode;

//setting up LCD INPUT pins
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);

//setting seconf and miliseconds to 0
```

```

int s=0;

int ms=0;

//defines pin for all buttons

const int solinoid_pin = A2;
const int levelsensor_pin=A3;
const int Heater_pin = 10;
const int LED40C_pin = 8;
const int LED100C_pin = 9;
const int mode40C_pin = 7;
const int mode100C_pin = 6;

int testvalue = 0;

//defines starting points (in my case 0)

int mode40C=0;
int mode100C=0;
double Temp1=0;
double Temp2=0;
int NTCEquation1 =0;
int NTCEquation2 =0;
double Viscosity=0;

void setup()
{

```

```
//SetPoint=500;

E=0;
Ep=0;
Epp=0;
e=0;
ep=0;
epp=0;
Output1=0;
LastOutput1=0;
Output2=0;
LastOutput2=0;
T=0.01;
kp=4.9;
ki=0.1;
kd=0.009;

Serial.begin(9600);
Timer1.initialize(10000); // initialize timer1
Timer1.attachInterrupt(Pid);

//defining pins if they are INPUT or OUTPUT pins

pinMode(mode40C_pin,INPUT);
```

```

pinMode(mode100C_pin,INPUT);
pinMode(levelsensor_pin,INPUT);
pinMode(solinoid_pin,OUTPUT);
pinMode(Heater_pin,OUTPUT);
pinMode(LED40C_pin,OUTPUT);
pinMode(LED100C_pin,OUTPUT);

// set up the LCD's number of columns and rows:
lcd.begin(20, 4);

// Print a message to the LCD.
lcd.setCursor(0, 1);
lcd.print(" Saybolt Universal");
lcd.setCursor(5, 2);
lcd.print("Viscometer ");
delay(2000);
lcd.clear();
lcd.setCursor(4, 1);
lcd.print("Project Team");
delay(2000);
lcd.clear();
lcd.setCursor(0, 1);
lcd.print("Eng.Mahmmod Mohammad");
lcd.setCursor(8, 2);
lcd.print("Zoul");
delay(2000);
lcd.clear();
lcd.setCursor(0, 1);
lcd.print("Eng.Mohammad Ibrahim");

```

```

lcd.setCursor(7, 2);
lcd.print("Alshaer");
delay(2000);
lcd.clear();
lcd.setCursor(1, 1);
lcd.print("Eng.Ibrahim Dawoud");
lcd.setCursor(8, 2);
lcd.print("Hmaid");
delay(2000);
lcd.clear();
lcd.setCursor(5, 1);
lcd.print("SuperVisor");
lcd.setCursor(1, 2);
lcd.print("Eng.Majde Zalloum");
delay(2000);
lcd.clear();
lcd.setCursor(0, 1);
lcd.print("Select Testing Mode");
lcd.setCursor(3, 2);
lcd.print("40 C or 100 C");
}
void loop()
{

delay(5);
Temp1=analogRead(A0);
Temp2=analogRead(A1);

```



```
NTCequation1=(0.0000000000021*Temp1*Temp1*Temp1*Temp1*Temp1)-  
(0.0000000051*Temp1*Temp1*Temp1*Temp1)+(0.0000048*Temp1*Temp1*Temp  
1)-(0.0022*Temp1*Temp1)+(0.6*Temp1)-50;
```

```
NTCequation2=(0.0000000000021*Temp2*Temp2*Temp2*Temp2*Temp2)-  
(0.0000000051*Temp2*Temp2*Temp2*Temp2)+(0.0000048*Temp2*Temp2*Temp  
2)-(0.0022*Temp2*Temp2)+(0.6*Temp2)-50;
```

