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STUDY OF ASYMMETRY CONFIGURATION EFFECTS ON PLATE HEAT EXCHANGER PERFORMANCE

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Abstract

Plate heat exchanger efficiency was a result of the plate geometry. Former studies have discovered that chevron angle and aspect ratio geometry take part in enhancing heat transfer rate by the manipulated flow. Hence, in this study, the flow velocity is manipulated by setting asymmetry configuration to plate heat exchanger. The asymmetric plate heat exchanger provides various fluid cross-section areas that affect fluid velocity. As the fluid flow through various cross-section areas, its velocity is changed and affects the heat transfer coefficient which is consistent with the experimental result. The results show that by setting plate heat exchanger in either compressed upper side – expanded lower side or compressed cold side – expanded hot side configurations, overall heat transfer coefficient can be enhanced comparing with its in symmetry configuration.

Keywords: Plate heat exchangers, Heat transfer, Experiment, Enhancement, Asymmetry

1. Introduction

In various industry [1], the plate heat exchanger is an interesting choice for engineers among another heat exchanger due to its efficiency compared to other heat exchangers at the same installation size. The plate heat exchanger's distinction is its heat transfer area the can be contained in a compact size.

The plate heat exchanger is also designed to contain more heat transfer area by being stamped a corrugated pattern. The corrugated pattern provides more heat transfer area than a flat plate. In addition, the corrugated pattern can function as a guild vane distributing the fluid flow all over the heat transfer area. Dović et al [2] experimental result explains pattern geometry which impacts on heat transfer efficiency by balancing the heat transfer mode, between heat conduction and convection in each flow configuration. In some flow configuration may need more heat convection than heat conduction to operate at its best performance or may need more heat conduction. Freund et al. [3] study describes more details in balancing heat transfer mode at the local heat transfer area. Heat transfer mode in the plate heat exchanger is a compound of heat conduction and convection. Moving fluid inside a channel creates the heat convection and helps to transfer heat within the same fluid. Heat conduction is derived from swirling stationary fluid that has been heated up from fluid at another side of the plate.

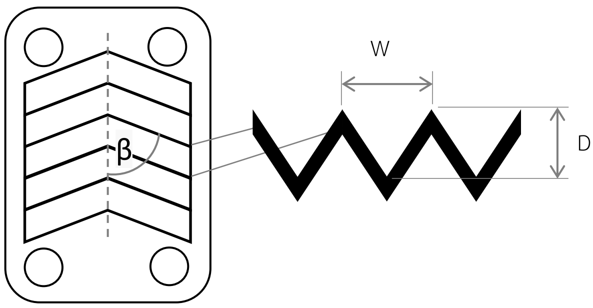

Fig. 1 plate geometry characteristics

There are two major characteristics of corrugated pattern that take a major part in balancing heat transfer mode: Chevron angle as illustrated in Fig. 1, the angle that bends corrugation furrow and edge, and aspect ratio, the ratio between furrow width and furrow depth.

Mechanism of how chevron angle affects the flow is explained by Zhang et al. [4]. Their computational model shows that the more obtuse of the angle, the more flow is likely to change directions along corrugation edge back and forth as a zigzag pattern which means that the flow is distributed all over the channel. In addition, the flow can stay longer in the channel and allow more heat to conduct from the other side. On the other hand, if the angle is acute, more flow will remain in the same direction and flow through channel faster than the obtuse angle which means that the fluid carries heat out of the heat transfer area faster and allows the following fluid to enter heat transfer area.

Both studies by Focke et al. [5] and Dović et al [2] show that the efficiency of heat transfer is proportionally rising with the chevron angle to certain angles and then the efficiency will drop. The study explains that at some points when the amount of heat convection and conduction are balanced, the plate heat exchanger will operate in the best condition.

Besides the chevron angle, the aspect ratio is also an important geometric characteristic of the plate heat exchanger influencing the flow. When the edge of the corrugated pattern crosses as shown in Fig. 2, it forms a boundary of contact space that allows the fluid to exchange between the flow in the lower and upper furrow. The ratio of flow that exchanges between furrows is characterized by aspect ratio.

