CH 3522: Unit Operations Lab

Fin Tube Heat Exchanger

Batch - R, Group - 05
Date of Experiment: 12th February, 2025
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Roll Numbers	Group Members
CH22B019	N.Pranavi
CH22B020	Deepanjhan Das
CH22B021	Siddhartha R
CH22B022	P.Ganesh

1. Objectives

- Observe the variation in inlet and outlet temperatures of hot and cold fluids circulating in heat exchangers.
- Determine the overall heat transfer coefficient in a finned-tube double-pipe heat exchanger using experimental data.
- Analyze the effect of flow rate on the overall heat transfer coefficient for both hot and cold fluids.
- Calculate the fin efficiency of the given heat exchanger.

2. Introduction

Finned tube heat exchangers are widely used in various industries to enhance heat transfer between two fluids. The addition of fins to the outer surface of the tubes increases the surface area, improving thermal performance compared to conventional tube designs. These heat exchangers can have longitudinal fins, used for fluid flow parallel to the tube axis, or transverse fins, used for perpendicular fluid flow. Different fin designs, such as spikes, pins, studs, or spines, can be employed to optimize heat transfer based on flow conditions.

3. Theory

The performance of a finned tube heat exchanger is determined by several key equations governing mass flow rate, heat transfer area, and fin efficiency.

1. Mass flow rate of air:

$$Q_m = \frac{C_d A_2}{\sqrt{1-\beta^4}}\sqrt{2\Delta P \rho_{air}} \tag{1}$$

Where,

Q_m = mass flow rate of air (kg/s)

C_d = Discharge coefficient of orifice metre = 0.9 which is a standard value to use.

A_2 = Cross-sectional area of orifice

β = ratio of orifice hole diameter to pipe diameter

ΔP = Difference in pressure

ρ_{air} = Density of air

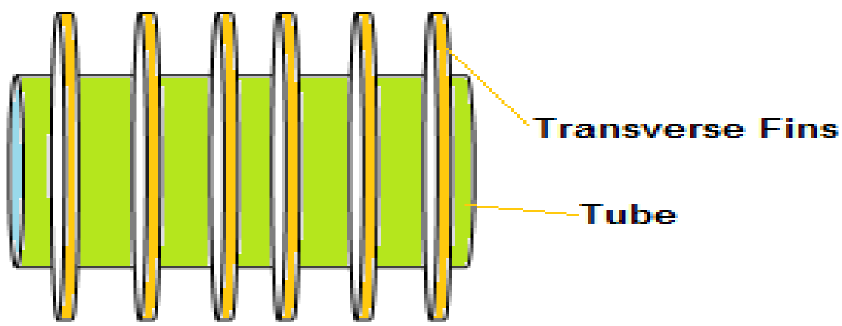

Figure 1: Transversely Finned Tube

2. To compute heat transfer area:

$$A_{tube} = \text{tube area} = 2\pi r l \tag{2}$$

$$A_{fin} = 2lh + lb + 2bh \tag{3}$$

$$N = \text{Number of fins}$$

$$A_{total} = A_{tube} + NA_{fin} - N(lb) \tag{4}$$

Where the last term in A_{total} corrects for the area lost due to attachment of fins

3. To calculate overall fin efficiency:

$$\eta_o = 1 - \frac{A_{fins}}{A}(1 - \eta_f) \tag{5}$$

$$\eta_f = \frac{\tanh(mL)}{mL} \tag{6}$$

$$m = \sqrt{\frac{hL}{kA}} \tag{7}$$

Where,

η_o = overall efficiency of fin
h = film heat transfer coefficient from fin surface (W/m²·K)
k = thermal conductivity of fin (W/m·K)
C = circumference of fin (m)
A = cross-sectional area of fin (m^2)

These equations help in analyzing the thermal performance and efficiency of finned tube heat exchangers in various applications.

Figure 2: Longitudinal Fins Finned Tubes

4. Apparatus Required

The apparatus required for this experiment are listed below;

- Finned tubes heat exchanger setup.
- Pressure gauges
- Orifice meter and pipes
- Thermocouples, Temperature detectors.
- U-tube manometer, Stopwatch

5. Schematic of Experimental Setup

Experimental setup includes the following components:

- **Fin Tube Heat Exchanger**: The core component where heat transfer occurs. Fins increase the surface area for improved heat dissipation.
- **Tubes**: Carry the working fluid (hot/cold water, steam, or air) and **Fins** which are attached to tubes to enhance heat transfer efficiency.
- **Hot & Cold** fluid sources, Pump, Rotameters for overall fluid circulations.
- Heating & Cooling systems, Temperature controllers, Sensors such as thermocouples.
- **Manometers/Pressure Gauges**: Measure pressure drop across the heat exchanger.

Figure 3: The Experimental Setup for Fin Tube Heat Exchanger Experiment

6. Procedure

- Arrange the finned-tube heat exchanger in a controlled environment and connect thermocouples, temperature probes, flow meters, and pressure indicators at appropriate locations.

- Use steam as the hot fluid and ensure a consistent, regulated heat supply while maintaining a controlled flow of the cooling medium (water).
- Set a specific steam pressure and allow it to stabilize for approximately 5 minutes.
- Once stable, partially open the control valve for the cold fluid and wait for about 4 minutes until the U-tube manometer readings stabilize.
- Record precise temperature readings from the switchable temperature display along with the differential height measurements from the U-tube manometer.
- Adjust the cold fluid flow rate by turning the valve further and wait until the manometer readings stabilize before recording new data.
- For a fixed incoming steam pressure, take three sets of height readings by using the control valve of cold fluid.
- Repeat the process for three different steam pressure values, ensuring stability before each set of measurements.

7. Experimental Observations

In the following table, we include the observations of our experiment and the laboratory datasheet is also provided at the end of this report.

Pressure (Psi)	**h1 (cm)**	**h2 (cm)**	**T1** (℃)	**T2** (℃)	**T5** (℃)	**T4** (℃)
1	38.3	27	118	115	29	96
1	36.4	29.4	116	102	29	99
1	37.6	28	117	100	29	101
2	37.5	28	130	130	28	112
2	38.5	27	130	130	28	113
2	38.2	27.3	130	130	28	115
3	38	27.4	140	135	28	116
3	38.9	26.7	140	122	28	120
3	39.4	26	141	140	28	122

Table 1: Experimentally observed and tabulated values of various quantities.

8. Sample Calculations

<u>**Experimental Determinations:**</u>

First, we compute various parameters required for determining the mass flow rate through orifice meter as explained in the theory section. The values required for these computations have been shown in the observations, with the exception of the density of air, which is an accepted constant. For reference to the notations, please refer to the "*Theory*" section of this report.
$\beta = 0.6579$, $C = 0.99836$, $A_2 = 4.9087 \times 10^{-4}$, $\rho_{air} = 1.1640$. And these are all in their respective SI units.

Now, we compute the pressure drop from the manometer readings in the observations. The equation employed is $\Delta P = \rho g \Delta h$.
Hence, we compute the mass flow rate using the equation derived in the "*Theory*" section and the complete tabulation is provided in the "*Results & Discussion*" section.

For heat transfer area, using the heat exchanger data from the above, we do the following:
The tube area using $A_{tube} = 2 \times \pi \times r \times l$
The fin area $A_{fin} = 2lh + lb + 2bh$
And the total heat exchange area becomes $A = A_{tube} + N \times A_{fin} - Nlb$, where the last term corrects for the area lost due to attachment of fins. And by putting the values we get,
$A_{fin} = 0.026533\, m^2$, $N = 10$, $A_{fin,\, total} = 0.265329\, m^2$, $A_{tube} = 0.237673\, m^3$.
And thus total area comes out to be, $A_{total} = 0.47931\, m^2$.

Since the flow of air is counter-current with the flow of steam, the formula for LMTD is as follows;

$$LMTD_{counter-current\ flow} = \frac{(T_{hot,in} - T_{cold,\, out}) - (T_{hot,out} - T_{cold,in})}{ln(\frac{(T_{hot,in} - T_{cold,\, out})}{(T_{hot,out} - T_{cold,\, in})})} \qquad (8)$$

We have shown the equivalent calculation in the subsequent report "Shell_Tube_Heat_Exchanger" and here also it follows the same and the complete tabulation is provided in the following section.

Then U (overall HTC) is calculated using these experimental values and using the following expression

$$Q = MC_p(T_o - T_i) \qquad (9)$$

$$U = \frac{Q}{A\Delta T_{LMTD}} \qquad (10)$$

At the end to compare these values, theoretical correlations are used and it also follows the same flow of calculations as shown in the "Shell_Tube_Heat_Exchanger" report to obtain the two types of heat transfer coefficient to finally obtain the overall HTC using the following equation,

$$\frac{1}{U_{theoretical}} = \frac{1}{h_o} + \frac{D_o}{h_i D_i} + \frac{D_o ln(D_o/D_i)}{2K} \tag{11}$$

9. Results & Discussions

Experimental Results:

All the values for the pressure change and the mass flow rate of air at any section of the pipe is provided in the following table (table 2).

h1 (cm)	h2 (cm)	Δh (cm)	ΔP (Pa)	Q_m (Kg/s)
38.3	27	11.3	1.2890	0.0009882
36.4	29.4	7.00	0.7985	0.0007778
37.6	28	9.60	1.0951	0.0009108
37.5	28	9.50	1.0837	0.0009061
38.5	27	11.50	1.3118	0.0009968
38.2	27.3	10.90	1.2434	0.0009705
38	27.4	10.60	1.2092	0.0009571
38.9	26.7	12.20	1.3917	0.0010268
39.4	26	13.40	1.5286	0.0010761

Table 2: Experimental Values of Mass Flow Rate at any section of Pipe

Now the LMTD values are provided in the following table (table 3) which have been calculated using the expressions discussed before.

T1 (℃) Steam In	T2 (℃) Steam Out	T5 (℃) Air In	T4 (℃) Air Out	T2 - T5 (℃)	T1 - T4 (℃)	ΔT LMTD (℃)
118	115	29	96	86	22	46.945
116	102	29	99	73	17	38.429
117	100	29	101	71	16	36.910

130	130	28	112	102	18	48.426
130	130	28	113	102	17	47.439
130	130	28	115	102	15	45.385
140	135	28	116	107	24	55.527
140	122	28	120	94	20	47.817
141	140	28	122	112	19	52.422

Table 3: The Experimental Values used to calculate LMTD

The following table (table 4) contains the experimentally calculated values of overall HTC and the heat exchanged per unit time.

T5 (℃) Air In	**T4 (℃) Air Out**	**ΔT LMTD (℃)**	Q_{air} **(W)**	**Exp HTC U** (W/m^2K)
29	96	46.945	66.7369	2.96582
29	99	38.429	54.8781	2.97926
29	101	36.910	66.1028	3.73625
28	112	48.426	76.7172	3.30506
28	113	47.439	85.4121	3.75618
28	115	45.385	85.1108	3.91233
28	116	55.527	84.8961	3.18971
28	120	47.817	95.2181	4.15434
28	122	52.422	101.9606	4.05773

Table 4: Experimentally calculated overall HTC U

Theoretical Results:

Now we provide the theoretically obtained results for the heat transfer coefficients (of heating & cooling process of air and steam respectively) using Dittus-Boelter correlations in the following two tables (table 5 & 6).

Q_m (Kg/s)	V of air (m/s)	Re	Pr	Nu	h_{air} (W/m^2K)
0.0009882	1.7295	3040.521	1.2321	15.2877	8.2808
0.0007778	1.3612	2393.084	1.2321	12.62267	6.8373
0.0009108	1.5941	2802.493	1.2321	14.3225	7.7580
0.0009061	1.5857	2787.858	1.2321	14.2627	7.7256
0.0009968	1.7447	3067.311	1.2321	15.3954	8.3392
0.0009705	1.6986	2986.222	1.2321	15.0689	8.1623
0.0009571	1.6750	2944.841	1.2321	14.9016	8.0717
0.0010268	1.7970	3159.285	1.2321	15.7636	8.5386
0.0010761	1.8833	3311.016	1.2321	16.3664	8.8651

Table 5: Theoretical values of HTC for the heating of air.

V of steam (m/s)	Re	Pr	Nu	h_{steam} (W/m^2K)
0.7485	568.8977	2.78512×10^{-5}	0.1582	8950.824
0.5892	447.7586	2.78512×10^{-5}	0.1306	7390.449
0.6899	524.3612	2.78512×10^{-5}	0.1482	8385.716
0.6863	521.6230	2.78512×10^{-5}	0.1476	8350.666
0.7551	573.9101	2.78512×10^{-5}	0.1593	9013.859
0.7352	558.7379	2.78512×10^{-5}	0.1559	8822.715
0.7250	550.9952	2.78512×10^{-5}	0.1542	8724.770
0.7778	591.1189	2.78512×10^{-5}	0.1631	9229.445
0.8151	619.5086	2.78512×10^{-5}	0.1694	9582.384

Table 6: Theoretical values of HTC for the cooling of steam.

At the end we use the HTC data from table 5 & 6 to obtain the overall HTC using the equation mentioned in the "*Sample Calculations*" section.

h_{air} (W/m^2K)	h_{steam} (W/m^2K)	**Theoretical HTC U** (W/m^2K)
8.2808	8950.824	3.7142
6.8373	7390.449	3.0676
7.7580	8385.716	3.4801
7.7256	8350.666	3.4655
8.3392	9013.859	3.7403
8.1623	8822.715	3.6611
8.0717	8724.770	3.6205
8.5386	9229.445	3.8296
8.8651	9582.384	3.9757

Table 7: Theoretically calculated overall HTC U

10. Conclusions

- Regarding the datasheet we have uploaded, we accidentally forgot to open the valve attached with the steam-pipe and that's why we got some erroneous results which we have cut through and had retaken the data.
- The heat transfer coefficients are computed as above. They increase with increase in flow rate, as predicted by theory. However, the similarity between theory and experiment ends there, as can be clearly seen from the values. This is a result of a number of assumptions we make, which do not hold true in reality.
- Flow through pipes is not lossless. The pipes are not completely smooth. The fins are not insulated at their ends. The steam is not homogenous and undergoes partial phase change inside the setup. All these non-idealities contribute to a mismatch in values.
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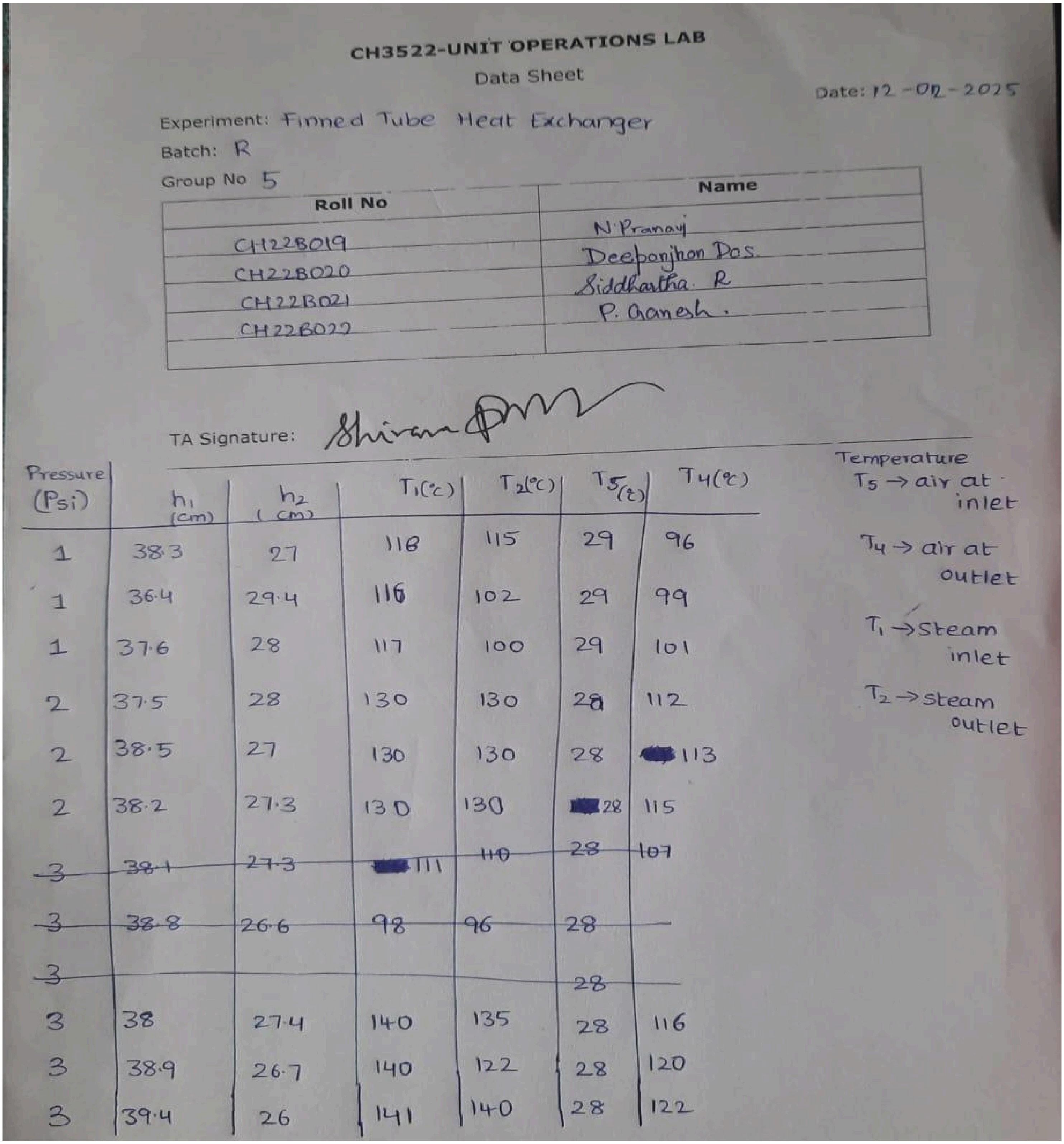
11. References

- The Engineering Toolbox to obtain the thermal conductivity of metals.
- The Engineering Toolbox to obtain the viscosity values.
- The GitHub repository contains all the related coded scripts used for calculations.



CH3522-UNIT OPERATIONS LAB

Data Sheet

Date: 12-02-2025

Experiment: Finned Tube Heat Exchanger

Batch: R

Group No 5

Roll No	Name
CH22B019	N. Pranay
CH22B020	Deeponjhon Das.
CH22B021	Siddhartha. R
CH22B022	P. Ganesh.

TA Signature: Shiram

Pressure (Psi)	h_1 (cm)	h_2 (cm)	T_1(°C)	T_2(°C)	T_5(°C)	T_4(°C)
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2	38.5	27	130	130	28	113
2	38.2	27.3	130	130	28	115
~~3~~	~~38.1~~	~~27.3~~	~~111~~	~~110~~	~~28~~	~~107~~
~~3~~	~~38.8~~	~~26.6~~	~~98~~	~~96~~	~~28~~	
~~3~~					~~28~~	
3	38	27.4	140	135	28	116
3	38.9	26.7	140	122	28	120
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Temperature
$T_5 \rightarrow$ air at inlet
$T_4 \rightarrow$ air at outlet
$T_1 \rightarrow$ steam inlet
$T_2 \rightarrow$ steam outlet

Figure 4: Laboratory Data 1