Efficiency and Effectiveness calculation of Helical Fins in Double-pipe Heat Exchanger

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PROBLEM STATEMENT

This project aims to analyze the performance of a double heat exchanger with helical fins by checking fin efficiency and effectiveness of heat transfer as compared to a conventional double heat exchanger without fins.

OBJECTIVE:

1. To calculate heat transfer coefficient
2. Comparison with simple double heat exchanger with the model
3. Efficiency and Effectiveness of the fin

BACKGROUND

In a double heat exchanger, hot and cold fluids exchange thermal energy due to a temperature difference. The fluids typically flow in counter-current directions, maximizing the temperature gradient between them for efficient heat transfer. Convection dominates the heat transfer process within the fluids, while conduction occurs at a slower rate through the physical barrier separating them.

Heat transfer coefficient, a property depending on fluid characteristics and exchanger geometry, quantifies the rate of heat transfer. It can be calculated using various dimensionless numbers like Reynolds number and Nusselt number.

Fins, or extended surfaces, significantly enhance heat transfer by increasing the available surface area. This not only improves the rate of heat transfer but also promotes a more uniform temperature distribution. Helical fins, specifically, offer a distinct advantage. Their spiral shape provides a larger surface area compared to straight fins of the same length. Additionally, the rotation induced by the helical fins promotes better mixing within the fluid, disrupting stagnant zones and enhancing convective heat transfer. Consequently, helical fins lead to a higher rate of heat transfer compared to straight fins.

I. MATERIALS USED:

Circular Finned Pipe: This pipe, with a cylindrical shape and circular rings surrounding it (as an alternative to helical fins), serves as the primary heat transfer element. It enhances the heat transfer efficiency by increasing the surface area exposed to the surrounding environment.
Reason for this Alternative: Weilding of helical shaped rings was not feasible on the pipe, due to risk of breaking off, and buying Helical fins from the market was getting out of our budget, so as suggested and recommended by the Machine shop, we switched to circular rings as fins.
Material - Aluminium

Normal Pipe: The normal pipe acts as a comparison baseline in the experiment. It allows for assessing the performance enhancement achieved by the helical fins in heat transfer.
Material - Aluminium

Outer Pipe: The connecting pipe links the heat pipes to the thermal source and sink. It ensures the flow of the heat transfer medium (e.g., fluid) through the system, facilitating heat transfer from one end to the other.
Material: PVC

Connecting Pipe: The connecting pipe links the heat pipes to the thermal source and sink. It ensures the flow of the heat transfer medium (e.g., fluid) through the system, facilitating heat transfer from one end to the other.
Material: Plastic

Thermocouples: Thermocouples are temperature sensors used to measure the temperature at various points within the system. By strategically placing thermocouples along the length of the heat pipes, we can monitor temperature gradients and assess the effectiveness of heat transfer.

Valves: Valves control the flow of the heat transfer medium within the system. They regulate the heat exchange rate and enable adjustments to optimize thermal performance or simulate different operating conditions. By integrating these components into the prototype, you can conduct comprehensive thermal analysis experiments to evaluate the effectiveness of the double heat pipe exchanger with helical fins in enhancing heat transfer efficiency.

Material: PVC

II. ASSUMPTIONS

- Material of outer pipe is PVC - to neglect the heat transfer into the surrounding.
- Steady state - constant mass flow rate(1 kg/s) as that of the tap for both the fluids.
- Material of inner pipe is aluminium - good conductor.
- Specific heat capacities of both hot and cold water are assumed to be same.
- The regime is assumed to be laminar and thus constant wall temperature for aluminium pipe.
- Assuming pipes smooth.
- friction is neglected
- Fouling is neglected.
- Velocity of fluid is assumed to be 1 m/s
- Viscosity of water 0.001 Pa-s .

III. NOMENCLATURE

- $\Delta T_i = T_{hi} - T_{ce}$
- $\Delta T_e = T_{he} - T_{ci}$
- k = conductivity of aluminium
- $m^{\cdot}$ = mass flow rate
- C_{ph} = specific heat of hot fluid
- C_{pc}= specific heat of cold fluid
- A_i = area of inner cylinder
- A_o = area of outer cylinder
- A_f = total area of fins
- Temperatures:
  - Initial hot fluid = T_{hi}
  - Exit hot fluid = T_{he}
  - Initial cold fluid = T_{ci}
  - Exit cold fluid = T_{ce}

IV. SIMPLE DOUBLE PIPE HEAT EXCHANGER

- Counter flow of fluids is used to maintain higher temperature gradient and thus higher heat transfer.
- An Aluminium pipe is inserted inside a PVC pipe with grater diameter such that there is enough space between the pipe pies for a fluid to flow as well as another fluid from inside the inner Aluminium pipe.
- Aluminium being conductive in nature, allows heat exchange from the inner side of the pipe to its outer side.
- Further on, the sddition of circular fins around the inner

a. Calculation of overall Heat transfer co-efficient

We know that: $Q = A*U*\Delta T_m$

But for cylindrical pipe it is:
$Q = A_i*U_i*\Delta T_m$ or $Q = A_o*U_o*\Delta T_m$

