Plate Heat Exchanger Efficiency

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Abstract

The research project to find the efficiency of the model plate heat exchanger. Plate heat exchanger with the flowrate of co-current and counter current. The study analyze between hot water constant and cold water constant of the power lost, efficiency, LMTD and the heat transfer coefficient. Experiment with an experimental heat exchanger model under different flow rates for the hot and cold water (2LPM, 4LPM, 6LPM, 8LPM, 10LPM) .The key parameter are the water flow rates and temperature. The study maintaining hot water and cold water constant flow rate (7.5LPM), reveal that the efficiency for the counter current drop as the flow rates increases. The co-current flow especially the hot water constant shows that the efficiency is increasing stable showing a stable plate heat exchanger compare to counter current flow

1. Introduction

Heat Exchanger is an apparatus for transferring thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between a solid particulates and a fluid that is one if which is relatively hot and the other is relatively cool and in thermal contact that mostly no need external heat and work provide. Usually, heat exchangers are categorized based on the way of fluids that flow. When the hot and cool fluids moving in the same direction, it is called as a *parallel-flow* arrangement, while when the differential temperature of fluids are in opposite direction, it is called *counterflow* or also known as *crossflow* arrangement, where the two fluids flow cross each other perpendicularly [1]. A plate heat exchanger is constructed from a series of thin, corrugated metal plates held together in a frame. The plates form alternating channels for hot and cold fluids, maximizing the surface area for heat transfer while maintaining a small footprint. The corrugations on the plates enhance turbulence, further improving heat transfer efficiency[1-3].

The performance of a plate heat exchanger depends significantly on its flow configuration. The two primary configurations are **co-current flow** and **counter-current flow**, each offering unique thermal and operational characteristics. In co-current flow, both the hot and cold fluids move in the same direction through the exchanger. The temperature difference between the fluids is highest at the inlet and decreases along the flow path. This configuration is suitable for processes where gradual heat exchange is sufficient or when minimizing thermal stresses is essential. While for the counter current flow configuration, the hot and cold fluids flow in opposite directions. This arrangement maintains a near-constant temperature gradient, enabling higher heat transfer efficiency and closer temperature approaches between the fluids. Counter-current flow is the preferred choice for applications requiring maximum thermal energy recovery[4, 5].

The proposed research explores the use of plate heat exchanger model to study the thermodynamic and heat transfer behaviour and find the efficiency of the plate heat exchanger model. As the model have been abandoned more than 20 years, Previous studies have shown that the plate heat exchanger for the counter current flow is more efficient compare to the co-current flow[6]. This where the gap that need to be fill by experiment the plate heat exchanger for the co-current flow and the counter current flow and find the power lost, efficiency, LMTD and the heat tranfer coefficient between hot plate and cold plate.

Nomenclature
HE   heat exchanger
PHE   plate heat exchanger
HTC   heat transfer coefficient
COP   coefficient of performance
L/G   overall heat transfer coffiecient, W/m^2K
$\dot{m}$ mass flow rate, kg/s
ΔT_{ml} logarithmic mean temperature difference
A   overall heat exchange area
λ thermal conductivity
ΔT_p temperature difference
H_2O water
T   temperature, ˚C
Q   heat transfer rate, W
η heat transfer efficiency, %
Subscripts
pi   process fluid inlet
ui   utility fluid inlet
po   process fluid outlet
uo   utility fluid outlet

