YEDİTEPE UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING
ME333 FLUID MECHANICS LABORATORY

FRICTION FACTOR

Instructor: Ali Bahadır Olcay
Group Id: 4G1
Group Members:

Ömer Dolaş	20200705001
İlker Kuzey Alkaşi	20210705076
Neşet Fatih Biçkin	20200705006
Artun Yağar	20200705055

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Abstract

The objective of this experiment was to measure the friction factor using a microtube and to compare the results with values in the literature. The experiment was conducted by measuring the pressure drop across the microtube for different flow rates and calculating the friction factor using the Haaland and Colebrook equations. The results were presented in Table 1 and plotted as a function of Reynolds number on a log-log scale in Figure 4. The findings showed that the experiment was successful in measuring the friction factor over the range of laminar to turbulent flow using a microtube. The results obtained were consistent with values in the literature, and the sources of error were identified and discussed. Overall, this experiment provides valuable insights into the flow of liquids in pipes and can be used to inform the design and sizing of pipes in various applications.

Introduction

Fluid mechanics is an important aspect of mechanical engineering because it explains how fluids behave in various systems. The study of friction components is critical in this subject since it sheds light on the complexities of fluid flow. A Data Acquisition System (DAQ), a computer, thermocouples, an electronic balance, a capillary tube, a water tank, and pressure transducers are shown in Figure 1. The technique, as seen in Figure 3, comprises the use of a ruler to take precise measurements of water height fluctuations during each experimental cycle.

Table 1 completely details the dataset, which includes crucial variables such as tube length, diameter, pressure range, water temperature, dynamic viscosity, density, net water weight, and the time necessary for water collection. This information serves as the basis for further computations such as mass flow rate, Reynolds number, and friction factor. The experiment involves critical calculations and relations. Understanding system dynamics is founded on the pressure differential equation (Equation 2). The Reynolds number (Equation 3) categorizes flow regimes, and the friction factor is calculated empirically (Equation 1) and theoretically (Equation 5) using the Colebrook (Equation 4) and Haaland (Equation 5) equations, which are customized for specific flow circumstances. This method provides for a concise yet thorough investigation of frictional behavior in the capillary tube. Velocity (Equation 7) is a critical quantity that connects the experimental data to the measured friction. The primary purpose is to investigate the link between Reynolds number and friction, as seen visually in Figure 4.

In essence, this experiment not only gives hands-on experience with fluid mechanics, but also emphasizes the practical use of theoretical models in forecasting frictional behavior in engineering systems.