- From dimensions of the pipe we can calculate A_i and A_o.
- For Q, we take average of the heat gained by cold fluid and lost by hot fluid.
  - $Q_h= m*C_{ph}*(T_{hi} - T_{he})$
  - $Q_c = m*C_{pc}*(T_{ce} - T_{ci})$
  - $Q_{avg} = (Q_h+ Q_c)/2$

$dQ = U*A*\Delta T_m$

$\Delta T_m = (\Delta T_i - \Delta T_e) / \ln(\Delta T_i/\Delta T_e)$ (log mean temperature difference)

$U_i = Q^{\cdot}_{avg} /(A_i*\Delta T_m)$ or $U_o = Q^{\cdot}_{avg} /(A_o*\Delta T_m)$

- Here we consider using Uo
- AS we know that,

b. Calculation of Heat transfer co-efficient (H_i or H_o)

$$1/Uo = 1/ho + Ri * ln(Ro/Ri)/k + Ro/hi * Ri$$

Here we apply method to ho which can also be used to find h_i: $Nu = h_o * D_o / k$

We can find Nu using suitable expressions based on the value of Reynolds number and Prandalt number where

*Re = (rho*V*D)/u*

Pr = $(u*C_p)/k$

where V is velocity of fluid and u is the viscosity of fluid

V. DOUBLE -PIPE HEAT EXCHANGER WITH CIRCULAR FINS

In this the calculation remains the same as we have done for simple double pipe heat exchanger only the area changes because now due to fins the area is more as compared to other.

$A = A_{unfinned} + Efficiency_{fin} * A_{fin}$

A_{fin} = total surface area of all fins

As we know the other values like heat transfer coefficient from previous calculations we can calculate the rate of heat transfer when there are fins attached to the pipe with taking the new surface area and compare it with the rate of heat transfer when the fins are absent.

a. Fin Efficiency

$$Efficiency = \frac{\begin{array}{c}Actual\ heat\ transfer\\ from\ the\ Fin\ base\ area\ Ab\end{array}}{Ideal\ heat\ transfer\ if\ the\ fin\ were\ a\ Base\ temperature}$$

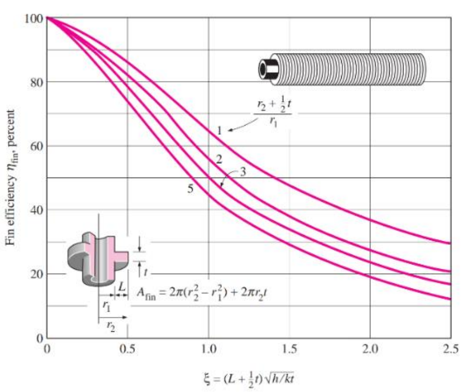

Figure 1. Graph for determining Efficiency value

In our case as we are using the circular fins over the cylinder this can be directly used where L is the Length of the fin , t is the thickness and h is the heat transfer coefficient. Also the area of a single fin can be find as mentioned.

b. Fin Effectiveness

$$Effectivness = \frac{Heat\ transfer\ from\ fin\ wuth\ base\ area\ Ab}{Heat\ transfer\ from\ base\ area\ Ab}$$

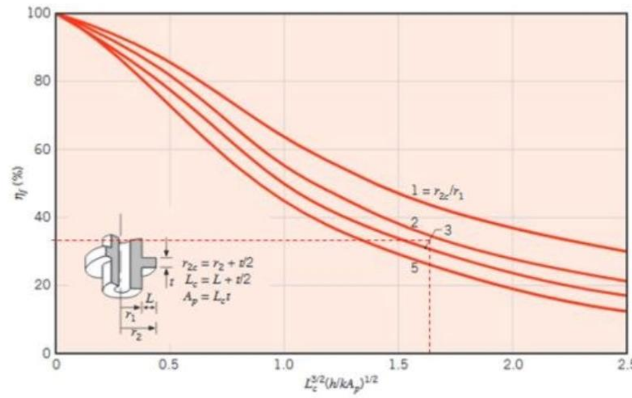

Figure 2. Graph for determining Effectiveness value

Fin effectiveness can be calculated using the Area of fins to calculate heat transfer through the fins only.

And using the base area of cylinder of that fin to calculate the heat transfer through that base area.

