YEDİTEPE UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING
ME333 FLUID MECHANICS LABORATORY

CAPILLARY VISCOMETER

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Abstract

Capillary viscometer, examination of viscosity changing with the effect of temperature. Here we must first calculate the mass flow rate from different water temperatures. We insert the values we obtained into the first and second equations and calculate the diameter of the tube and the viscosity. As a result, we find the dynamic viscosity of water with the data we find. What we need to pay attention to here is to measure the values correctly in the laboratory.

Mertkan Kaça
Neşet Fatih Biçkin

Introduction

The main objectives in this experiment are the following: first to calibrate the inner diameter of a microtube using water with a known viscosity, secondly, to find out how water viscosity changes as a function of temperature. To achieve our objectives we use a stainless steel microtube, a water tank, 4 thermocouples, an electronic balance, and a data acquisition system (DAQ).

These instruments serve as the foundation of our experiment, letting us gather and examine data with accuracy. We apply the extended Bernoulli equation, a fundamental concept in fluid mechanics within our conceptual structure. This equation forms the basis of our calculations, allowing us to establish connections between variables such as pressure, height, velocity, and head loss within the capillary tube. We dig into critical elements such as the correction factor(α) and the head loss through this equation which plays a vital part in our experiment analysis. As a result of our experiment, we now have an accurate understanding of fluid behavior.

Procedure

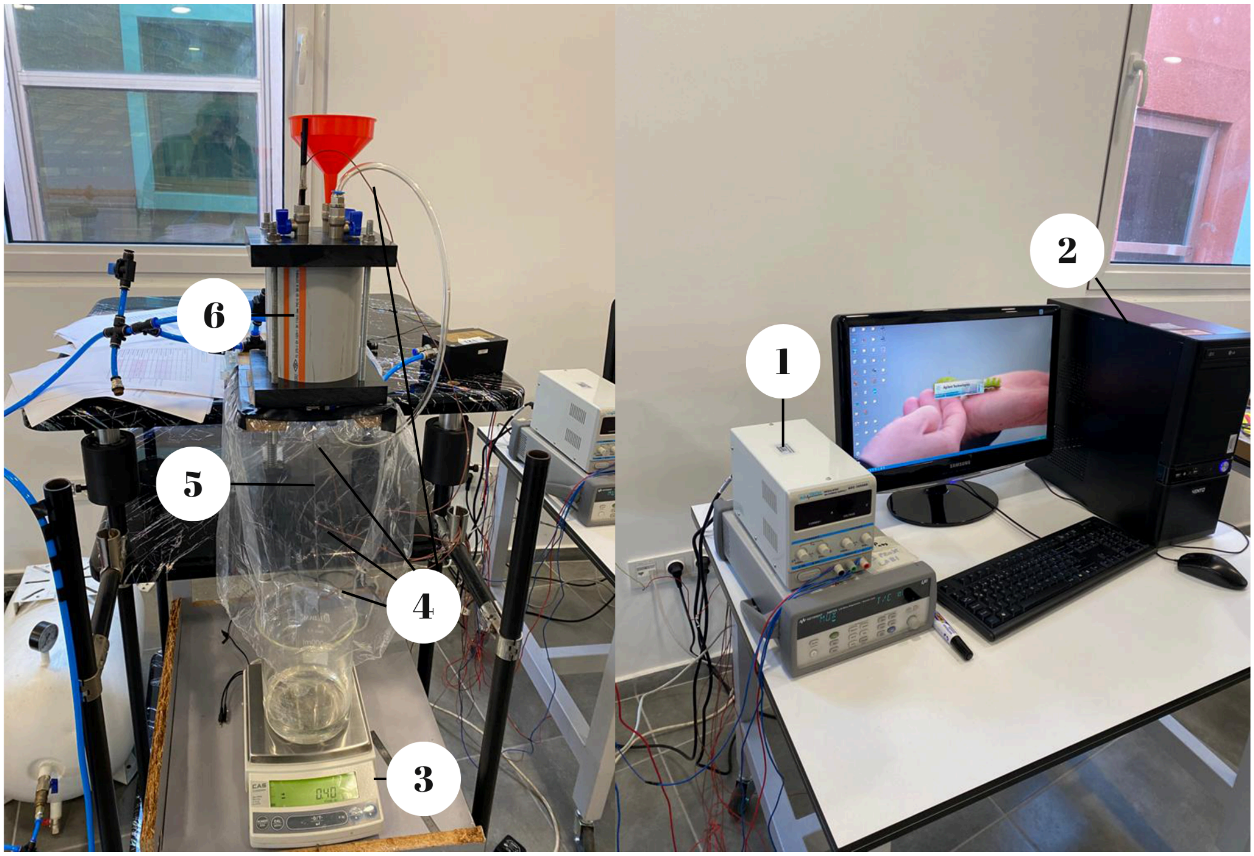

Figure 1 : Test Setup

Equipment used in the lab can be seen in Figure 1, respectively:

1) DAQ
2) Computer
3) Electronic Balance
4) Thermocouples
5) Capillary Tube
6) Water Tank

Additionally, a ruler is used for measuring the initial and final height of water in the tank for each cycle.