2. Methodology

The heat exchanger diagram in **Fig. 1** shows how water flows through the exchanger and highlights the main components involved in the plate heat exchange process. This study investigates how heat of hot water constant and heat of cold water constant lost by obtaining the power lost, its efficiency, logarithmic mean temperature difference and heat transfer coefficient of hot plate and cold plate in the plate heat exchanger.
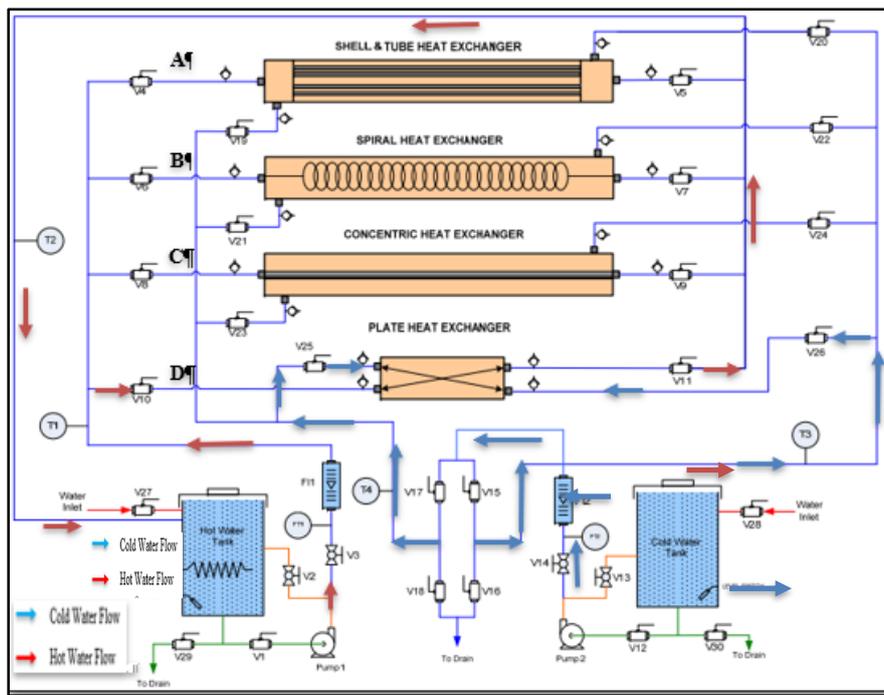
Fig. 1 *Schematic diagram of the heat exchanger*

Hence, the experiment involves two different flow rates configurations:
  i.   Hot water constant flow rate
  ii.   Cold water constant flow rates

In achieving these objectives, an experimental heat exchanger setup will establish a controlled environment for conducting the required experiments and measurements. The heat exchanger used in this study is a heat exchanger model HE158C. It aims to see the temperature of plate heat from the start of the cold water

enter the plate and exit the hot water. The plate heat exchanger (PHE) is a compact and efficient device designed to facilitate the transfer of heat between two fluids. Understanding the flow of hot and cold water through the PHE is essential for optimizing its performance in both co-current and counter-current configurations. The flow arrangement, as illustrated in the provided schematic, highlights the systematic movement of water through the system, ensuring efficient thermal energy transfer. Accurate temperature data can be obtained by taking measurements after the system has been operational for around 5 to 10 minutes. The process begins with hot water being pumped from the hot water tank by Pump 1 (P1). The flow is initiated through the hot water inlet controlled by Valve V1, which directs the hot water into the plate heat exchanger. Once inside, the hot water flows across alternating plates, creating channels that allow it to exchange heat with the cold water. Depending on the configuration, the hot water can flow in the same direction as the cold water (co-current flow) or in the opposite direction (counter-current flow). After transferring its thermal energy to the cold water, the hot water exits the exchanger through the outlet. From there, it is either returned to the hot water tank or drained through valves such as V26, completing the cycle. Simultaneously, cold water is drawn from the cold water tank by Pump 2 (P2). This flow is controlled by Valve V12, which directs the cold water into the plate heat exchanger through its designated inlet. Inside the exchanger, the cold water flows through alternating channels, running parallel to the hot water but in separate paths to prevent mixing. The direction of flow is determined by the operational configuration: in co-current flow, the cold water enters and travels in the same direction as the hot water, while in counter-current flow, it moves in the opposite direction, ensuring maximum heat transfer efficiency. As the cold water absorbs heat from the hot water, it exits the exchanger through the cold water outlet, managed by valves such as V25, before being returned to the tank or drained. The PHE can operate in two distinct flow configurations: co-current and counter-current. In co-current flow, both the hot and cold water enter the exchanger from the same side and flow in the same direction. This arrangement provides a gradual temperature exchange but results in a lower overall heat transfer efficiency. In contrast, counter-current flow involves the hot and cold water entering from opposite sides and flowing in opposite directions. This configuration maintains a consistent temperature gradient across the exchanger, allowing for more efficient heat transfer and closer temperature approaches between the fluids. The plate efficiency, LMTD, and heat transfer coefficient may be determined using these data. Applying Equation (1) from the derivation presented by Nilpueng K et al., the predicted value heat plate efficiency is computed utilizing data acquired from the heat exchanger experiment. In contrast, the LMTD value is determined using Equation (2) from the exact derivation. The constants c and n, taken from previous research, are set at $C = 0.224$ and $n = 0.295$.

