University of Cincinnati
College of Engineering and Applied Science
Department of Mechanical & Materials Engineering

Course Code : **MECH-5072C**
Course Title : **EXPERIMENTAL METHODS/ME**

Experiment Number : #4
Experiment Title : **Extended Surface Heat Transfer**

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Group Code : **F-01**
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: **LIU, Xinran: Objective 2 & 3, 2 hours**
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1. Objectives

At the end of this experiment, the students are expected to:

(a) Determine the average combined convective and radiative heat transfer coefficient given the kind of material and the temperatures at the selected points of a long rod protruding from a heat reservoir under steady state conditions.

(b) Determine the thermal conductivities of other rods placed in identical arrangements. Compare with the catalog values of the same material.

(c) Estimate average convective heat transfer coefficient after correcting for the radiative portion.

(d) If the rods were coated with bee was, determine the demarcation points between the clear and the milky coating for each of the rods as measured from the brass plate.

(e) Calculate the end (tip) temperature of the rod with the highest thermal conductivity and compare this value with the observed temperature.

(f) Determine the rate of heat loss from each rod and the fin efficiency.

(g) Verify the convective heat transfer coefficient using the free (natural) convection correlations.

2. Theoretical Background

With Known thermal conductivity of brass and values of adjacent thermocouples, the Combined heat transfer coefficient could be determined by:

$$\frac{\theta_4}{\theta_5} = \frac{T_4 - T_\infty}{T_5 - T_\infty} = e^{-mx} \tag{1}$$

$$h_t = \frac{kd}{4}\left[\frac{\ln\left(\frac{\theta_4}{\theta_5}\right)}{x_b - x_c}\right]^2 \tag{2}$$

To calculate the thermal conductivity for short (aluminum) fin, an equation can be used.

$$k_{al} = \frac{4h_t}{m^2 d} \tag{3}$$

h_t is the combined heat transfer coefficient;

d is the diameter of the rod.

m can be calculated according to the equation below:

$$0.002m^4 + 0.111m^2 + \left(1 - \frac{\theta_1}{\theta_{10}}\right) = 0 \tag{4}$$

θ_1 is the temperature difference between point 1 and the room temperature;

θ_{10} is the temperature difference between point 10 and the room temperature.

$$\frac{\theta_1}{\theta_{10}} = \frac{T_1 - T_\infty}{T_{10} - T_\infty} \tag{5}$$

The tip temperature of aluminum could be determined by:

$$\frac{\theta}{\theta_0} = \frac{\cosh(mL - mx) + (\frac{h}{mk})\sinh(mL - mx)}{\cosh(mL) + (\frac{h}{mk})\sinh(mL)} \tag{6}$$

Where,

$$m = \sqrt{\frac{hP}{kA_C}}$$

$x = L, length\ of\ the\ fin$

$h = combined\ heat\ transfer\ coefficient$

$k = thermal\ conductivity\ of\ aluminum$

The heat loss from each of these rods can be calculated in the relation.

$$q_{ss} = \sqrt{\frac{hk\pi^2 d^3}{4}}\theta_0 \tag{7}$$

$$q_{al} = \sqrt{\frac{hk\pi^2 d^3}{4}}\theta_0 \frac{\left(\frac{h}{mk}\right)\cosh(mL) + \sinh(mL)}{\cosh(mL) + \left(\frac{h}{mk}\right)\sinh(mL)} \tag{8}$$

Where p is the perimeter of the fin, h is the h_t, L is the fin length, and θ_0 is θ at the fin base.

The fin efficiency is defined as follow:

$$q_{max} = hpL\theta_0 \tag{9}$$

$$\eta = \frac{q}{q_{max}} \tag{10}$$

Where the denominator is the amount of the heat transferred if the entire fin were at base temperature.

Formula for Nusselt Correlation:

$$Nu = 0.68 + \frac{0.67(Ra)^{1/4}}{[1 + \left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}]^{4/9}} \tag{11}$$

$$Ra = Gr \times Pr = \frac{g\beta\Delta T d^3}{v^2}Pr \tag{12}$$

Where,

$$T_f = \frac{T + T_\infty}{2}$$

$$\Delta T = T - T_\infty$$

$$\beta = \frac{1}{T_f}$$

d = diameter of the rod

3. Experimentation

The experiment will be carried out with three rods with different thermal conductivity, which are aluminum, brass, and steel respectively as Figure 1 shown.