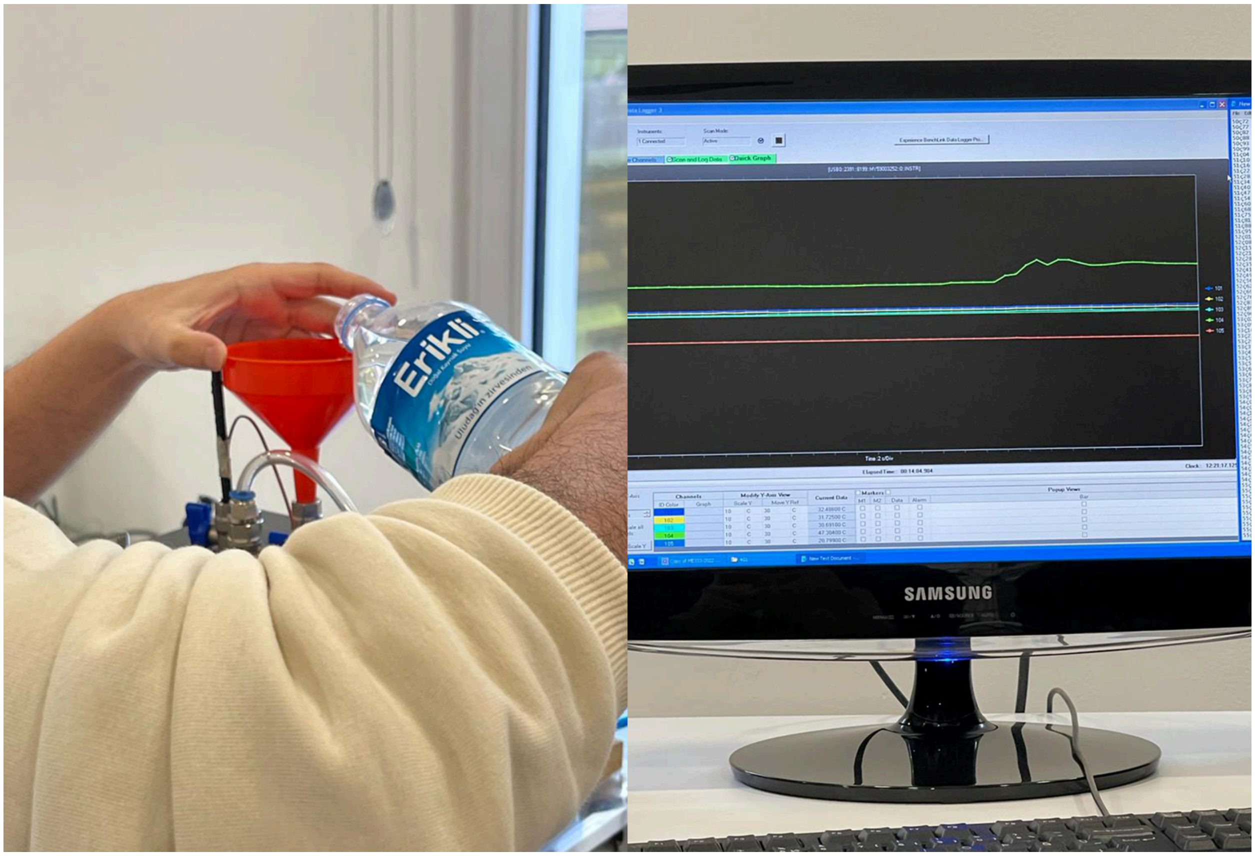

Figure 2: The Process of Pouring Water into the Water Tank and Data Collection on the Computer

In the first part of the experiment, which aims to calibrate the inner diameter of the microtube, the water at room temperature is poured into the water tank and then the initial height is measured. Simultaneously temperature values are recorded by the thermocouples from top to bottom (Can be seen in Figure 2 on the right side). Subsequently the mass measurement of water is taken from the electronic balance, and finally the final height is measured. All the data collected from DAQ is stored on the computer. This process is repeated three times.