Procedure

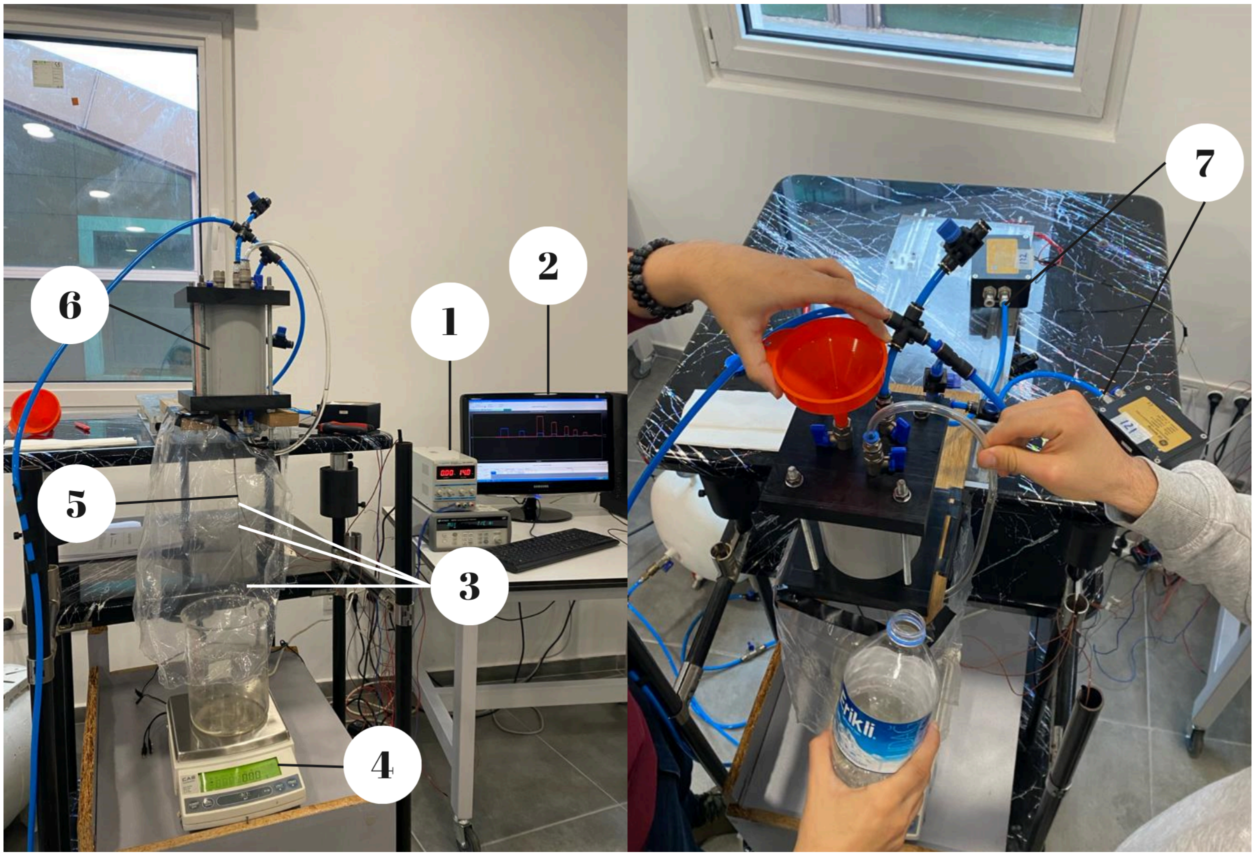

Figure 1 : Test Setup

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

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

Additionally, a ruler is used for measuring the initial and final height of water in the tank for each cycle. (Can be seen in Figure 3)

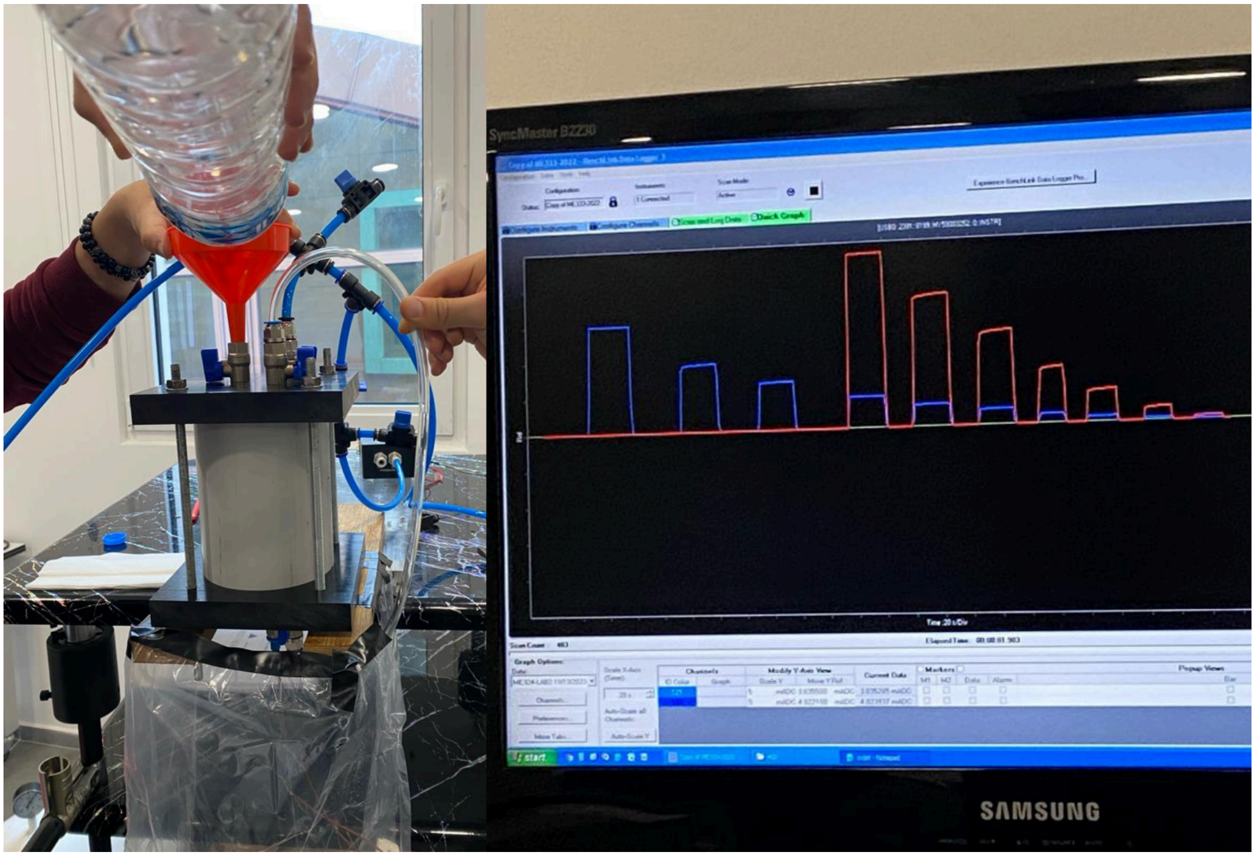

Figure 2: The Process of Pouring Water into the Water Tank and Data Collection on the Computer

Two pressure converters with different intervals were used during the experiment to measure the ampere values. These values were then collected on the computer via DAQ. The graph showing the ampere values during the experiment is presented in Figure 2.

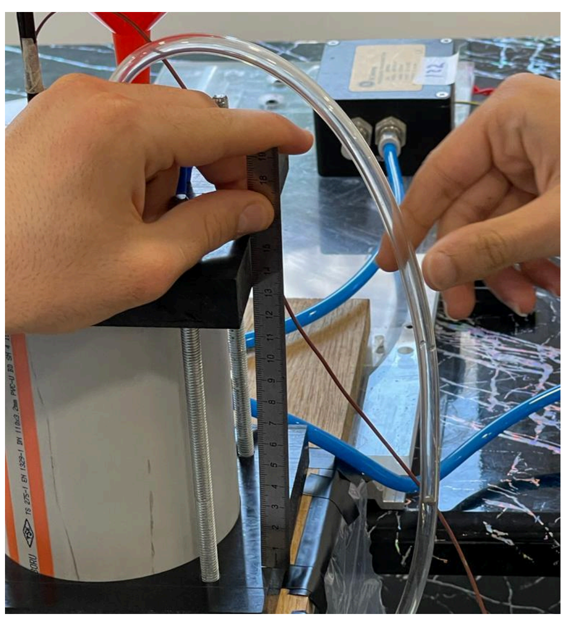

Figure 3: Measurement of Water Height in the Water Tank Using a Ruler.

Data Presentation

Table 1 : Dataset for the experiment.

