ME341A – Heat and Mass Transfer

EXPERIMENT 2
PIN FIN FORCED CONVECTION

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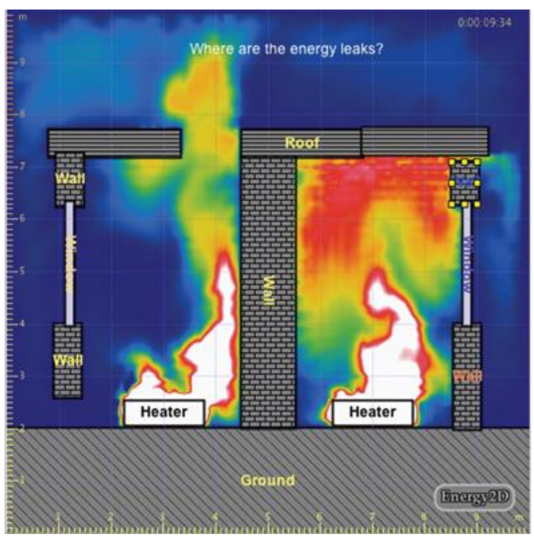
Department of Mechanical Engineering
Indian Institute of Technology Kanpur



Group – G1 (a)

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OBJECTIVE:

I. To obtain the variation of temperature along the length of pin fin under forced convection from experiment
II. To determine the value of heat transfer coefficient under forced convection from the experiment.
III. To evaluate:
    a. Theoretical values of temperature along the length of the fin.
    b. Effectiveness and efficiency of the fin.

EXPERIMENTAL PROCEDURE:

1. Connect the equipment to electric power supply.
2. Keep the thermocouple selector switch to zero position.
3. Switch on the blower.
4. Turn the dimmer stat knob clockwise and adjust the power input to the heater to the desired value.
5. Allow the unit to stabilize; approximate waiting time is 40-50 minutes.
6. Turn the thermocouple selector clockwise and note down the temperature T1 to T6.
7. Note down the difference in the level of the manometer.
8. Repeat the experiment for different power input to the heater.

RESULTS AND OBSERVATIONS:

Case 1:
Power = 35W
Pressure drop (h) = 6.2 cm

Temperature measurement (till steady state)							
S.N	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_4 (ºC)	T_5 (ºC)	T_6 (ºC)	Time (min.)
1.	83	71	64	59	57	22	0

Case 2:
Power = 40W
Pressure drop (h) = 6.4 cm

Temperature measurement (till steady state)							
S.N	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_4 (ºC)	T_5 (ºC)	T_6 (ºC)	Time (min.)
1.	83	71	64	59	57	22	0
2.	88	75	67	62	59	23	10
3.	90	77	69	64	60	23	20
4.	91	78	70	65	61	23	30
5.	92	78	71	65	62	23	40
6.	92	79	71	65	62	23	50

DISCUSSIONS AND CONCLUSIONS:

The magnitude of the temperature gradient decreases with increasing x, which is in perfect consonance with the theory, as the amount of heat being conducted through the rod decreases with increasing x due to dissipation from forced convection. As thermal conductivity and cross section area remains constant throughout the rod, hence temperature gradient is bound to decrease.
The difference in the theoretical and experimental value of temperature can be attributed to various sources of errors which might have crept in like imperfect insulation at rod end, thermocouple not calibrated properly, material of fin is not uniform, etc. Also the experiment shows that the fin is ~60% ideal and not even closer to complete ideal nature which may also be considered as one of the reason of deviation of experimental values from the theoretical ones.

