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Experimental Analysis on Parallel flow and Counter flow Heat Exchanger

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Abstract: This study analyzes the performance of parallel flow and counter flow heat exchangers with specific emphasis on the surface area required for effective heat transfer. In a parallel flow heat exchanger, both fluids enter at the same end and move in the same direction, resulting in a rapidly decreasing temperature difference along the flow path. This reduction lowers the overall heat transfer rate, necessitating a larger surface area to achieve a desired thermal performance. In contrast, a counter flow heat exchanger, where fluids move in opposite directions, maintains a more uniform and higher average temperature difference throughout the length of the exchanger. This promotes more efficient heat transfer, allowing the same heat duty to be accomplished with a significantly smaller surface area. Consequently, counter flow heat exchangers are more compact, cost-effective, and thermally efficient compared to parallel flow designs. The analysis concludes that, from the perspective of area utilization, the counter flow configuration is superior.

Keywords: Parallel flow, Counter flow, LMTD, Surface area, Overall heat transfer co-efficient, Specific heats, Mass flow rate.

I. INTRODUCTION

Heat exchangers are essential devices used to transfer thermal energy between two or more fluids at different temperatures. Their performance is influenced by several factors, one of the most important being the surface area available for heat transfer. Two common types of heat exchangers are the parallel flow and counter flow configurations.

In a parallel flow heat exchanger, both the hot and cold fluids enter at the same end and move in the same direction. This arrangement causes the temperature difference between the fluids to decrease rapidly along the flow path, reducing the driving force for heat transfer. As a result, a larger surface area is generally required to achieve the desired heat transfer rate.

In contrast, a counter flow heat exchanger allows the fluids to move in opposite directions. This configuration maintains a higher and more uniform temperature difference over the entire length of the exchanger, leading to a more effective and efficient heat transfer process. Consequently, a counter flow heat exchanger can achieve the same thermal performance with a smaller surface area compared to a parallel flow design.

This study focuses on analyzing and comparing parallel and counter flow heat exchangers specifically in terms of their area requirements, highlighting the impact of flow arrangement on thermal efficiency and system design.

II. TYPES OF HEAT EXCHANGERS

In order to meet the widely varying applications, several types of heat exchangers have been developed which are classified on the basis of nature of heat exchange process,

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relative direction of fluid motion, design and constructional features, and physical state of fluids.

1. Nature of heat exchange process

Heat exchangers, on the basis of nature of heat exchange process, are classified as follows:
(1) Direct contact (or open) heat exchangers.
(ii) Indirect contact heat exchangers.

2. Relative direction of fluid motion

According to the relative directions of two fluid streams the heat exchangers are classified into the following three categories:
(i) Parallel flow or unidirectional flow
(ii) Counter flow
(iii) Cross-flow

III. PARALLEL FLOW HEAT EXCHANGER

In a parallel flow heat exchanger, as the name suggests, the two fluid streams (hot and cold) travel in the same direction. The two streams enter at one end and leave at the other end. The flow arrangement and variation of temperatures of the fluid streams in case of parallel flow heat exchangers are shown in figure 1. It is evident that the temperature difference between the hot and cold fluids goes on decreasing from inlet to outlet. Since this type of heat exchanger needs a large area of heat transfer, therefore, it is rarely used in practice.

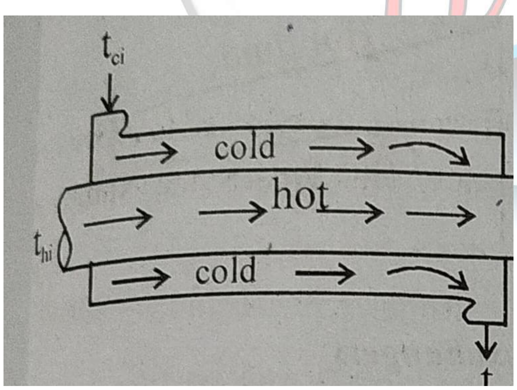

Figure 1. Parallel flow heat exchanger

IV. COUNTER-FLOW HEAT EXCHANGERS

In a counter-flow heat exchanger, the two fluids flow in opposite directions. The hot and cold fluids enter at the opposite ends. The flow arrangement and temperature distribution for such a heat exchanger are shown schematically in figure 2. The temperature difference between the two fluids remains more or less nearly constant. This type of heat exchanger, due to counter flow, gives maximum rate of heat transfer for a given surface area. Hence such heat exchangers are most favoured for heating and cooling of fluids.