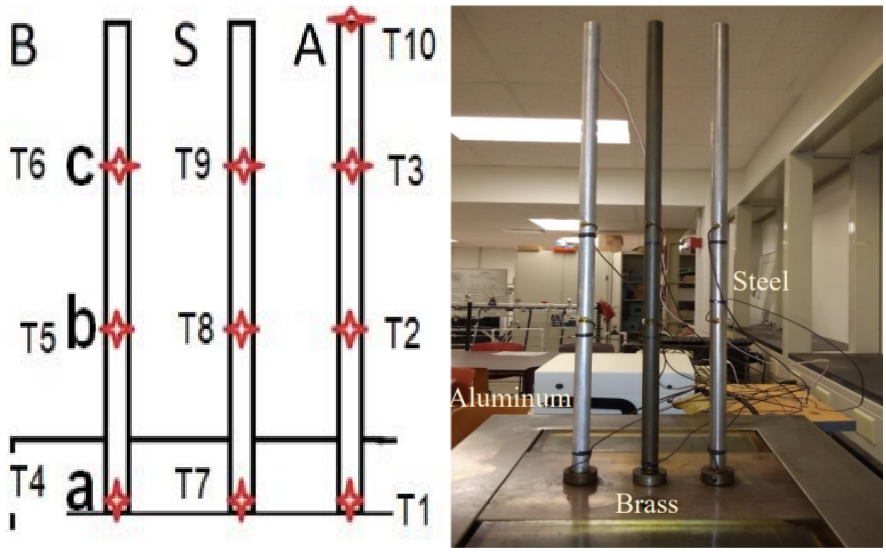

Figure 1. Experiment Equipment

Since brass rod is the least conductive, when T_6 shown in Figure 1 stops varying with time, all these rods were conducting at steady state.

The steady state curve of T_6 shown as follow:

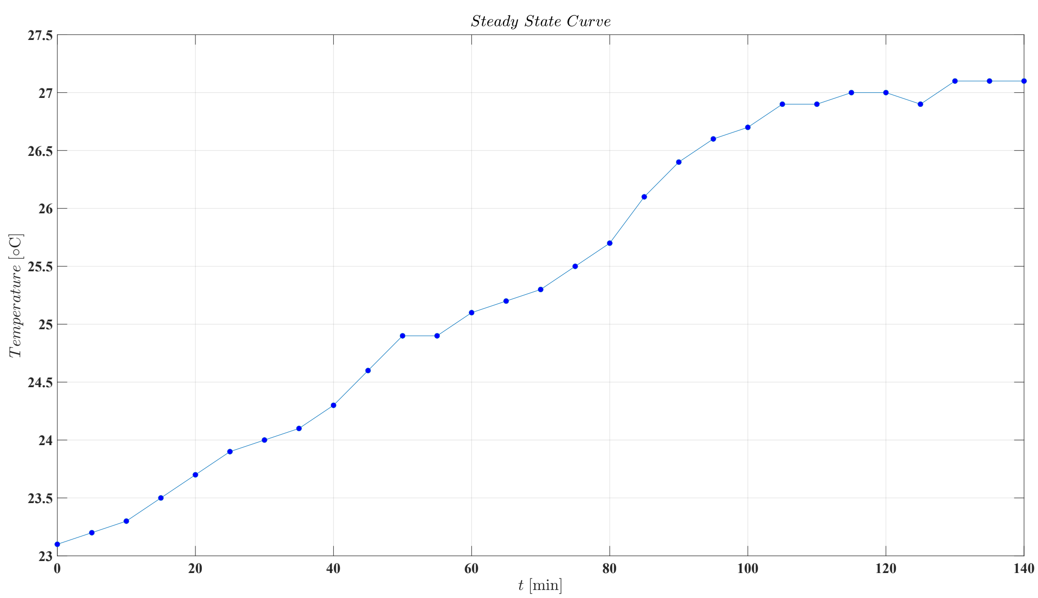

Figure 2. Steady State Curve

All the temperature shown in Figure 1 shown in the Table 1.

