Lab Div.: 05 **Names: Jordan Dobstaff, Agathiya Tharun, Alexander James**

Lab Date: 11/29/2023 **Instructor: Tarun Singh**

ME315 Heat and Mass Transfer

Summary Report

Open Lab – Analysis of Annular Fins

Executive Summary

The goal of the experiment was to analyze annular fin efficiency as it varies with thickness. After referencing the textbook, it was decided that the collected data would be validated data against Figure 3.20 from the Fundamentals of Heat and Mass Transfer - Eighth Edition textbook. To do this, equations for h_{fin}, q_f, and θ/θ_b were selected from the textbook. The temperatures at both the tip and base of the fins were needed as well as the power going into the system to satisfy the equations' requirements. A heating cartridge was used to assume constant heat flux was entering the system, which was placed at the center of the annular fins. Drawings of each annular fin setup were created in CAD and an appropriate heating cartridge was purchased.

After machining each fin setup and acquiring the heating cartridge, an experimental setup was developed. The experimental setup involved using the power stat and wattmeter to measure a constant, controllable input power. With the heating cartridge secured in the center of the fin, which was placed on an insulated stand, the blower would create forced convection around the fin. Once the system was given constant input power and the blower was turned on, the setup was measured with the thermal imaging camera and monitored until steady state was reached. Once steady state was reached a thermal image was taken and processed to gather the base and tip temperatures. This process was completed for each fin setup, having thicknesses of 1 mm, 2 mm, 3.5 mm, and 5 mm each.

With the collected data and the aforementioned equations, the experimental data was compared to Figure 3.20. The equations were programmed on Google Colab to analyze the data and yield results for the experiment. Data validation proved that while the results fit the general trend of the graph shown in Figure 3.20, the slope was greater than expected. The main reason the data was steeper stems from the equation for h_{fin} as there were some significant simplifying assumptions made when deriving the equation. Another reason the data may have been steeper was because only one thermal image was taken for each fin at steady state. This implies that some error must have been present in the true steady-state temperature. Finally, the assumption that all power from the outlet goes through the heating cartridge and to the annular fin is not correct as there is some contact resistance between the heating cartridge and the annular fin. Despite these limitations, this experiment worked well and helped broaden understanding of annular fins and the potential that they hold.

1. Introduction

Annular fins, characterized by their ring-shaped configuration, are strategically employed to augment heat transfer rates by increasing the surface area available for convective heat exchange. Annular fins are frequently used to dissipate heat in pipe flow scenarios and are important for many industries including chemical, oi-refining, food and beverage, and automotive. The ability to harness the full potential of annular fins ensures not only improved thermal performance but also contributes to energy efficiency and system longevity in diverse real-world settings.

The goal of the experiment was to analyze how annular fin efficiency varies with thickness. After reviewing the relevant sections in the course textbook, Fundamental of Heat and Mass Transfer – Eighth Edition, it was decided the experimental goal was to validate the results acquired against Figure 3.20. To do this, equations for h_{fin}, q_f, and $\frac{\theta}{\theta_b}$ were pulled from the textbook. The temperature at both the tip and base of the fins were needed as well as the power going into the system to satisfy the equations' requirements.

To heat each annular fin setup to steady state, it was decided a heating cartridge would be placed at the center. The heating cartridge in **Fig. 2.3** was chosen as it gave a sufficient amount of heat and was an appropriate size relative to the annular fin setup design. Furthermore, the use of a heating cartridge allowed for a constant heat flux assumption, simplifying the calculations needing to be one later. Once the heating cartridge was ordered and approved each fin setup was machined in the ME machine shop out of 6061 T6 general purpose aluminum alloy.

The 3.5 mm fin thickness annular fin setup was machined to the specifications set out in **Fig. 2.2**, while the 1 mm, 2 mm, and 5 mm had similar drawings with the thickness being varied appropriately.

2. Experimental Model System

To record the temperature of the fins during the experiment, a thermal imaging camera was used. However, aluminum is extremely thermally reflective which made it difficult for the camera to properly read the temperature. To combat this, the fins were painted black before beginning the experiment. Also, to minimize the effects of conduction from the fins into the supporting stand, insulated foam was added throughout the stand as seen in **Fig. 2.1**.