APPENDIX:

Length of the fin L= 150mm
Diameter of the fin (D) = 12mm
Thermal conductivity of the fin material (brass) = 110 W/m-K
Diameter of the orifice (d_0) = 20
Width of the duct W = 15 cm
Breadth of the duct B = 10 cm
Coefficient of discharge of the orifice = 0.85
Density of manometric fluid water = 1000 Kg/m^3

***Sample Calculation for Case 1*:**

Rate of heating, q =35 W

i. Average surface temperature of fin is given by $T_s = (T_1 + T_2 + T_3 + T_4 + T_5)/5 = 66.6\ ^oC$

T_6 = ambient temperature = 22 ^oC

T_m = mean temperature = $(T_s + T_6)/2 = 44.4^oC$

ii. Properties of air are evaluated at T_m (317.5K):

a. Kinematic viscosity (v) = $17.65*10^{-6}\ m^2/s$
b. Prandtl no.(Pr) = 0.7045
c. Thermal conductivity of air (K_a) = $27.6*10^{-3}$ W/m-K

Note: Values obtained through linear interpolation of the properties specified at temperature range 300-350K.

iii. Velocity at orifice $$(V_o) = C_d\sqrt{\frac{2gh(\rho_w-\rho_a)}{\rho_a}}*(1-\beta^4)^{-0.5}$$

Where β = 0.52
Coefficient of discharge (C) = 0.85
Density of manometric fluid (ρ_w) = 1000 Kg/m^3
Density of air(ρ_a) = 1.16 Kg/m^3

$\Rightarrow V_o = 28.45$ m/s

iv. Velocity of air in the duct (V) = $\frac{\text{(Velocity at orifice)*(Cross-sectional area of orifice)}}{\text{(Cross-sectional area of duct)}}$

$$V_a = V_o\frac{\pi}{4*W*B}d_o^2$$

Where d_o is the diameter of orifice = 0.02m
W = width of the duct = 0.15m
B = Breadth of the duct = 0.1m

$\Rightarrow V_a = 0.5959$ m/s

v. Nusselt no. (Nu) = C $Re^n.Pr^{1/3}$

$Nu = \frac{hD}{k_f}$ where h is heat transfer coefficient.

Reynolds number (Re) = $\frac{DV_a}{\nu}$

C is a constant and n is index values, which are given in table below for different ranges of Reynolds number.

Reynolds No.	C	n
0.4-40	0.989	0.33
4-40	0.911	0.385
40-4000	0.683	0.466
4000-40000	0.293	0.618
40000-400000	0.27	0.805

D = 12mm

$\Rightarrow$ Re = (0.012*0.5959)/(17.65*10^{-6})

$\Rightarrow$ Re = 405.144

$\therefore$ C = 0.683, n = 0.466, $k_f = K_a = 27.6*10^{-3}$ W/m-K and Pr = 0.7045

$\therefore$ Nu = $\dfrac{hD}{k_f}$ = C $Re^n.Pr^{1/3}$ = 10.0

$\Rightarrow$ h = (27.6*10^{-3} *0.683*$(405.144)^{0.466}(0.7045)^{1/3}$)/ 0.012 = 22.94 W/$m^2$-K

Now,

$$m = \sqrt{\frac{hP}{kA}}$$; K = 110 W/m-K

$$\frac{P}{A} = \frac{4\pi D}{\pi D * D}$$

$$\therefore \frac{P}{A} = \frac{4}{D} \qquad \Rightarrow m = \sqrt{\frac{4h}{kD}}$$

$\Rightarrow$ m = 8.34 m^{-1}

Now,

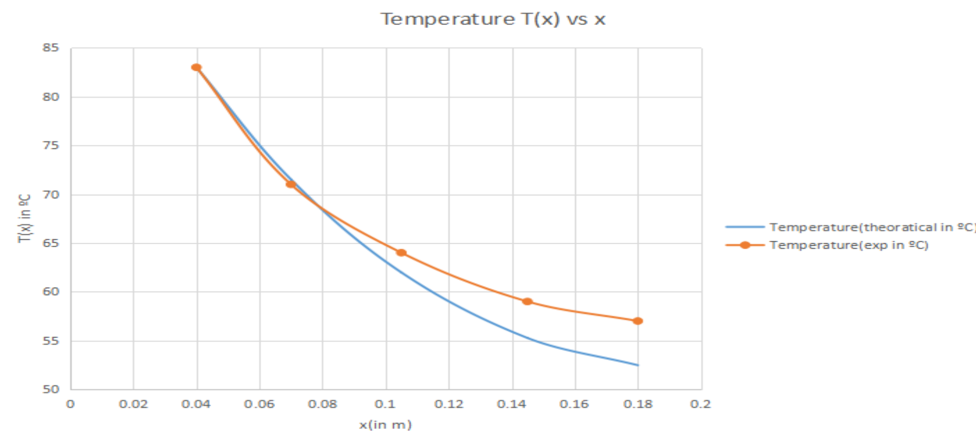
$$\frac{\theta}{\theta_0} = \frac{T - T_\infty}{T_1 - T_\infty} = \frac{\cosh m(L-x)}{\cosh mL}$$