Table 1.Thermal Fluid Lab-Extended Heat Transfer-Data

Rod Metals	Temperature
Aluminum	**T_1 =** 59.7 ℃
	T_2 = 46.8 ℃
	T_3 = 40.2 ℃
Brass	**T_4 =** 65.4 ℃
	T_5 = 41.9 ℃
	T_6 = 34.9 ℃
Steel	**T_7 =** 60.7 ℃
	T_8 = 30.3 ℃
	T_9 = 27.1 ℃
Aluminum Rod Tip Temperature	**T_{10} =** 35.4 ℃
Surrounding Temperature	**T_∞ =** 19 ℃

3.1 Combined Heat Transfer Coefficient

3.1.1 Sample Calculations

The combined heat transfer coefficient could be determined by equation (2) with 3 measured points:

$$h_t = \frac{109\,\frac{W}{mK} \times 0.0127m}{4}\left[\frac{\ln\left(\frac{65.4℃ - 19℃}{41.9℃ - 19℃}\right)}{0.1524m}\right]^2 = 7.4303\ \mathrm{W}/m^2\mathrm{K}$$

$$h_t = \frac{109\,\frac{W}{mK} \times 0.0127m}{4}\left[\frac{\ln\left(\frac{65.4℃ - 19℃}{34.9℃ - 19℃}\right)}{0.2539m}\right]^2 = 6.1575\ \mathrm{W}/m^2\mathrm{K}$$

$$h_t = \frac{109\,\frac{W}{mK} \times 0.0127m}{4}\left[\frac{\ln\left(\frac{41.9℃ - 19℃}{34.9℃ - 19℃}\right)}{0.1524m - 0.2539m}\right]^2 = 4.4709\ \mathrm{W}/m^2\mathrm{K}$$

3.1.2 Experimental Results

The result of combined heat transfer coefficient is:

Table 2. Calculation Result of Combined Heat Transfer Coefficient

Combined Heat Transfer Coefficient h_t	**6.0196 W/m^2K**

3.1.3 Analysis & Discussion

Comment on reasonability of combined heat transfer coefficient (i.e., order of magnitude)

The combined heat transfer coefficient is 6.0196 W/m^2K. The steady state occurs at around 140 min. To improve the accuracy, the calculation formula uses 3 measuring points. A more accurate result can be obtained by taking the average value when doing the calculation.

3.2 Thermal Conductivity

3.2.1 Procedure Objectives

Find the thermal conductivity for short (aluminum) and long (stainless steel) fin conditions.

3.2.2 Sample Calculation

To calculate the thermal conductivity for short (aluminum) fin, an equation can be used.

$$k_{al} = \frac{4h_t}{m^2 d}$$

h_t is the combined heat transfer coefficient;

d is the diameter of the rod.

m can be calculated according to the equation below:

$$0.002m^4 + 0.111m^2 + \left(1 - \frac{\theta_1}{\theta_{10}}\right) = 0$$

θ_1 is the temperature difference between point 1 and the room temperature;

θ_{10} is the temperature difference between point 10 and the room temperature.

$$\frac{\theta_1}{\theta_{10}} = \frac{T_1 - T_\infty}{T_{10} - T_\infty}$$

By solving equation, 4 solutions of m can be solved.

$$m = 3.3347, -3.3347, 8.1641i, -8.1641i$$

Since the experiment only needs the direction along the positive side of the rod, only the positive real value of m can be taken. So k_{al} can be calculated as follows:

$$k_{al} = \frac{4h_t}{m^2 d} = 170.4902 W/mK$$

$$Error = \frac{170.4902 - 164}{164} \times 100\% = 3.96\%$$

To calculate the thermal conductivity for long (stainless steel) fin, an equation can be used.

$$\frac{k_{ss}}{k_{br}} = \left[\frac{\ln\left(\frac{\theta_4}{\theta_5}\right)}{\ln\left(\frac{\theta_7}{\theta_8}\right)}\right]^2$$

Since k_{br} is given, k_{ss} can be calculated as follows:

$$k_{ss} = \left[\frac{\ln\left(\frac{\theta_4}{\theta_5}\right)}{\ln\left(\frac{\theta_7}{\theta_8}\right)}\right]^2 k_{br} = 31.8823\ W/mK$$

$$Error = \frac{36 - 31.8823}{36} \times 100\% = 11.44\%$$

3.2.3 Experiment Result

Table 3. Thermal conductivity for short and long fins

Parameters	Thermal conductivity (W/mK)	Error
Aluminum	170.4902	3.96%
Stainless steel	31.8823	11.44%

3.2.4 Analyze and Discussion

According to the calculation, the thermal conductivity of Aluminum is 170.4902 W/mK, and stainless steel is 31.8823 W/mK.The standard value of Aluminum's thermal conductivity under room temperature is 164 W/mK, and Stainless steel's thermal conductivity is 36 W/mK. Both errors are in an acceptable range. This section illustrates the temperature distribution for fins of uniform cross-sections for short and long fins. The possible reasons for the errors are as follows:

Systematic error:

The temperature of the lab is not exactly at 19 degrees Celsius, which will cause errors.