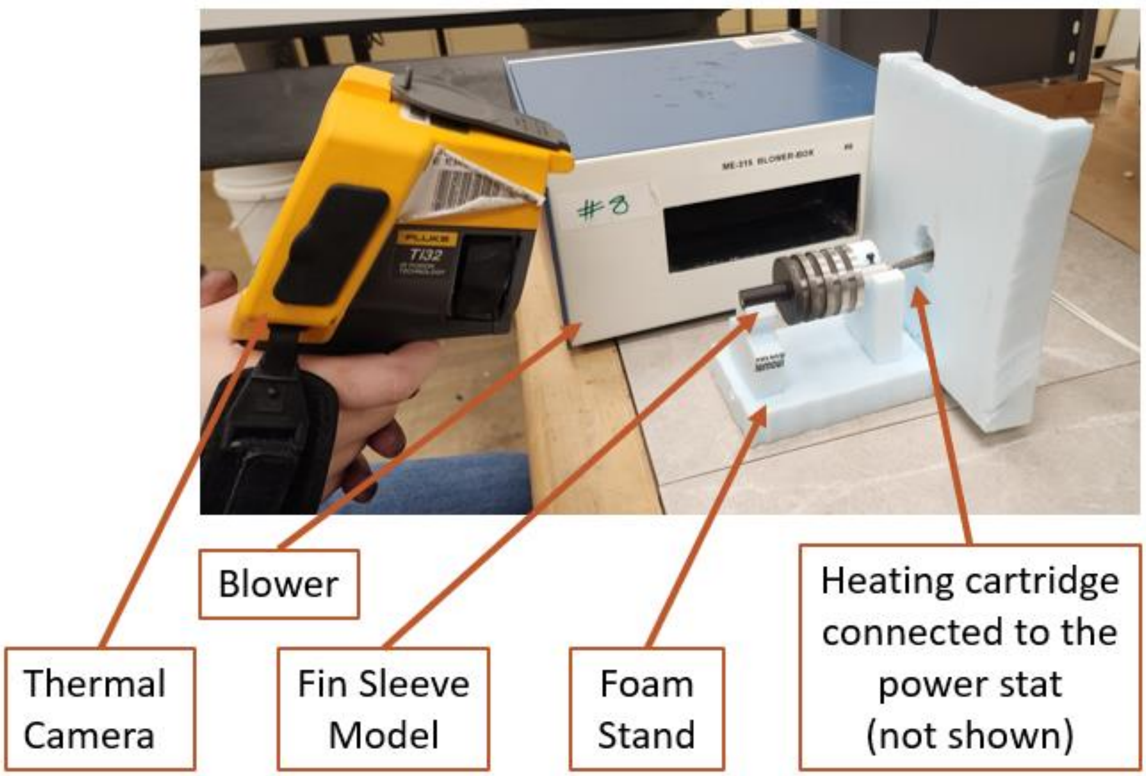

Figure 2.1: Experimental Setup

To begin the experiment, the heating cartridge, as seen in **Fig. 2.2**, was plugged into the power stat, and the power stat was plugged into the outlet through a wattmeter, allowing for a known and controllable power input to the system. Before plugging in the heating cartridge, a static consumption from the power stat was read on the wattmeter, which was later subtracted from the overall power into the system.

Figure 2.2: DERNORD 120V 200W Cartridge Heater

Once the static consumption was measured, the active consumption could be taken by plugging in the heating cartridge and recording the measurement from the wattmeter. The blower box shown in **Fig. 2.1** was also set to its maximum speed at this time. The system was then left to heat until steady state, at which point a thermal image was taken to record the temperature at both the base and the tip of the fin. This was repeated for the 1 mm, 2 mm, 3.5 mm, and 5 mm fins. All fins were machined from aluminum; a sample drawing of the 3.5mm fin can be seen in **Fig. 2.3** below.

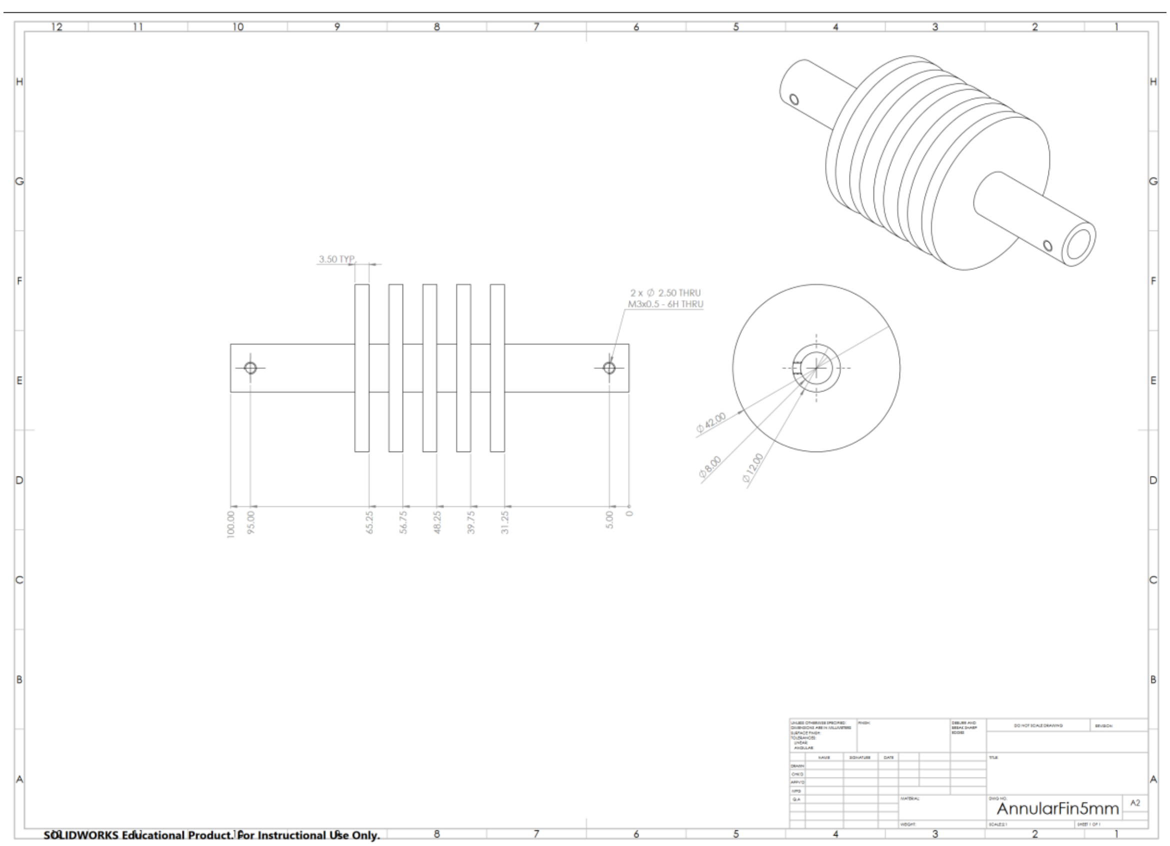

Figure 2.3: Sample annular fin drawing of the 3.5mm thickness model

3. Analysis

The four main equations used in the analysis of annular fins are shown in **Eq. 3.1**, **3.2**, **3.3**, and **3.4**. All the data for **Eq. 3.1** was found during the experiment, with an ambient temperature of 23 degrees Celsius.

$$\frac{\theta}{\theta_b} = \frac{T_{tip} - T_{ambient}}{T_{base} - T_{ambient}}$$

Equation 3.1: Dimensionless temperature ratio.

The power consumption was found using **Eq. 3.2** by subtracting the static consumption of 2.8 W from the total consumption of 31.5 W. It was found that the input power was 28.7 W.

$$h_{fin} = \frac{Power}{A_f * \left(T_{tip} - T_{ambient}\right)}$$

Equation 3.2: Heat transfer coefficient for an annular fin.

A_f was found using **Eq. 3.5** where t is thickness, r_2 is the outer radius of 21 mm and r_1 is the inner radius of 6 mm. This was used to find q_f by leveraging **Eq. 3.3** and a thermal conductivity, k, of 152 W/mK, a $d\theta$ of $T_{tip} - T_{base}$ and a dr of $r_2 - r_1$. The k value given for **Eq. 3.3** is a property of aluminum which was found in the Fundamentals of Heat and Mass Transfer - Eighth Edition textbook.

$$q_f = -kA_{c,b} \left.\frac{dT}{dr}\right|_{r=r_1} = -k(2\pi r_1 t) \left.\frac{d\theta}{dr}\right|_{r=r_1}$$

Equation 3.3: Heat transfer rate for an annular fin.

