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Experimental Analysis of Thermal Contact Resistance in Heat Exchanger

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ABSTRACT: *The thermal contact resistance is a principal parameter interfering with heat transfer in a fin tube heat exchanger. The objective of the present study is to examine the heat transfer rate and thermal contact resistance of hot and cold fluids. The heat transfer rate and thermal contact resistance of hot and cold fluids have been investigated through the experimental numerical method.*
Key word: *heat exchanger, thermal contact resistance, fluid*

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I. INTRODUCTION

A device which is used to transfer heat from a fluid on one side of barrier to another fluid on the other side without bringing the fluids into direct contact is called heat exchanger [2]. The fin-tube heat exchanger is such type of heat exchanger in which heat is transferred through a fin. Fins are assembled over the tubes either by mechanical expansion of the tubes into the fin collars or by the brazing process. In this type of process heat is flowing in tube and fin is attached to transfer the heat. In this type of arrangement fin is usually made with aluminum plate and tube is usually made of copper tube. In the fabrication of this type of heat exchanger, tubes are generally augmented for the purpose to tighten and shield the contact between fin collar and the outer surface of the tube [3].

When two conducting surfaces do not fit together and a thin layer of fluid is trapped between them, then the resistance is developed at such places which is called **thermal contact resistance** [10]. Such type of resistance is primarily a function of surface roughness, the pressure holding the two surfaces in contact, the interfaces fluid and the interface temperature. The direct contact between the solids surfaces takes place at a limited number of spots and the voids between them usually are fitted with air or the surroundings fluids. Heat transfer through the fluid filling the voids is mainly by conduction, since there is no convection in such a thin layer of fluid and radiation effects are negligible at normal temperature [10]. For the thermal contact resistance let the heat flux through the two solid surfaces in contact is $\overline{q}$ and the temperature difference across the fluid gap is Δt, the interface resistance is R_{th} is defined by

$$R_{th}=\frac{\Delta t}{\overline{q}}$$

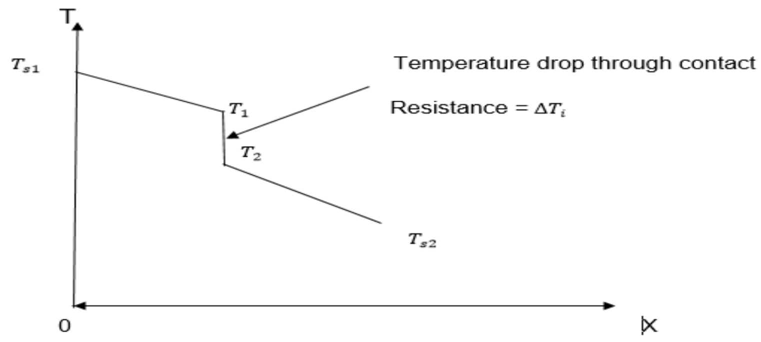

Fig 1.3 - Contact resistance between two solid bodies

Because of an increase in contact pressure can reduce the contact resistance as significant value. The intermediate fluids affect the thermal resistance, putting a viscous liquid like glycerin on the interface reduces the contact resistance 10 times with respect to air at a given pressure. A thermally conducting liquid such as thermal grease, silicon oil is applied between the contact surfaces before they were pressed against each other. This is mainly occurring when attached electronic component such as power transistors to heat sinks [10].

Table 1: Thermal contact resistance at different contact pressure under vacuum condition [10].

Intermediate material	Resistance R_i in $(\frac{m^2k}{w} \times 10^4)$	
	Contact pressure (1 bar)	Contact pressure (100 bar)
Stainless steel	6 – 2.5	0.7-.40
Copper	1 – 10	0.1-0.5
Magnesium	1.5 – 3.5	0.2-0.4
Aluminum	1.5 - 5.0	0.2-0.4

A finned tube Heat exchanger is taken of nominal diameter 12.25 mm tube diameter and finned is attached to the out-side of tube. There are 8 tube in this experimental set up. The tube length is 50 cm and gapping between the centers of the two tubes is about 3 cm. The length of fin is 25 cm approximately. Plywood box for covering fin tube heat exchanger. We have insulated this by the thermocoal. The size of box is 27 inches in length 13 inches in height and 4 inches in breadth. There are 4 holes of size 0.5 inch each in the box for the purpose of pipe fitting in tube. Out of four holes two for cold water and two for hot water pipe fitting.