```
delay(100);
```

```
if(digitalRead(mode40C_pin)==HIGH&&digitalRead(levelsensor_pin)==HIGH)
```

```
{
```

```
SetPoint=40;
```

```
if(NTCequation2<40)
```

```
digitalWrite(Heater_pin,HIGH);
```

```
digitalWrite(LED40C_pin,HIGH);
```

```
lcd.clear();
```

```
lcd.setCursor(0, 0);
```

```
lcd.print("Testing Mode:");
```

```
lcd.setCursor(14, 0);
```

```
lcd.print("40C");
```

```
lcd.setCursor(0, 1);
```

```
lcd.print("Actual Temp:");
```

```
lcd.setCursor(14, 1);
```

```
lcd.print(NTCequation1);
```

```
lcd.setCursor(18, 1);
```

```
lcd.print("C");
```

```
lcd.setCursor(0, 2);
```

```

lcd.print("Sample Temp:");
lcd.setCursor(14, 2);
lcd.print(NTCequation2);
lcd.setCursor(18, 2);
lcd.print("C");
lcd.setCursor(0, 3);
lcd.print("Timer:");
lcd.setCursor(8, 3);
lcd.print(s);
lcd.setCursor(16, 3);
lcd.print("Sec");

    if(NTCequation2>=40)
    {
testvalue=1;
    }

    if(testvalue==1&&digitalRead(levelsensor_pin)==HIGH)
    {
stopwatch(); //goes to sub program stopwatch
digitalWrite(Heater_pin,LOW);
digitalWrite(solenoid_pin,HIGH);

    }

    else
    {
digitalWrite(solenoid_pin,LOW);

```

```
}
```

```
}
```

```
else
```

```
{
```

```
digitalWrite(LED40C_pin,LOW);
```

```
digitalWrite(Heater_pin,LOW);
```

```
}
```

```
if(digitalRead(mode100C_pin)==HIGH&&digitalRead(levelsensor_pin)==HIGH)
```

```
{
```

```
SetPoint=100;
```

```
if(NTCEquation2<100)
```

```
digitalWrite(Heater_pin,HIGH);
```

```
digitalWrite(LED100C_pin,HIGH);
```

```
lcd.clear();
```

```
lcd.setCursor(0, 0);
```

```
lcd.print("Testing Mode:");
```

```
lcd.setCursor(13, 0);
```

```
lcd.print("100C");
```

```
lcd.setCursor(0, 1);  
lcd.print("Actual Temp:");  
lcd.setCursor(14, 1);  
lcd.print(NTCeuation1);  
lcd.setCursor(18, 1);  
lcd.print("C");
```

```
lcd.setCursor(0, 2);  
lcd.print("Sample Temp:");  
lcd.setCursor(14, 2);  
lcd.print(NTCeuation2);  
lcd.setCursor(18, 2);  
lcd.print("C");
```

```
lcd.setCursor(0, 3);  
lcd.print("Timer:");  
lcd.setCursor(8, 3);  
lcd.print(s);  
lcd.setCursor(16, 3);  
lcd.print("Sec");
```

```
    if(NTCeuation2>=100)  
    {  
testvalue=2;  
    }
```

```
if(testvalue==2&&digitalRead(levelsensor_pin)==HIGH)
```

```

{
stopwatch(); //goes to sub program stopwatch
digitalWrite(Heater_pin,LOW);
digitalWrite(solinoid_pin,HIGH);

}

else
{
digitalWrite(solinoid_pin,LOW);

}

}

else
{
digitalWrite(LED100C_pin,LOW);
digitalWrite(Heater_pin,LOW);
}

if(digitalRead(mode100C_pin)==LOW&&digitalRead(mode40C_pin)==LOW)
{
SetPoint=0;
s=0;
testvalue=0;
digitalWrite(Heater_pin,LOW);
digitalWrite(solinoid_pin,LOW);
lcd.clear();
}

```