Finally, to calculate fin efficiency, η_f, from **Eq. 3.4**, all the above terms were calculated and used. All the calculations were done in Google Colab using the code listed in Appendix B.

$$\eta_f = \frac{q_f}{2h\pi(r_2^2 - r_1^2)\theta_b}$$

Equation 3.4: Annular fin efficiency.

These calculated values were then compared to **Fig. 3.1** to check if the results found from the equations used were accurate.

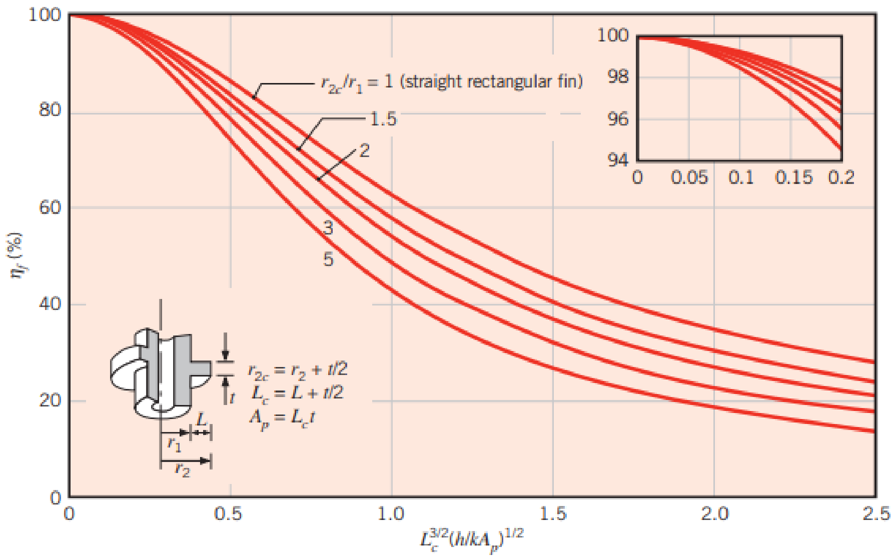

FIGURE 3.20 Efficiency of annular fins of rectangular profile.

Figure 3.1: Figure 3.20 in Heat and Mass Transfer Eighth Edition

The equation to solve for A_f can be seen below.

$$A_f = 2\pi\left(\left(r_2 + \frac{t}{2}\right)^2 - (r_1)^2\right)t$$

Equation 3.5: Fin surface area.

4. Results and Discussion

The temperature data collected from the experiment can be seen through the thermal images below in **Figs. 4.1**, **4.2**, **4.3**, and **4.4**.