VI. SETUP

a. Dimensions

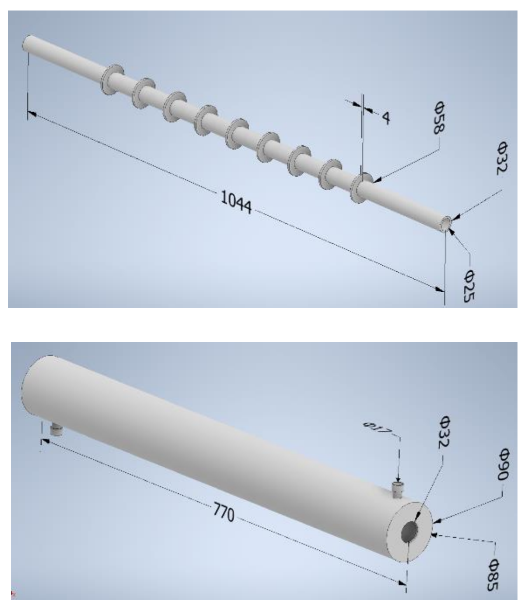

Figure 3-a,b. Dimensions of all the pipes and fins used

b. Our Model

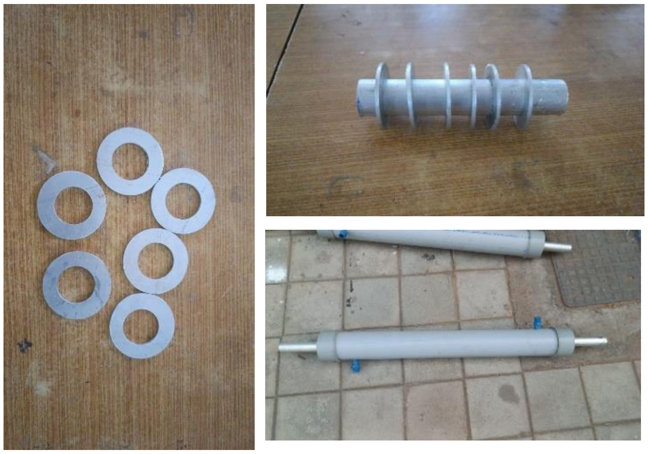

Figure 4-a,b,c. Circular rings, Finned pipe, complete setup

c. ANSYS Stimulation of flow patterns inside the pipe

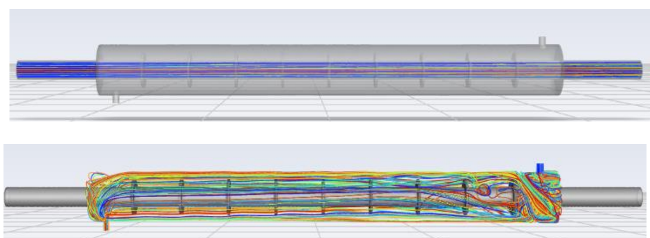

Figure 5-a,b ANSYS stimulation in the internal pipe and external pipe respectively.

From ANSYS simulations, important information can be obtained about the differences between ideal and experimental values through observations. Even with a margin of error, the estimated ideal values after 200 iterations showed a remarkable degree of closeness to the experimental data. This disparity is expected, mainly because environmental conditions are dynamic and always affect real-world outcomes.

The ANSYS model's usefulness in predictive analysis is demonstrated by how well it replicates the outcomes of actual experiments. The efficiencies obtained from ANSYS simulations were found to be more closely aligned with experimental values, especially under optimal conditions. The accuracy and dependability of the ANSYS software in simulating real-world phenomena is demonstrated by the convergence of theoretical predictions and empirical observations.

VII. OBSERVATIONS

The physical set-up and experiment lead to the observations given below in the table, we were successfully able to determine the inlet and outlet temperatures of the fluid in counter-current flow after giving enough time to the set-up. Using the values obtained from the set-up we can calculate various other parameters such as overall heat transfer coefficient, convective heat transfer coefficients and efficiency of the heat exchanger.

Without circular Fins

T_h(i)	***T_h(e)***	***T_c(i)***	***T_c(e)***
56.3	53.5	28.4	30.5
62	58	34.3	38

With circular Fins

T_h(i)	***T_h(e)***	***T_c(i)***	***T_c(e)***
56.3	51.5	28.4	34
62	56	32	43.5

VIII. RESULTS

Without circular Fins

U_i	***h_i***	***1/h_o***	***h_o***	***efficiency***
4912.692174	3437.58	0.0004479552601	2232.365794	*0.5401713527*
8237.433954	3437.58	0.0005531166682	1807.936838	*0.6632696775*

With circular Fins

U_i	***h_i***	***1/h_o***	***h_o***	***efficiency***
7879.421365	3437.58	0.0005460563871	1831.312706	*0.6532746951*
14241.74529	3437.58	0.0006186282391	1616.479716	*0.7730103226*

The heat exchanger demonstrates varying levels of efficiency, with the second set of data showing a higher efficiency compared to the first.

Changes in inlet temperatures and convective heat transfer coefficients can significantly influence heat transfer rates and overall efficiency.

Further analysis is required to understand the factors contributing to the observed differences in heat transfer performance and efficiency between the two data set, one such reason is the changing environmental conditions and initial temperature of the heat exchanger itself along with the change in flow rates due to unavailability of pumps.

Efficiency of fins from efficiency of circular fins with length L and thickness t from the graph,
Efficiency of fins = 34 % approximately.
Effectiveness of fins = 45 % approximately.

IX. ACKNOWLEDGEMENT

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