```

lcd.setCursor(0, 1);
lcd.print("Select Testing Mode");
lcd.setCursor(3, 2);
lcd.print("40 C or 100 C");
}

if(digitalRead(mode100C_pin)==HIGH&&digitalRead(levelsensor_pin)==LOW)
{

digitalWrite(LED100C_pin,HIGH);
digitalWrite(Heater_pin,LOW);
digitalWrite(solinoid_pin,LOW);
if(s<=100)
{
  Viscosity =(0.226*s)-(195/s);
}
else if(s>100)
{
  Viscosity =(0.220*s)-(135/s);
}

lcd.clear();

lcd.setCursor(0, 0);
lcd.print("The Time is =");
lcd.setCursor(0, 1);
lcd.print(s);

lcd.setCursor(5, 1);
lcd.print("Seconds");

lcd.setCursor(0, 2);

```

```

lcd.print("The Viscosity is =");
lcd.setCursor(0, 3);
lcd.print(Viscosity);
}
else if(digitalRead(mode40C_pin)==HIGH&&digitalRead(levelsensor_pin)==LOW)
{
digitalWrite(LED40C_pin,HIGH);
digitalWrite(Heater_pin,LOW);
digitalWrite(solinoid_pin,LOW);

if(s<=100)
{
Viscosity =(0.226*s)-(195/s);
}
else if(s>100)
{
Viscosity =(0.220*s)-(135/s);
}

lcd.clear();
lcd.setCursor(0, 0);
lcd.print("The Time is =");
lcd.setCursor(0, 1);
lcd.print(s);
lcd.setCursor(5, 1);
lcd.print("Seconds");
lcd.setCursor(0, 2);
lcd.print("The Viscosity is =");

```

```
lcd.setCursor(0, 3);  
lcd.print(Viscosity);  
}  
  
}
```

```
//-----SUB PROGRAMS-----
```

```
void stopwatch()  
{  
  
ms=ms+10;  
delay(10);  
  
if(ms==150) //if state for counting up seconds  
{  
ms=0;  
s=s+1;  
}  
  
}
```



```

void Pid() {

    E = SetPoint - NTCequation2;

    alpha = 2*T*kp + ki*T*T + 2*kd;

    beta = T*T*ki -4*kd -2*T*kp;

    gamma = 2*kd;

    Output1 = (alpha*E + beta*Ep + gamma*Epp +2*T*LastOutput1)/(2*T);

    LastOutput1 = Output1;

    Epp= Ep;

    Ep=E;

    if(Output1>255)

        Output1=255;

    if(Output1<-255)

        Output1= -255;

    if(Output1>0&&digitalRead(mode40C_pin)==HIGH&&digitalRead(levelsensor_pin)
    ==HIGH&&NTCequation2<40)

    {

        digitalWrite(Heater_pin,Output1);

    }

    else if(Output1
    <0&&digitalRead(mode40C_pin)==HIGH&&digitalRead(levelsensor_pin)==HIGH
    &&NTCequation2<40)

    {

```

```

digitalWrite(Heater_pin,abs(Output1));

}

else

{

    digitalWrite(Heater_pin,LOW);

}

if(Output1>0&&digitalRead(mode100C_pin)==HIGH&&digitalRead(levelsensor_pi
n)==HIGH&&NTCequation2<100)

{

    digitalWrite(Heater_pin,abs(Output1));

}

else if(Output1
<0&&digitalRead(mode100C_pin)==HIGH&&digitalRead(levelsensor_pin)==HIGH
&&NTCequation2<100)

{

    digitalWrite(Heater_pin,abs(Output1));