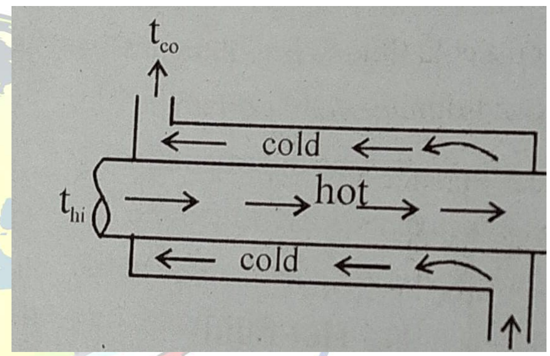

Figure 2. Counter flow heat exchanger

V. CROSS-FLOW HEAT EXCHANGER

In cross-flow heat exchangers, the two fluids (hot and cold) cross one another in space, usually at right angles. Figure 3 shows a schematic diagram of common arrangements of cross-flow heat exchangers.

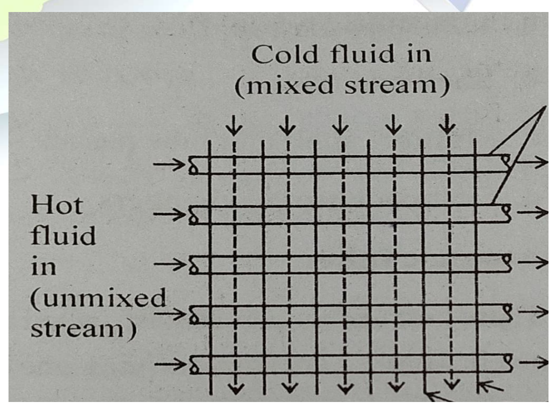

Figure 3. . Cross-flow heat exchangers

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VI. LOGARITHMIC MEAN TEMPERATURE DIFFERENCE (LMTD)

Logarithmic mean temperature difference (LMTD) is defined as that temperature difference which, if constant, would give the same rate of heat transfer as actually occurs under variable conditions of temperature difference.

In order to derive expression for LMTD for various types of heat exchangers, the following assumptions are made:
1. The overall heat transfer coefficient U is constant.
2. The flow conditions are steady.
3. The specific heats and mass flow rates of both fluids are constant.
4. There is no loss of heat to the surroundings, due to the heat exchanger being perfectly insulated.
5. There is no change of phase either of the fluid during the heat transfer.
6. The changes in potential and kinetic energies are negligible.
7. Axial conduction along the tubes of the heat exchanger is negligible.

VII. HEAT EXCHANGER ANALYSIS

For designing or predicting the performance of a heat exchanger it is necessary that the total heat transfer may be related with its governing parameters:
(i)overall heat transfer coefficient due to various modes of heat transfer (U),
(ii)total surface area of the heat transfer (A), and
(iii)the inlet and outlet fluid temperatures (Thi, Tci and Tho, Tco).
Figure shows the overall energy balance in a heat exchanger.
m = mass flow rate, kg/s.
C_p = specific heat of fluid at constant pressure J / kg ^{0}C,
T = temperature of fluid, °C.
Subscripts h and c refer to the hot and cold fluids respectively, subscripts i and o correspond to the inlet and outlet conditions respectively.

Assuming that there is no heat loss to the surroundings and potential and kinetic energy changes are negligible, from the energy balance in a heat exchanger, we have:

Heat given up by the hot fluid,
$Q = m_h Cp_h$ (Thi – Tho)
Heat picked up by the cold fluid,
$Q = m_c Cp_c$ (Tco – Tci)

Total heat transfer rate in the heat exchanger, $Q = UA\ \theta_m$
Where,
U = overall heat transfer coefficient between the two fluids,
A = effective heat transfer area, and
θ_m = appropriate mean value of temperature difference or logrithmic mean temperature difference (LMTD).

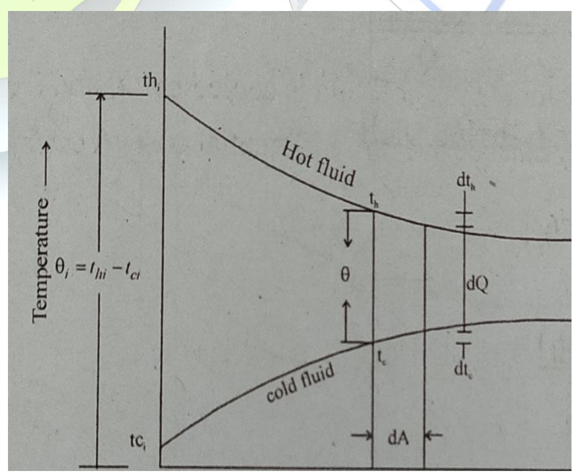
For this experimental analysis, one counter-flow double pipe heat exchanger is taken for observations and records the readings.