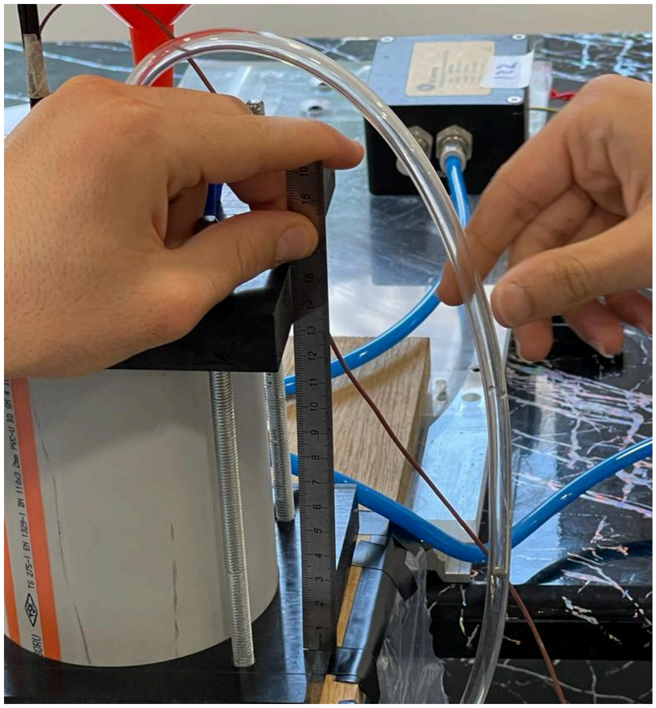

Figure 3: Measurement of Water Height in the Water Tank Using a Ruler.

Following this, another procedure is done to measure the viscosity of water; the experiment is done with different temperatures, other steps remain the same. Again this procedure is repeated three times.

