Mech 306

Lab #3 Part A
Heat Transfer

Group 35

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Question i)

Variable	Measurement
Mass of Rod (m_{rod})	*215g*
Diameter of Rod (d_{rod})	*14.2mm*
Length of Rod (L_{rod})	*158.5mm*
Outer diameter of insulation (d_{ins})	*38mm*
Thermocouple spacings on rod	*3mm, 54mm, 104mm, 155mm*

Table 1 - Experimental Measurements

The equation that relates all experiment parameters is :

$$\frac{T(x,t)-T_i}{T_s-T_i} = 1 - erf\left(\frac{x}{2\sqrt{\alpha t}}\right)$$

The only value that we do not know from the experiment directly is thermal diffusivity α, and we choose to analyze the data points from the third thermocouple at 104mm to estimate it. We plot a graph of temperature over time with experimental data in MATLAB. The ten circles at each data sample point represents ten different α values. The top circle has the minimum α value and is increasing as the circles go down. We can conclude from Figure 1 that the fourth circle basically best fits the curve, and a good estimation of α would be **0.00003**.

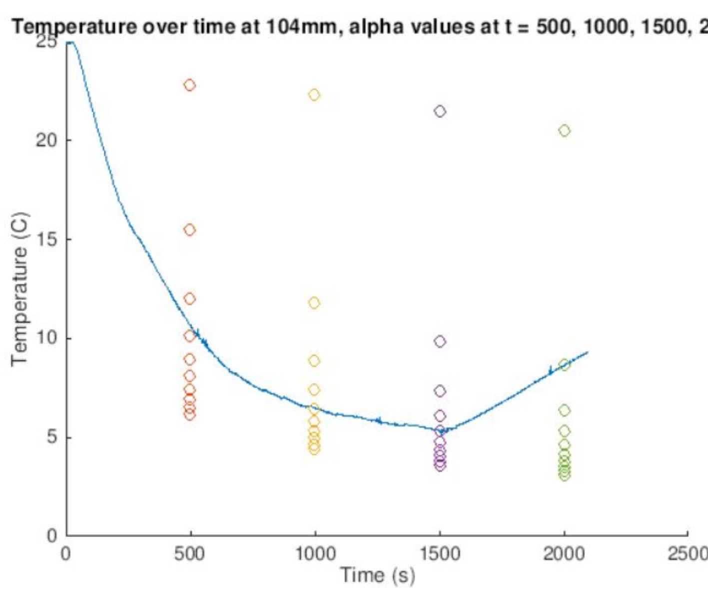

Figure 1 - Temperature vs Time with Ten α Values

The third column of the following graph corresponds to α value, and first row is the top circles in Figure 1. The fourth α value is around 0.0000003 * 1.0e+02 = 0.00003. To get more precise α value, we need to do multiple data collection at the same location; however, due to time constraint, we only have one set of data which is the main source of discrepancy.

```
a =

   1.0e+02 *

   5.000000000000000   0.227770571219580   0.000000010000000
   5.000000000000000   0.154722588434886   0.000000110000000
   5.000000000000000   0.120164685309641   0.000000210000000
   5.000000000000000   0.101520500967744   0.000000310000000
   5.000000000000000   0.089485868604361   0.000000410000000
   5.000000000000000   0.080907349149482   0.000000510000000
   5.000000000000000   0.074397774899492   0.000000610000000
   5.000000000000000   0.069241093557217   0.000000710000000
   5.000000000000000   0.065025863178994   0.000000810000000
   5.000000000000000   0.061496768581529   0.000000910000000
```

Figure 2 - Ten α Trial Values

From the thermal diffusivity table we figure out that the material of rod in this experiment could be **iron** (α = 2.3 x 10^{-5}). The specific heat capacity (C) of iron is 4.12 x 10^{-4} J/(kg*K). Since we cannot find enough information about the thermal diffusivity of different material, iron might not be the best candidate material.