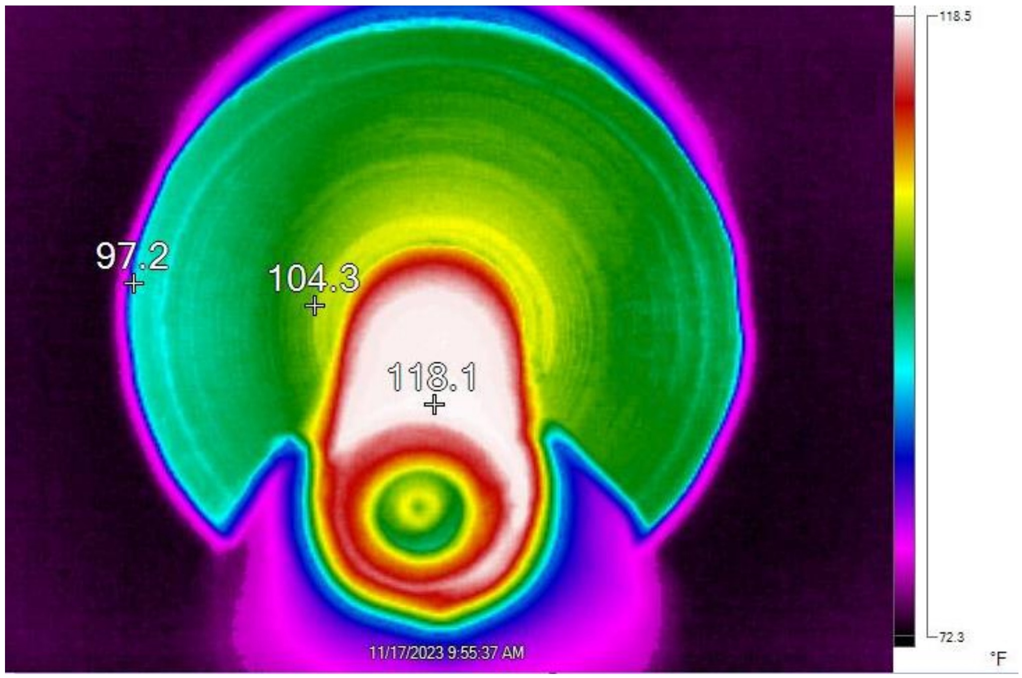

Figure 4.1: Temperature readings of the 1mm annular fin at steady state

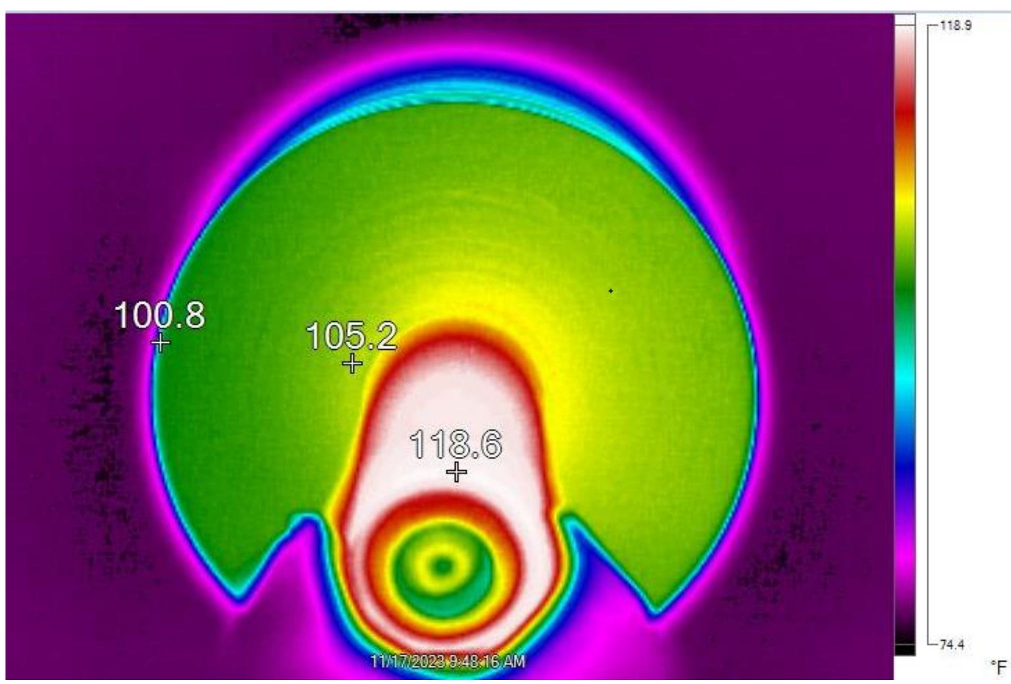

Figure 4.2: Temperature readings of the 2mm annular fin at steady state

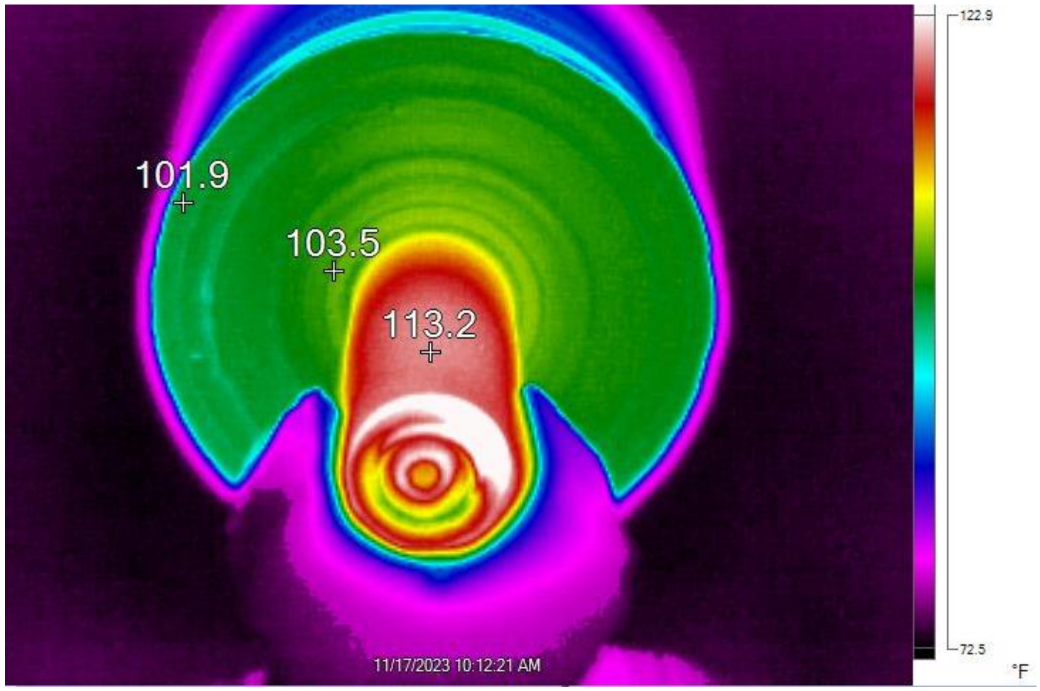

Figure 4.3: Temperature readings of the 3.5mm annular fin at steady state

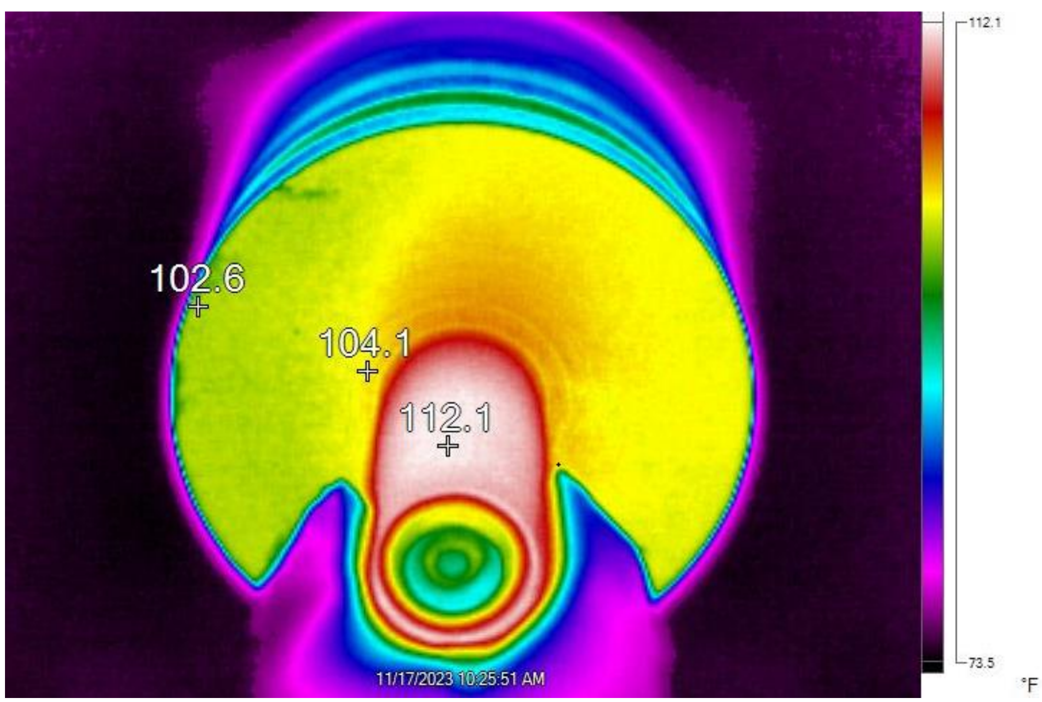

Figure 4.4: Temperature readings of the 5mm annular fin at steady state

A control image of the fins with no heating can be seen below in **Fig. 4.5**:

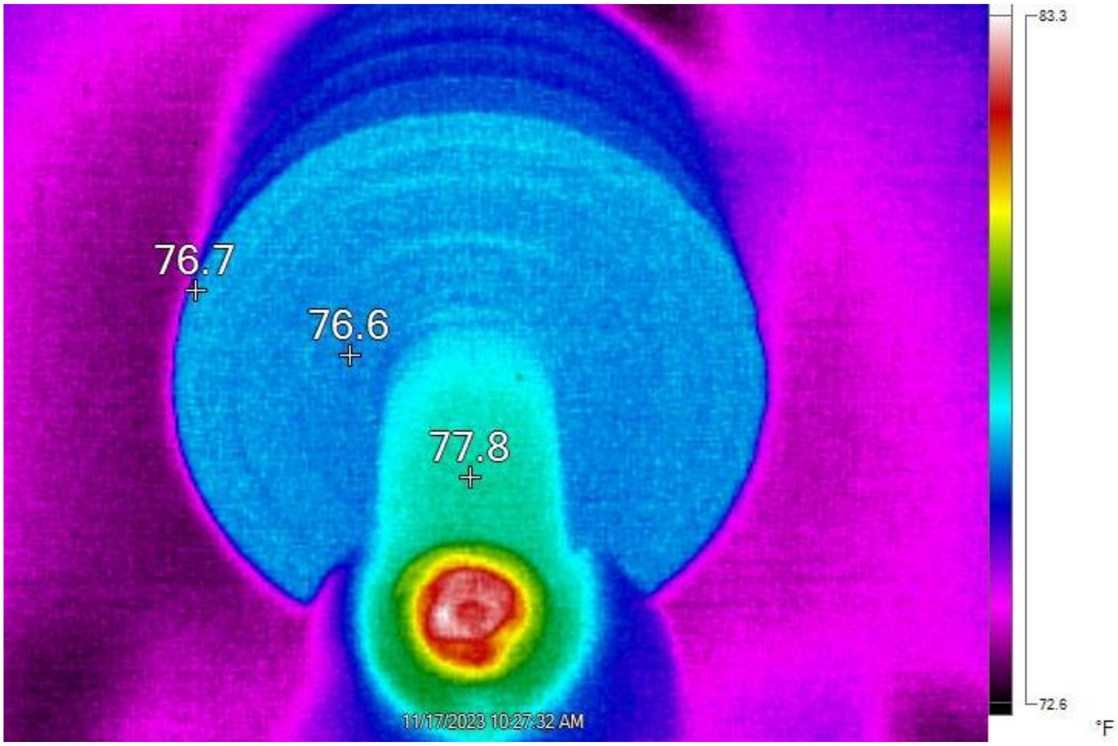

Figure 4.5: Thermal control image

It was evident from the data that fin tip temperature steadily increased as fin thickness increased. This is most likely due to the thicker fins having less thermal resistance allowing for more conduction to the tip of the fin. Because heat flows more quickly to the tip of the fin as the fin thickness increases, it can also dissipate heat more quickly as this is a more effective surface area. The increase in effectiveness is limited, as the thickness of the fins increases it trends toward a solid thick-walled pipe. Having a thick-walled pipe would mean a larger mass and much more material which may present issues in a real-world application.

After analyzing the data using the equations listed in **Eq. 3.1** through **3.4**, the thermal resistance was calculated and is listed in **Fig. 4.6** while the rest of the data that was calculated is listed in **Table 4.1**.

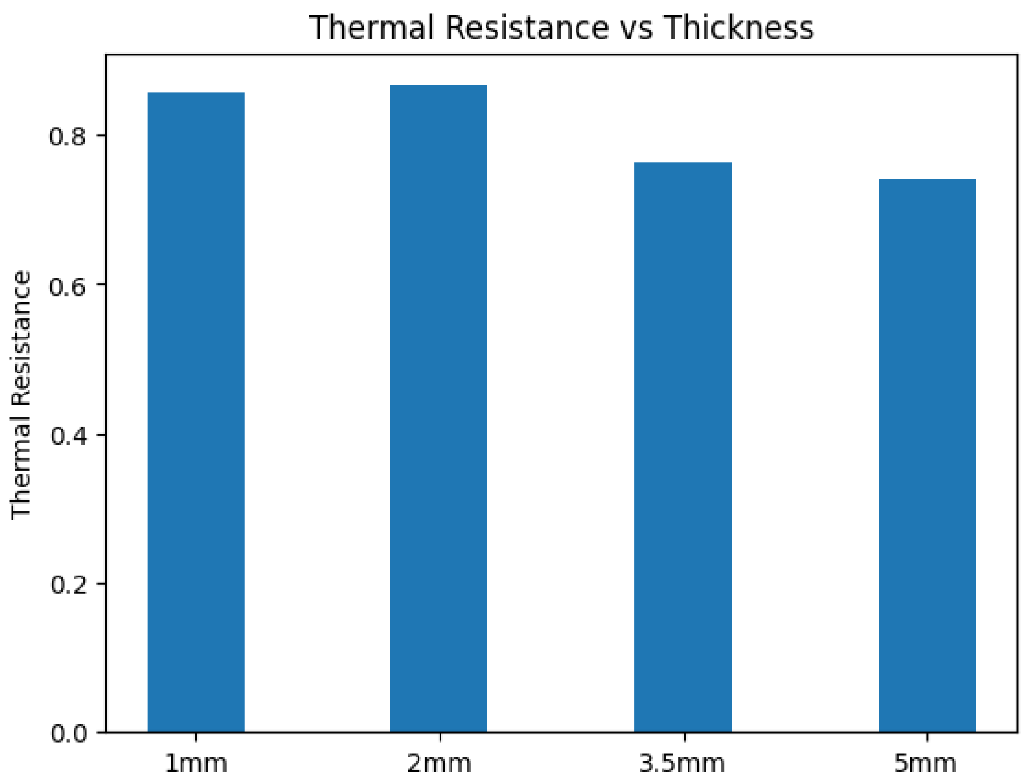

Figure 4.6: Thermal Resistance vs Thickness

Table 4.1: Calculated Data

Thickness [mm]	θ/θ_b **[K]**	**h [W/m^2K]**	q_f **[W]**	η [ ]
1	0.53	163.79	2.19	0.21
2	0.61	135.36	3.73	0.43
3.5	0.72	121.07	4.14	0.61
5	0.75	110.22	4.97	0.82

The biggest issue was when comparing the data to **Fig. 4.7**, the slope of the data points was larger than expected. Despite this, the data for the fin thicknesses used seems to match quite well with **Fig. 4.7**, as the data points closely match the trend of Figure 3.20.

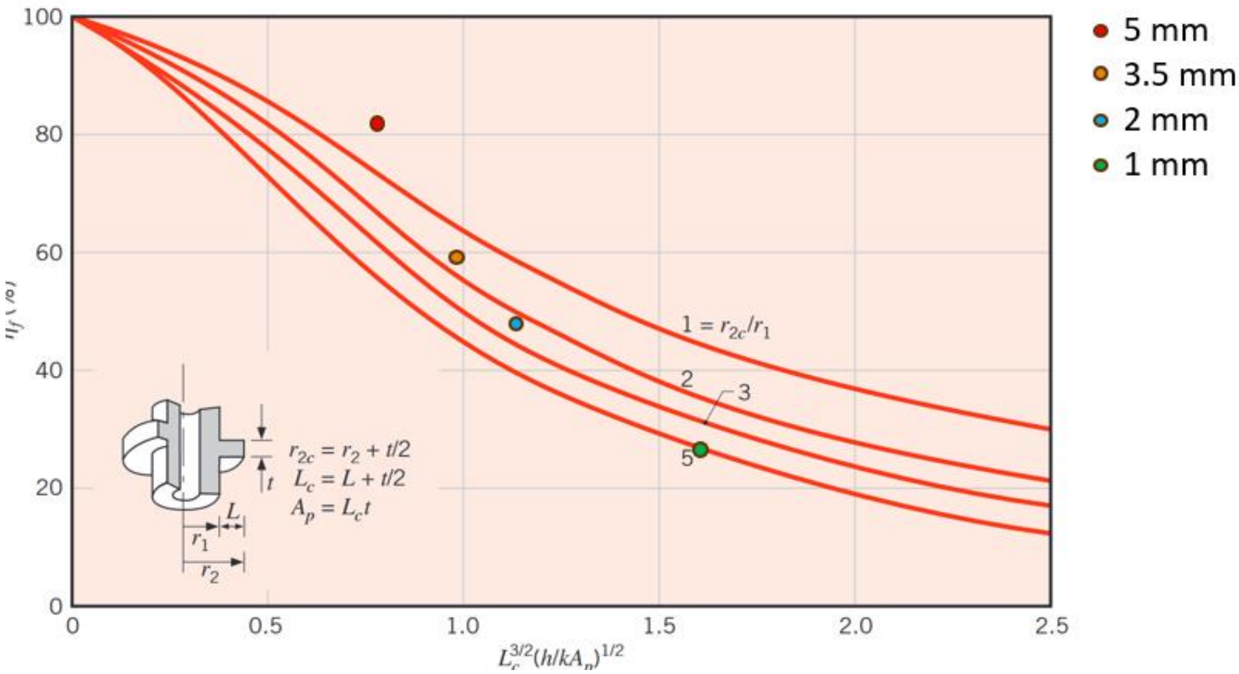

Figure 4.7: Comparison to Figure 3.20 in the textbook

The main source of error in the data and calculations comes from the equation for h_{fin}, as there were errors in the equation due to oversimplification using assumptions. Another source of error that may affect the data is the use of only one thermal image per fin setup as the fins may not have reached a true steady state at the time of the image. If there is variation between the true steady state temperature and the temperature recorded, this would have a profound impact on the end results of the data analysis. Finally, an assumption is made that all power recorded from the wattmeter goes into the system, however there are losses due to contact resistance, exposed ends, contact with the insulated base, and other areas where power may be lost due to other sources than forced convection through the fin region.

5. Conclusion

The goal of this open lab was to see how changing the thickness of an annular fin would affect the overall efficiency of the fin. The data collected, calculations done, and results found from this experiment all work to create a better understanding of annular fins and their properties when under forced convection. While the experimental calculations did have some errors that affected the overall data, this experiment still showed that increasing the thickness of an annular fin allows for an increase in efficiency. Some future work that could be done involving fixing the fin convection coefficient term to allow for more accurate results, as well as trying to record more data to alleviate any errors with finding the steady state values of each fin. Also, given more time, another experiment could be done that varies radius instead and an analysis could be completed to show whether changing radius or changing thickness has more of an effect on the efficiency of the fin.

References

Bergman, T. L., and Adrienne S. Levine. *Fundamentals of Heat and Mass Transfer*. John Wiley & Sons, Inc., 2019.

Appendix A

Assumptions:

- Each fin has the same temperature distribution
- Negligible radiation
- Negligible contact resistance
- Input power is constant
- 1-D heat transfer
- Constant temperature distribution along given radius

Sample Calculation for 5mm fin thickness:

$\frac{\theta}{\theta_b} = \frac{T_{tip} - T_{ambient}}{T_{base} - T_{ambient}} = \frac{312.37 - 296.15}{317.65 - 296.15} = \frac{16.22}{21.5} = 0.754$
$h_{fin} = \frac{Power}{5A_f * (T_{tip} - T_{ambient})} = \frac{29}{5\left(2\pi\left(\left(r_2 + \frac{t}{2}\right)^2 - r_1^2\right)\right)}$ $\rightarrow \frac{29}{0.0032(16.22)} = 110.22 \frac{W}{m^2K}$
$q_f = -5kA_{c,b}\frac{dT}{dr}\Big\vert_{r=r_1} = -5k(2\pi r_1 t)\frac{T_{tip} - T_{base}}{r_2 - r_1}$ $\rightarrow 5(-152(2\pi)(0.006)(0.005))\left(\frac{312.37 - 317.65}{\left(\frac{42}{2} - \frac{12}{2}\right) * 10^{-3}}\right) = 50.41W$
$\eta_f = \frac{q_f}{2h\pi(r_2^2 - r_1^2)\theta_b} = \frac{50.41}{2\pi(0.024^2 - 0.006^2)(110.22)(21.5)} = 0.82$

Uncertainty analysis:

$$u_{q_f} = \pm\sqrt{\left(\frac{\partial q_f}{\partial T_{tip}}\right)^2 + \left(\frac{\partial q_f}{\partial T_{base}}\right)^2}$$

$$u_{q_f} = \pm\sqrt{\left(-\frac{10k\pi r_1 t}{r_2 - r_1}\right)^2 + \left(\frac{10k\pi r_1 t}{r_2 - r_1}\right)^2}$$

$$u_{q_f} = \pm\sqrt{(-0.1433)^2 + (0.1433)^2} = \pm 0.202W$$

Appendix B

```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
import math
# Data I know

T_amb = 23 + 273.15 #K

T_cont_base = (77.8-32)*5/9 + 273.15
T_1mm_base = (118.1-32)*5/9 + 273.15
T_2mm_base = (118.6-32)*5/9 + 273.15
T_35mm_base = (113.2-32)*5/9 + 273.15
T_5mm_base =  (112.1-32)*5/9 + 273.15

T_cont_base_fin = (76.6-32)*5/9 + 273.15
T_1mm_base_fin = (104.3-32)*5/9 + 273.15
T_2mm_base_fin = (105.2-32)*5/9 + 273.15
T_35mm_base_fin = (103.5-32)*5/9 + 273.15
T_5mm_base_fin = (104.1-32)*5/9 + 273.15

T_cont_tip = (76.7-32)*5/9 + 273.15
T_1mm_tip = (97.2-32)*5/9 + 273.15
T_2mm_tip = (100.8-32)*5/9 + 273.15
T_35mm_tip = (101.9-32)*5/9 + 273.15
T_5mm_tip = (102.6-32)*5/9 + 273.15

K = 152 #W/m*K -- material prop.

Len = 100*10**(-3) #m (length of fin)
r1 = (12/2)*10**(-3) #m (radius of base)
r2 = (42/2)*10**(-3) #m (radius of tip)
L = r2-r1 #m (distance from base to tip)
t = np.array([1,2,3.5,5])*10**(-3) #m (thickness of each fin)
L_c = L + t/2
r2_c = r2 + t/2
Af = 5*2*np.pi*(r2_c**2-r1**2)
A_c = 2*np.pi*(r2**2-r1**2)*t
A_p = L_c*t
V = np.pi*(r2**2-r1**2)*t
P = 5*2*math.pi*r2

Power_In = 29  # [W]
```

```
R_1mm = (T_1mm_base-T_amb)/(Power_In) # deltaT/q  -- type out the equation
for calculating total plate resistance based on the measured temperatures
R_2mm = (T_2mm_base-T_amb)/(Power_In)
R_35mm = (T_35mm_base-T_amb)/(Power_In)
R_5mm = (T_5mm_base-T_amb)/(Power_In)

print(f'The thermal resistance of \n1mm : {R_1mm: .2f}[K/W]')
print(f'2mm : {R_2mm: .2f}[K/W]')
print(f'3mm : {R_35mm: .2f}[K/W]')
print(f'5mm : {R_5mm: .2f}[K/W]')

# Create a figure and a set of subplots
fig, ax = plt.subplots()

# Create a bar chart
ax.bar(['1mm','2mm', '3.5mm','5mm'], [R_1mm,R_2mm,R_35mm,R_5mm], width
=0.4)

# Set labels
ax.set_ylabel('Thermal Resistance')
ax.set_title('Thermal Resistance vs Thickness')

# heat transfer coefficient for flat plate
A_fin = 2*np.pi*(r2**2-r1**2)*t + 2*np.pi*r1*Len

# heat transfer coefficient for One fin

theta_by_theta_b_1mm = (T_1mm_tip-T_amb)/(T_1mm_base-T_amb)
theta_by_theta_b_2mm = (T_2mm_tip-T_amb)/(T_2mm_base-T_amb)
theta_by_theta_b_35mm = (T_35mm_tip-T_amb)/(T_35mm_base-T_amb)
theta_by_theta_b_5mm = (T_5mm_tip-T_amb)/(T_5mm_base-T_amb)

print(f'  Theta/theta_b for 1mm : {theta_by_theta_b_1mm: .2f} [W/m^2-K]')
print(f'  Theta/theta_b for 2mm : {theta_by_theta_b_2mm: .2f} [W/m^2-K]')
print(f'  Theta/theta_b for 3mm : {theta_by_theta_b_35mm: .2f} [W/m^2-K]')
print(f'  Theta/theta_b for 5mm : {theta_by_theta_b_5mm: .2f} [W/m^2-K]')

# h values

h_fin_1mm = Power_In/(Af[0] * (T_1mm_tip - T_amb)) # [W/ m^2-K] Af + P*t?
h_fin_1mm_test = 1/(R_1mm*Af[0]) # [W/ m^2-K] Af + P*t?
h_fin_2mm = Power_In/(Af[1] * (T_2mm_tip - T_amb)) # [W/ m^2-K]
h_fin_2mm_test = 1/(R_2mm*Af[1])
h_fin_35mm = Power_In/(Af[2] * (T_35mm_tip - T_amb)) # [W/ m^2-K]
h_fin_35mm_test = 1/(R_35mm*Af[2])
```

```
h_fin_5mm = Power_In/(Af[3] * (T_5mm_tip - T_amb)) # [W/ m^2-K]
h_fin_5mm_test = 1/(R_5mm*Af[3])

print(f'  L_c^(3/2)*(h/k*A)^1/2 of 1mm :
{L_c[0]**(3/2)*(h_fin_1mm/(K*A_p[0]))**(1/2): .2f} []')
print(f'  L_c^(3/2)*(h/k*A)^1/2 of 2mm :
{L_c[1]**(3/2)*(h_fin_2mm/(K*A_p[1]))**(1/2): .2f} []')
print(f'  L_c^(3/2)*(h/k*A)^1/2 of 3.5mm :
{L_c[2]**(3/2)*(h_fin_35mm/(K*A_p[2]))**(1/2): .2f} []')
print(f'  L_c^(3/2)*(h/k*A)^1/2 of 5mm :
{L_c[3]**(3/2)*(h_fin_5mm/(K*A_p[3]))**(1/2): .2f} []')
# total heat disspated through fins

# Bessel function attempt
m  = np.sqrt((2*h_fin_1mm) / K * t[0]) # m^2 = 2h/kt
#M = np.sqrt(h_fin_OneFin * P * K * A_c) * theta_by_theta_b_OneFin

K0_r1 = 3 #bessel function numbers from table using x = m*r
K1_r1 = 8 #*e^x
K1_r2 = 8
I0_r1 = 0.9 #*e^-x
I1_r1 =  0.04
I1_r2 = 0.04
bessel = (K1_r1*I1_r2-I1_r1*K1_r2)/(K0_r1*I1_r2+I0_r1*K1_r2)

#q_fin_1mm = 2*np.pi*K*r1*t[0]*(T_1mm_base-T_amb)*m #need to find this
somehow

#using earlier method before bessel derivation in textbook
q_fin_1mm = 5*-K*(2*np.pi*r1*t[0])*(T_1mm_tip-T_1mm_base)/((r2-r1)) #-
K*(2*np.pi*r1*t)*d(theta)/d(r)
q_fin_2mm = 5*-K*(2*np.pi*r1*t[1])*(T_2mm_tip-T_2mm_base)/((r2-r1))
q_fin_35mm = 5*-K*(2*np.pi*r1*t[2])*(T_35mm_tip-T_35mm_base)/((r2-r1))
q_fin_5mm = 5*-K*(2*np.pi*r1*t[3])*(T_5mm_tip-T_5mm_base)/((r2-r1))

q_fin_1mm_test = A_fin[0]*h_fin_1mm_test*((T_1mm_tip - T_amb))
q_fin_2mm_test = A_fin[1]*h_fin_2mm_test*((T_2mm_tip - T_amb))
q_fin_35mm_test = A_fin[2]*h_fin_35mm_test*((T_35mm_tip - T_amb))
q_fin_5mm_test = A_fin[3]*h_fin_5mm_test*((T_5mm_tip - T_amb))

# Fin efficiency
eta_1mm = q_fin_1mm/((2*np.pi*(r2**2-r1**2))*h_fin_1mm*(T_1mm_base-T_amb))
eta_2mm = q_fin_2mm/((2*np.pi*(r2**2-r1**2))*h_fin_2mm*(T_2mm_base-T_amb))
eta_35mm = q_fin_35mm/((2*np.pi*(r2**2-r1**2))*h_fin_35mm*(T_35mm_base-
T_amb))
```

```
eta_5mm = q_fin_5mm/((2*np.pi*(r2**2-r1**2))*h_fin_5mm*(T_5mm_base-T_amb))

eta_1mm_tes = q_fin_1mm_test/((2*np.pi*(r2**2-
r1**2))*h_fin_1mm_test*(T_1mm_base-T_amb))
eta_2mm_test = q_fin_2mm_test/((2*np.pi*(r2**2-
r1**2))*h_fin_2mm_test*(T_2mm_base-T_amb))
eta_35mm_test = q_fin_35mm_test/((2*np.pi*(r2**2-
r1**2))*h_fin_35mm_test*(T_35mm_base-T_amb))
eta_5mm_test = q_fin_5mm_test/((2*np.pi*(r2**2-
r1**2))*h_fin_5mm_test*(T_5mm_base-T_amb))

# Contact resistance
#1/eta*h*A_t #fin array
#R_contact_OneFin = (SS_TC1_OneFin_mean-
SS_TC2_OneFin_mean)/(q_fin_OneFin/A_c) #(Ts-Tf,b)/qf (idk if contact
resist applies this time)

# print all the values to be reported on the table
print(f'  h_1mm : {h_fin_1mm: .2f} [W/m^2-K]')
print(f'  h_2mm : {h_fin_2mm: .2f} [W/m^2-K]')
print(f'  h_3.5mm : {h_fin_35mm: .2f} [W/m^2-K]')
print(f'  h_5mm : {h_fin_5mm: .2f} [W/m^2-K]')
print(f'  q_fin_1mm : {q_fin_1mm: .2f} [W]')
print(f'  q_fin_2mm : {q_fin_2mm: .2f} [W]')
print(f'  q_fin_3.5mm : {q_fin_35mm: .2f} [W]')
print(f'  q_fin_5mm : {q_fin_5mm: .2f} [W]')
print(f'  eta_1mm : {eta_1mm: .2f} []')
print(f'  eta_2mm : {eta_2mm: .2f} []')
print(f'  eta_3.5mm : {eta_35mm: .2f} []')
print(f'  eta_5mm : {eta_5mm: .2f} []')

# Create a figure and a set of subplots
fig, ax = plt.subplots()

# Create a bar chart
ax.bar(['1mm','2mm', '3.5mm','5mm'],
[theta_by_theta_b_1mm,theta_by_theta_b_2mm,theta_by_theta_b_35mm,theta_by_
theta_b_5mm], width =0.4)

# Set labels
ax.set_ylabel('Theta/Theta_b')
ax.set_title('Theta/Theta_b vs Thickness')

fig, ax = plt.subplots()
# Create a bar chart
```

```
ax.bar(['1mm','2mm', '3.5mm','5mm'],
[h_fin_1mm,h_fin_2mm,h_fin_35mm,h_fin_5mm], width =0.4)

# Set labels
ax.set_ylabel('h [W/m^2K]')
ax.set_title('Heat Transfer Coefficent vs Thickness')

fig, ax = plt.subplots()
# Create a bar chart
ax.bar(['1mm','2mm', '3.5mm','5mm'],
[q_fin_1mm,q_fin_2mm,q_fin_35mm,q_fin_5mm], width =0.4)

# Set labels
ax.set_ylabel('q_fin [W]')
ax.set_title('Heat Transfered Rate vs Thickness')

fig, ax = plt.subplots()
# Create a bar chart
ax.bar(['1mm','2mm', '3.5mm','5mm'], [eta_1mm,eta_2mm,eta_35mm,eta_5mm],
width =0.4)

# Set labels
ax.set_ylabel('Fin Efficency [ ]')
ax.set_title('Fin Efficency vs Thickness')



ax.set_xlabel('L_c^(3/2) * (h/(K*A))^(1/2)')
ax.set_ylabel('eta [%]')

plt.plot(L_c[0]**(3/2)*(h_fin_1mm/(K*A_p[0]))**(1/2),eta_1mm*100,marker='x
')
plt.plot(L_c[1]**(3/2)*(h_fin_1mm/(K*A_p[1]))**(1/2),eta_2mm*100,marker='x
')
plt.plot(L_c[2]**(3/2)*(h_fin_1mm/(K*A_p[2]))**(1/2),eta_35mm*100,marker='
x')
plt.plot(L_c[3]**(3/2)*(h_fin_1mm/(K*A_p[3]))**(1/2),eta_5mm*100,marker='x
')
plt.show()
```