$$q = \dot{m}_p C_p \Delta T_p - q_l \tag{1}$$

$$\Delta T_{ml} = \frac{(T_{pi} - T_{ui}) - (T_{po} - T_{uo})}{ln\frac{(T_{pi} - T_{ui})}{(T_{po} - T_{uo})}} \tag{2}$$

In the plate heat exchanger analysis, it is important to determine the efficiency of these systems. To clarify this, it can be referred to equation (3), which is a fundamental result obtained through previous research. Where T_{in} is the inlet water temperature (hot temperature), T_{out} is the outlet water temperature (cold temperature) and the T_{wb} is the wet bulb temperature .

$$\eta = \frac{T_{in} - T_{out}}{T_{in} - T_{wb}} \tag{3}$$

3. Result and discussion

The study examines the impact of four important factors, specifically the power lost, LMTD, heat transfer coefficient and efficiency, operation of a plate heat exchanger. The experiment involves two separate of flow configuration. Co-current flow and counter current flow. Furthermore, configuration of flow are parameter that helps understand the plate heat exchanger's design and potential performance.
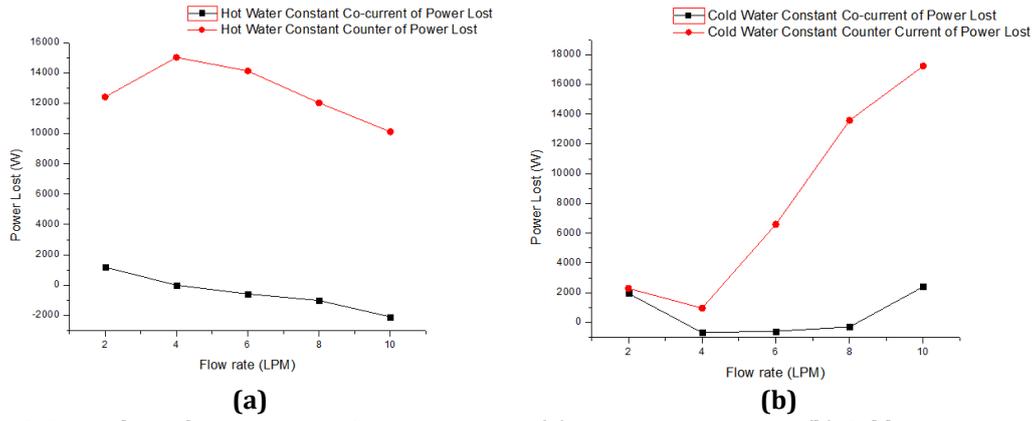
Fig. 2 *Power lost of co-current vs Counter current. (a) Hot water constant (b) Cold water constant*
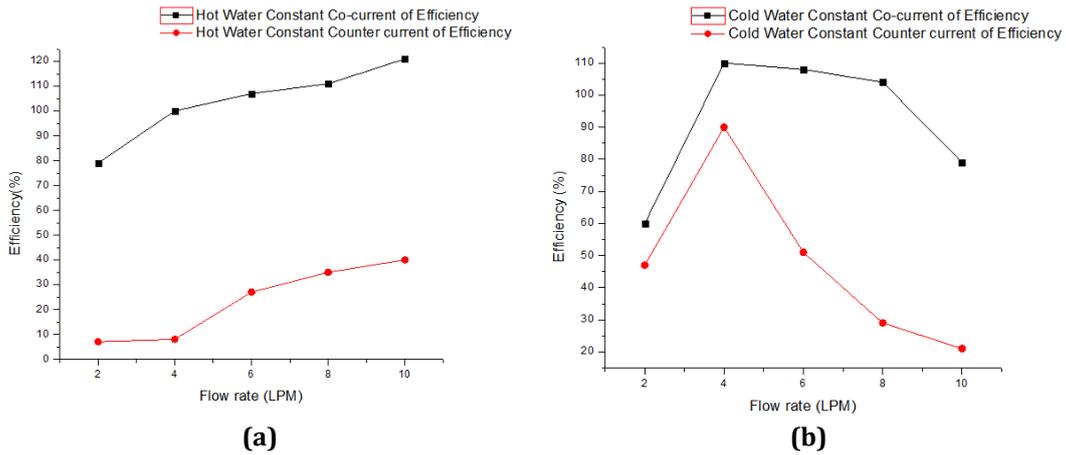