The thermal conductivity of brass used in the calculation is not the actual value under this room temperature.

Random error:

The reading fluctuates rapidly, experimenters were not able to read a steady measurement.

When the experimenters walk around the experiment table, the air will be accelerated and cause unexpected errors on convection.

3.3 Convective and Radiant Heat Transfer Coefficient

3.2.1 Procedure Objectives

Find the radiant thermal conductivity and convection thermal conductivity separately for the three materials.

3.2.2 Sample Calculation

Radiant heat transfer coefficient for Aluminum:

For point 1:

$$h_{r1} = \varepsilon\sigma({T_1}^2 + {T_\infty}^2)(T_1 + T_\infty) = 2.0852 \text{ W}/m^2\text{K}$$

For point 2:

$$h_{r2} = \varepsilon\sigma({T_2}^2 + {T_\infty}^2)(T_2 + T_\infty) = 1.9545 \text{ W}/m^2\text{K}$$

For point 3:

$$h_{r3} = \varepsilon\sigma({T_3}^2 + {T_\infty}^2)(T_3 + T_\infty) = 1.8904\ \mathrm{W}/m^2\mathrm{K}$$

Take the average of the three point, the radiant heat transfer coefficient can be calculated:

$$h_{ral} = \frac{h_{r1} + h_{r2} + h_{r3}}{3} = 1.9767\mathrm{W}/m^2\mathrm{K}$$

The convective heat transfer is gotten by subtracting radiant from combined:

$$h_{cal} = h_t - h_{ral} = 4.0429\ \mathrm{W}/m^2\mathrm{K}$$

The other two materials can be calculated through the same procedure mentioned above.

3.2.3 Experiment Result

Table 4. Radiant and convective heat transfer coefficient for three materials

Material	Radiant heat transfer coefficient ($\mathrm{W}/m^2\mathrm{K}$)	Convective heat transfer coefficient ($\mathrm{W}/m^2\mathrm{K}$)
Aluminum	1.9767	4.0429
Brass	1.9641	4.0555
Stainless steel	1.9641	4.0555

3.2.4 Analyze and Discussion

The radiant and convective heat transfer coefficient is calculated for all three materials. Compared to the convective heat transfer coefficient, the radiant heat transfer coefficient is relatively small. The accuracy of the result is affected by the temperature taken down by the experimenters. The reading fluctuates rapidly, experimenters were not able to read a steady measurement. This section illustrated the calculation of radiant heat transfer coefficient and the relationship between combined heat transfer coefficient and convective and radiant parts.

3.4 Tip Temperature of Aluminum

3.4.1 Sample Calculations

The tip temperature of aluminum could be determined by equation (6):

$$\frac{\theta_{10}}{\theta_1} = \frac{T_{10} - T_\infty}{T_1 - T_\infty} = \frac{\cosh(mL - mx) + (\frac{h}{mk})\sinh(mL - mx)}{\cosh(mL) + (\frac{h}{mk})\sinh(mL)}$$

$$m = \sqrt{\frac{hP}{k_{al}A_C}} = \sqrt{\frac{6.0196\frac{\mathrm{W}}{m^2\mathrm{K}} \times \pi(0.0127\ m)}{170.0107W/mk \times \frac{\pi(0.0127\ m)^2}{4}}} = 3.3347\ m^{-1}$$

$$\frac{T_{10} - 19℃}{59.7℃ - 19℃}$$

$$== \frac{\cosh(3.3394\ m^{-1}0.4699\text{m} - 3.3394\ m^{-1}0.4699\text{m}) + (\frac{6.0196\ \text{W}/m^2\text{K}}{3.3394\ m^{-1}170.0107W/mk})\sinh(3.3394\ m^{-1}0.4699\text{m} - 3.3394\ m^{-1}0.4699\text{m})}{\cosh(3.3394\ m^{-1}0.4699\text{m}) + (\frac{6.0196\ \text{W}/m^2\text{K}}{3.3394\ m^{-1}170.0107W/mk})\sinh(3.3394\ m^{-1}0.4699\text{m})}$$

$$= 0.3961$$

$$T_{10} = 0.3961 \times (59.7℃ - 19℃) + 19℃ = 35.1213\ ℃$$

3.4.2 Experimental Results

The result of tip temperature of aluminum is:

Table 5. Result of Tip Temperature of Aluminum

Actual Temperature(℃)	Theoretical Temperature(℃)	Percent Error(%)
35.4	35.1213	0.7874

3.4.3 Analysis & Discussion

Comment how calculated tip temperature compares to actual tip temperature for aluminum. What does this say about calculated h, m, k(al)?

The percent error between actual temperature and theoretical temperature of the result demonstrates that the accuracy of the experiment. The result determined by equation (6) is quite accurate.

As for calculated h, m, k(al), the low percent error demonstrated the accuracy of the results of h, m, k(al).

3.5 Calculating Heat Transfer and Efficiency

3.5.1 Sample Calculations

The heat loss from each of these rods can be calculated in the relation.

$$\text{q}_{\text{ss}} = \sqrt{\frac{hk\pi^2d^3}{4}}\theta_0$$

$$\text{q}_{al} = \sqrt{\frac{hk\pi^2d^3}{4}}\theta_0 \frac{\left(\frac{\text{h}}{\text{mk}}\right)\cosh(\text{mL}) + \sinh(\text{mL})}{\cosh(mL) + \left(\frac{h}{mk}\right)\sinh(mL)}$$

Where p is the perimeter of the fin, h is the h_t, L is the fin length, and θ_0 is θ at the fin base. The fin efficiency is defined as follow.

$$\text{q}_{\text{max}} = hpL\theta_0$$

$$\eta = \frac{\text{q}}{\text{q}_{max}}$$

Where the denominator is the amount of the heat transferred if the entire fin were at base temperature.

For al:

$$q_{al} = \sqrt{\frac{6.0196\frac{W}{m^2K} * 170.4902\frac{W}{mK} * \pi^2(0.0127m)^3}{4}} * (59.7.0℃ - 19.0℃)$$

$$* \frac{\left(\frac{6.0196\frac{W}{m^2K}}{3.3347\mathrm{m}^{-1} * 170.4902\frac{W}{mK}}\right)\cosh(3.3347\mathrm{m}^{-1} * 0.4699\mathrm{m}) + \sinh(3.3347 * 0.4699\mathrm{m})}{\cosh(3.3347\mathrm{m}^{-1} * 0.4699\mathrm{m}) + \left(\frac{6.0196\frac{W}{m^2K}}{3.3347\mathrm{m}^{-1} * 170.4902\frac{W}{mK}}\right)\sinh(3.3347\mathrm{m}^{-1} * 0.4699\mathrm{m})}$$

$$= 2.6915\mathrm{W/m^2}$$

$$q_{\mathrm{al,max}} = hpL\theta_0 = 6.0196\frac{W}{m^2K} * \pi * 0.0127m * 0.4699m * (59.7℃ - 19.0℃) = 4.5933W/m^2$$

$$\eta_{\mathrm{al}} = \frac{q_{\mathrm{al}}}{q_{al,max}} = \frac{2.6915\mathrm{W/m^2}}{4.5933W/m^2} = 58.60\%$$

For ss:

$$q_{\mathrm{ss}} = \sqrt{\frac{hk\pi^2d^3}{4}}\theta_0 = \sqrt{\frac{6.0196\frac{W}{m^2K} * 31.882\frac{W}{mK} * \pi^2(0.0127m)^3}{4}}(60.7℃ - 19.0℃) = 1.2987\mathrm{W/m^2}$$

$$q_{\mathrm{ss,max}} = hpL\theta_0 = 6.0196\frac{W}{m^2K} * \pi * 0.0127m * 0.4699m * (60.7℃ - 19.0℃) = 4.7061W/m^2$$

$$\eta_{\mathrm{ss}} = \frac{q_{\mathrm{ss}}}{q_{ss,max}} = \frac{1.2987\mathrm{W/m^2}}{4.7061W/m^2} = 27.60\%$$