Fig 2: Fin tube heat exchanger

Fig 3: Plywood box of dimension 27*13*4 inches

We have covered this box by using of thermocoal in order to have maximum heat transfer. About 0.5-inch thickness of thermocoal is used for covering the box by using cello tape and fevicol.

Fig 4: A plywood box covered with thermocoal

Water tank

Two water tank one for cold water restore and another for hot water restore. For hot water we have collected water in a water tank and water is heated to a desired temperature by the use of immersion rod. We measure the temperature of water by the using the digital thermometer.

Fig 5- Water tank for hot water and cold water restore

water heater is used for heating water have capacity of Voltage- 230. Frequency-50 Hz. Operating power- 1000 watt. Thermometer measures the temperature by using different temperature gradient principle. We have used this type of thermometer to find out how much temperature of water is heated in the hot water tank.

Fig 6: Water heater

Fig 7: Thermometer.

II. WORKING PRINCIPLE

The experimental set up consist of two water tanks of similar size, one for cold water reservoir and another for hot water reservoir. First of all, we take sufficient amount of water in a tank and then heat by immersion rod and checked time to time the temperature of water by digital thermometer, when the required temperature is reached then the hot water and cold water is send to fin tube heat exchanger by the use of centrifugal pump. And measure their mass flow rates by using the rotameter. Here there are four thermocouple attached, two for cold water inlet and outlet temperature and two for hot water inlet and outlet temperature. The thermocouple is attached to digital temperature indicator by the use of thermocouple wire. When hot water is in and out the temperature is measured by DTI and noted in table 2, and same process is repeated for cold water inlet and outlet temperature. The hot water and cold water is controlled by bypass valve and how much LPM of water is running in the tube is found out by Rotameter. There are two Rotameter in our set up. Excess water is out by use of bypass valve. Finally, we have tabulated two Rotameter reading and four temperature reading and by using this all reading we have calculated the heat transfer rate of hot and cold water by the use of 12.25 mm fin tube heat exchanger and the effect of thermal contact resistance for hot and cold water passing through the tube.

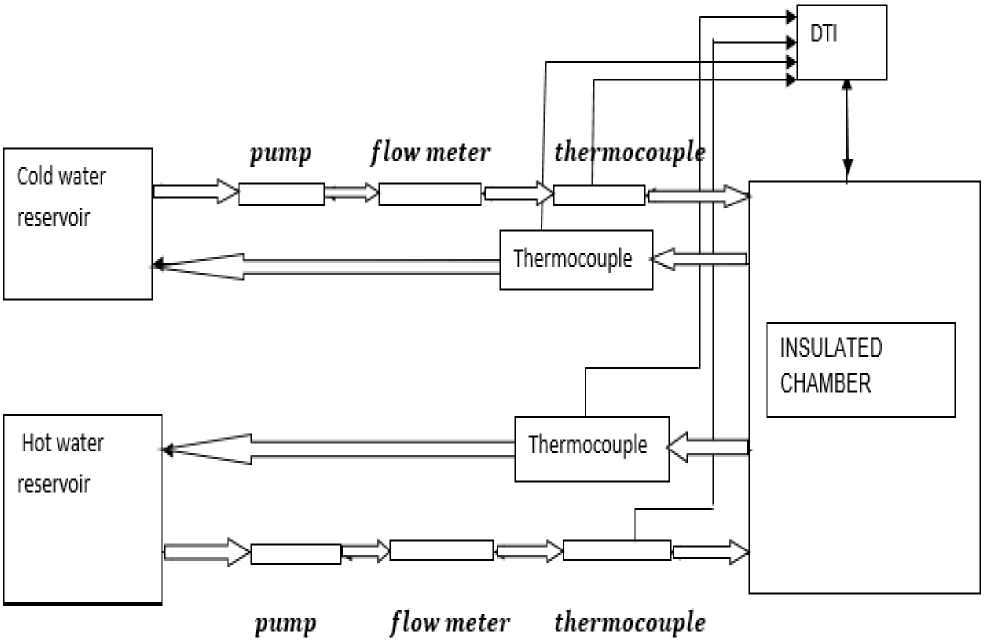

Fig 8:Layout of Experimental Set up

III. RESULT AND DISCUSSION

Experiments were done for different temperatures and flow rates and data has been recorded and tabulated below.

Table 2:

Case	T_{ci} (°C)	T_{co} (°C)	T_{hi} (°C)	T_{ho} (°C)	m_c (kg/min)	m_h (kg/min)
1	24.7	26.3	41.3	39.5	2.1	2.3
2	24.8	26	40	38.3	2.6	2.3
3	24.8	25.7	40.4	39.2	2.5	2.3
4	24.6	26.3	38.2	35.8	1.7	1.9
5	24.6	26.9	37.8	35.3	1.6	1.8
6	24.7	26.5	39	37.2	1.8	2
7	24.6	26.4	39.8	37.9	2.1	2.3
8	24.7	26.5	39.5	37.4	2	2.2
9	24.8	26.4	39	37.3	2	2.1
10	24.7	26.3	41.3	39.5	2.2	2.3
11	24.6	25.8	40.9	39.5	2.5	2.4
12	23.6	25.8	39.5	37.2	1.7	1.9
13	23.6	25.3	41	39.2	1.9	2.1
14	23.7	25.9	40.5	38.2	1.8	2
15	23.6	25.7	38.8	36.4	1.6	1.8

Mathematical calculation

Assumption for calculation of fin tube heat exchanger

(a) The flow arrangement is counter flow.
(b) Flow condition are under steady state.
(c) Conductive resistance has been neglected to make the calculation and the experimental procedure simpler.
(d) The specific heat and mass flow rates are constant.
(e) Axial conduction along the tube is negligible.
(f) Heat exchange has been computed on the basis of log mean temperature difference.
(g) No phase change occurs during heat transfer.

Let,

T_1 = surface temperature of tube

T_2 = temperature of fin
T_h = avg. fluid (hot) temperature.
Therefore, heat flowing radially outwards is given by,
Q = $h_h \times \pi$Dl $\times (T_h - T_s) = \frac{(T_1 - T_2)}{R_{th}}$

$$\frac{Q}{h_h \pi Dl} = (T_h - T_1) \quad (3.1)$$

$$\frac{Q}{1/R_{th}} = (T_1 - T_2) \quad (3.2)$$

Adding (3.1) and (3.2), we get,

$$(T_h - T_2) = Q(\frac{1}{h_h \pi Dl} + R_{th})$$

$$Q = (\frac{\Delta T}{1/h_h \pi Dl + R_{th}})$$

$(\frac{1}{h_h \pi Dl})$ = convective resistance
R_{th} =thermal contact resistance
On an average basis ΔT has been taken to be the log mean temperature

IV. CONCLUSION

The heat transfers of cold fluid and hot fluid vary with respect to mass flow rates and also vary w.r.t the inlet and outlet temperature difference of cold fluid which is clearly shown in fig.9. fig 10. mass flow rates are dependent on temperature difference of hot and cold fluid. If mass flow rates are increasing the temperature difference of hot and cold fluids are decreasing due to contact time is very less as shown in fig. 11 and 12. The thermal contact resistance of cold fluid and hot fluid vary with respect to mass flow rate and also dependent on the inlet and outlet temperature of cold fluid. The temperature difference and mass flow rates of cold fluids are increasing the thermal contact resistance are also increasing as shown by graph 13. and in graph 14. difference of the HE utilized for experimentation

Now calculation for obtained data:

$\dot{m}_h$ = 2.3 $(^{kg}/_{min})$, T_{hi} = 41.3℃, T_{ho} = 39.5 ℃

$\dot{m}_c$ = 2.1 $(^{kg}/_{min})$, T_{ci} = 24.7℃,T_{co} = 26.3 ℃

$Q_{hot} = \frac{2.3 \times 4.215 \times 1000\,(41.3 - 39.5)}{60}$

Q_{hot} = 290.835 W

$Q_{cold} = \frac{2.1 \times 4.215 \times 1000\,(26.3 - 24.7)}{60}$

Q_{cold} = 236.04 W

$q = av$

$v_{hot} = \frac{2.3 \times 10^{-3} \times 10^{6} \times 4}{60 \times 3.14 \times 12.25^{2}}$

$\boldsymbol{v_{hot}}$ = 0.325 $^{m}/_{s}$

$v_{cold} = \frac{2.1 \times 10^{-3} \times 4 \times 10^{6}}{60 \times 3.141 \times 12.25^{2}}$

v_{cold} = .297 $^{m}/_{s}$

$R_e = \frac{\rho v d}{\mu}$ at 40.4 ℃

R_e For hot fluid = $\frac{992.215 \times 0.325 \times 12.25 \times 10^{-3}}{0.653 \times 10^{-3}}$ = 6049.396

R_e For hot fluid = 6049.396

R_e For cold fluid = $\frac{996.916 \times 0.297 \times 12.25 \times 10^{-3}}{0.891 \times 10^{-3}}$

R_e For cold fluid = 4070.74

$N_u = 0.00172 \times R_e^{1.2} \times P_r^{0.3}$ (3000<R_e<21000) reference [2]

Now, by interpolation method we find prandtl no. at 40.4 and 25.5 ℃

P_r At 40.4 ℃ = $4.34 - \frac{(4.34 - 3.02)}{20} \times 0.4$

P_r At 40.4 ℃ = 4.3136

Now, P_r at 25.5 ℃ = $7.02 - \frac{(7.02 - 4.34)}{20} \times 5.5$

P_r At 25.5 ℃ = 6.283

N_u For hot fluid = $0.00172 \times 6049.396^{1.2} \times 4.3136^{0.3}$
N_u For hot fluid = 92.052
N_u For cold fluid = $0.00172 \times 4070.74^{1.2} \times 6.283^{0.3}$
N_u For cold fluid = 64.05
We know, $N_u = \frac{hD}{k}$
K is thermal conductivity at 40.4 and 25.5 ℃ is calculated by interpolation method.
K at 40.4 ℃ = $0.628 + \frac{(0.6513 - 0.6280)}{20} \times 0.4$
K at 40.4 ℃ = 0.6289
K at 25.5 ℃ = $0.5978 + \frac{(0.628 - 0.5978)}{20} \times 5.5$
K at 25.5 ℃ = 0.6064
So, h for hot fluid = $\frac{92.052 \times 0.6289}{12.25 \times 10^{-3}}$
h for hot fluid = 4726.588 in $W/_{m^2 k}$
h for cold fluid = $\frac{64.05 \times 0.6064}{12.25 \times 10^{-3}}$
h for cold fluid = 3170.60 in $W/_{m^2 k}$
now, $\theta_m = \frac{\theta_1 - \theta_2}{ln\frac{\theta_1}{\theta_2}}$, where θ_1 is inlet temperature difference and θ_2 is outlet temperature difference of fluid.
Here, θ_1 = $41.3 - 26.3$ = 15℃
θ_2 = $39.5 - 24.7$ = 14.8℃
So, θ_m = 14.899℃ by using above formulae
Now, convective resistance = $\frac{1}{h\pi Dl}$
So, convective resistance for hot fluid = $\frac{1}{4726.588 \times 3.14 \times 12.25 \times 50 \times 10^{-5}}$
Convective resistance for hot fluid = 0.01099
Convective resistance for cold fluid = $\frac{1}{3170.60 \times 3.14 \times 12.25 \times 50 \times 10^{-5}}$
Convective resistance for cold fluid = 0.01639
$Q = \frac{\theta_m}{0.01099 + R_{th}}$, for hot fluid
So, R_{th} for hot fluid = $\frac{14.899}{290.835} - 0.0109$
R_{th} For hot fluid = 0.04023 or 4.023 %

R_{th} For cold fluid = $\frac{14.899}{236.04} - 0.01639$
So, R_{th} for cold fluid =0.04673 or 4.67 %

After solving the above data, first of all we have calculated heat transfer by hot and cold fluid. We have also calculated the velocity of fluid flowing. We have calculated the Reynolds number, Nusselt number, convective heat transfer coefficient and Prandtl number at different temperature. By using convective heat transfer coefficient, we found convective thermal resistance and then finally calculated thermal contact resistance by using different formulae for hot and cold water. Now all the above results are shown in table3 and 4