Fig. 3 *Efficiency of co-current Vs counter current (a)Hot water constant (b)Cold water constant*
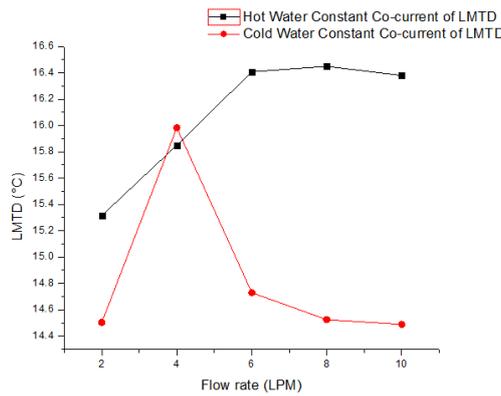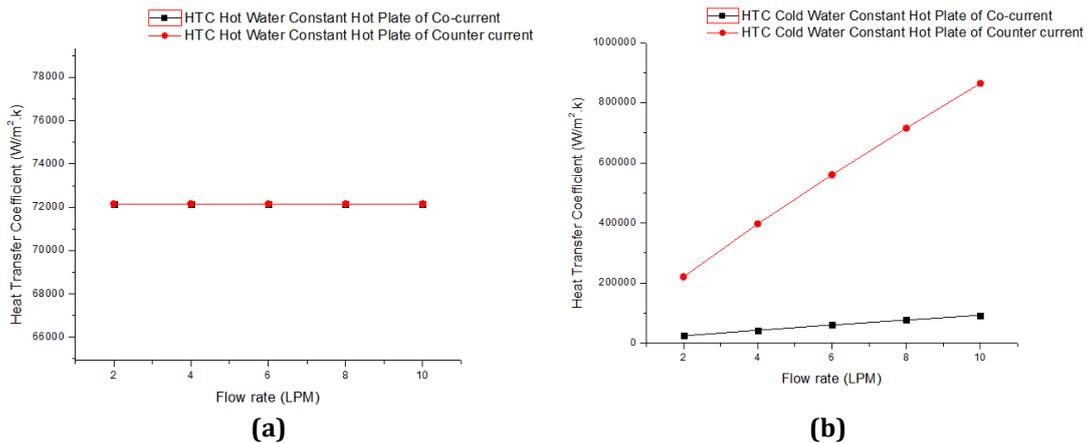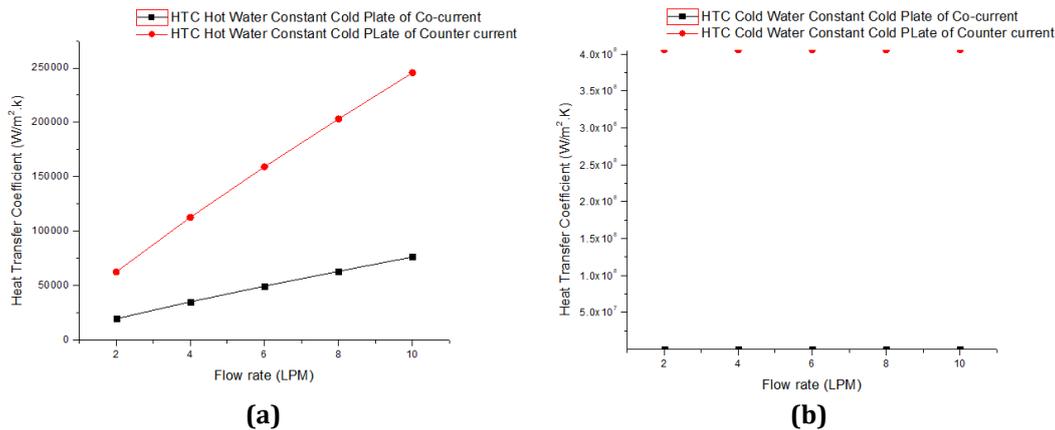

