YEDİTEPE UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING
ME324 HEAT TRANSFER LABORATORY

Unsteady Heat Conduction In Spheres

Instructor: Bayram Şahin
Group Id: 1C
Group Members:

Kerem Aydınlı	20200705092
Ömer Faruk Kaptan	20200705057
Ömer Dolaş	20200705001
Batuhan Sönmez	20200705009

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Abstract

This experiment was carried out to investigate the thermal conductivity and convection heat transfer properties of solid spheres. The heat transfer properties of spheres made of two different materials were measured and calculated under various conditions. The analysis of the data enabled the determination of important thermal parameters such as Biot number, Fourier Number and dimensionless temperature (θ). The data used in the experiment were utilized to determine the thermal conductivity and convection coefficient values for the brass and steel spheres. In addition, the thermal diffusivity and other important thermal properties of the steel sphere were calculated. The results obtained show that different materials have different thermal conductivity and heat transfer properties. This study can contribute to the understanding of fundamental thermal phenomena such as thermal conductivity and convection heat transfer.

Introduction

This experiment provided the establishment of analytical methods to determine temperature distribution and heat flow as functions of time and location for basic solid structures at constant temperature. Calculations were made using graphs where the entire surface was subjected to temperature fluctuations for spherical structures. Two spheres of the same size but made of different materials (brass and stainless steel) were used in the experiment. Additionally, another approach allowed us to find the Bi number using the Heisler chart, which helped us clearly see the difference between brass and stainless steel. Subsequently, thermal diffusivity conductivity could be computed. Computations were performed utilizing dimensionless data flows formulas before observing the graphs.

Below are the equations that we used for this experiment.

$$\theta = \frac{T(r,t)-T_{\infty}}{T_i-T_{\infty}} \qquad Equation\ 1$$

$$Fo = \frac{a*t}{r_0^2} \qquad Equation\ 2$$

$$Bi = \frac{h*r_0}{k} \qquad Equation\ 3$$

$$a = \frac{k}{\rho*C_p} \qquad Equation\ 4$$

- Equation 1 Dimensionless temperature.
- Equation 2 Dimensionless time of Fourier number.
- Equation 3 Biot number.
- Equation 4 Thermal diffusivity.

Experimental Setup

- The computer is linked to the DAQ.
- The hot water bath lid must be installed, and flexible tubing must be used to link the input at the flow duct's base to the circulating pump's outlet.
- Additionally, the water bath's drain valve must be closed. Following verification, clean water is added to the bath until the level matches the center of the holes in the vertical flow duct.
- The T1 thermocouple is attached to the water bath's flow channel.
- The T2 thermocouple is attached to the shape holder.
- The T3 thermocouple is attached to the brass sphere.
- The metal bodies were arranged in various forms and positions so that they could be kept in balance at room temperature. Depending on each shape, the laboratory materials are hung on stands using insulated rods if they are accessible.
- The stabilization of the uniform temperature on the shape will be delayed if the shape by holding the metal rods located in the system is transfered. For this reason, insulated rods should always be used to hold metal shapes.

Procedure

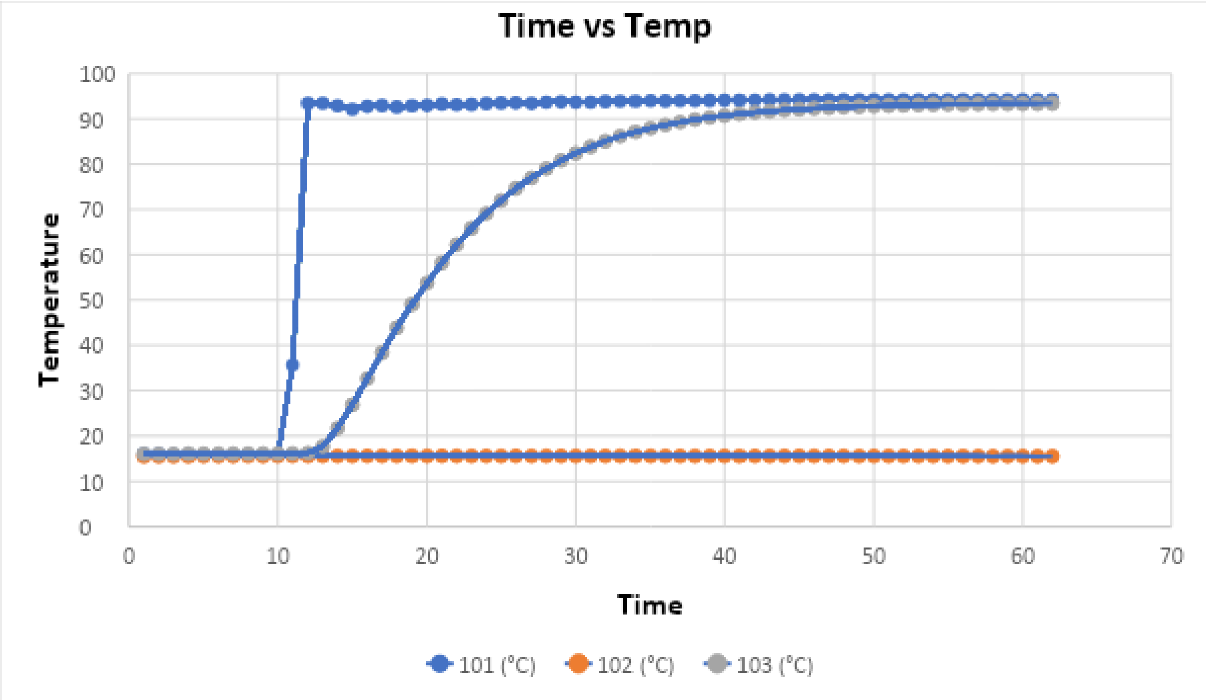
- The circulating pump has a voltage setting of 12 volts.
    - It is found that the water temperature, denoted as T1, is stable between 80°C and 90°C.
    - The transverse pin is used to fasten the insulated rod after it has been placed into the holder.
    - The brass sphere has the form holder fastened to it.
    - T3 on the DAQ is linked to the thermocouple that is affixed to the form.
    - the shape's temperature to see if it has stabilized is verified.

- The metal form is rapidly dropped into the flow tube. However, care is taken to make sure the holder's handle fits concentrically in the top of the flow tube.
    - By keeping an eye on temperature T3, the shape's temperature can be stabilized at the hot water temperature.

- The DAQ when the shape T3's temperature stabilizes should be stopped
  - The stainless steel sphere is put into the shape holder once the brass sphere has been taken out of it.
  - To acquire the transient response, the process is repeated for the stainless steel.

Presentation of Data

Calculations for Brass:



Graph 1: Collective temperatures versus time graphic that shows the data gathered under three different temperatures for brass.

The graph indicates three different temperature values with completely different behaviors. 101 shows the behavior of water while 102 and 103 show stainless-steel and brass respectively. As it can be seen by the graph 1, when the heated brass sphere contacts with water, the temperature value of water increases drastically. The reason why the temperature value of stainless-stell stays still is because it is located outside of the system in this process so there is no any heat transfer observed.

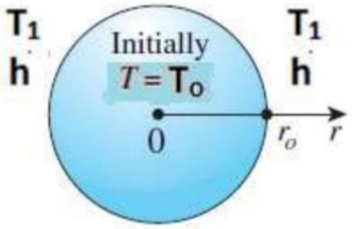
Scan Number	101 (°C)	102 (°C)	103 (°C)
13	93.424	15.593	17.734
14	92.87	15.595	21.687
15	92.102	15.579	26.914
16	92.727	15.598	32.65
17	92.94	15.598	38.396
18	92.584	15.587	43.895
19	92.905	15.611	49.035
20	92.949	15.598	53.806
21	93.26	15.614	58.203
22	93.127	15.598	62.242
23	93.16	15.587	65.826
24	93.379	15.585	69.087
25	93.487	15.579	72.003
26	93.522	15.609	74.638
27	93.41	15.585	76.934
28	93.648	15.595	78.988
29	93.735	15.582	80.813
30	93.683	15.585	82.417
31	93.695	15.585	83.815
32	93.821	15.587	85.036
33	93.864	15.611	86.13
34	93.91	15.579	87.074
35	94.016	15.601	87.91
36	93.941	15.574	88.639
37	94.025	15.577	89.26
38	94.032	15.582	89.831
39	94.058	15.574	90.316
40	94.074	15.593	90.726
41	94.123	15.56	91.102
42	94.123	15.579	91.435
43	94.168	15.566	91.689
44	94.147	15.595	91.956
45	94.158	15.601	92.133
46	94.186	15.59	92.317
47	94.207	15.587	92.46
48	94.189	15.593	92.616
49	94.231	15.555	92.717
50	94.205	15.574	92.834

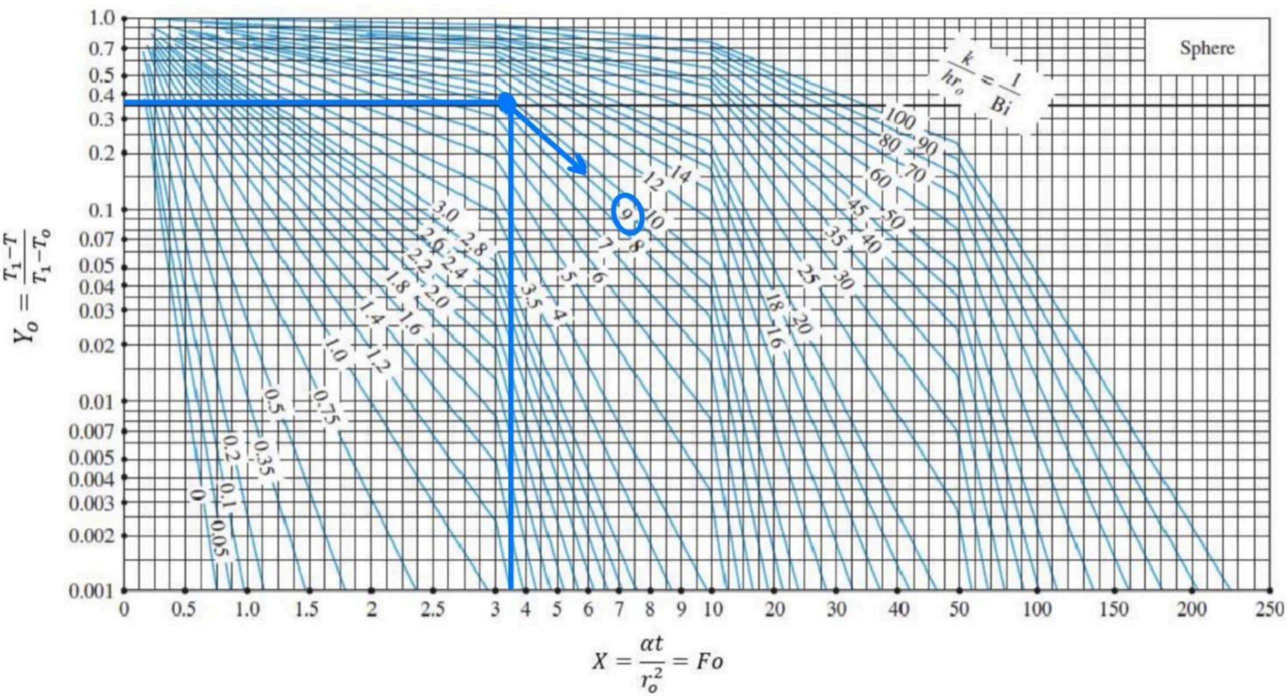
Table 1: Scan numbers between 13-50 time intervals that shows the different temperature readings.

thermal diffusivity	k	R0(m)	101 (average)	Ti	Tinf
0.000037	121	0.02225	93.60136111	17.734	93.6013611

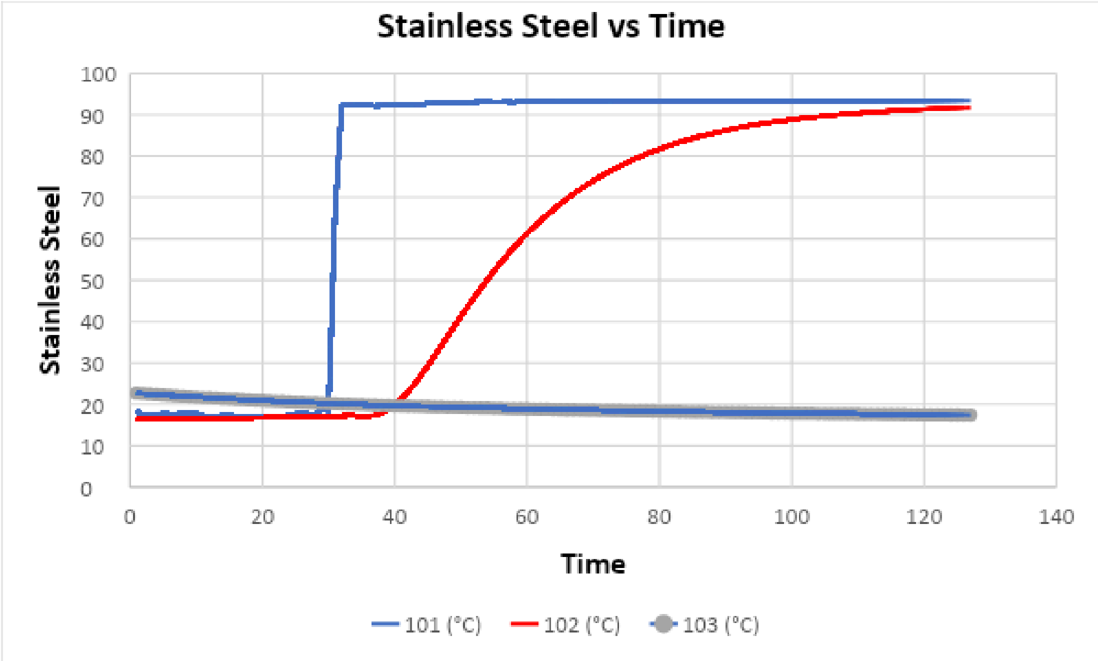
	theta()	Fo	1/Biot	biot	h	h(average)
scan 23 (time 22)	0.36239493	1.644236839	4	0.25	1359.55056	887.4843945
scan 33 (time 32)	0.371728582	2.39161722	6	0.166667	906.367041	
scan 43 (time 42)	0.375759022	3.138997601	8	0.125	679.775281	
scan 50 (time 49)	0.376249569	3.662163868	9	0.111111	604.244694	

Table 2: Calculations for brass obtained after solving the required equations.


T1
h
Initially
T = To
T1
h
0
r_o
r


Sphere
k/(hr_o) = 1/Bi
Y_o = (T1 − T)/(T1 − To)
X = αt/r_o^2 = Fo

Calculations for Stainless-Steel:



Graph 2: Collective temperatures versus time graphic that shows the data gathered under three different temperatures for stainless steel.

Scan Numl	101 (°C)	102 (°C)	103 (°C)
40	92.367	19.811	19.684
41	92.484	21.264	19.614
42	92.463	23.004	19.584
43	92.573	24.922	19.533
44	92.542	27.03	19.482
45	92.695	29.309	19.472
46	92.799	31.634	19.405
47	92.89	34.037	19.398
48	92.89	36.447	19.341
49	92.913	38.842	19.32
50	92.862	41.208	19.281
51	92.873	43.53	19.235
52	93.046	45.832	19.197
53	93.179	48.045	19.175
54	93.128	50.176	19.148
55	93.088	52.225	19.097
56	93.102	54.195	19.046
57	93.153	56.072	19.003
58	93.062	57.894	18.968
59	93.249	59.604	18.944
60	93.244	61.238	18.909
61	93.282	62.792	18.888
62	93.298	64.312	18.839
63	93.312	65.724	18.831
64	93.263	67.088	18.775
65	93.188	68.391	18.721
66	93.354	69.632	18.694
67	93.357	70.838	18.689
68	93.366	71.955	18.643
69	93.359	72.988	18.622
70	93.394	74.036	18.614
71	93.38	74.999	18.568
72	93.373	75.91	18.544
73	93.441	76.769	18.511
74	93.446	77.589	18.493
75	93.446	78.348	18.455
76	93.457	79.091	18.415
77	93.464	79.833	18.407
78	93.45	80.493	18.38
79	93.49	81.135	18.356
80	93.45	81.717	18.307
81	93.46	82.289	18.283
82	93.436	82.833	18.264
83	93.478	83.348	18.253
84	93.502	83.816	18.221
85	93.504	84.277	18.189
86	93.46	84.699	18.159
87	93.495	85.113	18.149
88	93.478	85.496	18.127
89	93.49	85.884	18.108
90	93.488	86.219	18.098
91	93.492	86.57	18.06
92	93.483	86.891	18.036
93	93.488	87.195	18.025
94	93.497	87.479	17.986
95	93.493	87.744	17.975
96	93.514	88.001	17.96
97	93.481	88.21	17.919
98	93.479	88.439	17.9
99	93.472	88.64	17.872
100	93.456	88.853	17.856
101	93.456	89.031	17.832
102	93.461	89.231	17.843
103	93.449	89.392	17.812
104	93.44	89.558	17.777
105	93.452	89.732	17.775
106	93.442	89.872	17.748
107	93.447	89.994	17.74
108	93.431	90.124	17.716

*Table SEQ Table * ARABIC 3: Scan numbers between 40-108 time intervals that shows the different temperature readings.*

Biot number calculation

$$\frac{\theta}{\theta_o} = \frac{T(t) - T_\infty}{T_o - T_\infty} = e^{-Bi\,Fo} \qquad (1)$$

In order to find the value for the calculated biot number, iteration method is used by using the equation 1 above. At the end of the biot number comparison and iteration, the final **k** value is obtained as 16.

h(average)	cp	p	r0	101 (average)	Ti	Tinf	time	theta
	480	8000	0.02225	93.2666087	19.811	93.2666087	68	0.04491986

k	Bi (graph)	1/bi	Thermal Diffusivity	Fo	theta	h	bi(calculated)
30	1.538461538	0.650	7.81E-06	1.073	0.045	2074.330	2.892
20	2.857142857	0.350	5.21E-06	0.715	0.045	2568.218	4.337
15	10	0.100	3.91E-06	0.537	0.045	6741.573	5.783
13	25	0.040	3.39E-06	0.465	0.045	14606.742	6.673
25	2	0.500	6.51E-06	0.894	0.045	2247.191	3.470
22	2.5	0.400	5.73E-06	0.787	0.000	2471.910	3.943
17	4.545454545	0.220	4.43E-06	0.608	0.000	3472.932	5.103
16	5.555555556	0.180	4.17E-06	0.572	0.000	3995.006	5.422

Table 4: Calculations for stainless steel obtained after solving the required equations.

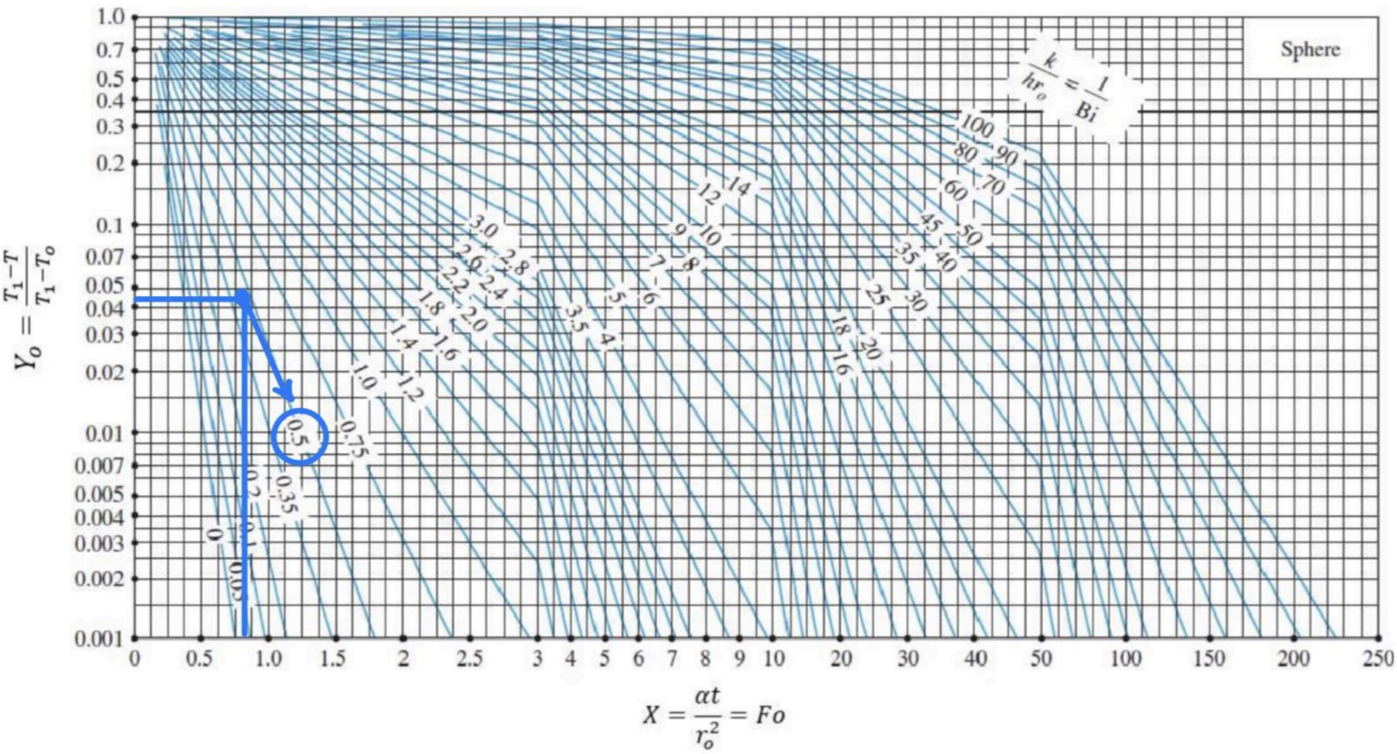


*Figure SEQ Figure * ARABIC 3 The 1/Bi number value measured for the values found in k=25.*

Conclusion

This experiment was carried out to investigate the thermal conductivity and convection heat transfer properties of solid spheres. The heat transfer properties of spheres made of two different materials were measured and calculated under various conditions. A point t=0 was selected from the data obtained from the experiment (Graph 1). Biot number, Fourier Number and dimensionless temperature (θ) and h values and average h value were obtained using the given table. The thermal conductivity and convection coefficient of the brass sphere were determined. The data obtained from the experiment were also used for the steel sphere (Table 3). Thermal diffusivity, Fourier Number, convection heat transfer coefficient and biot number were calculated for the steel sphere. Biot number was also read from the table. The convection heat transfer coefficient value of the first sphere helped to determine the thermal conductivity and diffusivity of the second sphere. These values are shown in table 2 and table 4. The results obtained show that various materials have different thermal conductivity and heat transfer properties. Experimental results show that the convection coefficient can vary with time and material properties. In addition, the thermal conductivity of the steel sphere was verified by comparing the experimentally determined values with the literature values.