Data Presentation

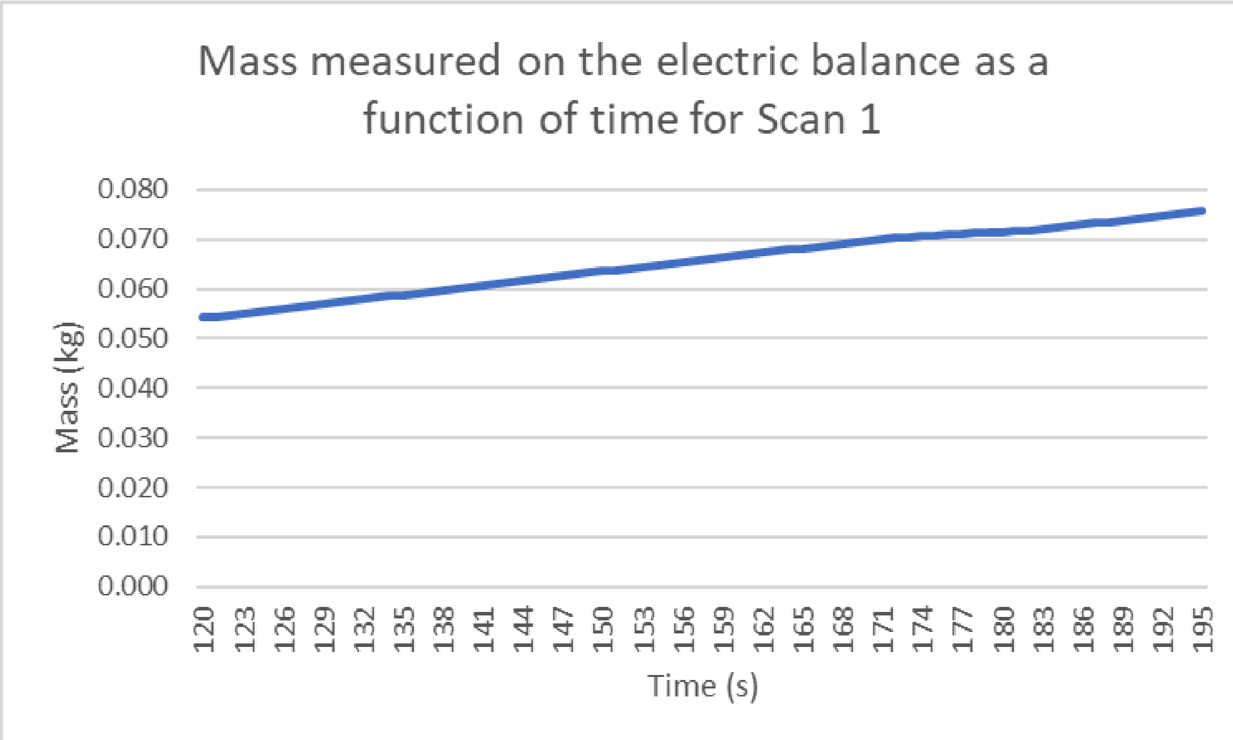

Figure 3: Mass measured vs Scan 1 Time Interval

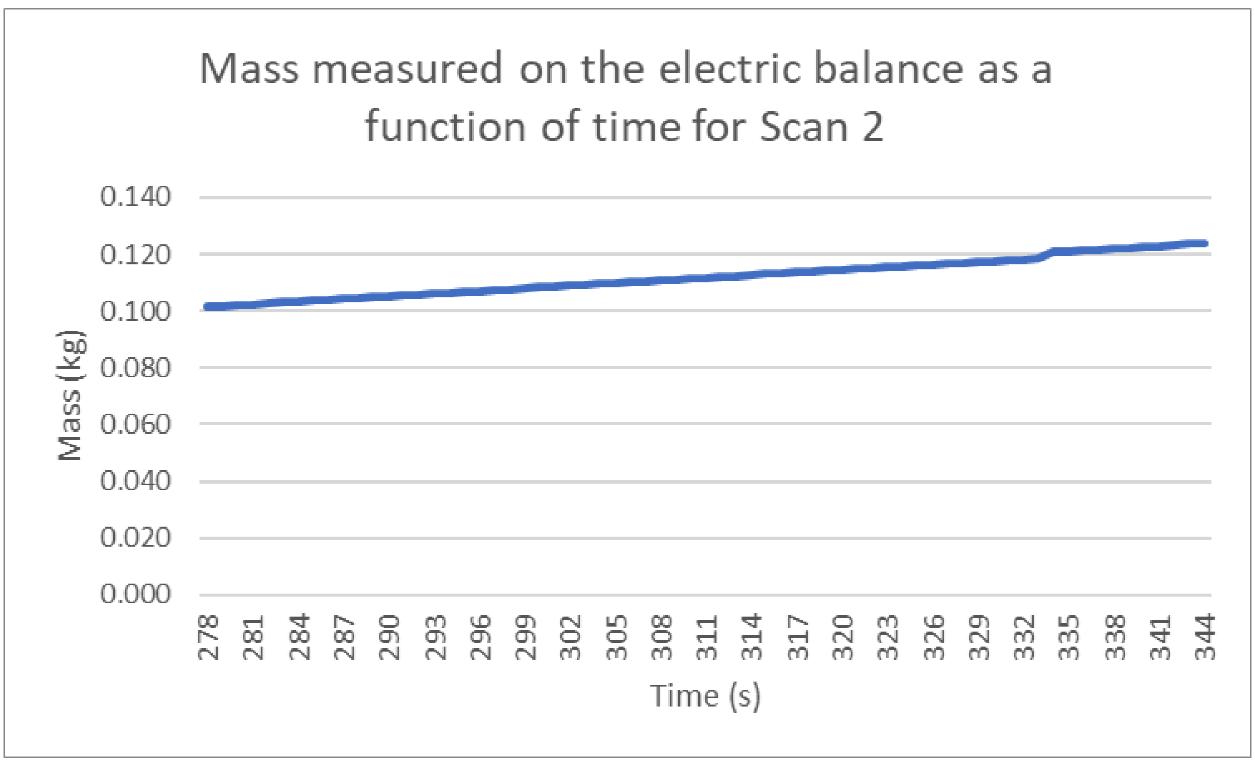

Figure 4: Mass measured vs Scan 2 Time Interval