For br:

$$q_{\mathrm{br}} = \sqrt{\frac{hk\pi^2d^3}{4}}\theta_0 = \sqrt{\frac{6.0196\frac{W}{m^2K} * 109\frac{W}{mK} * \pi^2(0.0127m)^3}{4}}(65.4℃ - 19.0℃) = 2.6720\mathrm{W/m^2}$$

$$q_{\mathrm{br,max}} = hpL\theta_0 = 6.0196\frac{W}{m^2K} * \pi * 0.0127m * 0.4699m * (65.4℃ - 19.0℃) = 5.2365W/m^2$$

$$\eta_{\mathrm{ss}} = \frac{q_{\mathrm{ss}}}{q_{ss,max}} = \frac{2.6720\mathrm{W/m^2}}{5.2365W/m^2} = 51.03\%$$

3.5.2 Experimental Results

Table 6. The heat transfer for each rods

Parameters	Aluminum	Brass	Steel

K(W/mK)	170.4902	109.00	31.882
qs(W/m^2)	2.6915	2.6720	1.2987
qmax(W/m^2)	4.5933	5.2365	4.7061
η(%)	58.60	51.03	27.60

3.5.3 Analysis & Discussion

1. Heat transfer for each of three rods

Different materials have different heat transfer efficiencies. From the experimental point of view, the heat transfer efficiency of aluminum is the largest, and the heat transfer efficiency of steel is the lowest. In lecture, aluminum has the highest electrical conductivity and steel the lowest. The two results match each other.

2. Fin efficiencies

For an ideal fin, the fin should have high thermal conductivity and be able to rapidly cool or heat the fluid flowing around it. From the experimental point of view, aluminum is the most efficient material for heat transfer.

3.6 Nusselt Number

3.6.1 Sample Calculations

Formula for Nusselt Correlation:

$$Nu = 0.68 + \frac{0.67(Ra)^{1/4}}{[1 + \left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}]^{4/9}}$$

In this Formula,

$$T_\infty = 19℃$$

Then,

$$Pr = 0.707$$

$$Ra = Gr \times Pr = \frac{g\beta\Delta T d^3}{v^2} Pr$$

Where,

$$d = 0.0127\ m$$

$$g = 9.81\ m^2/s$$

$$v = 1.568 \times 10^{-5}\ m^2/s$$

$$T_f = \frac{T + T_\infty}{2} = \frac{(41.9 + 273.15) + (19 + 273.15)}{2} = 303.6K$$

$$\Delta T = T - T_\infty = 41.9 - 19 = 22.9K$$

$$\beta = \frac{1}{T_f} = \frac{1}{303.6} = 0.0033$$

Then,

$$Ra = Gr \times Pr = \frac{g\beta\Delta T d^3}{v^2} Pr = 4366.7355$$

Insert into the Nusselt correlation that matches the Rayleigh number,

$$Nu = 0.68 + \frac{0.67(Ra)^{1/4}}{\left[1 + \left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}\right]^{4/9}} = 4.8583$$

Experimental value of Nusselt number:

$$Nu = \frac{h_c d}{k_{air}}$$

where,

$$h_{cal} = 4.0429K$$

$$h_{cbr} = 4.0555K$$

$$h_{css} = 4.0555K$$

$$k_{air} = 0.02624 \frac{W}{m} K$$

$$Nu_{expal} = \frac{h_{cal} d}{k_{air}} = \frac{4.0429 \times 0.0127}{0.02624} = 1.9567$$

$$Nu_{expbr} = \frac{h_{cbr} d}{k_{air}} = \frac{4.0555 \times 0.0127}{0.02624} = 1.9628$$

$$Nu_{expss} = \frac{h_{css}d}{k_{air}} = \frac{4.0555 \times 0.0127}{0.02624} = 1.9628$$

$$Error_{al} = \frac{\mathrm{Nu} - Nu_{expal}}{Nu} = \frac{4.8583 - 1.9567}{4.8583} = 59.72\%$$

$$Error_{br} = \frac{\mathrm{Nu} - Nu_{expbr}}{Nu} = \frac{4.8583 - 1.9628}{4.8583} = 59.6\%$$

$$Error_{ss} = \frac{\mathrm{Nu} - Nu_{expbr}}{Nu} = \frac{4.8583 - 1.9628}{4.8583} = 59.6\%$$

3.6.2 Experimental Results

Table 7 Result for Nusselt number

Material	Experimental Nusselt	Theoretical Nusselt (℃)	Percent Error(%)
Aluminum	1.9567	4.8583	59.72
Brass	1.9628	4.8583	59.6
Steel	1.9628	4.8583	59.6

3.6.3 Analysis & Discussion

Comment how theoretical Nusselt compares to experimental, what does this means in terms of the dimensionless value).