$$\therefore T_2 = T(x=7cm) = \left(\frac{\cosh(8.34(0.2-0.07))}{\cosh(8.34(0.2-0.04))} * (83-22)\right) + 22$$

$\Rightarrow$ T_2 = T(x=7cm) = 71.5ºC

Similarly we can find values of temperature at x=10.5, 14.5 and 18 cm i.e. T_3, T_4 and T_5 respectively (for Heat input=35W).

Sr. No	Temperature(exp in ℃)	x(m)	Temperature(theoratical in ºC)
1	83	0.04	83
2	71	0.07	71.50045601
3	64	0.105	61.97997399
4	59	0.145	55.26481235
5	57	0.18	52.46795613
6	22	-	22



Fin effectiveness:

$$\varepsilon = \sqrt{\frac{Pk}{hA}} \tanh mL \quad \Rightarrow \varepsilon = 37.228$$

Fin efficiency:

$$\eta = \frac{\tanh mL}{mL} \quad \Rightarrow \eta = 0.5584 \text{ or } 55.84\%$$

<u>Sample Calculation for Case 2:</u>

Rate of heating, q = 40 W

i. Average surface temperature of fin is given by Ts = (T1+ T2 + T3 + T4 + T5)/5 = 73.8 ^{o}C

T6 = ambient temperature = 23 ^{o}C

Tm = mean temperature = (Ts + T6)/2 = 48.4 ^{o}C

ii. Properties of air are evaluated at Tm (321.5K):

a.Kinematic viscosity (v) = 17.96*10-6 m2/s

b.Prandtl no.(Pr) = 0.7045

c.Thermal conductivity of air (Ka) = 27.8*10-3 W/m-K

Note: Values obtained through linear interpolation of the properties specified at temperature range 300-350K.

iii. Velocity at orifice

$$(Vo) = C_d \sqrt{\frac{2gh(\rho_w - \rho_a)}{\rho_a}} * (1-\beta^4)^{-0.5}$$

Where β = 0.52

Coefficient of discharge (C_d) = 0.85

Density of manometric fluid (ρw) = 1000 Kg/m3

Density of air(ρa) = 1.15 Kg/m3

Vo = 29.15 m/s

iv. Velocity of air in duct (V) = $\frac{\text{(Velocity at orifice)*(Cross-sectional area of orifice)}}{\text{(Cross-sectional area of duct)}}$

$$V_a = V_o \frac{\pi}{4 * W * B} d_o^2$$

V_a = 0.61 m/s

v. Nusselt no. (Nu) = C $Re^n.Pr^{1/3}$

Nu = hD/k_f ,where h is heat transfer coefficient.

Reynolds number (Re) =D V_a / v

C is a constant and n is index values, which are given in table below for different ranges of Reynolds number.