Fig. 4 *LMTD of hot water constant vs cold water constant Co-current*

The presented experimental results investigate the impact of different flow configurations, power loss, efficiency and LMTD on the performance of a plate heat exchanger, as shown in **Fig. 1** through **Fig. 4** . The evaluation of power loss in heat transfer systems is critical for optimising thermal management processes. The graphs presented illustrate power loss variations for hot and cold water systems in co-current and counter-current flow configurations across a range of flow rates. However, when the efficiency of a plate heat exchanger is calculated, as shown in **Fig. 3** , In both arrangements, the interaction of flow rate, turbulence, and residence duration affects the PHE's efficiency patterns. Although counter-current flow performs better thermally at larger flow rates, its efficiency may drop. For situations where a lower efficiency is acceptable, co-current flow offers steady performance despite its lower efficiency. In industrial processes, where choosing the right flow configuration and operating conditions may greatly improve energy recovery and system efficiency, these insights are essential for building and improving PHE systems. The calculated data for LMTD, as seen in **Fig. 4** , The LMTD starts at a moderate value, peaks at a mid-range flow rate (~4-6 LPM), and then declines significantly as the flow rate increases. The initial rise in LMTD indicates efficient heat transfer due to higher temperature differentials at moderate flow rates. As the flow rate increases further, the residence time of water in the system decreases, reducing the effectiveness of the heat exchange.

Fig. 5 *Heat transfer coefficient Co-current vs Counter current flow*
(a) Hot water constant flow rate (b) Cold water constant flow rate

Fig. 6 *Heat transfer coefficient Co-current Vs Counter current flow*
(a) Hot water constant flow rate (b) Cold water constant flow rate.

Based on **Fig. 5** through **Fig. 6**, the plate heat exchanger is most effective in the counter-current configuration, particularly at higher flow rates. The counter-current design sustains a larger temperature gradient across the length of the heat exchanger, maximising the heat transfer rate and efficiency.. The HTC in the counter-current configuration remains consistently higher than in the co-current configuration across all flow rates. The counter-current HTC stabilises at approximately 74,000 W/m2·K, while the co-current HTC is slightly lower and exhibits minimal variability. This behaviour arises from the fundamental advantage of the counter-current configuration, which sustains a larger temperature gradient throughout the heat exchanger. In contrast, the co-current system experiences a rapid reduction in the temperature difference between the hot and cold fluids as they move in the same direction, limiting heat transfer efficiency. The HTC for the counter-current configuration increases significantly with flow rate, following a linear pattern, while the co-current configuration demonstrates a much slower growth. At higher flow rates, the HTC for counter-current reaches values far exceeding those of the co-