}

}

}

```

## **Chapter 7: Test Procedure & Results**

### **7.1 Test Procedure**

### **7.2 The Results**

## 7.1 Test Procedure

- 1- Set up the Saybolt Universal viscometer where it will be free from drafts and rapid changes in temperature. And to prevent the effect of external factors on the experiment. Then fill heating chamber amount of heating oil, approximately 7 liter.

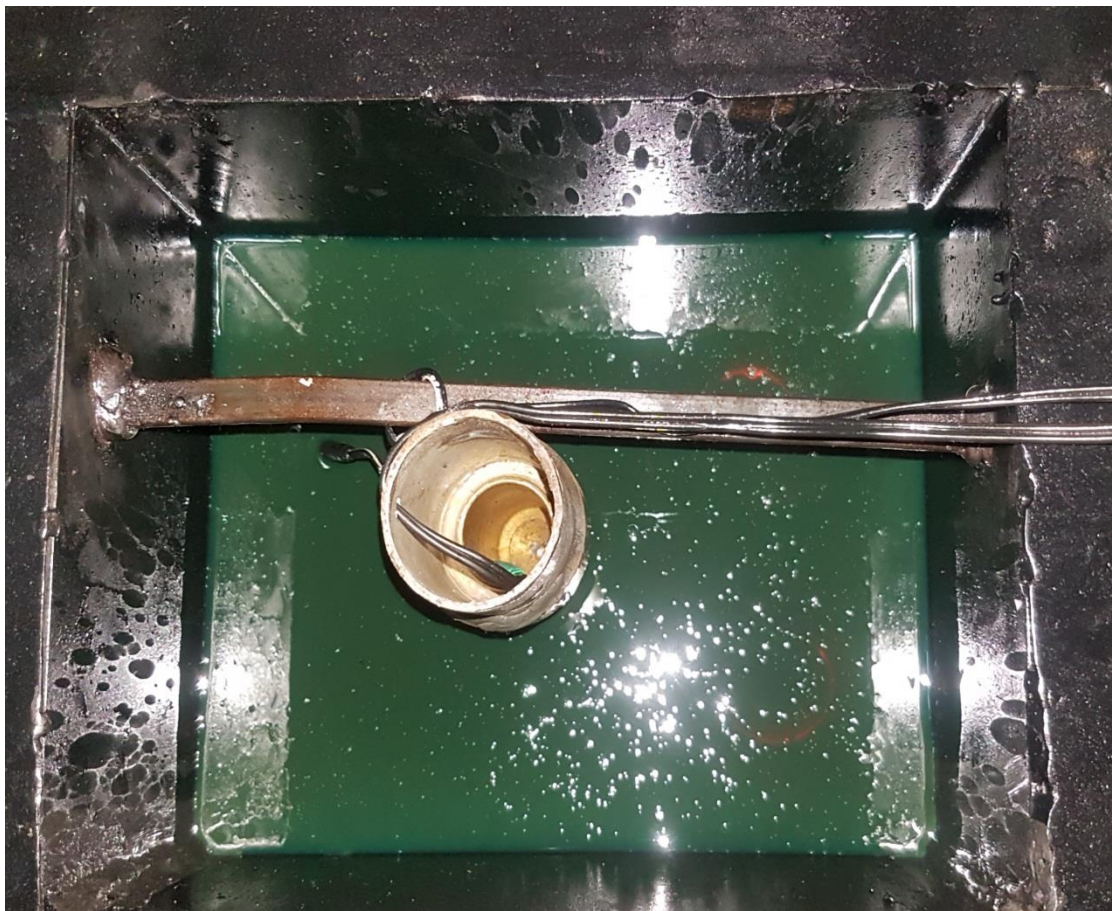


Figure 7.1 heating chamber with heating oil .

- 2- Clean the tube with an effective nontoxic solvent and remove all solvent from the flask and orifice tube.



Figure 7.2 cleaning the tube.

- 3- Filter the prepared sample of liquid before entering the tube, to purification the liquid from any impurities and dirt.



Figure 7.3 filter the prepared sample.

- 4- Put the flask directly under the orifice, where the float has been calibrated to be inside the flask, to give indicator that the oil reaches 60 ml.



Figure 7.4 flask, and the float.

- 5- Set the test temperature by choice of two degrees (40, 100), and then the heater will run.



Figure 7.5 testing temperature mode.

- 6- There is solenoid valve located at the gap orifice tube, also it consider normally closed which is controlled by an arduino microcontroller, when the temperature test is reached the desired value, the controller will send a command as following: heater to stop, solenoid to open and to the timer to start calculating the time.



Figure 7.6 solenoid valve.

- 7- The float determines the liquid level, and when liquid reaches 60 ml the float send a signal to the arduino microcontroller which is directly send a command to solenoid valve to make it closed, also the timer will stop and the controller will record the time value .

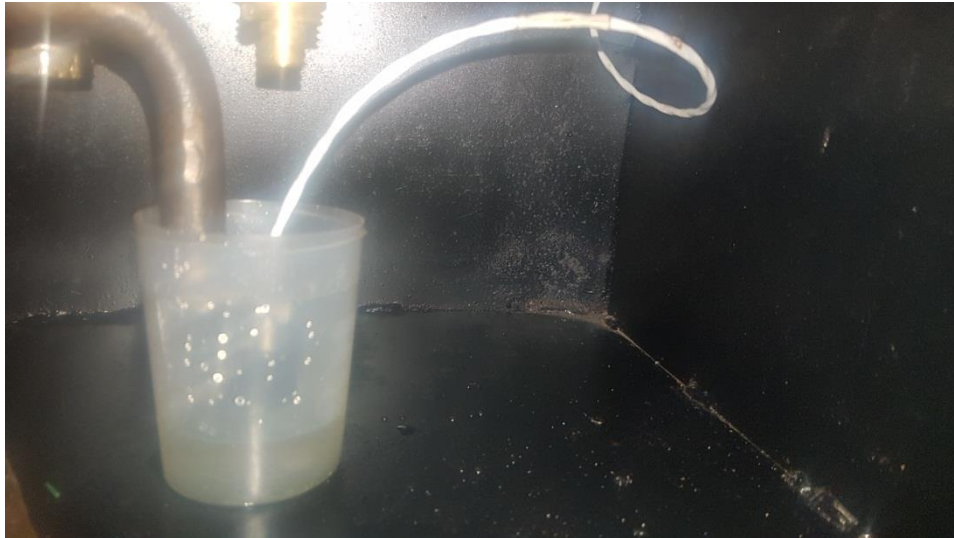


Figure 7.7 the float inside the flask.

- 8- The controller takes time, which was recorded, then apply it in one of two equations of viscosity according to the time value, then compares with tables of viscosity, which was inserted to the controller to determine the viscosity and showing the results on the screen.



Figure 7.8 Interface of read time and results for water at 40 C.



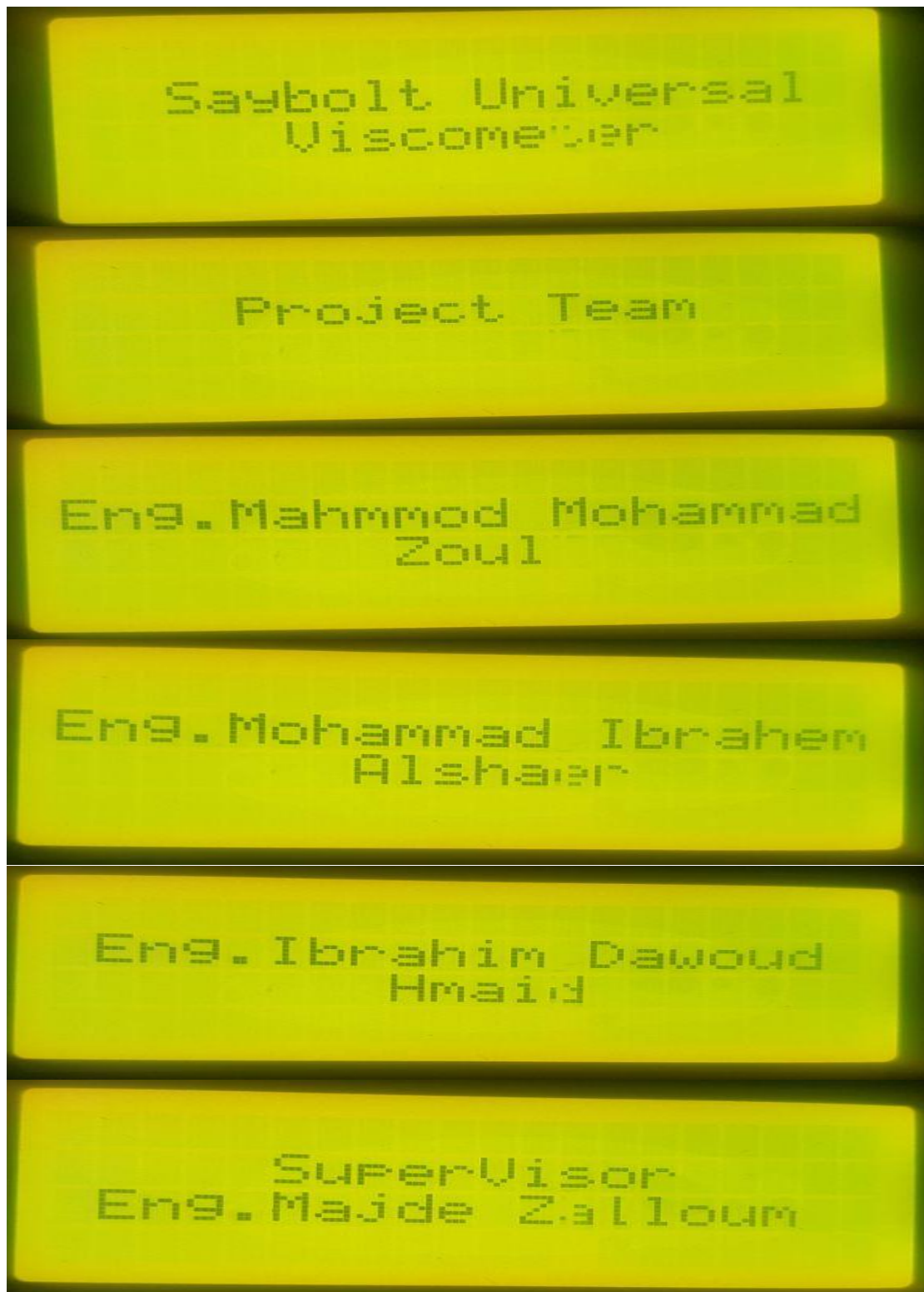


Figure 7.9 Start interface.

## Important Notes

- Viscosity determinations shall not be made at temperature below the dew point of the room's atmosphere.
- The room temperature shall be kept between 68 and 86 F, and the actual temperature shall be recorded.
- The plunger should never be used for cleaning as overflow rim and walls of the viscometer may be damaged using it.
- Never adjust the temperature by immersing hot or cold bodies into the sample. Such thermal treatment may affect the sample and precision of the test.
- Never preheat any sample within 50F of its flash point.
- Do not touch the overflow rim or the effective head of the sample will be reduced.

## 7.2 Test Results

The Saybolt Universal Viscometer measures the time required, in seconds, for 60 milliliters of the tested liquid at 40 C or 100 C to pass through a standard orifice. The time measured is used to express the liquid's viscosity, in Saybolt Universal Seconds. This time multiplied by the temperature constant of viscometer in use to provide the viscosity, expressed in centistokes. The following formulas used to convert Saybolt Universal Seconds(SUS units) to approximate centistokes (cSt units).

For SUS values between 32 and 100:

$$cSt = 0.226 \times SUS - \frac{195}{SUS} \quad [2]$$

For SUS values greater than 100:

$$cSt = 0.220 \times SUS - \frac{135}{SUS} \quad [2]$$

<b>Water</b>	Experiment	Theoretical
Test temperature	40 °C	40 °C