The Nusselt number is also called free (natural) convection correlation. According to the result, the theoretical Nusselt is 4.8583, and the experimental Nusselt of Aluminum, Brass and Steel are 1.9567, 1.9628, 1.9628 respectively. The percent error between theoretical Nusselt and experimental Nusselt is 59.72%, 59.6%, 59.6% respectively. This presents that the difference between Nusselt number calculated by convective heat transfer coefficient and the conductivity of air, and Nusselt number calculated by Prandtl number and Rayleigh Number is very large. From this result, we think it's possible that the air formed a turbulent rather than laminar flow around the rod, thus affecting the final result.

4. Conclusions

1. In objective1, the comprehensive heat transfer coefficient is 6.0196 W/m^2 K. Steady state occurs around 140 min.

2. In objective2, the thermal conductivity of aluminum is 170.4902 W/mK, and that of stainless steel is 31.8823 W/mK. The standard value of the room temperature thermal conductivity of

aluminum is 164 W/mK, and that of stainless steel is 36 W/kg. The errors are 3.96% and 11.44%, respectively, both within the acceptable range.

3. In Objective3, the radiative and convective heat transfer coefficients are calculated for all three materials, illustrating the calculation of the radiative heat transfer coefficient and the relationship of the combined heat transfer coefficient to the convective and radiative components.

4. In objective4, the percentage error between the actual temperature and the theoretical temperature of the result is 0.7874%, which proves the accuracy of the experiment.

5. In objective5, the experimental results prove that different materials have different heat transfer efficiencies, aluminum has the highest heat transfer efficiency, and steel has the lowest heat transfer efficiency. And it proved that for an ideal fin, which should have high thermal conductivity and be able to quickly cool or heat the fluid flowing around it, aluminum is the material with the highest heat transfer efficiency.

6. In objective6, the experimental Nusselts of aluminum, brass and steel are 1.9567, 1.9628 and 1.9628 respectively. The percentage errors between the theoretical and experimental Nusselt are 59.72%, 59.6%, and 59.6%, respectively. The error is large and may be due to the air creating a turbulent rather than laminar flow around the rod, affecting the results.

