Viser Technology Pte. Ltd.
Mechanical Engineering Science
DOI: 10.33142/mes.v6i2.15052

Research Article Open Access

Experimental Study on the Performance of Plate Heat Exchangers

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Abstract

The heat exchanger, a crucial device facilitating heat transfer between different temperature media, finds extensive application across diverse industries such as chemical, metallurgy, electric power, and construction, playing a pivotal role in energy conservation. It encompasses various structural configurations including tubular, shell-and-tube, and plate heat exchangers, and operates through different heat transfer modes including convection, radiation, and composite convection-radiation mechanisms.This study focuses on experimentation with a plate heat exchanger to ascertain optimal heat transfer parameters via manipulation of heat transfer mode and flow rate. The findings underscore the significant enhancement in heat transfer efficiency achievable through judicious adjustments in working medium flow rate and heat transfer mode.

Keywords: *heat exchanger; flow rate; heat transfer mode; thermal efficiency*

1 Introduction

The heat exchanger is a device utilized to facilitate the transfer of heat between fluids at different temperatures, transferring heat from a high-temperature fluid to a low-temperature fluid in order to regulate the temperature of the fluids. It is utilized in various fields, including chemical engineering, metallurgy, electric power, and pharmaceuticals[1]. Heat exchangers are widely used in air separation units, petroleum refining, refrigeration engineering, and other fields, making them one of the most important pieces of process equipment in the chemical industry. The development of heat exchangers represents a significant technological advancement, as it can enhance energy utilization efficiency and reduce energy waste[2]. Two common types of heat exchangers are shell-and-tube heat exchangers and plate heat exchangers, each with its own advantages and disadvantages and suitable for different scenarios. Shell-and-tube heat exchangers facilitate heat exchange between fluids inside and outside the tubes, featuring a simple structure and long service life, albeit with a relatively smaller heat exchange surface area. On the other hand, plate heat exchangers consist of multiple thin plates for heat exchange between fluids in the gaps between the plates, offering a larger heat exchange surface area but requiring specialized technical personnel for operation and being more susceptible to factors such as contaminants. When selecting an appropriate heat exchanger, comprehensive considerations based on diverse application fields, process conditions, and fluid characteristics are necessary to achieve optimal heat transfer efficiency.

This study examines the impact of varying fluid flow velocities on heat exchanger performance. By conducting a comparative analysis of experimental data, it aims to identify the optimal flow pattern and velocity conducive to efficient heat exchange.

2 Experimental Principle

In order to investigate the impact of flow velocity on the performance of a heat exchanger, we selected a shell-and-tube heat exchanger for experimentation and conducted performance tests. During the experiment, we measured parameters such as actual heat transfer efficiency, logarithmic mean temperature difference, and overall heat transfer coefficient to examine the influence of different flow velocities and flow patterns on the heat exchanger's performance[3]. These parameters serve as fundamental physical quantities that characterize the heat exchanger's performance. Through the calculation of their relationships, we can gain a comprehensive understanding of the heat exchanger's working principle and performance, which will establish a solid foundation for subsequent experimental analysis and conclusions[4].

(1) The heat released by hot water.

$$Q_{heat} = G_{heat} C_{p,heat} (t_{h1} - t_{h2}) \tag{1}$$

(2) The heat absorbed by cold water.

$$Q_{cold} = G_{cold} C_{p,cold} (t_{c2} - t_{c1}) \tag{2}$$

In the formula: G_{heat} ——the mass flow rate of hot

Received on September 11, 2024; Accepted on October 27, 2024

water, kg/s;

G_{cold}——the mass flow rate of cold water,kg/s;

$C_{p,heat}$——the specific heat of hot water at constant pressure, kJ/(kg·℃);

$C_{p,cold}$——the specific heat of cold water at constant pressure, kJ/(kg·℃);

t_{h1}——the inlet temperature of the hot water, ℃;

t_{h2}——the outlet temperature of hot water,℃;

t_{c1}——the inlet temperature of the cold water,℃;

t_{c2}——the outlet temperature of cold water,℃。

(3) Regardless of whether it is downstream or upstream, the logarithmic mean temperature difference can be used. The formula for this is as follows:

$$\Delta t = \frac{\Delta t_{\max} - \Delta t_{\min}}{\text{In}\,\frac{\Delta t_{\max}}{\Delta t_{\min}}} \tag{3}$$

Δt_{max}——Temperature difference between the inlet temperature of the heat source and the outlet temperature of the cold source;

Δt_{min}——Temperature difference between the outlet temperature of the heat source and the inlet temperature of the cold source.