Test time	31 sec	-----
Viscosity	0.71 cSt	0.65 cSt

<b>Water</b>	Experiment	Theoretical
Test temperature	100 °C	100 °C
Test time	30 sec	-----
Viscosity	0.28 cSt	0.29 cSt

<b>5W-30 oil</b>	Experiment	Theoretical
Test temperature	40 °C	40 °C
Test time	297 sec	-----
Viscosity	64.7 cSt	63.2 cSt

<b>5W-30 oil</b>	Experiment	Theoretical
Test temperature	100 °C	100 °C
Test time	62 sec	-----
Viscosity	10.9 cSt	10.5 cSt

## Percentage of error:

**For water at 40 C :**

$$\begin{aligned}\% \text{error} &= \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} * 100\% \\ &= \frac{0.71 - 0.65}{0.65} * 100\% \\ &= 10.7\%\end{aligned}$$

**For water at 100 C :**

$$\begin{aligned}\% \text{error} &= \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} * 100\% \\ &= \frac{0.29 - 0.28}{0.29} * 100\% \\ &= 3.4\%\end{aligned}$$

**For 5W-30 oil at 40 C :**

$$\begin{aligned}\% \text{error} &= \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} * 100\% \\ &= \frac{64.7 - 63.2}{63.2} * 100\% \\ &= 2.37\%\end{aligned}$$

**For 5W-30 oil at 100 C :**

$$\begin{aligned}\% \text{error} &= \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} * 100\% \\ &= \frac{10.9 - 10.5}{10.5} * 100\% \\ &= 3.8\%\end{aligned}$$

## References

- [1] D. S. Viswanath and G. Natavajan, *Data book on the viscosity of liquids*. New York, NY (USA); Hemisphere Publishing; None, 1989, p. Medium: X; Size: Pages: (990 p).
- [2] Instrumentationandcontrollers.blogspot.com/2012/09/saybolt-viscometer-efflux-cup.html
- [3] ASTM Standard D88-08. Standard Test Method for Saybolt Viscosity. West Conshohocken, PA: ASTM International,"www. astm.org/Standards/D88.htm"
- [4] N. Katzourakis, *An introduction to viscosity solutions for fully nonlinear PDE with applications to calculus of variations in  $L^\infty$* . Springer, 2014.