APPENDICES

A – MATLAB Code (or Excel, other computational software, etc)

```
%% LAB 4
%% Code
close all
clear all
clc
set(0,'DefaultAxesFontName', 'Times New Roman')
set(0,'DefaultAxesFontSize', 22)
set(0,'defaultlinelinewidth',0.5)
set(0,'DefaultLineMarkerSize', 8)
set(0,'defaultAxesFontWeight','bold')
% Ob 0
t = 0:5:140;
T =[23.1 23.2 23.3 23.5 23.7 23.9 24.0 24.1 24.3 24.6 24.9 24.9 25.1 25.2 25.3 25.5 25.7 26.1 26.4 26.6 26.7 26.9 26.9 27.0 27.0 26.9 27.1 27.1 27.1];

figure
plot(t,T,'o-','MarkerFaceColor','b')


xlabel(['$ t\;\mathrm{[min]} $'],'interpreter','latex')
ylabel(['$ Temperature\;\mathrm{[\circ C]} $'],'interpreter','latex')
title(['$ Steady\ State\ Curve $'],'interpreter','latex')
grid on

%% Ob 4
h = 6.0196;
d = 0.0127;
k = 170.;
L =  0.4699;

m = sqrt(h*pi*d/(k*0.25*pi*d^2))
theta = (cosh(0)+(h/(m*k))*sinh(0))/(cosh(m*L)+(h/(m*k))*sinh(m*L))


%ob 5

Clear ;close all ; clc

h=6.0196;

kss=31.8823;

kal=170.4902;

kbr=109;
```

```
L=0.4699;

d=0.0127;

theta0ss=60.7-19;

theta0al=59.7-19;

theta0br=65.4-19;

m=3.3347;

qss=sqrt((h*kss*(pi^2)*d^3)/4)*theta0ss;

qal=sqrt((h*kal*(pi^2)*d^3)/4)*theta0al*((h/(m*kal))*cosh(m*L)+sinh(m*L))/(cosh(m*L)+(h/(m*kal))*
sinh(m*L));

qbr=sqrt((h*kbr*(pi^2)*d^3)/4)*theta0br;

qmax_ss=h*pi*d*L*theta0ss;

qmax_al=h*pi*d*L*theta0al;

qmax_br=h*pi*d*L*theta0br;

w_ss=qss/qmax_ss;

w_al=qal/qmax_al;

w_br=qbr/qmax_br;

disp(qss)

disp(qal)

disp(qbr)

disp(w_ss)

disp(w_al)

disp(w_br)

%% Math Lab 2023 Spring semester
% Name: Tracy Liu
% Date: 1-Feb-2023
% Description: Lab 4.2

%% Clear Processor
clear; clc;close all
```

```
% Dictionary
L = 0.4699;
h = 6.0196;
x = 0;
d = 0.0127;

% Solve m
syms m
theta10 = (59.7-19)/(35.4-19);
%theta10 = (cosh(m*L-m*x)+(h/(m*k)*sinh(m*L-m*x)))/(cosh(m*L)+(h/(m*k))*sinh(m*L));
msolve = solve(0.002*m^4+0.111*m^2+(1-theta10),m);
disp(msolve)
realm = ((3*41^(1/2)*110129^(1/2))/164 - 111/4)^(1/2);
fprintf('m = %0.4f\n',realm)

% kal
k = 4*h/(realm^2*d);
fprintf('Kal = %0.4f\n',k)

% Kss
theta45 = (65.4-19)/(41.9-19);
theta78 = (60.7-19)/(30.3-19);
Kss = 109*(log(theta45)/log(theta78))^2;
fprintf('Kss = %0.4f\n',Kss)


%% Math Lab 2023 Spring semester
% Name: Tracy Liu
% Date: 1-Feb-2023
% Description: Lab 4.3

%% Clear Processor
clear; clc;close all

% Dictionary
s = 0.3;
th = 5.67*10^(-8);
T1 = 59.7+273.15;
T2 = 46.8+273.15;
T3 = 40.2+273.15;
T4 = 65.4+273.15;
T5 = 41.9+273.15;
T6 = 34.9+273.15;
T7 = 60.7+273.15;
T8 = 30.3+273.15;
T9 = 27.1+273.15;
Tin = 19+273.15;

% Al
h1 = s*th*(T1^2+Tin^2)*(T1+Tin);
```

```
h2 = s*th*(T2^2+Tin^2)*(T2+Tin);
h3 = s*th*(T3^2+Tin^2)*(T3+Tin);
hal = (h1+h2+h3)/3;
fprintf('For radiant heat transfer coefficient:\n')
fprintf('hal = %0.4f\n',hal)

% Brass
h4 = s*th*(T4^2+Tin^2)*(T4+Tin);
h5 = s*th*(T5^2+Tin^2)*(T5+Tin);
h6 = s*th*(T6^2+Tin^2)*(T6+Tin);
hbr = (h4+h5+h6)/3;
fprintf('hbr = %0.4f\n',hbr)

% Stainless steel
h7 = s*th*(T7^2+Tin^2)*(T7+Tin);
h8 = s*th*(T8^2+Tin^2)*(T8+Tin);
h9 = s*th*(T9^2+Tin^2)*(T9+Tin);
hss = (h4+h5+h6)/3;
fprintf('hss = %0.4f\n',hss)

% hc
hcal = 6.0196-hal;
hcbr = 6.0196-hbr;
hcss = 6.0196-hss;
fprintf('For convection heat transfer coefficient:\n')
fprintf('hal = %0.4f\n',hcal)
fprintf('hbr = %0.4f\n',hcbr)
fprintf('hss = %0.4f\n',hcss)
```

B – Scanned Lab Notes

Lab 4: Thermal Fluid Lab-Extended Heat Transfer-Data Sheet

Rod Metals	Temperatures
Aluminum	T1= 59.7 °C
	T2= 46.8 °C
	T3= 40.2 °C
Brass	T4= 65.4 °C
	T5= 41.9 °C
	T6= 34.9 °C
Steel	T7= 60.7 °C
	T8= 30.3 °C
	T9= 27.1 °C
Aluminum Rod Tip Temperature	T10= 35.4 °C
Surrounding Temperature	$T_{infinity}$= 19 °C

Report Group: F-1

Date: Jan. 27. 2023

Signature of TA: