YEDİTEPE UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING
ME324 HEAT TRANSFER LABORATORY

Heat Loss from a Vessel

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1. Abstract

This experiment was carried out to measure the heat loss of hot water in a vessel and to evaluate the effect of various factors (convection, radiation, insulation, etc.). The temperature of the water and the Plexiglas wall was measured over time using thermocouples and infrared thermometers. The data obtained showed how heat loss is affected by different factors and emphasized the importance of insulation, convection heat transfer coefficient on the outer surface and heat loss through the cover. Furthermore, the effect of the estimated values of qloss_top on the convection heat transfer coefficient was studied.The results of this experiment provide a deeper understanding of heat transfer and energy balance, while emphasizing the importance of insulation in industrial applications.

2. Introduction

In our experiment, our aim was to determine the heat released by the hot water poured from the kettle into a water tank made of Plexiglas, and to find the heat transfer coefficient (h). Initially, we identified that heat is lost from the hot water through convection from the water to the tank wall, conduction throughout the wall, and convection and radiation from the outside surface of the wall to the surrounding air. By quantifying each of these heat losses, we obtained the total heat loss using Equation 1. The term $q_{\text{insulator}}$ in the equation represents the insulator at the bottom.

$$q_{total} = q_{convection} + q_{radiation} + q_{insulator} + q_{top} \qquad (\,Equation\ 1\,)$$

We find the heat transfer coefficient (h) using Equation 2, along with detailed equations presented in the Data Presentation section.

$$h = \frac{1}{A_{side} * (T_{IR} - T_{104})}\left[-M_w * C_{pw} * \frac{dT_w}{dt} - M_{PG} * C_{PG} * \frac{dT_{PG}}{dt} - A_{side} * \varepsilon * \sigma * \left({T_{IR}}^4 - {T_{104}}^4\right) - k_{insulator} * A_{bottom} * \frac{(T_{102} - T_{103})}{\Delta X_{ins}} - q_{top}\right] \quad (\,Equation\ 2\,)$$

Note that the value of T_{PG} in Equation 2 came from Equation 3, where the critical point is: It is assumed that the water average values are equal to the outer surface temperature.

$$T_{PG} = \frac{1}{2}(T_{101} + T_{IR}) \quad (\,Equation\ 3\,)$$

T_{PG} = Temperature of Plexiglass

3. Procedure

- The individual masses of water and Plexiglas are determined using measuring equipment.
- Water is heated with a kettle and poured into the Plexiglas (to a depth of 89 centimeters).
- A mixer inside the Plexiglas operates to ensure uniform distribution of temperature throughout the water.
- The system is initiated from the computer, and data from the thermocouples are processed graphically. However, values are not recorded for the first few seconds.
- A person measures the temperature of the Plexiglas using a thermometer every 10 seconds and records the values.
- This process continues for approximately 40 readings.

4. Experimental Setup

- Preheated hot water is placed in a container which has five wall-mechanism, and a mixer powered by a motor on top keeps the water in the vessel at a steady temperature.

- The experiment was conducted with five thermocouples that are indicated as ‘TC’ in figure 1 to measure temperatures at different locations.

- The convective heat transfer coefficient at the container's surface is calculated as a function of time after determining the rates for different heat losses as a function of time and estimating various additional heat losses in the system.

- A thermocouple (TC 101) is used to measure the temperature of water that is located at the inside of the container while TC 102 takes part between the bottom of the container and the top of the insulator material. At the very bottom of the insulator, there comes TC103. In order to obtain the temperature value of the surrounding, TC104 was used. TC105 is for measuring the air temperature due to boiled water inside the container but in this experiment, the data obtained from this thermocouple is not included into the calculations. All the readings and datas are acquired from DAQ system.

- While these thermocouples were making the readings automatically, the other measurement device is an infrared thermometer which is used to get the temperature of the outside surface of the container

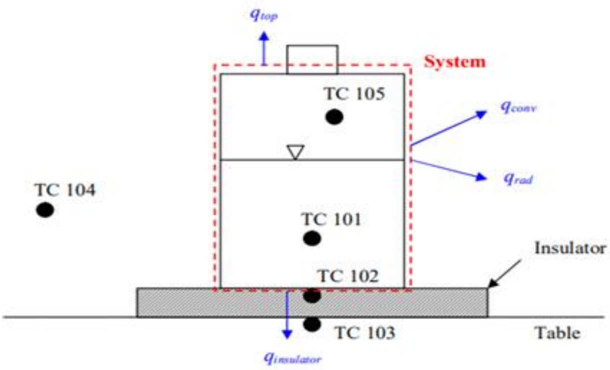


Figure 1

5. DATA OF PRESENTATION

The values in Tables 1, 2, and 3 below were obtained by computing the experimental data. Equation 8, which is displayed after the Tables, was used to compute the convective heat transfer coefficient.

Stefan Boltzmann Constant	5.67E-08
Thickness Of Insulator (m)	0.01
Thickness Of Plexiglass (m)	0.0043
A Side-1 (m^2)	0.022606
A bottom (m^2)	0.00517816
Emissivity (e)	0.96
Plexiglass Mass (kg)	0.22264
Water (kg)	0.33287
Thermal Conductivity PG (W/mC)	0.18
Thickness Of Insulator (m)	0.01
Thermal Conductivity Insulator (W/mC)	0.04
Thickness Of Plexiglass (m)	0.0043
cp plexiglass (J/kg.K)	1450
cp water (J/kg.K)	4200

Table 1: This table shows the quantitative numbers that are required for this experiment.

Side-1	Side-2	Height	height (water)
68	59	149.3	93.3
76.6	67.6	145	89

Table 2:The lengths of the size of the vessel are shown.

Scan Number	Tir
295.00	53.8
305.00	53.9
315.00	53.9
325.00	53.9
335.00	53.8
345.00	53.7
355.00	53.7
365.00	53.7
375.00	53.7
385.00	53.6
395.00	53.6
405.00	53.7
415.00	53.5
425.00	53.5
435.00	53.3
445.00	53.5
455.00	53.3
465.00	53.3
475.00	53.4
485.00	53.3
495.00	53.2
505.00	53.1
515.00	53.2
525.00	53.1
535.00	52.9
545.00	53
555.00	53
565.00	52.9
575.00	52.8
585.00	52.6
595.00	52.7
605.00	52.7
615.00	52.6
625.00	52.6
635.00	52.6
645.00	52.6
655.00	52.4
665.00	52.3
675.00	52.3
685.00	52.3
695.00	52.3
705.00	52.2
715.00	52.2
725.00	52.1
735.00	52
745.00	52
755.00	51.9
765.00	51.9
775.00	51.7
785.00	51.7

Table 3:Tır-scan number relationship. Tır indicates the temperature of the wall.

Scan Number	101 @ Water	102 @ Ins-Top	103 @ Ins-Bottom	104 @ Air-T	105 @ Inside-T	T(IR)	dTw/dt	dTpg/dt	Q(ins)	T (plexi-glass)	Q(top-estimated-1)
295.00	60.05	45.87	25.53	20.34	46.03	53.8	-0.0800	-0.0060	0.4214	56.9248	1.2641
305.00	59.99	45.87	25.53	20.34	46.11	53.9	-0.0800	-0.0060	0.4213	56.9435	1.2638
315.00	59.87	45.88	25.55	20.33	46.15	53.9	-0.0800	-0.0060	0.4212	56.8834	1.2636
325.00	59.82	45.90	25.55	20.34	46.21	53.9	-0.0800	-0.0060	0.4215	56.8621	1.2644
335.00	59.72	45.90	25.56	20.34	46.29	53.8	-0.0800	-0.0060	0.4213	56.7606	1.2640
345.00	59.62	45.89	25.57	20.42	46.35	53.7	-0.0800	-0.0060	0.4209	56.6595	1.2627
355.00	59.51	45.89	25.57	20.41	46.37	53.7	-0.0800	-0.0060	0.4209	56.6072	1.2626
365.00	59.43	45.90	25.58	20.43	46.41	53.7	-0.0800	-0.0060	0.4209	56.5633	1.2627
375.00	59.35	45.90	25.60	20.41	46.45	53.7	-0.0800	-0.0060	0.4205	56.5227	1.2614
385.00	59.24	45.90	25.60	20.34	46.47	53.6	-0.0800	-0.0060	0.4204	56.4217	1.2611
395.00	59.15	45.89	25.61	20.38	46.51	53.6	-0.0800	-0.0060	0.4202	56.3757	1.2606
405.00	59.08	45.87	25.62	20.38	46.55	53.7	-0.0800	-0.0060	0.4196	56.3924	1.2589
415.00	59.05	45.87	25.63	20.39	46.58	53.5	-0.0800	-0.0060	0.4194	56.2735	1.2581
425.00	58.92	45.90	25.66	20.41	46.61	53.5	-0.0800	-0.0060	0.4192	56.2088	1.2577
435.00	58.90	45.93	25.68	20.45	46.61	53.3	-0.0800	-0.0060	0.4192	56.0976	1.2577
445.00	58.83	45.95	25.71	20.47	46.62	53.5	-0.0800	-0.0060	0.4192	56.1637	1.2577
455.00	58.74	45.96	25.74	20.49	46.62	53.3	-0.0800	-0.0060	0.4188	56.0217	1.2565
465.00	58.66	45.98	25.77	20.53	46.63	53.3	-0.0800	-0.0060	0.4187	55.9810	1.2561
475.00	58.58	45.97	25.77	20.45	46.61	53.4	-0.0800	-0.0060	0.4184	55.9882	1.2552
485.00	58.50	45.97	25.78	20.41	46.60	53.3	-0.0800	-0.0060	0.4182	55.9015	1.2546
495.00	58.45	45.96	25.79	20.39	46.57	53.2	-0.0800	-0.0060	0.4177	55.8240	1.2530
505.00	58.36	45.95	25.80	20.39	46.53	53.1	-0.0800	-0.0060	0.4175	55.7292	1.2524
515.00	58.29	45.94	25.81	20.35	46.52	53.2	-0.0800	-0.0060	0.4170	55.7446	1.2510
525.00	58.22	45.93	25.81	20.35	46.48	53.1	-0.0800	-0.0060	0.4167	55.6611	1.2501
535.00	58.12	45.93	25.81	20.35	46.46	52.9	-0.0800	-0.0060	0.4166	55.5079	1.2497
545.00	58.03	45.91	25.81	20.27	46.44	53	-0.0800	-0.0060	0.4163	55.5155	1.2489
555.00	57.95	45.90	25.82	20.31	46.41	53	-0.0800	-0.0060	0.4159	55.4750	1.2476
565.00	57.87	45.89	25.83	20.28	46.37	52.9	-0.0800	-0.0060	0.4154	55.3862	1.2463
575.00	57.78	45.88	25.83	20.28	46.34	52.8	-0.0800	-0.0060	0.4151	55.2913	1.2454
585.00	57.69	45.87	25.83	20.27	46.28	52.6	-0.0800	-0.0060	0.4152	55.1428	1.2456
595.00	57.60	45.86	25.84	20.27	46.23	52.7	-0.0800	-0.0060	0.4147	55.1510	1.2441
605.00	57.54	45.86	25.85	20.25	46.17	52.7	-0.0800	-0.0060	0.4144	55.1199	1.2433
615.00	57.46	45.83	25.84	20.17	46.13	52.6	-0.0800	-0.0060	0.4141	55.0317	1.2424
625.00	57.34	45.82	25.84	20.14	46.11	52.6	-0.0800	-0.0060	0.4139	54.9725	1.2416
635.00	57.26	45.81	25.84	20.14	46.06	52.6	-0.0800	-0.0060	0.4137	54.9288	1.2410
645.00	57.17	45.80	25.86	20.13	46.01	52.6	-0.0800	-0.0060	0.4131	54.8870	1.2394
655.00	57.11	45.79	25.84	20.22	45.95	52.4	-0.0800	-0.0060	0.4131	54.7565	1.2393
665.00	57.04	45.78	25.85	20.25	45.89	52.3	-0.0800	-0.0060	0.4129	54.6715	1.2386
675.00	56.93	45.76	25.86	20.28	45.85	52.3	-0.0800	-0.0060	0.4123	54.6149	1.2370
685.00	56.89	45.76	25.86	20.24	45.80	52.3	-0.0800	-0.0060	0.4123	54.5950	1.2369
695.00	56.77	45.76	25.86	20.26	45.75	52.3	-0.0800	-0.0060	0.4121	54.5325	1.2362
705.00	56.74	45.74	25.86	20.28	45.69	52.2	-0.0800	-0.0060	0.4118	54.4722	1.2353
715.00	56.61	45.74	25.88	20.24	45.66	52.2	-0.0800	-0.0060	0.4114	54.4072	1.2343
725.00	56.54	45.74	25.87	20.26	45.62	52.1	-0.0800	-0.0060	0.4115	54.3215	1.2344
735.00	56.46	45.73	25.88	20.27	45.56	52	-0.0800	-0.0060	0.4111	54.2324	1.2333
745.00	56.43	45.71	25.89	20.29	45.51	52	-0.0800	-0.0060	0.4106	54.2162	1.2319
755.00	56.33	45.71	25.90	20.28	45.46	51.9	-0.0800	-0.0060	0.4104	54.1159	1.2312
765.00	56.25	45.72	25.92	20.24	45.40	51.9	-0.0800	-0.0060	0.4102	54.0768	1.2306
775.00	56.15	45.73	25.94	20.23	45.33	51.7	-0.0800	-0.0060	0.4100	53.9273	1.2299
785.00	56.14	45.73	25.94	20.28	45.29	51.7	-0.0800	-0.0060	0.4098	53.9178	1.2294

Table 4

Q(top-estimated-2)	Q(rad)(total)	Q(conv)(total)	Q (total)	h1(calculated)	h2(calculated)	104(Kelvin)	Tir(Kelvin)
2.1068	9.8477	-314.7831	-145.8584	-208.08	-209.19	293.34	326.80
2.1064	9.8809	15.6720	19.4020	10.33	9.22	293.34	326.90
2.1060	9.8835	-9.3518	6.8924	-6.16	-7.27	293.33	326.90
2.1073	9.8820	321.9770	172.5563	212.20	211.09	293.34	326.90
2.1067	9.8484	321.8514	172.4595	212.74	211.62	293.34	326.80
2.1045	9.7937	10.7809	16.8678	7.16	6.05	293.42	326.70
2.1044	9.7960	5.4176	14.1883	3.60	2.48	293.41	326.70
2.1045	9.7902	3.2338	13.0907	2.15	1.03	293.43	326.70
2.1023	9.7968	321.8648	172.4110	213.83	212.71	293.41	326.70
2.1018	9.7803	6.7767	14.8501	4.51	3.39	293.34	326.60
2.1009	9.7689	-313.2925	-145.1966	-208.60	-209.72	293.38	326.60
2.0981	9.8023	613.0609	318.0112	407.01	405.90	293.38	326.70
2.0969	9.7331	18.9205	20.8708	12.64	11.52	293.39	326.50
2.0962	9.7278	608.2414	315.5254	406.54	405.42	293.41	326.50
2.0961	9.6479	-624.5490	-300.9497	-420.57	-421.70	293.45	326.30
2.0961	9.7128	628.1253	325.4524	420.60	419.47	293.47	326.50
2.0941	9.6379	3.6196	13.1230	2.44	1.31	293.49	326.30
2.0934	9.6280	-306.8328	-142.1136	-207.12	-208.25	293.53	326.30
2.0920	9.6843	312.8733	167.7946	209.99	208.87	293.45	326.40
2.0909	9.6585	306.9866	164.8246	206.45	205.33	293.41	326.30
2.0884	9.6306	318.1841	170.3934	214.47	213.35	293.39	326.20
2.0874	9.5951	-312.0840	-144.7770	-211.04	-212.17	293.39	326.10
2.0850	9.6403	310.9066	166.7615	209.32	208.20	293.35	326.20
2.0835	9.6055	635.6237	329.0842	429.27	428.15	293.35	326.10
2.0828	9.5377	-306.9580	-142.2750	-208.57	-209.70	293.35	325.90
2.0814	9.5918	3.6675	13.0907	2.48	1.35	293.27	326.00
2.0794	9.5821	314.4538	168.4725	212.74	211.61	293.31	326.00
2.0771	9.5545	318.4188	170.4256	215.91	214.78	293.28	325.90
2.0757	9.5206	632.7392	327.5508	430.35	429.22	293.28	325.80
2.0759	9.4539	-307.1345	-142.4526	-210.15	-211.29	293.27	325.60
2.0735	9.4880	-2.2138	10.0400	-1.51	-2.64	293.27	325.70
2.0721	9.4948	314.2849	168.2950	214.20	213.07	293.25	325.70
2.0706	9.4806	15.9486	19.1114	10.88	9.75	293.17	325.60
2.0694	9.4864	5.9314	14.1076	4.04	2.91	293.14	325.60
2.0684	9.4863	4.6742	13.4781	3.19	2.06	293.14	325.60
2.0656	9.4895	621.1958	321.7399	423.17	422.04	293.13	325.60
2.0654	9.3999	312.3871	167.2458	214.70	213.57	293.22	325.40
2.0643	9.3593	14.5549	18.2882	10.04	8.90	293.25	325.30
2.0616	9.3504	-9.1508	6.4243	-6.32	-7.46	293.28	325.30
2.0615	9.3596	18.3036	20.1606	12.63	11.49	293.24	325.30
2.0603	9.3564	296.5345	159.2719	204.69	203.55	293.26	325.30
2.0588	9.3163	20.0409	20.9838	13.89	12.75	293.28	325.20
2.0572	9.3258	313.0326	167.4879	216.66	215.52	293.24	325.20
2.0573	9.2880	315.2710	168.5694	219.01	217.86	293.26	325.10
2.0556	9.2525	-11.3666	5.2137	-7.92	-9.07	293.27	325.00
2.0532	9.2462	322.6249	172.2012	225.05	223.91	293.29	325.00
2.0520	9.2149	3.5322	12.6226	2.47	1.32	293.28	324.90
2.0510	9.2262	634.0133	327.8736	442.89	441.74	293.24	324.90
2.0499	9.1616	-15.4924	3.0553	-10.89	-12.04	293.23	324.70
2.0490	9.1470	-21.5724		-15.19	-16.34	293.28	324.70

Table 5, 4:This table shows the measurements made during the experiment and the values that were calculated to find the heat lost.

Ω The following procedures were followed in order to use equations to calculate the variance in the total heat loss rate of the system as a function of time. Additionally, the heat losses at the bottom of the container and on the outside of the plexiglass wall could be determined as a function of time using equation 1. Table 7 displays these computations in detail. The test sheet's requested graphics are drawn separately below using the computed values found in Table 7.

$$q_{total} = q_{rad} + q_{conv} + q_{insulator} + q_{top} \qquad \textbf{(1)}$$

$$q_{total} = -M_w * C_{pw} * \frac{dT_w}{dt} - M_{PG} * C_{PG} * \frac{dT_{PG}}{dt} \qquad \textbf{(2)}$$

$$q_{conv} = h * A_{side} * (T_{IR} - T_{104}) \qquad \textbf{(3)}$$

$$q_{rad} = A_{side} * \varepsilon * \sigma * ({T_{IR}}^4 - {T_{104}}^4) \qquad \textbf{(4)}$$

$$q_{insulator} = k_{insulator} * A_{bottom} * \frac{(T_{102} - T_{103})}{\Delta X_{ins}} \qquad \textbf{(5)}$$

$$q_{top-1} = 3 * q_{insulator} \qquad \textbf{(6)}$$

$$q_{top-2} = 5 * q_{insulator} \qquad \textbf{(7)}$$

Ω Equation 5 is used to compute convection heat transfer on Plexiglas' exterior.

Ω Since the outside of Plexiglas is dark, we can infer that its emissive value will be close to 1. With the emissive value of 0.9, we used Equation 6 to calculate the radiation from the surface to the environment.

Ω To calculate the amount of heat lost from the insulator, use equation 7.

Ω We began our calculations by solving the experiment's logic, starting with Equation 1, but we are aware that the heat loss is insufficient to be predicted. For $\boldsymbol{qLoss\ Total}$, only these equations (1, 2, 5, 6, 7) are insufficient. (The Equation 8)

$$h = \frac{1}{A_{side} * (T_{IR} - T_{104})}\left[-M_w * C_{pw} * \frac{dT_w}{dt} - M_{PG} * C_{PG} * \frac{dT_{PG}}{dt} - A_{side} * \varepsilon * \sigma * \left({T_{IR}}^4 - {T_{104}}^4\right) - k_{insulator} * A_{bottom} * \frac{(T_{102} - T_{103})}{\Delta X_{ins}} - q_{top}\right] \qquad \textbf{(8)}$$

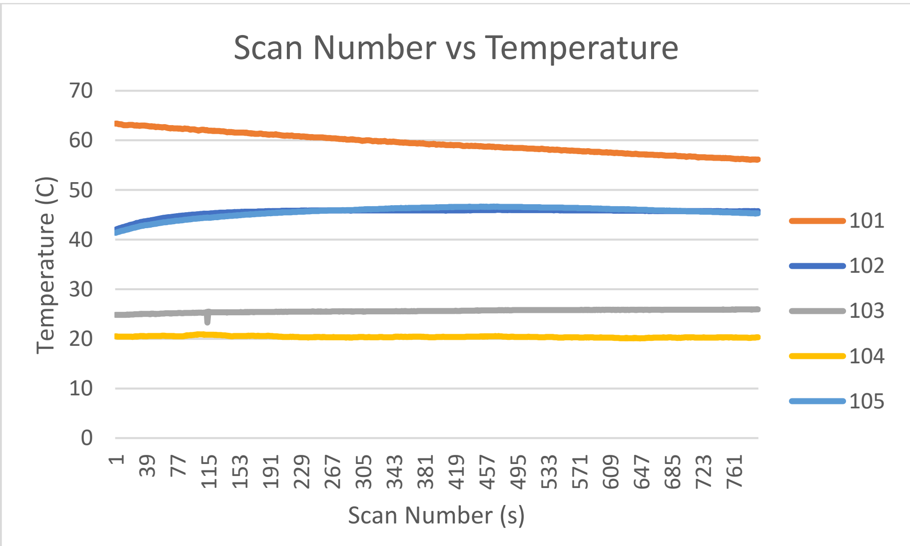
Ω Equation 3's energy estimate was used to calculate the convective heat transfer coefficient (h1 , h2) on the exterior of the container. Recall that the time variation of the heat transfer coefficient h that we have determined is caused by $\boldsymbol{TWater\ and\ TIR}$. This change in h is computed by Equation 8, and the results are shown in the table.

Ω Two h values were computed in order to compare the convective heat transfer coefficients. These calculations required separate computations of $\boldsymbol{q}$ convection for $h1$ and $h2$. It took $\boldsymbol{q}$ ball to figure out $\boldsymbol{qconv}$. While $\boldsymbol{qTop}$ 1 value is found, Table 7 illustrates that $\boldsymbol{qins} * 3$ and $\boldsymbol{qTop}$ 2 value are calculated by taking $\boldsymbol{qins} * 5$ coefficients.

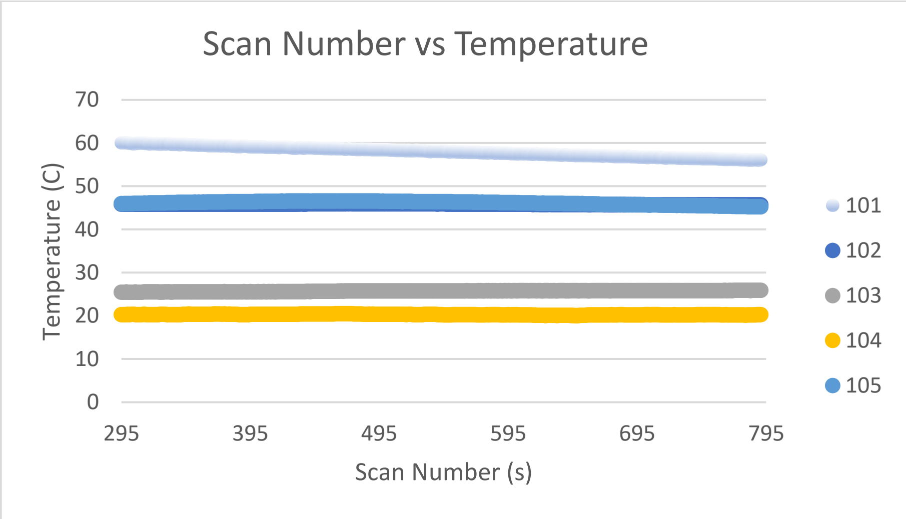
5.1. Graphics

The temperatures of the experiment as a function of time are represented by these values. Water (number 101), Insulator (number 102), Insulator (number 103), Insulator (the bottom portion of the vessel), Air temperature (number 105) and Outside (number 104). We have investigated the corresponding temperature values between 295 and 795 C using these temperature values.

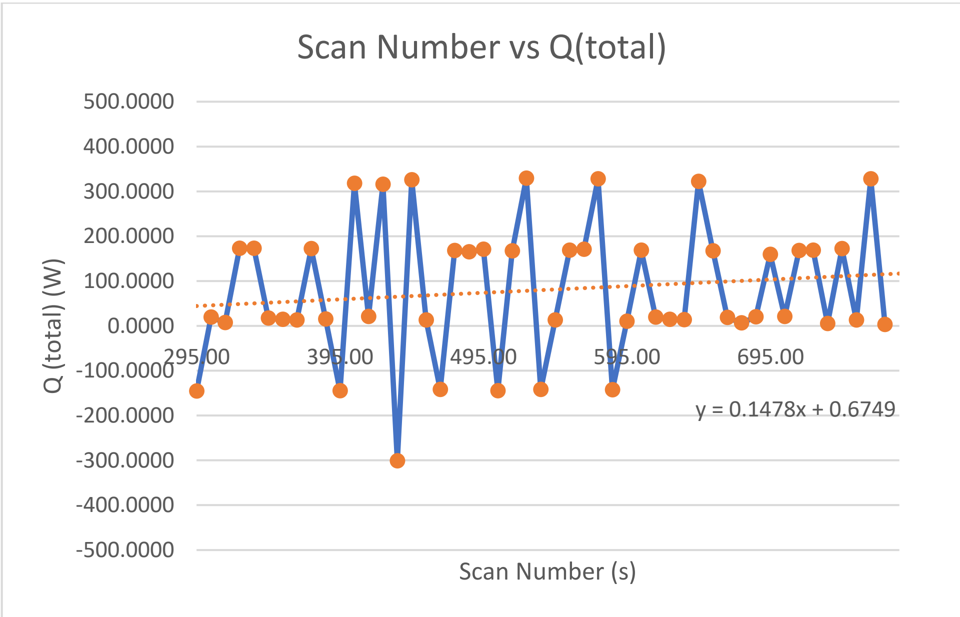
With the variables we provided, we created. Below are our graphics;



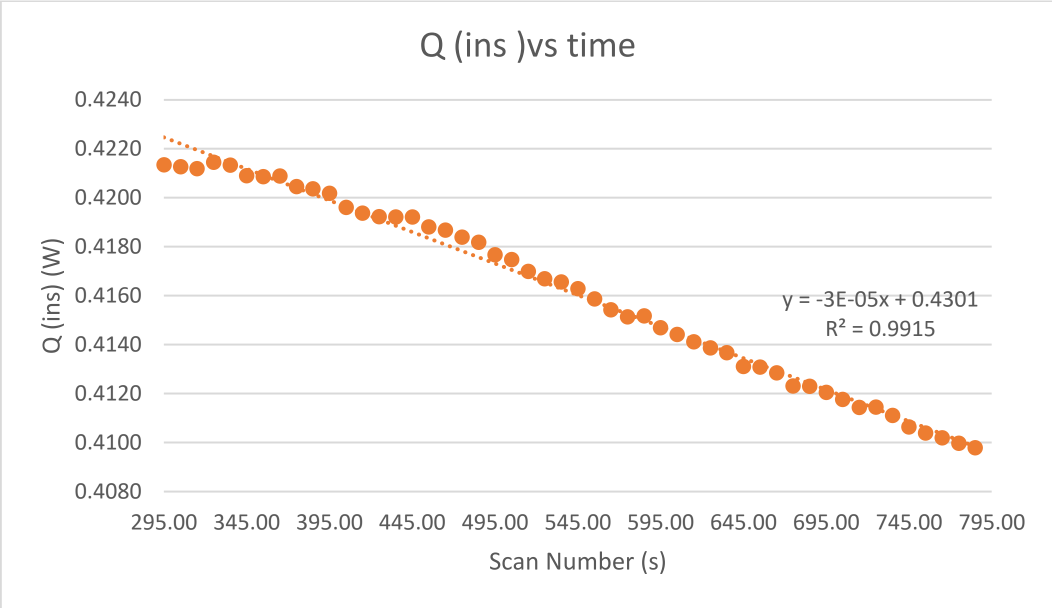
Graphic 1: The graph was created after analyzing temperature readings from 1 to 771 scans.



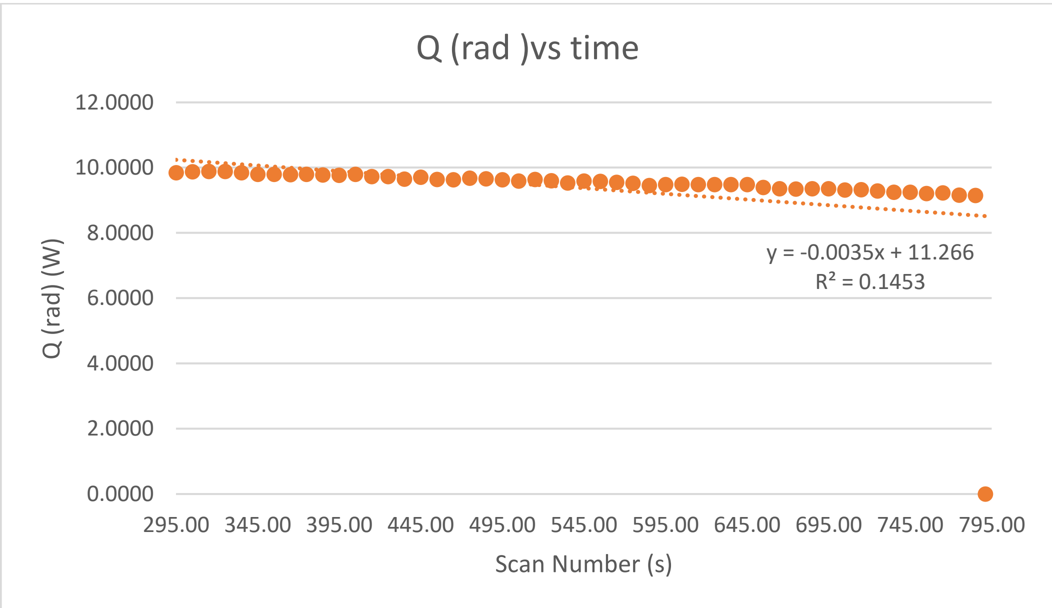
Graphic 2: The graph was created after analyzing temperature readings from 295 to 795 scans.



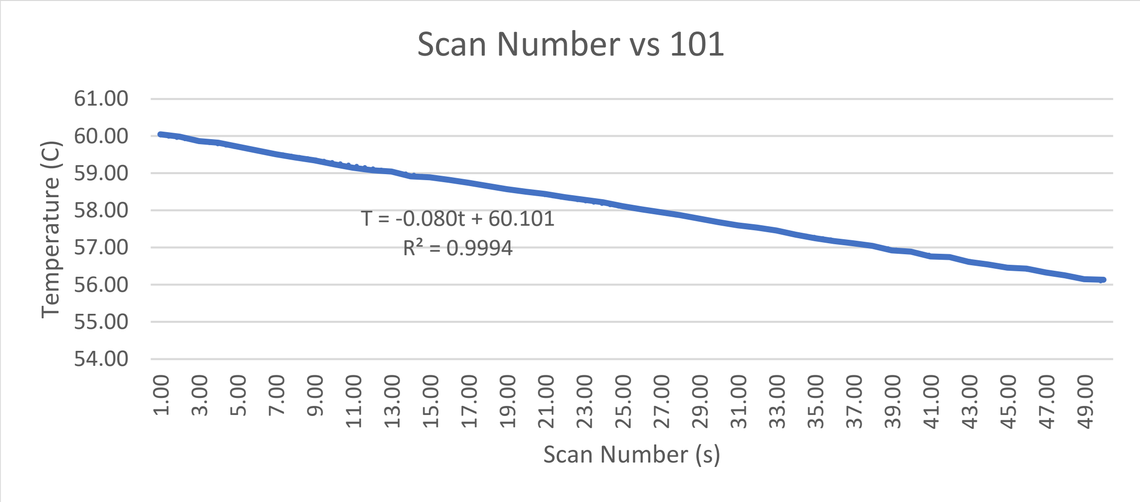
Graphic 3: The slope of the graph is constant between each scan interval, therefore It can be concluded as time independent.



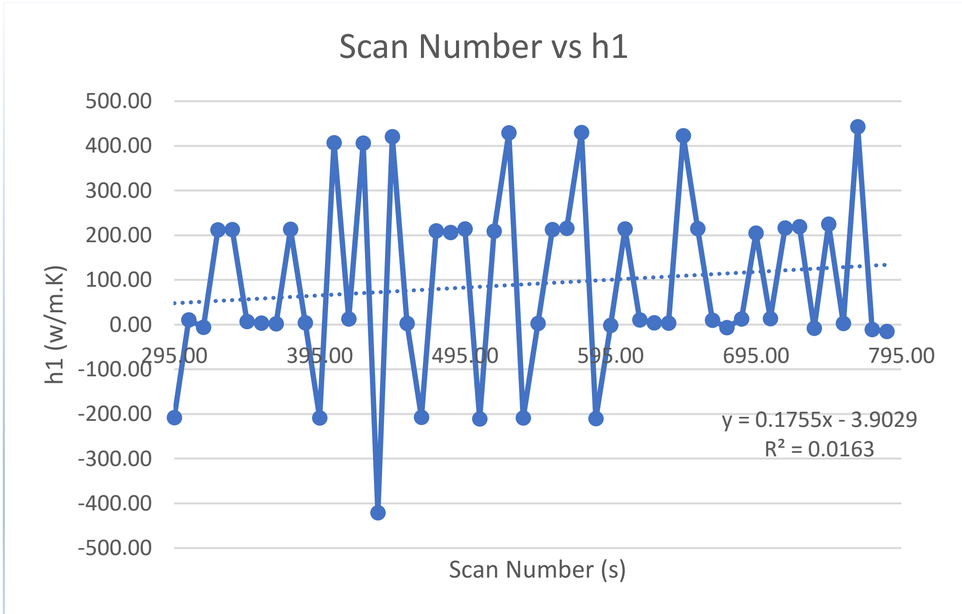
Graphic 4: As time passes, the heat loss of the insulator decreases because of the time dependency of the temperature. This occurs a negative slope.



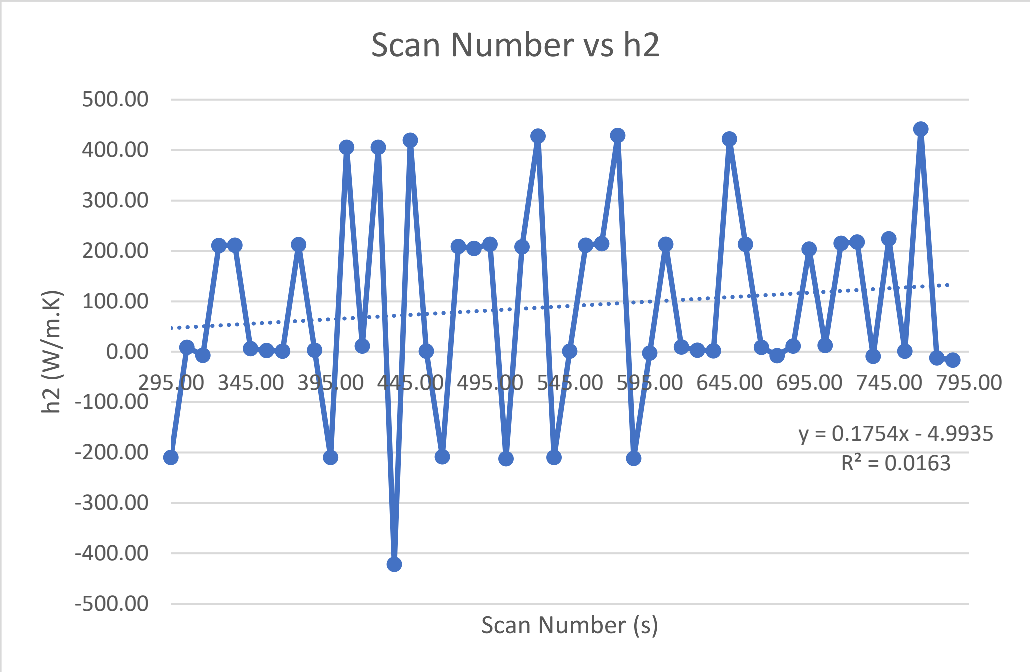
Graphic 5: Radiation is a mechanism of a heat transfer and the heat loss of the radiation reduces as a function of time



Graphic 6: T 101 is the average of the values taken from the thermocouple at every 10 scan interval. This graph shows the variation of these average values with respect to the scan number.



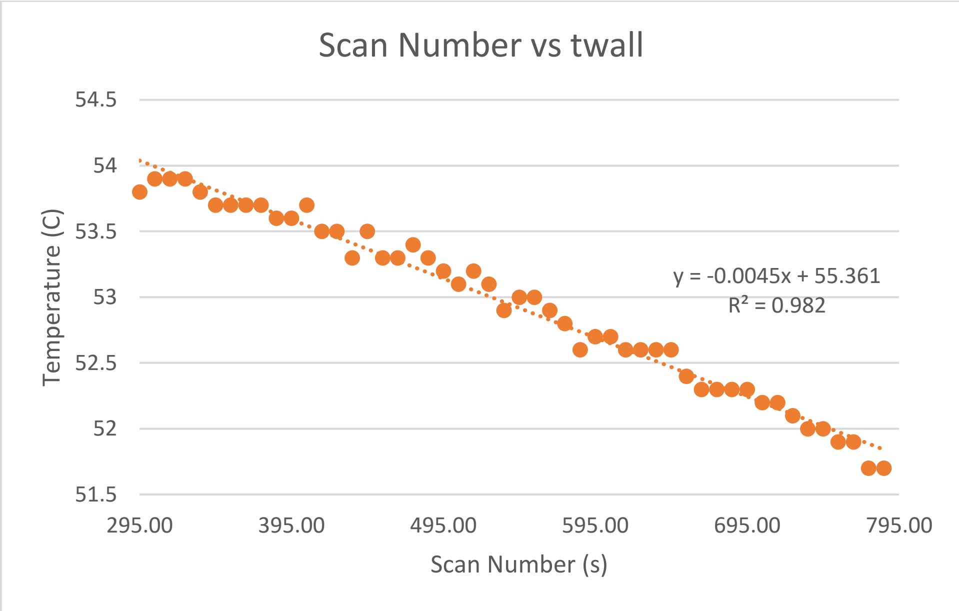
Graphic 7



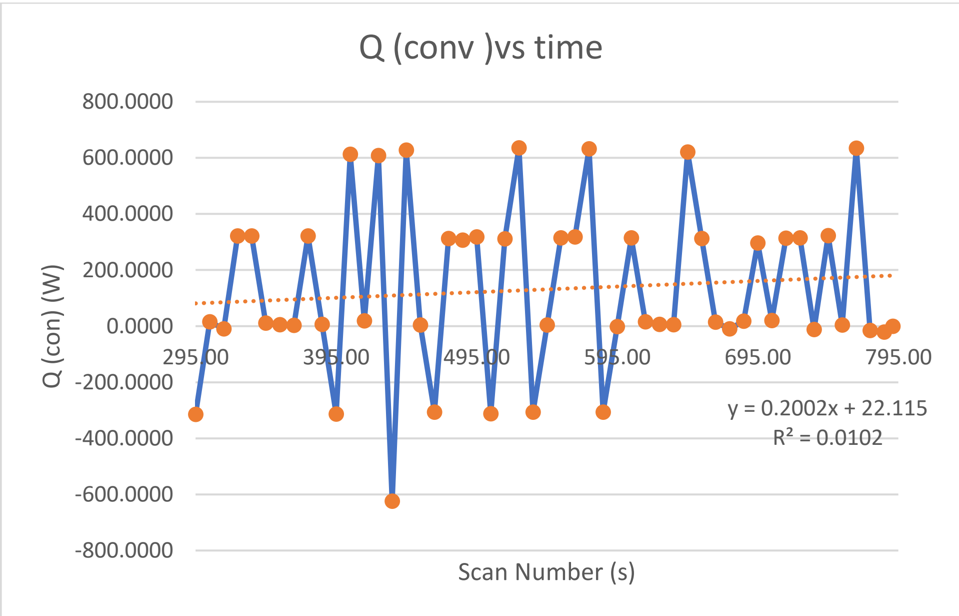
Graphic 8

Ω **Graphic 7 and graphic 8:** h_1 and h_2 represent the heat transfer coefficient calculated for 2 different values of Q_top. This coefficient determines the rate of heat transfer from the outer surface to the environment. This graph represents the variation of these values with respect to the scan number.

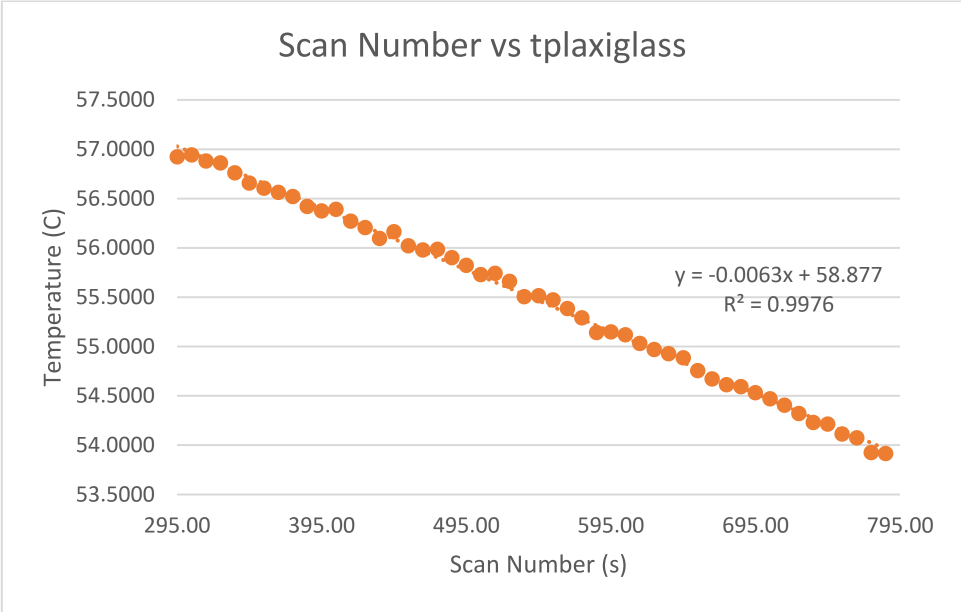
Ω In literature, it's understood that there can't be any negative values for h1 and h2. However, because Tir depends on the values we've taken, errors can occur. Specifically, we typically anticipate our water to cool down, but in our data, it occasionally increases, leading to a change in the Qtop value. This alteration directly impacts h1 and h2.



Graphic 9: Temperature value that are measured on the wall decreases as a function of time, therefore the slope is time dependent and negative due to reduced temperature.



Graphic 10: Q_convection is the total heat lost by convection from the sides of the vessel. This graph shows the variation of Q_convection lost with respect to the scan number. It can be seen that the Q_convection is directly proportional to Q_top and h1.



Graphic 11: This graph shows the variation of the temperature measurements of the plexiglass with respect to time. As can be seen from the graph, the temperature of the plexiglass decreases with time.

Ω After multiplying the $\boldsymbol{q_{ins}}$ value by 3 in $h1$ and 5 in $h2$, we were able to obtain the $\boldsymbol{q_{total}}$ values. We were then able to determine that there isn't really much of a difference by applying Equation 8, which we computed using the rationale behind showing their representations separately.

6. Conclusion

In this experiment, a detailed analysis of the heat loss of hot water in a container was performed. Different heat losses such as thermal conduction, convection and radiation were analyzed and how these losses change with time. Some results were obtained for the purpose of this experiment and are shown graphically in the presentation of data section. The temperatures of the water in the vessel, the walls of the vessel and the Plexiglass decreased. The rate of heat loss from hot water in the vessel decreased with time. Convection heat transfer coefficient was calculated in this experiment. These values took different values and did not follow any trend. Another result of this experiment is that the heat loss of the system is in equilibrium with the energy exchange rate of the system. It was also found that the estimation of the value of qloss_top has an effect on the convection heat transfer coefficient. The variability of these estimates affected the heat flux out of the outer surface, as well as the accuracy of our results.

Although the results obtained in this experiment are satisfactory, there are some uncertainties. These uncertainties need to be taken into account. Water vapor in the vessel is not taken into account. Measuring instruments such as thermocouples and infrared thermometers have a certain precision in the temperatures measured. It may be uncertain whether the assumptions (e.g. radiation properties of the external surface) exactly match the real-life conditions. There may be human error in measurement during the experiment. These uncertainties must be taken into account for the interpretation and reliability of the experimental results.