(4) The average of the heat released by hot water and the heat absorbed by cold water is taken as the heat flux of the entire heat transfer surface.

$$Q = \frac{Q_{heat} + Q_{cold}}{2} \tag{4}$$

(5) Heat transfer coefficient equation

$$K = \frac{Q}{A\Delta t_m} \tag{5}$$

(6) Heat Transfer Efficiency

$$\varphi = \frac{Q_{cold}}{Q_{heat}} \tag{6}$$

3 Experimental Data

In the experiment, the temperatures of the cold water tank and the hot water tank were maintained at a constant level. Only the flow patterns and flow rates of the hot and cold fluids were altered in order to examine their impact on the performance of the heat exchanger. Parameters such as the inlet and outlet temperatures of the cold and hot fluids were measured to evaluate the effectiveness of the plate heat exchanger. Experimental data for both co-current and counter-current flow configurations are presented in Tables 1 and 2, respectively.

4 Data of Experimental

The heat transfer efficiency diagram for parallel flow in plate heat exchangers is depicted in Figure 1, whereas for counterflow, it is illustrated in Figure 2.

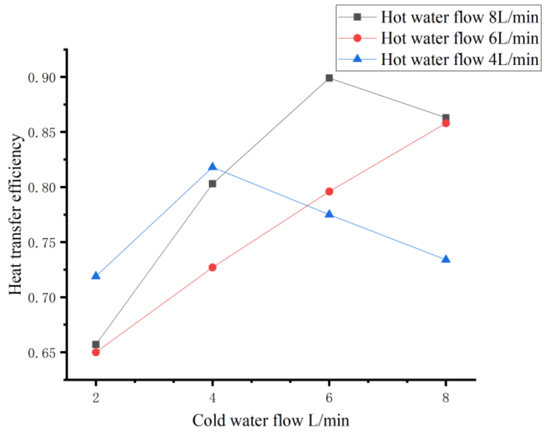

Figure 1 Illustrates the heat transfer efficiency of the parallel flow plate heat exchanger

Table 1 Experimental Data for Parallel Flow Heat Exchanger

The flux of hot water(L/min)	The flux of cold water (L/min)	The imported temperature of the hot water (℃)	The outlet temperature of hot water (℃)	The imported temperature of the cold water (℃)	The outlet temperature of cold water (℃)	The heat released by hot water (W)	The heat obtained by cold water (W)	Heat exchange efficiency	Logarithmic mean temperature difference (℃)	Heat Transfer (W)	Heat Transfer Coefficient W/(m^2·K)
8	2	50.2	40.3	14.3	40.3	5518	3623	0.657	16.67	4570	1904
8	4	50.2	37.5	14.3	34.7	7079	5686	0.803	19.09	6383	2322
8	6	50.2	35.6	14.3	31.8	8139	7316	0.899	19.81	7728	2709
8	8	50.1	34.0	14.3	28.2	8975	7748	0.863	20.78	8362	2794
6	2	50.2	38.1	14.3	37.9	5059	3289	0.650	17.42	4174	1664
6	4	50.0	34.5	14.3	31.2	6480	4710	0.727	19.49	5595	1994
6	6	50.3	33.1	14.3	28.0	7191	5727	0.796	20.50	6459	2188
6	8	49.2	31.5	14.3	25.7	7400	6355	0.858	20.19	6878	2366
4	2	50.1	35.7	14.3	35.0	4013	2884	0.719	18.07	3449	1325
4	4	50.2	32.6	14.3	28.7	4906	4013	0.818	19.86	4460	1559
4	6	50.4	29.3	14.3	25.2	5881	4557	0.775	19.66	5219	1843
4	8	50.2	27.6	14.3	22.6	6299	4626	0.734	19.59	5463	1936

Table 2 Experimental Data for Counterflow Plate Heat Exchanger.