Table 3- heattransfer at different-different temperature of hot and cold fluids

case	T_{ci}(℃)	T_{co}(℃)	T_{hi}(℃)	T_{ho}(℃)	m_c ($kg/_{min}$)	m_h ($kg/_{min}$)	$Q_{c(W)}$	$Q_{h(W)}$
1	24.7	26.3	41.3	39.5	2.1	2.3	236.04	290.235
2	24.8	26	40	38.3	2.6	2.3	219.18	274.677
3	24.6	25.7	40.4	39.2	2.5	2.3	177.03	193.69
4	24.6	26.3	38.2	35.8	1.7	1.9	203.03	306.99
5	24.6	26.9	37.8	35.3	1.6	1.8	258.52	316.125
6	24.7	26.5	39	37.2	1.8	2	227.61	252.9
7	24.6	26.4	39.8	37.9	2.1	2.3	265.545	306.992
8	24.7	26.5	39.5	37.4	2	2.2	252.9	324.55
9	24.8	26.4	39	37.3	2	2.1	224.6	250.792
10	24.7	26.3	41.3	39.5	2.2	2.3	247.28	290.835
11	24.6	25.8	40.9	39.5	2.5	2.4	210.75	236.04
12	23.6	25.8	39.5	37.2	1.7	1.9	262.75	306.992
13	23.6	25.3	41	39.2	1.9	2.1	226.90	265.54
14	23.7	25.9	40.5	38.2	1.8	2	278.19	323.15
15	23.6	25.7	38.8	36.4	1.6	1.8	236.04	303.48
16	25.2	26.8	36.8	34.3	2.2	1.5	247.28	263.4375

Table 4 - Experimental Results for thermal contact resistance.

Case	$R_e(c)$	$R_e(h)$	$h_c(\frac{W}{m^2{}^\circ C})$	$h_h(\frac{W}{m^2{}^\circ C})$	$R_{th(c)}(\%)$	$R_{th(h)}(\%)$
1	4070.74	6049.19	3170.6	4726.58	4.67	4.02
2	5030.30	5932.35	4092.83	4554.57	5	3.86
3	5417.10	6000.19	4467.8	4650.73	7.05	6.38
4	3317.90	4714.32	2355.57	3458.44	3.46	2.24
5	3139.08	4411.36	2318.05	3308.66	1.9	1.85
6	3503.05	5065.31	2651.72	3868.75	3.4	3.51
7	4123.37	5866.89	3209.61	4592.31	3.3	3.4
8	4123.37	5198.06	3219.37	3981.74	3.36	2.57
9	3895.052	5292.32	3004.94	4076.32	3.65	3.57
10	4065.55	6035.39	3142.6	4735.58	4.63	4.02
11	4834.32	6301.71	4777.38	4965.42	6.03	5.3
12	3250.45	4821.39	2426.94	3640.41	3.05	2.97
13	3608.87	5471.60	2754.12	4153.94	5.01	4.64
14	3480.21	5080.26	2633.25	3809.10	3.25	3.13
15	3059.07	4481.79	2256.93	3350.72	3.18	2.71
16	4359.92	3584.19	3434.24	2595.19	3.7	1.62
17	4824.70	6831.16	3863.2	5468.44	4.75	4.91
18	3965.88	3907.18	3066.21	2870.63	2.91	2.57
19	4896.21	3443.57	3685.4	2600.95	4.41	3.57
20	4569.29	3244.15	3405.52	2421.75	3.47	3.53

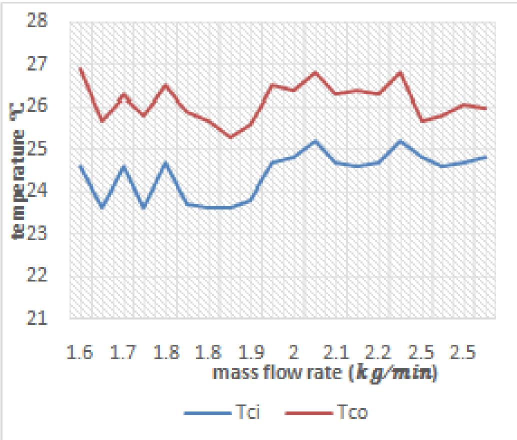

Fig 9-Graph between mass flow rates and outlet and inlet temperature variation of cold fluid.