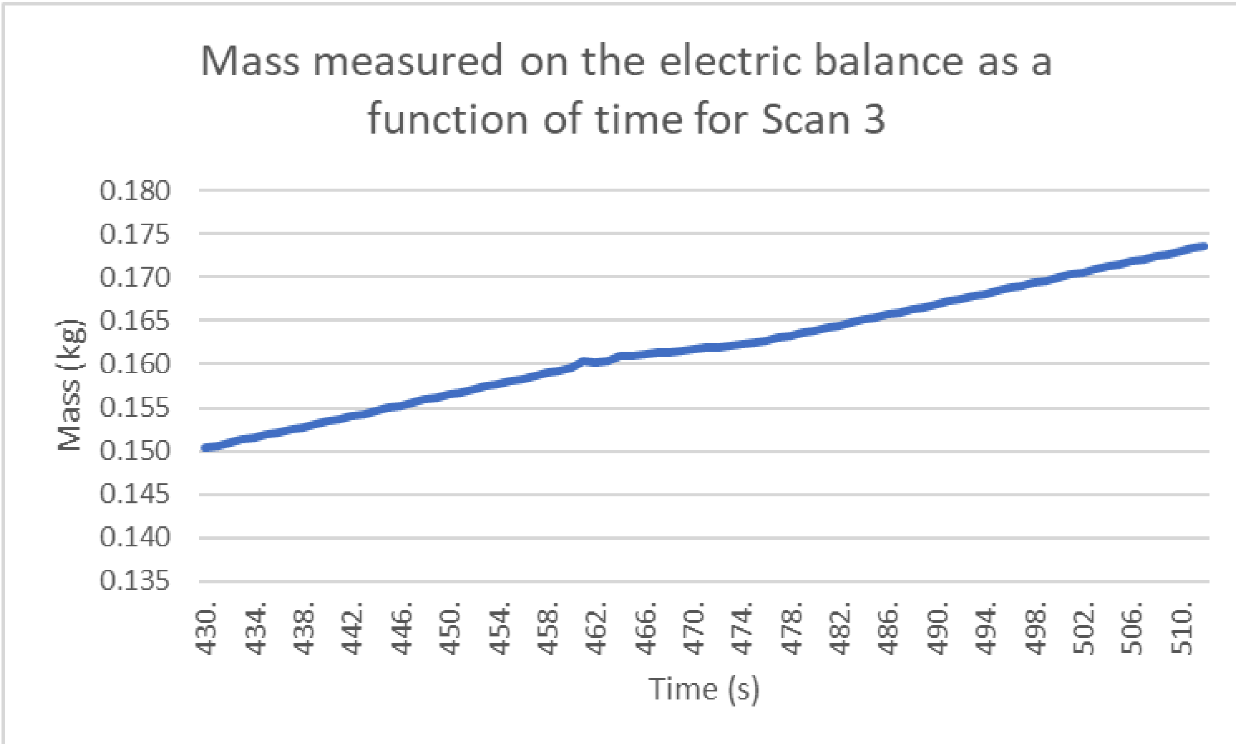

Figure 4: Mass measured vs Scan 3 Time Interval

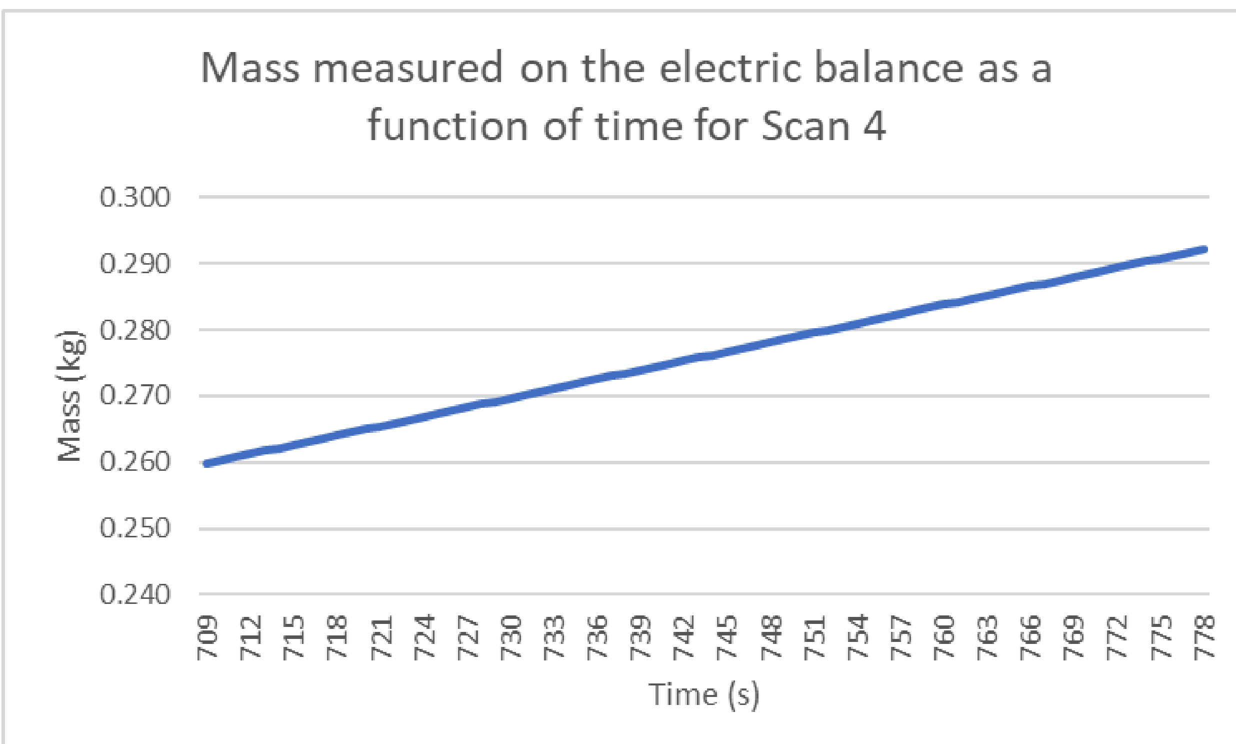

Figure 5: Mass measured vs Scan 4 Time Interval

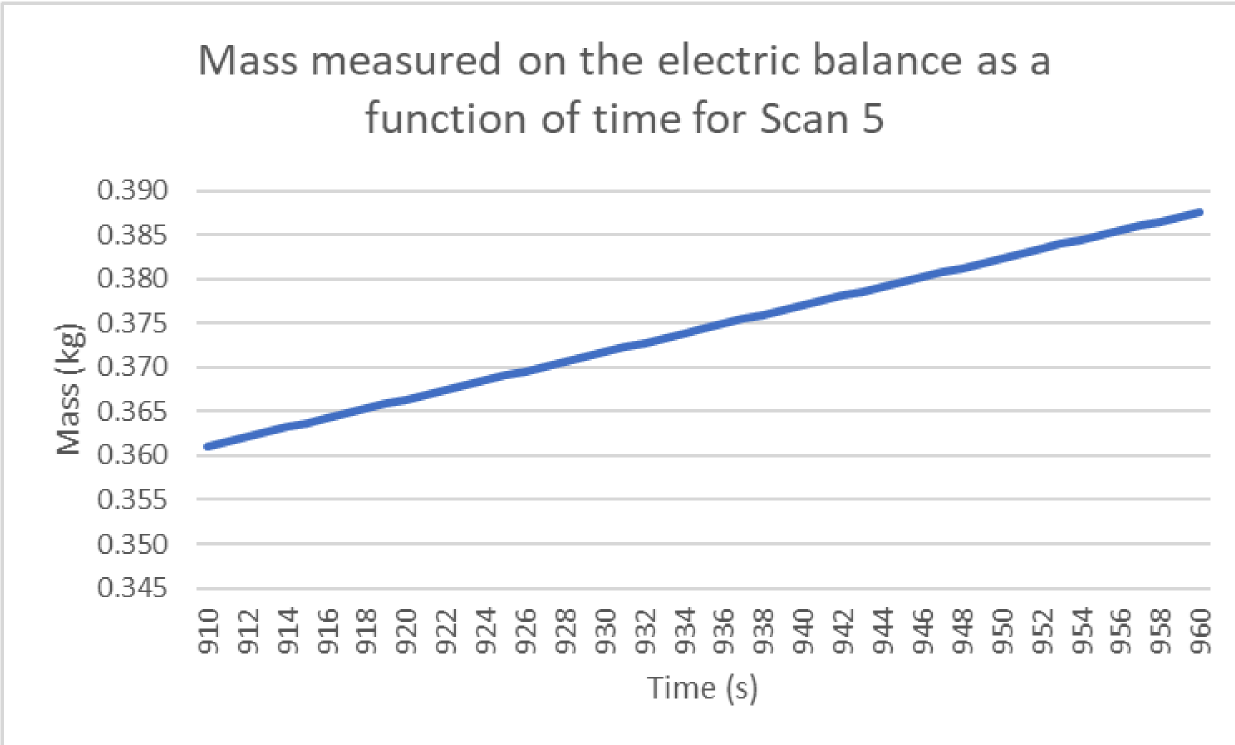