A counter-flow double pipe heat exchanger, hot fluid with a specific heat of 2300 J/kg K enters at 380°C and leaves at 300°C. Cold fluid enters at 25°C and leaves at 210°C. Take overall heat transfer co-efficient is 750 W/m^{2}K and mass flow rate of hot fluid is 1 kg/s. Calculate the heat exchanger area. What would be the increase in area if the fluid flows were parallel?

Observations

Mass flow rate of hot fluid m_h = 1 kg/s
Specific heat of hot fluid Cp_h = 2300 J/kg K
Entry temperature of hot fluid Th_i = 380°C
Exit temperature of hot fluid Th_o = 300°C
Entry temperature of cold fluid Tc_i = 25°C
Exit temperature of cold fluid Tc_o = 210°C
Overall heat transfer co-efficient U = 750 W/m^2 ^{0}C
To find:
Heat exchanger area for (1) Parallel flow (2) Counter flow

(1) For Parallel flow



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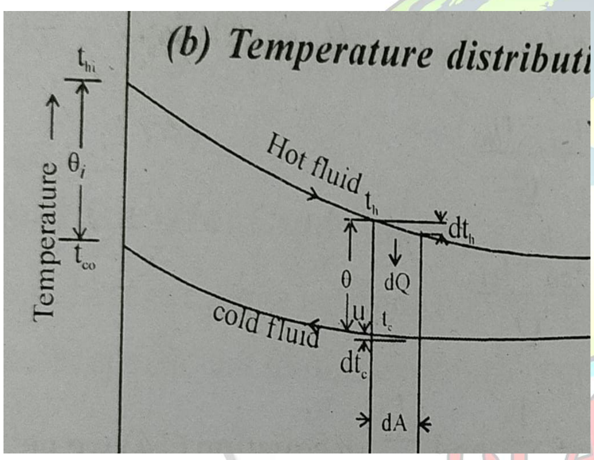
$\theta_m = (\theta_1 - \theta_2) / \ln(\theta_1/\theta_2)$
$= [(Thi–Tci) – (Tho–Tco)] / \ln [(Thi–Tci)/(Tho–Tco)]$
$= [(380–25) – (300–210)] / \ln [(380–25) / (300–210)]$
$\theta_m = 193.1^0C$

Heat transfer $Q = m_h Cp_h (Thi – Tho)$ (or) $m_c Cp_c (Tco – Tci)$
$= 1 \times 2300 \times (380 – 300)$
$Q = 184 \times 10^3$ W

Heat transfer $Q = UA (\theta_m)$
$184 \times 10^3 = 750 \times A \times 193.1$
Area $A = 1.27\ m^2$

(2) For Counter flow



$\theta_m = (\theta_1 - \theta_2) / \ln(\theta_1/\theta_2)$
$= [(Thi–Tco) – (Tho–Tci)] / \ln [(Thi–Tco)/(Tho–Tci)]$
$= [(380–210) – (300–25)] / \ln [(380–210) / (300–25)]$
$\theta_m = 218.3^0C$

Heat transfer $Q = UA (\theta_m)$
$184 \times 10^3 = 750 \times A \times 218.3$
Area $A = 1.12\ m^2$

Result

(1) Heat Exchanger Area required for Parallel flow $A=1.27\ m^2$
(2) Heat Exchanger Area required for Counter flow $A=1.12\ m^2$

Therefore, for the same heat transfer rate, counter flow heat exchangers require **less surface area** than parallel flow exchangers.

VIII. CONCLUSION

The analysis of parallel flow and counter flow heat exchangers with respect to surface area clearly demonstrates that the counter flow arrangement is superior. Due to the more uniform and higher average temperature difference maintained along its length, a counter flow heat exchanger achieves greater thermal efficiency. This allows it to transfer the same amount of heat with a significantly smaller surface area compared to a parallel flow design. In parallel flow exchangers, the rapid decline in temperature difference reduces the driving force for heat transfer, necessitating a larger area to meet performance requirements. Therefore, when area optimization and compact design are critical considerations, counter flow heat exchangers are the preferred choice.

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