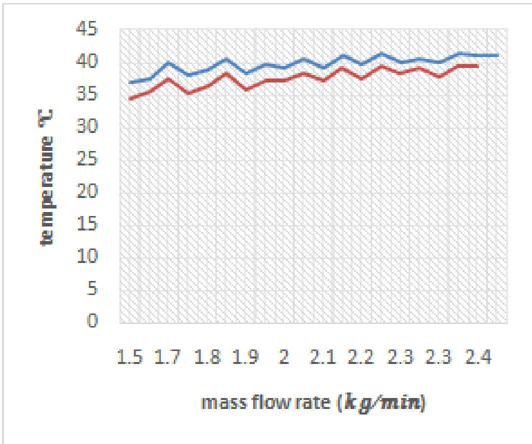

Fig 10- Graph between mass flow rates and outlet and inlet temperature variation of hot fluid

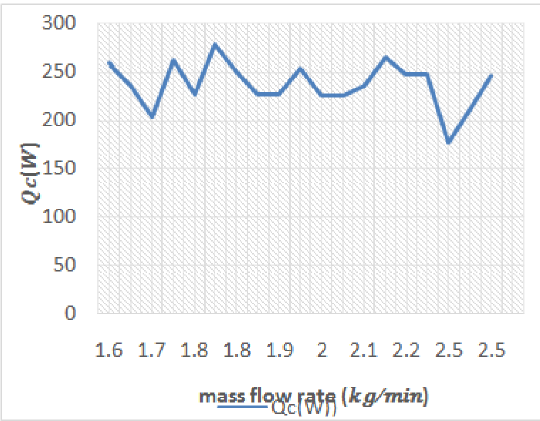

Fig11- Graph between mass flow rates and heat transfer at different-2 temperature difference of hot

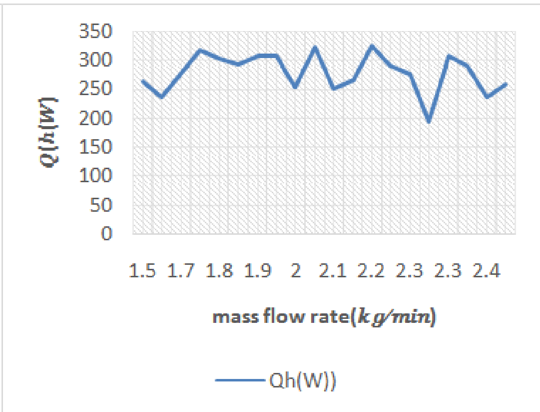

Fig12- Graph between mass flow rates and heat transfer at different-2 temperature difference of cold fluid.

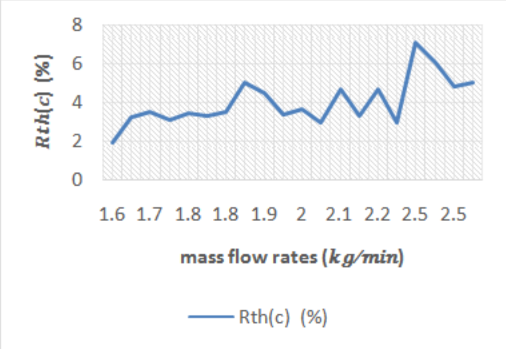

Fig13 Graph between mass flow rates and thermal contact resistance at different-2 temperature of cold

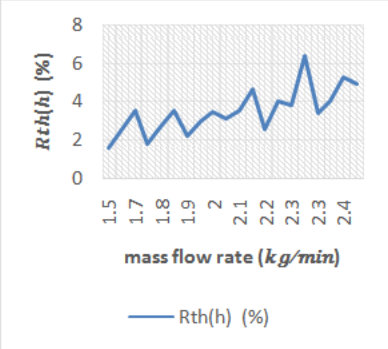

Fig14 Graph between mass flow rates and thermal contact resistance at different temperature of hot fluid.

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