- [5] A. Metzner and J. Reed, "Flow of non-newtonian fluids—correlation of the laminar, transition, and turbulent-flow regions," *Aiche journal*, vol. 1, no. 4, pp. 434-440, 1955.
- [6] C. Tanford, "Intrinsic viscosity and kinematic viscosity," *The Journal of Physical Chemistry*, vol. 59, no. 8, pp. 798-799, 1955.
- [7] C. F. Goodeve, "A general theory of thixotropy and viscosity," *Transactions of the Faraday Society*, vol. 35, pp. 342-358, 1939.
- [8] J. P. Bonnet, L. Devesvre, J. Artaud, and P. Moulin, "Dynamic viscosity of olive oil as a function of composition and temperature: A first approach," *European journal of lipid science and technology*, vol. 113, no. 8, pp. 1019-1025, 2011.
- [9] J. T. R. Watson, R. Basu, and J. V. Sengers, "An improved representative equation for the dynamic viscosity of water substance," *Journal of Physical and Chemical Reference Data*, vol. 9, no. 4, pp. 1255-1290, 1980.
- [10] J. Chevalier, P. Petrino, and Y. Gaston-Bonhomme, "Estimation method for the kinematic viscosity of a liquid-phase mixture," *Chemical engineering science*, vol. 43, no. 6, pp. 1303-1309, 1988.
- [11] A. Feteira, "Negative temperature coefficient resistance (NTCR) ceramic thermistors: an industrial perspective," *Journal of the American Ceramic Society*, vol. 92, no. 5, pp. 967-983, 2009.
- [12] M. S. Amico, "Resistance Temperature Detector (RTD) sensor for a heat and pressure fuser," ed: Google Patents, 1997.
- [13] T. Allam and S. Matla Raju, "Design of PID controller for DC Motor Speed Control Using Arduino Microcontroller," 2016.
- [14] S. Bennett, "Development of the PID controller," *IEEE control systems*, vol. 13, no. 6, pp. 58-62, 1993.
- [15] W. H. Herschel, *Standardization of the Saybolt universal viscosimeter* (no. 112). United States of America, Dept. of Commerce, 1919.