current configuration. The increase in HTC for counter-current configurations is attributed to enhanced turbulence at higher flow rates, which improves heat transfer. Moreover, the counter-current system maintains an optimal thermal gradient, ensuring efficient energy transfer. The co-current configuration, with its lower turbulence and diminishing temperature gradient, remains less effective. The HTC for the counter-current configuration increases significantly with flow rate, following a linear pattern, while the co-current configuration demonstrates a much slower growth. At higher flow rates, the HTC for counter-current reaches values far exceeding those of the co-current configuration. The increase in HTC for counter-current configurations is attributed to enhanced turbulence at higher flow rates, which improves heat transfer. Moreover, the counter-current system maintains an optimal thermal gradient, ensuring efficient energy transfer. The co-current configuration, with its lower turbulence and diminishing temperature gradient, remains less effective. It is clear that the plate heat exchanger's counter-current design works well, especially at greater flow rates. Its capacity to sustain a significant temperature differential along the exchanger's length results in enhanced heat transfer effectiveness. On the other hand, because of its intrinsic limits in temperature gradient management, the co-current system performs poorly despite having a simpler design [7].

4. Conclusions

In conclusion, the analysis of the plate heat exchanger for the power lost, efficiency, LMTD and heat transfer coefficient reveal that higher heat transfer coefficients and efficiency may be achieved with plate heat exchangers using the counter-current flow design. This arrangement is a popular option for applications needing effective energy transfer because it guarantees improved thermal performance by preserving a greater temperature differential throughout the heat exchanger. In counter-current setups, when the temperature gradient propels larger energy exchange rates, this approach is consistent with accepted principles of heat transfer. In most cases, the counter-current flow exhibits a significantly higher heat transfer coefficient compared to the co-current flow. This indicates more effective heat transfer in counter-current configurations due to the larger temperature gradient maintained across the heat exchanger plates. For both hot water and cold water constants, the efficiency of counter-current flow outperforms co-current flow at lower flow rates. However, as the flow rate increases, efficiency tends to decrease for counter-current flow, possibly due to reduced residence time of fluids. Counter-current flow shows higher power losses compared to co-current flow at higher flow rates. While higher power loss might seem unfavourable, it aligns with the higher heat transfer rates, suggesting more energy transfer between the fluids. The study recommends several strategies to enhance plate heat transfer efficiency:

i. Added a cooling tower model at the outlet of the cold water to decrease the temperature value before it is circulated back to the cold water inlet.
ii. Consider draining all the cold water outlets so that the temperature value of the cold water inlet will not exceed that of the hot water outlet, which can lead to misreading data and miscalculation.

Acknowledgement

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

References

[1] Rohsenow, W. M., Hartnett, J. P., & Cho, Y. I. (1998). Handbook of heat transfer (Vol. 3). New York: Mcgraw-hill.
[2] Hicks, T. G., Hicks, T. G., & Wills, K. D. (2006). Handbook of mechanical engineering calculations (No. 272477). New York: McGraw-Hill.
[3] García-Castillo, J. L., Crespo-Quintanilla, J. A., & Picón-Núñez, M. (2024). A novel design approach of plate heat exchangers considering the economic impact of chevron angles. Chemical Engineering and Processing-Process Intensification, 199, 109759, https://doi.org/10.1016/j.cep.2024.109759.
[4] Longo, G. A., Mancin, S., Righetti, G., & Zilio, C. (2022). Local heat transfer coefficients of R32 and R410A boiling inside a brazed plate heat exchanger (BPHE). Applied Thermal Engineering, 215, 118930, https://doi.org/10.1016/j.applthermaleng.2022.118930.

[5]   Arsenyeva, O., Perevertaylenko, O., Tovazhnyanskyy, L., Arsenyev, P., & Kapustenko, P. (2023). Experimental investigation of thermal and hydraulic performance of panel plate heat exchangers. Thermal Science and Engineering Progress, 43, 101984, https://doi.org/10.1016/j.tsep.2023.101984.

[6]   Cao, E. (2010). Heat transfer in process engineering (p. 576). New York: McGraw-Hill.

[7]   Azimy, H., Isfahani, A. H. M., Farahnakian, M., & Karimipour, A. (2021). Experimental investigation of the effectiveness of ultrasounds on increasing heat transfer coefficient of heat exchangers. International Communications in Heat and Mass Transfer, 127, 105575, https://doi.org/10.1016/j.icheatmasstransfer.2021.105575.