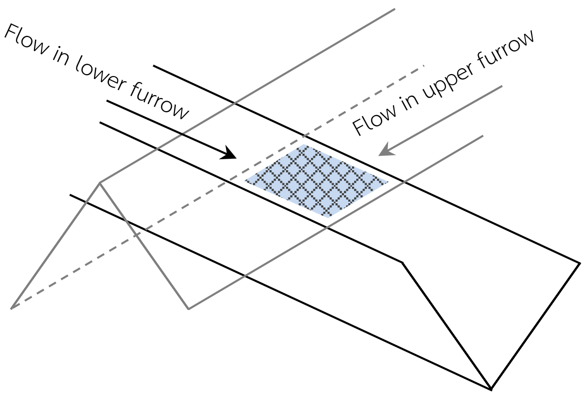

Fig. 2 conjugated corrugated furrow

The computational model developed by Zhang et al. [6] shows that the fluid in one furrow is induced by the flow in another furrow at contact space leading to the exchange of fluid between furrow. The shallow furrow tends to easily induce another flow to cross. Thus, the crossed fluid will circulate around the edge of the contact point which will promote more heat conduction. Han et al. [7] computational model shows that circulating flow around the contact point also induces a turbulent characteristic of flow which enhances the heat transfer. On the opposite side, the deeper furrow allows more fluid to remain in its own furrow and is hardly induced by fluid from another furrow. The fluid in a furrow can transport heat through the channel which likely to have better convection.

The study of Dović et al [2] also explains that the aspect ratio adjusts the balance of heat transfer mode with the chevron angle but the ratio's effect is less dominating than the chevron angle.

It should be noted that researches in the past related to the plate heat exchanger geometry mostly focus on the effects of the chevron angle and aspect ratio. All are based on the constant fluid channel cross-section area for the entire flow. There is no research that investigates the influence of the asymmetric configuration of the plate heat exchanger, in which the flow cross-section area is varied along with the flow. Theoretically, the flow behavior can be adjusted by altering the flow cross-section area, by decreasing the area to accelerate flow or increasing the area to deaccelerate the flow. In this study, we focus on investigating the effect of altered channel cross-section area along with the flow, as a result of the asymmetric shape of the plate heat exchanger, to the overall heat transfer performance.

2. Asymmetric Plate Heat Exchanger

Typically, the plate heat exchanger is assembled by stacking plates to create multiple channels for fluid flow. Then the plate heat exchanger is partitioned by a rubber gasket which not only restricts the fluid to not leak out of device but also controls the fluid direction in the plate heat exchanger to flow through only one channel at a time, which is called series flow, or flow through all the channel between plate at once, which is called parallel flow and also keep both fluids separate from each other.

Lastly, the plate heat exchanger will tighten up with bolts to stack plate and gasket together. The symmetric plate heat exchanger bolt must be tightened until the lengths of the plates are equal. When all sides are equal, all channel areas uniform along channel, in which fluid can flow with the same velocity along channel.

In this study, commercial plate heat exchanger from KAUDY, model M2 is used for observing the difference.

Fig. 3 KAUDY plate heat exchanger model M2 in the test rig

Model M2 heat exchanger is a compact size with 0.0373 m^2 heat transfer area per side, 47 cm length, 10 cm width and 0.5 mm thick with 1 cm furrow width and 3 mm in depth.