	Test1	Test2	Test3	Test4	Test5	Test6	Test7	Test8	Test9	Test10
Length of tube (m)	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.304
Diameter of Tube (m)	9.96E-04	9.96E-04	9.96E-04	9.96E-04	9.96E-04	9.96E-04	9.96E-04	9.96E-04	9.96E-04	9.96E-04
Delta P Range (Pa)	4.14E+05	4.14E+05	4.14E+05	6.90E+04	6.90E+04	6.90E+04	6.90E+04	6.90E+04	6.90E+04	6.90E+04
Average Water Temp (°C)	18.921	18.872	18.839	18.834	18.897	18.493	18.276	18.921	18.917	18.911
Dynamic Viscosity (Ns/m2)	1.03E-03	1.03E-03	1.04E-03	1.04E-03	1.03E-03	1.04E-03	1.05E-03	1.03E-03	1.03E-03	1.03E-03
Density of Water (kg/m3)	997.73	997.74	997.74	997.74	997.73	997.78	997.81	997.73	997.73	997.73
Net Water Weight (kg)	0.126	0.069	0.065	0.052	0.040	0.029	0.015	0.018	0.008	0.004
Time to Collect Water (s)	20	14	16	16	15	13	8	12	9	8
Mass Flow Rate (kg/s)	6.32E-03	4.93E-03	4.08E-03	3.24E-03	2.70E-03	2.27E-03	1.86E-03	1.47E-03	8.73E-04	4.93E-04
Reynolds Number	7.82E+03	6.09E+03	5.04E+03	4.00E+03	3.34E+03	2.77E+03	2.27E+03	1.82E+03	1.08E+03	6.09E+02
Flow Type	Turbulent	Turbulent	Turbulent	Transitional	Transitional	Transitional	Laminar	Laminar	Laminar	Laminar
Alpha	1.1	1.1	1.1	1.5	1.5	1.5	2	2	2	2
K_ent	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Ht at the start (m)	0.125	0.100	0.083	0.070	0.061	0.054	0.050	0.045	0.042	0.039
Ht at the end (m)	0.110	0.092	0.077	0.068	0.058	0.052	0.048	0.043	0.040	0.037
Average Ht (m)	0.118	0.096	0.080	0.069	0.060	0.053	0.049	0.044	0.041	0.038
H0 (m)	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
H (m)	0.185	0.163	0.147	0.136	0.127	0.120	0.116	0.111	0.108	0.105
Roughness of the tube (m)	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06
I1 (mA)	4.024	4.024	4.024	3.835	3.835	3.835	3.835	3.835	3.835	3.835
I2 (mA)	18.844	13.249	10.563	27.321	21.453	16.330	11.250	8.067	5.598	4.282
Pt-Pamb (Pa)	3.83E+05	2.39E+05	1.69E+05	1.01E+05	7.59E+04	5.38E+04	3.20E+04	1.82E+04	7.59E+03	1.93E+03
V (m/s)	8.135	6.345	5.253	4.169	3.472	2.914	2.396	1.890	1.123	0.634
Friction (Experimental)	0.0341	0.0353	0.0369	0.0342	0.0380	0.0392	0.0339	0.0337	0.0532	0.0897
Friction (Theoretical)(1)	0.0343	0.0366	0.0384	0.0409	0.0431	0.0455	0.0282	0.0352	0.0593	0.1051
Friction (Theoretical)(2)	0.0342	0.0366	0.0385	0.0412	0.0435	0.0462	0.0282	0.0352	0.0593	0.1051
							For laminar friction = 64/Re is used			

Where:

- Length of tube and diameter of tube is given in the lab manual,
- ΔP_{range} is 0-413900 Pa for test 1-3, 0-68950 Pa for test 4-10,
- 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

- 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 :
  $\frac{Net\ water\ weight\ (kg)}{Time\ for\ collecting\ water\ (s)}$
- Reynolds Number is calculated from equation 3,
- The flow type is determined by the following conditions:
  Flow is laminar when Re < 2300 and turbulent when Re > 4000. Flow is called transitional when 2300 < Re < 4000,
- α_2 (alpha) is the correction factor and and 2 for laminar flow, 1.5 for transitional flow and 1.1 for turbulent flow,
- K_{ent} represents the loss Coefficient of the pipe fitting and is equal to 0.25,
- Ht is measured at the beginning and end for each cycle, and then the average Ht is found from these two measurements,
- H_0 value is given in the lab manual,
- $H = H_0 + H_t$ is used for finding the H value,
- Roughness of the tube ϵ is given as 0.000001 m (1 micron) in the lab manual,

- I1 is the pressure transducer reading with no flow, calculated from the average of no flow region (Can be seen in Figure 5) for high pressure and low pressure transducers separately (mA),
- I2 is the pressure transducer reading with flow, calculated for each test with using the average data of the tests pressure transducer (For test 1-3 high pressure transducer is used, for test 4-10 low pressure transducer is used)(mA),
- Pt-Pamb is calculated from equation 2 (For test 1-3 high pressure transducer ΔP_{range} is used, for test 4-10 low pressure transducer ΔP_{range} is used),
- Velocity is calculated from equation 6,
- Friction (Experimental) is calculated from equation 1,
- Friction (Theoretical)(1) is calculated using the equation 4 (Colebrook Equation) for the non laminar flows only. The laminar flow friction is calculated from equation 6,
- Friction (Theoretical)(2) is calculated using the equation 4 (Haaland Equation) for the non laminar flows only. The laminar flow friction is calculated from equation 6.