Plotting theoretical values against experimental values, you can see that approximations are fairly accurate at x = 3, 54, 104 mm. However, it is less accurate at 155 mm. This could be due to its farthest distance from the cold source making it more susceptible to random errors when exchanging energy with the ice.

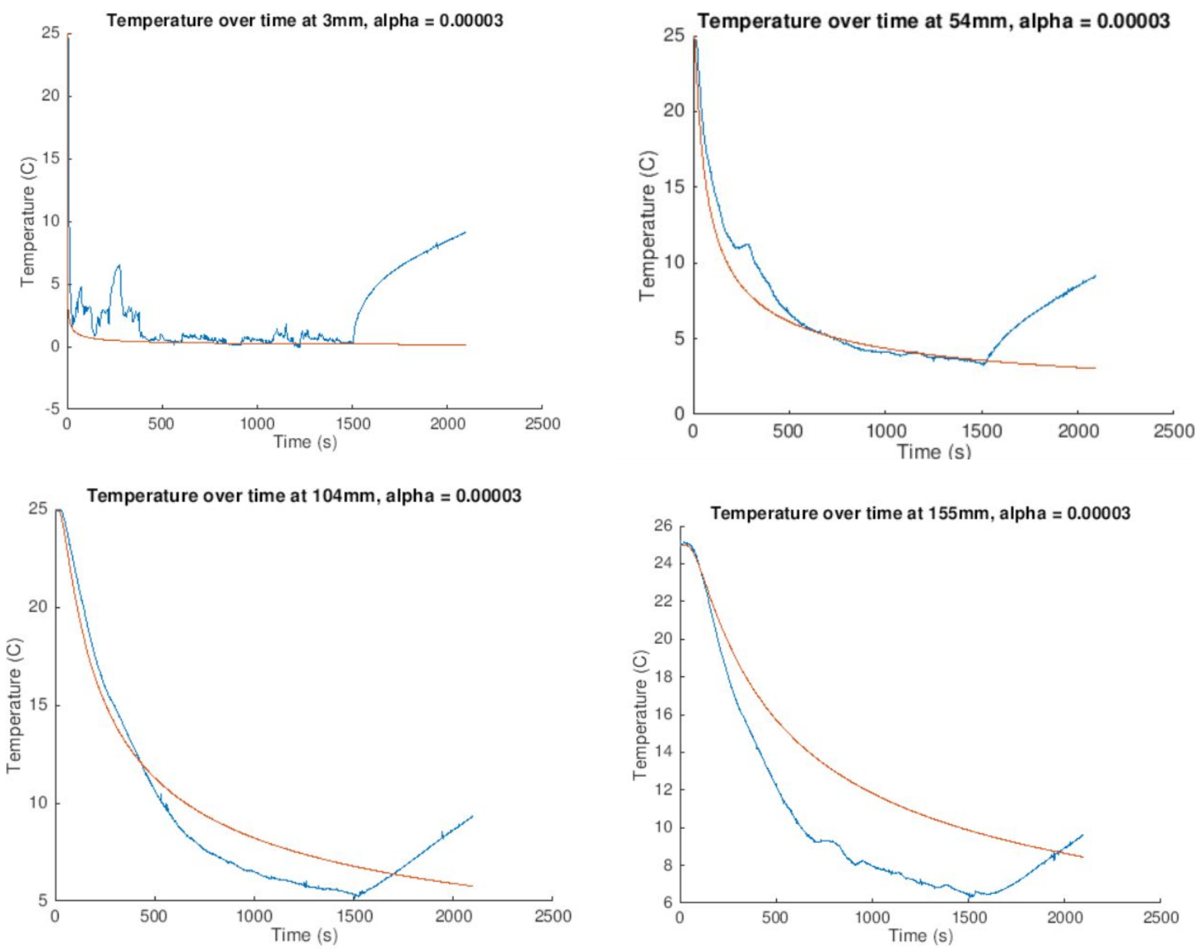

Figure 3 - Plotting Theoretical Values (red) vs Experimental values (blue)

Question ii)

For this part of the experiment, we use Newton's Law of Cooling and solve the differential equation to get:

$$T = 25 - C_1 e^{-\frac{t}{mCR}}$$

The data will be only from the last 10 minutes when the rod is taken out of the ice. With m measured and C found in the first part of the lab, we can estimate the time constant mCR from the temperature vs. time graph and calculate R. In this graph, when t = 0s, T = 3.86℃, so C_1 = 21.14, and from calculations when t = mCR, T = 25-21.14*e^{-1} = 17.223℃ or 290.373 K. Then we interpret from the graph, we get time constant t = 4305.82s.

Therefore, t = mCR = 4305.82s, with C = 4.12 x 10^{-4} J/(kg*K) and m = 215g,
R = t/mC = 4.86*10^7 K/W. Here R is the estimated overall thermal resistance of the insulation around the rod

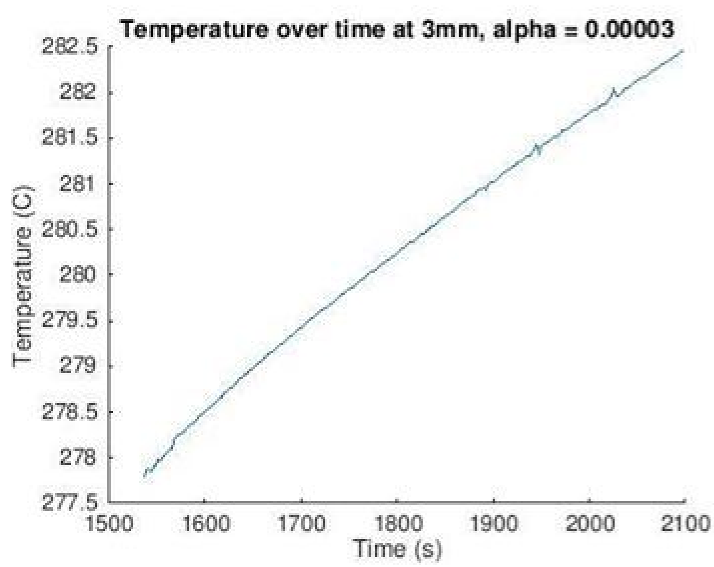

Figure 4 - Last 10 Minutes Temperature over Time

Question iii)

Getting Emissivity

1. Measure the exposed surface area (A) of each rod.
2. Mount a rod in crossflow from the fan.
3. Turn the fan on to the “low heat” setting.
4. Put the cartridge heater in the rod.
5. Heat the rod until the surface temperature of the rod is equal to the air temperature. This will effectively eliminate heat transfer due to convection.
   $q = h(Ts - Tf)$
   If $Ts = Tf$
   Then $q = 0$
6. Record the electrical power output of the cartridge (Either by a power output on the variac or by using the multimeter to calculate the resistance power $P = IV$), the air temperature using the air velocity probe, and the rod surface temperature using the infrared temperature gauge.
7. Repeat the steps above for each rod, and for each setting on the fan.
8. Plot (P/A) vs (Trod^4 - Tair^4) for each rod. The slope of this graph is equal to $\sigma\varepsilon$, where sigma is the Stefan-Boltzmann constant (5.67 x 10^-8 W/m^2/K^4), and epsilon is the emissivity. Dividing the value for the slope by the constant will give the emissivity.

Getting the Convection Heat Transfer Coefficient

1. Heat the rod to temperature greater than the hottest fan temperature.
2. Turn the fan onto the “no heat” setting.
3. Record the temperature of the rod, the temperature of the air, and the power output of the heating cartridge.
4. Use this equation to find the heat transfer coefficient. These steps can be repeated for different fan settings and rod temperatures to improve accuracy.
   $$h = \frac{P - \varepsilon\sigma A(T_{rod}^{\ 4} - T_{air}^{\ 4})}{A(T_{rod} - T_{air})}$$
   A = Surface Area of Rod
   Epsilon = Emissivity from previous steps