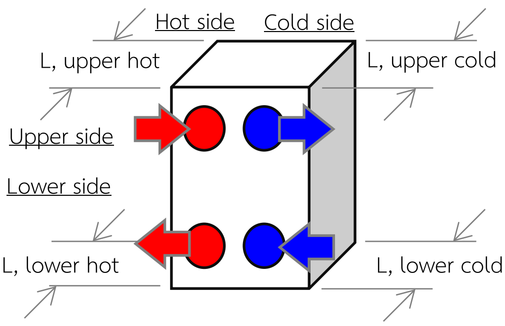

Fig. 4 KAUDY plate heat exchanger model M2, symmetric configuration schematic

Plates are stamped with horizontal chevron corrugated pattern with 60° refer to the main flow. The inlet and outlet ports are placed at the same side, the hot fluid inlet is placed over the outlet and the cold fluid inlet is placed under outlet as shown as an arrow in Fig. 3 and Fig. 4.

The same side of the ports provide convenience for users to add or remove a plate but in this study, it is convenient to adjust asymmetry side of the plate heat exchanger and keep the plate amount the same.

In order to create non-uniform cross-section areas along the channel, the length at each side will be adjusted. Plate heat exchanger length at upper (upper hot and cold) and lower (upper hot and cold) side in Fig. 4 must be differed from each other. If the upper length is shorter than lower length, the hot fluid channel will shape like a diffuser and the cold channel will shape like a nozzle. For the other case, if the lower length is shorter than the upper length, the hot fluid channel will shape like a nozzle and the cold channel will shape like a diffuser.

Another asymmetry configuration that is interesting is when the hot (upper and lower hot) length and cold (upper and lower cold) length are dissimilar. With this configuration, when the fluid enter the flow at the longer side, the flow has more inlet and outlet channel than usual and channel area between plate will decrease alongside to the other side. On the other side which enters at shorter side, the flow has less inlet and outlet channel areas than the default setting and the channel between plates will also increase along plate width. This configuration non-uniform cross-section areas in the vertical side along the width of the plate heat exchanger can be observed if the efficiency of plate heat exchanger has altered from the average case.

The result of the experiment consists of five configurations. First two are configurations that alter the upper and lower length, one is to compressed the upper (both hot and cold) length and expanded the lower (both hot and cold) length (CC-XL) as shown in Fig. 5 (a), and another configuration compressed the lower length and expanded the upper length (CL-XU) as shown in Fig. 5 (b).

And the other two cases are the case that intends to distinguish the effect of non-uniform channel areas between

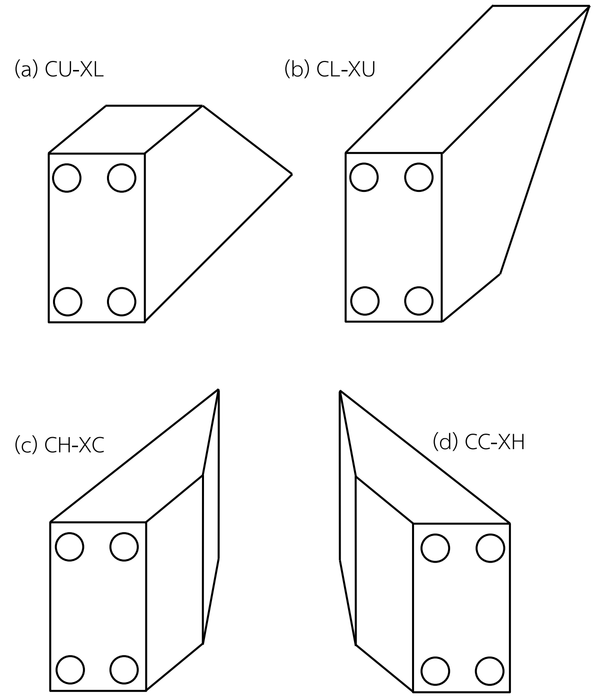

Fig. 5 asymmetry plate configurations

plate with two configurations. One is to compressed the hot side length (both upper and lower) and expanded the cold side length (both upper and lower) (CH-XC) as shown in Fig. 5 (c). The other configuration is to compressed the cold side length and expanded the hot side length (CC-XH) as shown in Fig. 5 (d).

The last case is the symmetry case that will be used to distinguish the difference of asymmetry plate heat exchanger heat transfer efficiency. The length of the symmetry case is an average value of all length in each configuration. Incidentally, both four configurations share the same average length. Therefore, only one symmetry will be used to compare to the asymmetry configuration.

In practice, the plate heat exchanger exceeds its maximum asymmetry length without leaking fluid by all geometry as shown in Table 1.

Table 1 plate heat exchanger configurations length in this study

Configurations	Lengths mm.			
	Upper hot	Upper cold	Lower hot	Lower cold
CU-XL	41.17	41.15	44.79	44.71
CL-XU	45.30	45.27	41.27	41.22
CH-XC	39.53	46.49	39.54	46.48
CC-XH	46.36	39.50	46.37	39.51
Symmetry	42.96	42.96	42.96	42.96

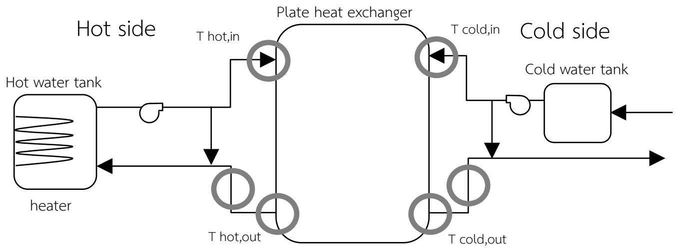

Fig. 6 test rig schematic

3. Experimental setup

This study attempts to compare the overall heat transfer coefficient, from the asymmetry plate heat exchanger configuration to the symmetry configuration by experimental method.

In order to obtain overall heat transfer coefficient at each configuration, the plate heat exchanger must be fed with liquid water for both sides at the same condition except plate heat exchanger length. In this study, the flow rate is set to be the same at 0.6 m^3/hr to keep the turbulence inside the channel [8] as in every case, but the hot fluid inlet temperature must be varied from 40°C-60°C in each case.

Hot flow rate

3.1. Test rig

The overview of the test diagram has been shown in Fig. 6. The details of each section will be described onward.

3.2. Hot side

Water in the hot loop will be stored at the tank which contains 6 2.5kW electrical heaters which are controlled by

a thermostat. Hot water will be fed by a pump to the plate heat exchanger. Between fluid fed to the plate heat exchanger, a by-pass pipe is tapped to extract some of the

Cold flow rate

flow returning to the tank and reheat in order to control the flow rate.

3.3. Cold side

Cold water will be stored at the tank within the conditioned temperature. Cold water will be fed by a pump to the plate heat exchanger with a by-pass pipe in order to control the flow similarly as the hot loop. After the cold water leaves the plate heat exchanger, it will be discarded.

3.4. Measurement

After the system stay steady for 5 minutes, all measurements will be collected. Each experiment configuration will be operated repeatedly 4 times.

3.4.1. Temperature

The temperature data will be collected using the calibrated type-K thermometer for the hot inlet, hot outlet, cold inlet, and cold outlet. A thermometer will be placed at the inlet and outlet then read with digital data logger with 0.1°C resolution.

3.4.2. Flow rate

The flow rate data will be collected by the calibrated rotameter which is placed after the hot and cold flow leave the outlet. The rotameter for both flows has 0.01 m^3/hr resolution.

3.5. Calculation

All calculation will be assumed based on these assumptions

1. Steady state
2. Overall mean value

3.5.1. Overall heat transfer rate

$$UA = \frac{\dot{Q}}{LMTD}$$ Error! Bookmark not defined.(1)

3.5.2. Heat transfer rate

$$\dot{Q} = \dot{m}c_p\left(\mathrm{T_{cold,out}} - \mathrm{T_{cold,in}}\right) \quad (2)$$

$$\dot{m} = \rho\dot{V} \quad (3)$$

3.5.3. Log mean temperature different

$$LMTD = \frac{\left(T_{hot,out}-T_{cold,in}\right)-\left(T_{hot,in}-T_{(cold,out)}\right)}{\log\left(\frac{T_{hot,out}-T_{cold,in}}{T_{hot,in}-T_{(cold,out)}}\right)} \quad (4)$$

3.6. Uncertainty Propagation

All data used in this study has been account for each precision and bias errors by the overall heat transfer efficiency error calculated from this equation.

$$e_{UA} = \sqrt{\left(\frac{e_{\dot{Q}}}{A\cdot LMTD}\right)^2 + \left(\frac{\dot{Q}e_{LMTD}}{A\cdot LMTD^2}\right)^2 + \left(\frac{\dot{Q}e_A}{A^2\cdot LMTD}\right)^2} \quad (5)$$

4. Result and Discussion

From Fig. 7, it is obvious that CU-XL and CC-XH configurations have better overall heat transfer coefficient than the average configuration and CL-XU, CH-XC configurations. experimental results, there are two interesting subjects to discuss, first, the local balanced point of the heat transfer mode on heat transfer surface and, second, the mechanism of increasing the heat transfer efficiency.

First, the balanced point of the heat transfer mode on heat transfer surface might be the best explanation why some configurations heat transfer efficiency are higher than the symmetry configuration, still, other configurations are not lower than the symmetry configuration but significantly the same as the symmetry configuration.

efficiency for the CL-XU and CH-XC efficiency remain the same as the symmetry configuration.

From the result, it can be concluded that the heat transfer mode which is promoted by CL-XU and CH-XC configuration not requiring the symmetry configuration. On the other hand, CU-XL and CC-XH are promoted with the

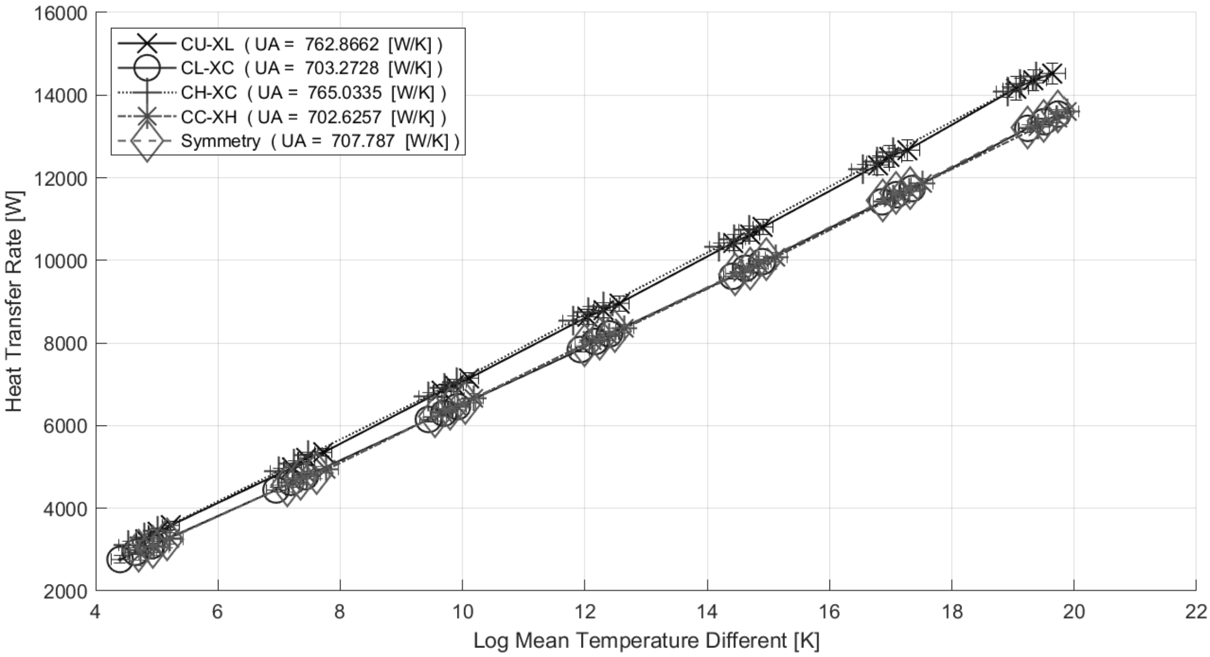

Fig. 7 heat transfer performance of plate heat transfer in: a) CU-XL config., b) CL-XC config., c) CH-XC config., d) CC-XH config., e) Symmetry config.

For the symmetry configuration, the plate heat exchanger has its own fixed ideal balanced point of the heat transfer mode which depends on its geometry. If the plate heat exchanger can operate with this balanced point between heat conduction and convention, it will operate with the best efficiency. However, practically, its heat convection and conduction rate, and the symmetry configuration cannot be operated at the balanced point for the lack of some mode of the heat transfer.

To promote either the heat convection or the heat conduction to the symmetry configuration, the symmetry configuration should be operated with the best efficiency. Nevertheless, in this study, the heat convection and heat conduction are promoted by changing the plate heat exchanger length in each configuration. The result shows that not all changing plate length configuration affects the exact heat transfer mode needed to improve efficiency. The next subject will discuss the heat transfer that are promoted to those configurations.

In addition, only CU-XL and CC-XH are the only two configurations promoted with the right heat transfer mode. CU-XL and CC-XH share the same compression of the upper cold side and expansion of the lower hot side which are not shared among other configurations.

Compressing the upper cold side and expanding the lower hot side of the symmetry configurations improving the efficiency means that changing the geometry in specific areas can affect the plate heat exchanger efficiency. Therefore, the local heat transfer area surface should have its own specific heat transfer mode balanced points that are various among its surface.

In summary, the symmetry configuration has its own specific ideal heat transfer mode balanced point in each area.

If the right heat transfer mode is promoted to balance, it will affect the overall heat transfer coefficient.

Second, the mechanism of increasing heat transfer efficiency. From the result, it is obvious that the plate geometry affects the heat transfer coefficient. The improvement of the efficiency can be done by balancing the heat transfer mode from the symmetry configuration.

CU-XL and CC-XH are promoted with the right heat transfer mode to the exact required location. CU-XL condition has compressed the upper cold side and expanded the lower hot side. The compressed upper cold side means that the fluid in the cold upper side (cold outlet) flow to smaller areas, which forces the flow to accelerate and enhance more heat convection to the balanced point.

Likewise, the expanded lower hot side means that the fluid in the lower hot side (hot outlet) flow to larger areas, which forces the flow to deaccelerate and enhance more heat conduction to the balanced point.

Unfavorably, the CC-XL configuration geometry is too complex to analyze the local mechanism of geometry that affects the heat transfer coefficient. At the compressed upper cold side (cold outlet), the lower cold side or cold inlet side are also compressed making the two not different in the port channel flow areas. However, the channels between plates keep declining along the plates' width. In this study, there is no affirmed evidence to determine the flow behavior inside the channels and thus requires further techniques to investigate.

In conclusion, the decrease of the flow cross-section areas can promote more heat convection by accelerating the flow and the increase of the flow cross-section areas can promote more heat conduction by deaccelerating the flow.

Overall, it can be confirmed that the change of flow cross-section areas can affect the heat transfer efficiency.

5. Conclusion

Four of asymmetry plate heat exchanger configurations by compressed the upper length and expanded the lower length (CC-XL), compressed the lower length and expand the upper length (CL-XU), compressed the hot side length and expanded the cold side length (CH-XC) and compressed the cold side length and expanded the hot side length (CC-XH) have been tested to compare the heat transfer coefficient to the symmetry configuration.

The result shows that CU-XL and CC-XH configurations have better efficiency than the symmetry configuration. Thus, CL-XU and CH-XC have the same efficiency with the symmetry configuration. Changing the plate heat exchanger length affects the heat transfer efficiency. The decrease of flow cross-section areas can promote more heat convection by accelerating he flow and the increase of the flow cross-section areas can promote more heat conduction by deaccelerating flow.

6. Acknowledgement

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