Equations that are used in the experiment:

The friction equation derived from the energy equations (Experimental) where;
g is gravitational acceleration ($g = 9.81\ m/s^2$)

$$f = \frac{d}{L}\left[\frac{2\{P_t - P_{amb} + \rho g(H+L)\}}{\rho V^2} - \alpha_2 - \kappa_{ent}\right] \tag{1}$$

Pressure differential equation:

$$P_t - P_{amb} = \Delta P_{range}\frac{I_2 - I_1}{20-4} \tag{2}$$

The dimensionless Reynolds number:

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

Colebrook Equation:

$$\frac{1}{\sqrt{f}} = -2log_{10}\left[\frac{\varepsilon}{3.7d} + \frac{2.51}{Re\sqrt{f}}\right] \tag{4}$$

Haaland Equation:

$$\frac{1}{\sqrt{f}} = -1.8log_{10}\left[\left(\frac{\varepsilon}{3.7d}\right)^{1.11} + \left(\frac{6.9}{Re}\right)\right] \tag{5}$$

Friction factor for laminar flow:

$$f = \frac{64}{Re} \tag{6}$$

Velocity (V) is derived from the formula of mass flow rate and velocity relationship ($\dot{m} = \rho \times V \times A$)

$$V = \frac{4\dot{m}}{\pi\rho d^2} \tag{7}$$

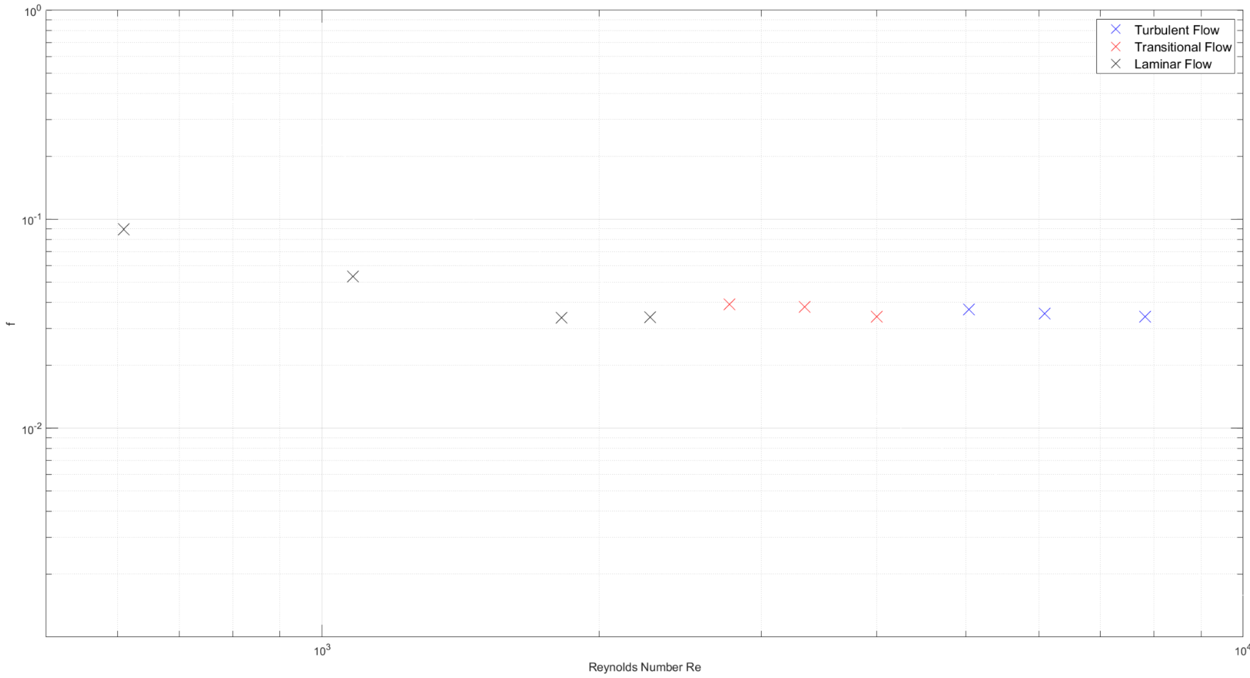

Figure 4: Reynolds Number vs Friction (log-log)