Reynolds No.	C	n
0.4-40	0.989	0.33
4-40	0.911	0.385
40-4000	0.683	0.466
4000-40000	0.293	0.618
40000-400000	0.27	0.805

Re = (0.012*0.61)/(17.96*10-6) = 408.175

C = 0.683, n = 0.466, kf = Ka = 27.8*10-3 W/m-K and Pr = 0.7045

Nu = *h D / k_f* = C $Re^n.Pr^{1/3}$ = 10.008

h = (27.8*10-3 *0.683*$(408.175)^{0.466}(0.7045)^{1/3}$)/ 0.012 = 23.18 W/$m^2$K

Now,

$$m = \sqrt{\frac{hP}{kA}}$$; K = 110 W/m-K

$$\frac{P}{A} = \frac{4\pi D}{\pi D * D} \qquad \Rightarrow m = \sqrt{\frac{4h}{kD}}$$

$$\therefore \frac{P}{A} = \frac{4}{D}$$

m = 8.382 m^{-1}

now,

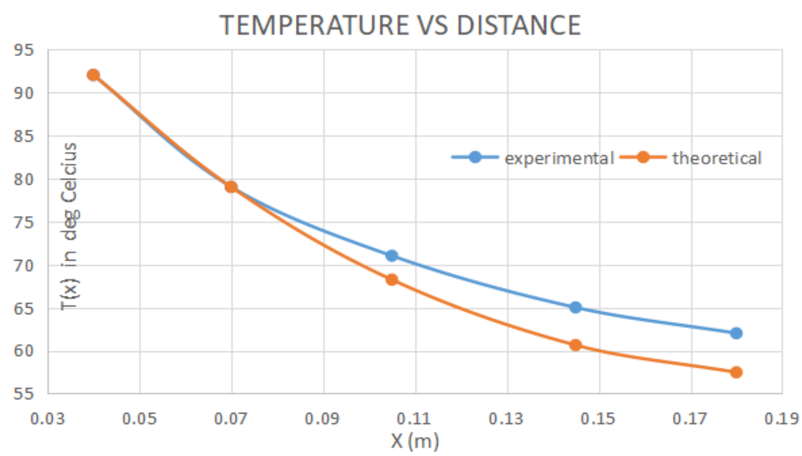
$$\frac{\theta}{\theta_0} = \frac{T - T_\infty}{T_1 - T_\infty} = \frac{\cosh m(L-x)}{\cosh mL}$$

$$\therefore T_2 = T(x{=}7cm) = \left(\frac{\cosh(8.38(0.2-0.07))}{\cosh(8.38(0.2-0.04))} * (92-23)\right) + 23$$

$$T_2 = T(x{=}7cm) = 78.9923\ ^oC$$

Similarly we can find values of temperature at x=10.5, 14.5 and 18 cm i.e. T3, T4 and T5 respectively (for Heat input=40 W).

Sr. No	Temperature(exp in ºC)	x(m)	Temperature(theoratical in ºC)
1	92	0.04	92
2	79	0.07	78.9923191
3	71	0.105	68.22324927
4	65	0.145	60.62741069
5	62	0.18	57.46375366
6	23	-	23



Fin effectiveness:

$$\varepsilon = \sqrt{\frac{Pk}{hA}} \tanh mL \quad \Rightarrow \; \varepsilon = 37.078$$

Efficiency:

$$\eta = \frac{\tanh mL}{mL} \quad \Rightarrow \; \eta \; = 0.55617 \text{ or } 55.617\%$$

PRECAUTIONS:

1. Switch on the blower before turning on the heater.
2. When the experiment is complete, first turn off the heater then some time turn off the blower.
3. Do not stop the blower in between the testing period.

REFERENCES:

1) Cengel, Y.A., Heat transfer a practical approach, McGraw Hill publication.
2) Heat and Mass Transfer lab manual
3) Sukhatme, Dr. S.P., A textbook of Heat Transfer, Universities Press
4) Holman, J.P., Heat transfer, McGraw Hill publication
5) Incropera, F.P., and Dewitt, D. P., Fundamentals of Heat and Mass Transfer, John Wiley & Sons, Inc.
6) https://www.engineeringtoolbox.com/air-properties-d_156.html

Uncertainity Analysis

for case-1 : P = 35 W.

$$V_0 = C_d \sqrt{2gh \frac{(\rho_w - \rho_a)}{\rho_a}} \left(1-\beta^4\right)^{-0.5}$$

$$\frac{\Delta V_0}{V_0} = \frac{1}{2}\frac{\Delta h}{h} = \frac{0.1 cm}{2 \times 6.2} \Rightarrow$$

Δh = least count of manometer

$$\boxed{\Delta V_0 = 0.238\ ms^{-1}}$$

$$\frac{\Delta V_a}{V_a} = \frac{\Delta V_0}{V_0} = \frac{0.1}{2 \times 6.2}$$

$$\boxed{\Delta V_a = 5 \times 10^{-3}\ ms^{-1}}$$

$$Nu = C\, Re^n\, Pr^{1/3}$$

$$\frac{\Delta Nu}{Nu} = n \times \frac{\Delta Re}{Re}.$$

$$Re = D V_a / \nu$$

$$\frac{\Delta Re}{Re} = \frac{\Delta V_a}{V_a} = \frac{0.1}{2 \times 6.2} \Rightarrow \boxed{\Delta Re = 3.2672}$$

$$\Delta Nu = Nu \times n \times \frac{\Delta R}{Re} \Rightarrow \boxed{\Delta Nu = 0.0375}$$

$$Nu = \frac{hD}{k_f}$$

$$\frac{\Delta Nu}{Nu} = \frac{\Delta h}{h}$$

$$\Delta h = 22.94 \times 0.466 \times \frac{0.1}{2 \times 6.2} = \boxed{0.0862\ W/m^2K}$$

Fin effectiveness $\varepsilon = \sqrt{\frac{P \cdot k}{h A}} \tanh(mL)$

$$\frac{\Delta \varepsilon}{\varepsilon} = \frac{\Delta h}{2h} + \frac{\operatorname{sech}^2(mL)}{\tanh(mL)} \times \frac{\Delta m}{m} \times \frac{\Delta h}{h}.$$

$$\frac{\Delta m}{m} = \frac{\Delta h}{2h} = \frac{0.08621}{22.94 \times 2} \Rightarrow \boxed{\Delta m = 0.015\ m^{-1}}.$$

$$\frac{\Delta \varepsilon}{\varepsilon} = \frac{0.08621}{2 \times 22.94} + \frac{\Delta h}{2h} \times \frac{\Delta h}{h} \times \frac{\operatorname{sech}^2(8.34 \times .15)}{\tanh^2(8.34 \times 0.15)}$$

$$\boxed{\Delta \varepsilon = 0.0699}$$

$$\eta = \frac{\tanh(mL)}{mL}.$$

$$\frac{\Delta \eta}{\eta} = \frac{\operatorname{sech}^2(mL)}{\tanh(mL)} \times \left(\frac{\Delta m}{m}\right)^2 \times \frac{\Delta h}{h}$$

$$\Delta \eta = \left(\frac{0.3}{4} \times \left(\frac{\Delta h}{h}\right)^3 \times 0.55\right).$$

$$\boxed{\Delta \eta = \approx 10^{-9}}$$

for case-2. P = 40 W.

$$\frac{\Delta V_0}{V_0} = \frac{1}{2} \times \frac{0.1}{6.4} \Rightarrow \boxed{\Delta V_0 = 0.227\ ms^{-1}}$$

$$\frac{\Delta V_a}{V_a} = \frac{1}{2} \times \frac{0.1}{6.4} \Rightarrow \boxed{\Delta V_a = 4.7 \times 10^{-3}\ ms^{-1}}$$

$$\frac{\Delta Re}{Re} = \frac{\Delta V_a}{V_a} = \frac{0.1}{2 \times 6.4}$$

$$\boxed{\Delta Re = 3.188}$$

$$\frac{\Delta Nu}{Nu} = n \frac{\Delta Re}{Re} = 0.466 \times \frac{0.1}{2 \times 6.4}$$

$$\boxed{\Delta Nu = 0.0364}.$$

$$\frac{\Delta Nu}{Nu} = \frac{\Delta h}{h} \Rightarrow \boxed{\Delta h = 0.0857\ W/m^2K}$$

$$\frac{\Delta \varepsilon}{\varepsilon} = \frac{\Delta h}{2h} + \frac{\operatorname{sech}^2(mL)}{\tanh^2(mL)} \frac{\Delta m}{m} \times \frac{\Delta h}{h}$$

$$\frac{\Delta m}{m} = \frac{\Delta h}{2\Delta h} = \frac{0.085}{2 \times 23.186} \Rightarrow \boxed{\Delta m = 0.0153\ m^{-1}}$$

$$\boxed{\Delta \varepsilon = 0.0679}$$

$$\frac{\Delta \eta}{\eta} = \frac{\operatorname{sech}^2(mL)}{\tanh^2(mL)} \times \left(\frac{\Delta m}{m}\right)^2 \times \frac{\Delta h}{h}$$

$$\Delta \eta \approx 10^{-10}.$$

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EXPERIMENT 3
CALIBERATION OF THERMOCOUPLES

Date: 23 / 01 / 2018

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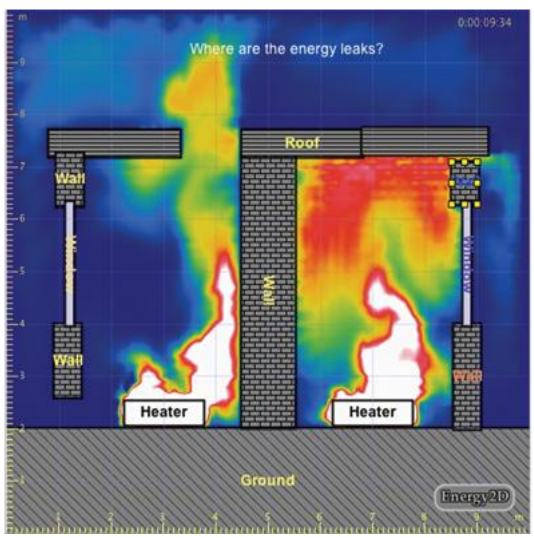

Group – G1 (a)

Members:

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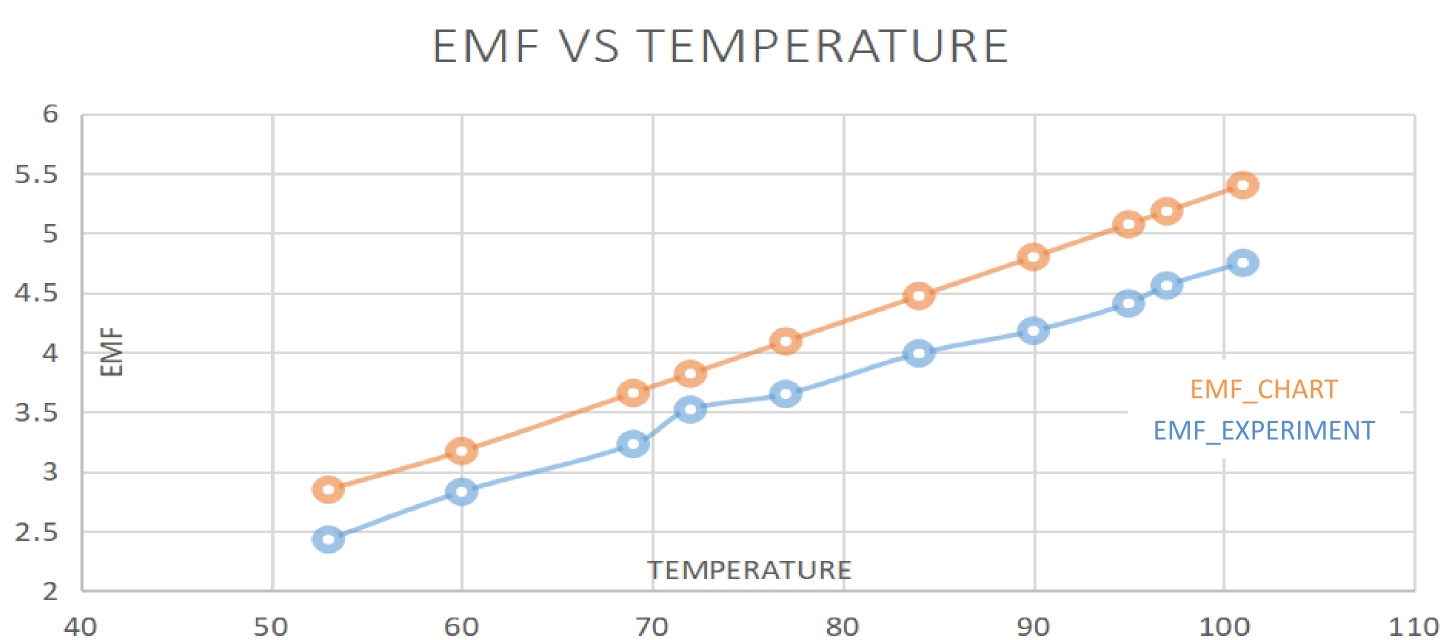
OBJECTIVE:
To calibrate the thermocouple

EXPERIMENTAL PROCEDURE:
1. Set the silicone oil bath temperature at a specified temperature greater than ambient temperature.
2. Switch on the heater of silicone oil bath.
3. Monitor the mercury thermometer reading every ten minutes till steady state is attained.
4. Note the value of e. m. f (mV) of the thermocouples T1.
5. Repeat the procedure for silicone oil bath temperatures at different temperatures.

RESULTS AND DISCUSSION:
$T_{amb} = 22\ ^{o}C$
Bath liquid = silicon
Material of thermocouple = iron and constantan

S N	Set temperature ^{o}C	Bath temperature T ^{o}C	$T - T_{amb}$ ^{o}C	Emf mV	Emf from chart E_{22-T} (mV)
1	75	75	53	2.43	2.848
2	80	82	60	2.83	3.171
3	90	91	69	3.23	3.658
4	95	94	72	3.52	3.82
5	100	99	77	3.65	4.091
6	105	106	84	3.99	4.472
7	110	112	90	4.18	4.799
8	115	117	95	4.41	5.073
9	120	119	97	4.56	5.182
10	125	123	101	4.75	5.401



DISCUSSIONS AND CONCLUSIONS:
We observe from the graph that experimental and theoretical values are not consistent, thus showing erroneous results. Sources of such error are:
The slight distortions in measurements are result of some possible error such as parallax error, error in multimeter reading, faulty thermometer, non-uniform distribution of temperature in silicone oil. Thermocouple may not be completely dipped in the bath. After heater is off that is when the desired temperature is reached, we should wait for temperature to get steady and become uniform throughout. Thus showing source of error.

APPENDIX:
Sample Calculation:
The chart of thermocouple is calibrated with respect to 0 ^{o}C. But here ambient is 22 ^{o}C, so we need to calibrate it.
From the chart, we first calculate $E_{0\text{-}22}$ = 1.122 mV
Now,

$$E_{0\text{-}T} = E_{0\text{-}22} + E_{22\text{-}T}$$

For any temperature T

So $E_{22\text{-}T}$ can be calculated.

For T = 99 ^{o}C
$E_{0\text{-}T}$ = 5.31 mV
$E_{0\text{-}22}$ = 1.122 mV
$E_{22\text{-}T} = E_{0\text{-}T} -- E_{0\text{-}22}$ = 5.31 – 1.122 = 4.091 mV

PRECAUTIONS:
1. Make sure that the thermocouples beads are properly made.
2. Ensure that there is no any loose connection in the experimental setup.
3. Thermocouples bead, inside the silicone oil bath should not come to the contact.
4. Turn off the multimeter after taking readings in mV

REFERENCES:

1) Cengel, Y.A., Heat transfer a practical approach, McGraw Hill publication.
2) Heat and Mass Transfer lab manual
3) Sukhatme, Dr. S.P., A textbook of Heat Transfer, Universities Press
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