Figure 6: Mass measured vs Scan 5 Time Interval

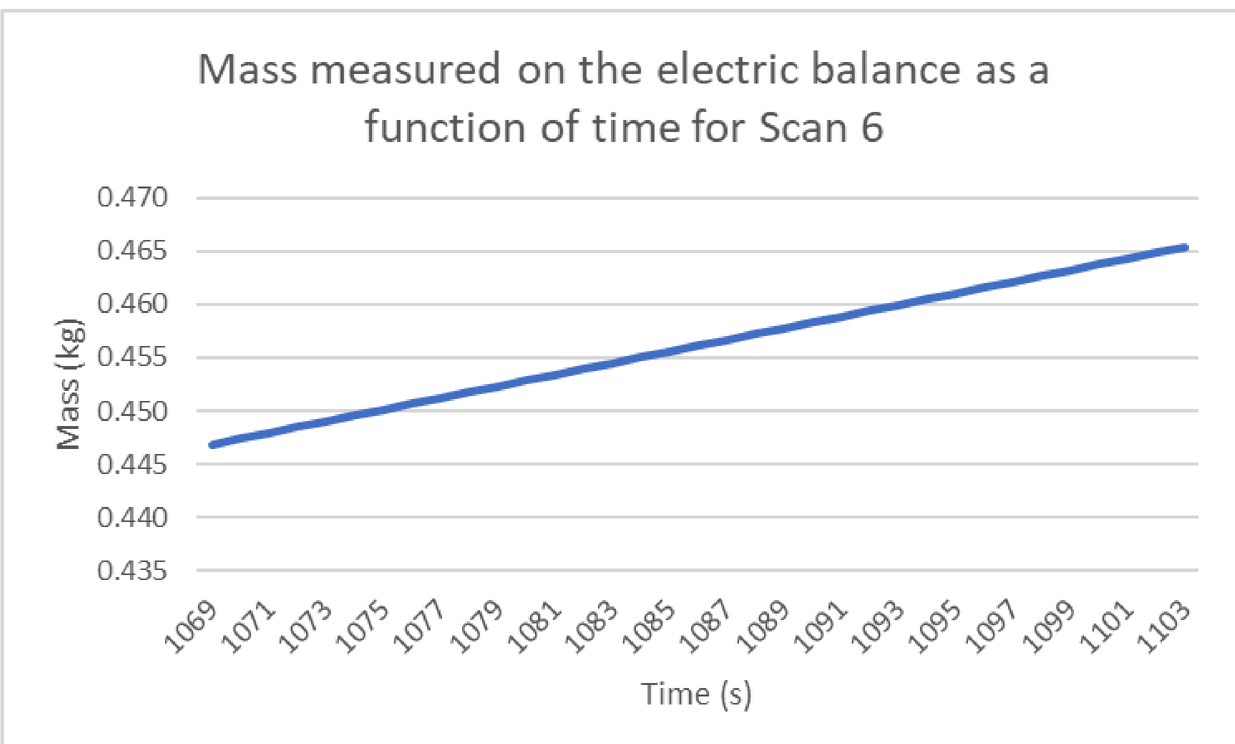

Figure 7: Mass measured vs Scan 6 Time Interval

How the mass flow rate is determined for each run is shown in the figures above.

Table (1): Data set for calibration of the diameter of a capillary tube

	Test 1	Test 2	Test 3	
Length of tube (m)	3.04E-01	3.04E-01	3.04E-01	
Alpha	2.00E+00	2.00E+00	2.00E+00	
K_ent	2.40E-01	2.40E-01	2.40E-01	
Average water temp (C)	2.17E+01	2.18E+01	2.20E+01	
Dynamic viscosity (Ns/m2)	9.66E-04	9.64E-04	9.60E-04	from property table
Density of water (kg/m3)	9.97E+02	9.97E+02	9.97E+02	from property table
Ht at the start (m)	4.30E-02	3.60E-02	3.10E-02	
Ht at the end (m)	4.00E-02	3.40E-02	2.70E-02	
Average Ht (m)	4.15E-02	3.50E-02	2.90E-02	
An elevation to be added (m)	1.06E-01	1.06E-01	1.06E-01	
Total elevation head (m)	1.48E-01	1.41E-01	1.35E-01	
Time to collect water (s)	7.50E+01	6.60E+01	8.20E+01	
Net water weight (kg)	2.15E-02	2.24E-02	2.33E-02	
Mass flow rate of water (kg/s)	2.87E-04	3.39E-04	2.85E-04	
Diameter of tube (m)	1.02E-03	1.06E-03	1.02E-03	Eq (7)

$$d = \left(\frac{\frac{128\mu L \dot{m}}{\rho\pi} + \left(\alpha_2 + K_{ent}\right)\frac{8\dot{m}^2}{\rho\pi^2}}{\rho g (H+L)} \right)^{1/4} \tag{1}$$

Where :

- Length of tube (m) is measured from the lab equipment and can be found in lab manual, α_2 (alpha) is the correction factor and K_{ent} represents the loss Coefficient of the pipe fitting under consideration, as given in the lab manual as 2.00 and 0.240.
- Average of the water temperature is calculated from the measurements of the first three thermocouples for each test.
- Dynamic viscosity is determined for each test through interpolation using the viscosity values of water at various temperatures (Given in lab manual):

Temp(K)	Dynamic viscosity (Ns/m2)
290 K	0.001080
295 K	0.000959

300 K	0.000855

- Density of water is determined for each test through interpolation using the Table A-3 from the Thermodynamics Book (Çengel 9th edition)

Temp(℃)	Density (kg/m^3)
0	1000
25	997
50	988
75	975

- Ht is measured at the beginning and end for each cycle, and then the average Ht is found from these two measurements. Then the given elevation (0.106 m) is added to the Ht average value.Then the total elevation head is found.
- The time for collecting the water for each test is collected from the DAQ data set.
- Net water weight for each test is obtained from the DAQ.
- Mass flow rate of water for each test is calculated as follows :
$$\frac{Net\ water\ weight\ (kg)}{Time\ for\ collecting\ water\ (s)}$$
- Then diameter of tube is found from equation (1)

Table (2): Data set for measuring viscosity as a function of temperature

	Test 1	Test 2	Test 3	
Diameter of tube (m)	1.03E-03	1.05E-03	1.04E-03	
Length of tube (m)	3.04E-01	3.04E-01	3.04E-01	
Alpha	2.00E+00	2.00E+00	2.00E+00	
K_ent	2.40E-01	2.40E-01	2.40E-01	
Average water temp	4.36E+01	5.24E+01	5.51E+01	
Density of water (kg/m3)	9.90E+02	9.87E+02	9.85E+02	from property table
Ht at the start (m)	4.20E-02	4.50E-02	4.90E-02	
Ht at the end (m)	3.70E-02	4.20E-02	4.60E-02	
Average Ht (m)	3.95E-02	4.35E-02	4.75E-02	
An elevation to be added (m)	1.06E-01	1.06E-01	1.06E-01	
Total elevation head (m)	1.46E-01	1.50E-01	1.54E-01	
Time to collect water (s)	6.90E+01	5.00E+01	3.40E+01	
Net water weight (kg)	3.24E-02	2.66E-02	1.86E-02	
Mass flow rate of water (kg/s)	4.70E-04	5.32E-04	5.48E-04	

Dynamic viscosity (Ns/m2)	5.80E-04	5.35E-04	4.87E-04	Eq (8)

$$\mu = \frac{\rho\pi d^4}{128L\dot{m}}\{\rho g(H + L)\} - (\alpha_2 + K_{ent})\frac{\dot{m}}{16\pi L} \tag{2}$$

Where :

- Length of tube (m) is measured from the lab equipment and can be found in lab manual, α_2 (alpha) is the correction factor and K_{ent} represents the loss Coefficient of the pipe fitting under consideration, as given in the lab manual as 2.00 and 0.240.
- Diameter of the tube is calculated as the average of the diameters listed in table (1). Same for each test in the table (2).
- The procedure used for calculating the average water temperature, Ht average, water density, total elevation head, time for collecting water, net water weight, and the mass flow rate of water is the same as in table (1).
- Then dynamic viscosity is calculated using the equation (2) for each test seperately.

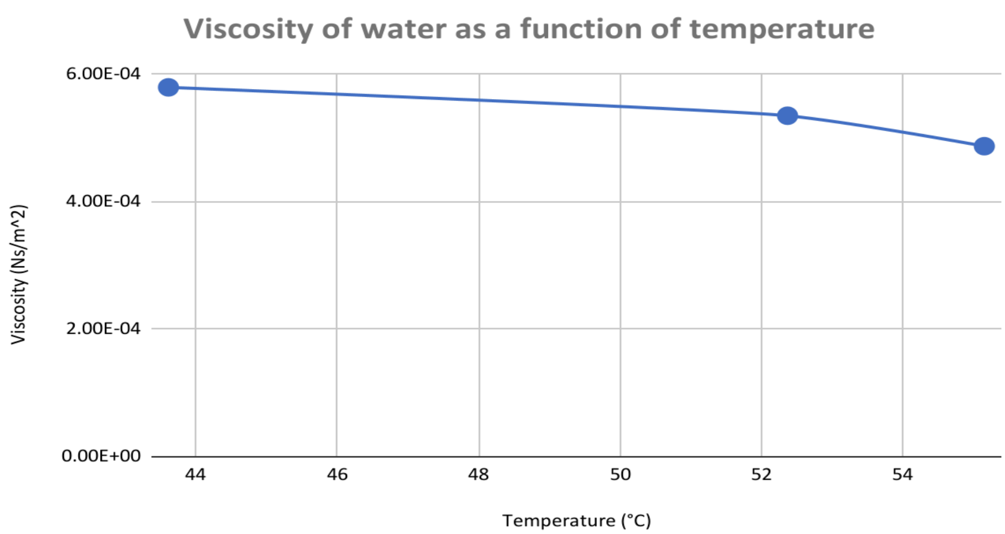

Figure 10: Viscosity of water as a function of temperature

$$Re = \frac{\rho V d}{\mu} = \frac{4\dot{m}}{\pi d\mu} \tag{3}$$

The Reynolds Number for each test is calculated using equation (3) can be seen in table(3).

Table (3): Reynolds Number value for each test

	Test 1	Test 2	Test 3
Reynolds Number	998.127	1,204.457	1,381.738

Result

For the first experiment, the viscosity and density of water were taken from property tables, the average temperature of the water is calculated from the given data, the mass of the water is measured during the experiment and the mass flow rate is calculated. With this data, the inner diameter of the microtube is calibrated for each test number using the equations above. Equation 1 is used for this calculation.

Dynamic viscosity is calculated with equation 2. **As the temperature of the water increases, the viscosity of the water decreases**. Reynolds numbers is calculated using equation 3. **Since the Reynolds numbers of each test are less than 2000, the flow of water is laminar.**

The viscosity of the water and the inner diameter of the microtube also depend on the K_{ent} and alpha values (α_2). These values are given to us in the lab manual. In addition, the viscosity of the water and the inner diameter of the microtube are affected by the mass flow rate, the density of the water and the length of the microtube (L).

Conclusion

In this experiment, the Capillary Viscometer method was employed with two different procedures. Initially, it was demonstrated that the inner diameter of the microtube could be measured using water with a known viscosity. Subsequently, it was observed that the viscosity of water can vary with temperature. At the end of the experiment, the inner diameter of the microtube was calculated, and it was concluded that as the temperature of water increased, its viscosity decreased. Furthermore, when applying the first procedure of this experiment, the Reynolds number was calculated using an equation. Since the Reynolds number was less than 2000, it is determined that the flow is laminar. The desired and intended results are successfully obtained in this experiment. Data is obtained through the fundamental principles of fluid mechanics, including the Poiseuille flow principle, the Bernoulli equation, and the equations derived from them. This data is interpreted to reach the conclusions of this experiment.

During the experiment, errors and uncertainties in length and temperature measurements may have influenced the accuracy and precision of the obtained results to some extent. However, the accuracy and precision of the obtained results are at a satisfactory level. Since measurement uncertainties and errors can impact the outcomes of the experiment, it is important for the experimental equipment and the person conducting the measurements to ensure precise measurements.