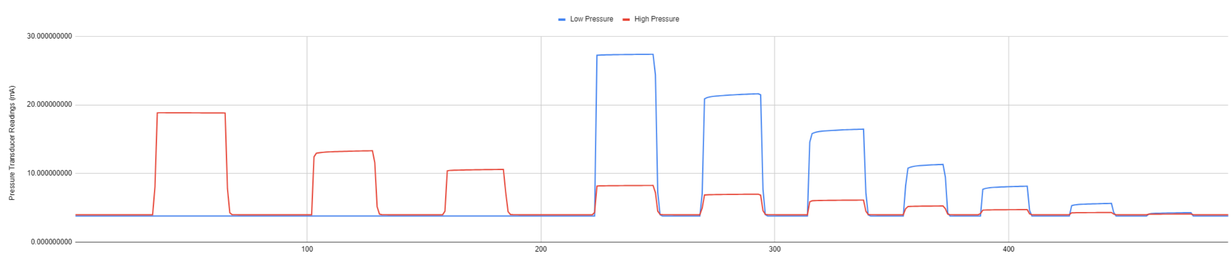

Figure 5 : Pressure Transducer Readings vs Time Graph.

Result

Reynolds numbers are calculated for each test using the 5th equation. If the Reynolds number is less than 2300, the flow is laminar, if it is between 2300-4000, the flow is transitional, and if the Reynolds number is greater than 4000, the flow is turbulent. Thus, tests 1-3 are turbulent, tests 3-6 are transitional, and tests 7-10 are laminar. The friction factor was calculated experimentally and theoretically. Friction factor, experimentally with equation 1; It was calculated theoretically with equations 4, 5, and 6. Equation 1 shows us that as the velocity of the fluid increases, the friction factor will decrease. Equations 4, 5, and 6 theoretically show that the friction factor has a relationship with the Reynolds number and therefore there is a relationship between the flow type and the friction factor. Additionally, equation 6 theoretically shows that laminar flow has an inverse relationship with Reynolds number.

Conclusion

This experiment aims to calculate the friction factor of a fluid in different flow regimes (from laminar flow to turbulent flow) in a microtube. The friction factor was found experimentally using equation 1. It was later calculated theoretically using equations (4), (5) and (6). In this experiment, the diameter of the tube and the density of the fluid are constant, but the speed of the fluid changes, so different Reynolds numbers and friction factor values arise. To find the friction factor, Reynolds numbers were first calculated. If the Reynolds number is less than 2300, laminar; The flow types of the fluid were found for each test, as it is transitional between 2300-4000 and turbulent if it is greater than 4000. Friction factors were calculated according to flow types. For laminar flow, the equation $f = \frac{64}{Re}$ was used. From this, it was understood that the friction factor for laminar flow is theoretically proportional to the Reynolds number. For other flow types, Colebrook and Haaland's equations were used. These equations show that there is a relationship between friction factor and Reynolds numbers. Although there were differences when comparing the experimental and theoretical results, satisfactory results were obtained.

During the experiment, there may be uncertainties and errors that will affect the results of the experiment. It is important for the reliability of the experiment. Especially in length measurements, factors such as accuracy, precision, and calibration of the measuring tools used should be taken into consideration. Additionally, uncertainties in temperature measurements should not be ignored. Despite the existence of these errors and uncertainties, the results we obtained are generally satisfactory. To increase the accuracy of the experiment, it is important that the equipment used in similar experiments in the future be calibrated more precisely and that the person performing the measurements works carefully.