The flux of hot water (L/min)	The flux of cold water (L/min)	The imported temperature of the hot water (℃)	The outlet temperature of hot water (℃)	The imported temperature of the cold water (℃)	The outlet temperature of cold water (℃)	The heat released by hot water (W)	The heat obtained by cold water (W)	Heat exchange efficiency	Logarithmic mean temperature difference (℃)	Heat Transfer (W)	Heat Transfer Coefficient W/(m^2 K)
8	2	50.1	38.9	13.7	45.8	6244	4473	0.716	11.82	5358	3148
8	4	50.1	36.1	13.7	39.7	7805	7274	0.929	15.64	7540	3347
8	6	50.1	34.5	13.7	33.8	8696	8403	0.966	18.45	8550	3217
8	8	50.0	32.8	13.7	29.7	9588	8919	0.930	19.69	9254	3263
6	2	50.1	36.5	13.7	44.6	5686	4306	0.757	12.16	4996	2853
6	4	50.1	34.1	13.7	36.7	6689	6410	0.958	16.66	6550	2730
6	6	50.1	31.2	13.7	32.0	7902	7651	0.968	17.80	7777	3033
6	8	50.0	29.9	13.7	27.2	7860	7525	0.957	19.31	7693	2766
4	2	50.0	33.0	13.7	42.1	4738	3958	0.834	12.76	4348	2366
4	4	50.0	28.6	13.7	33.6	5964	5546	0.930	15.63	5755	2556
4	6	50.2	26.4	13.7	29.0	6633	6396	0.965	16.58	6515	2728
4	8	50.0	27.2	13.7	24.7	6355	6132	0.964	18.79	6244	2307

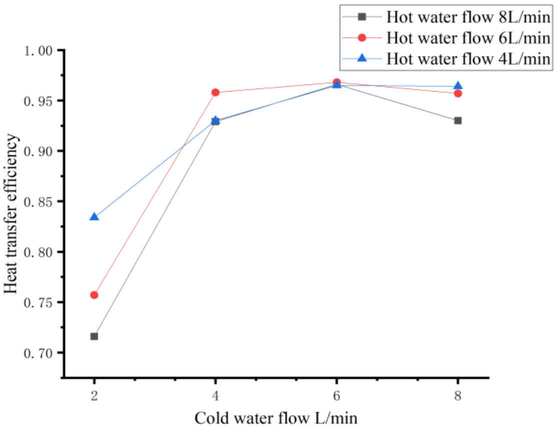

Figure 2 Heat Transfer Efficiency of Plate Heat Exchanger under Counterflow

The heat transfer coefficient diagram for parallel flow in a plate heat exchanger is shown in Figure 3, and the heat transfer coefficient diagram for counterflow is shown in Figure 4.

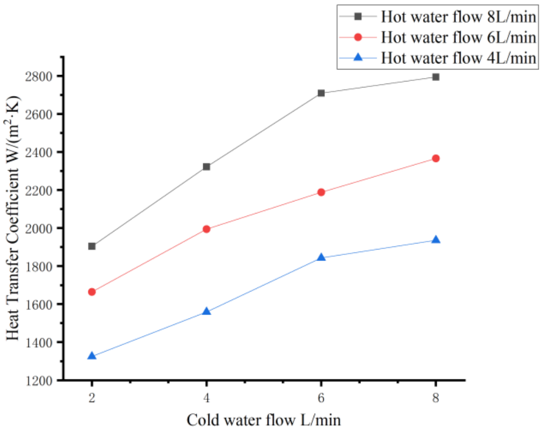

Figure 3 Illustrates the heat transfer coefficient of the parallel flow plate heat exchanger

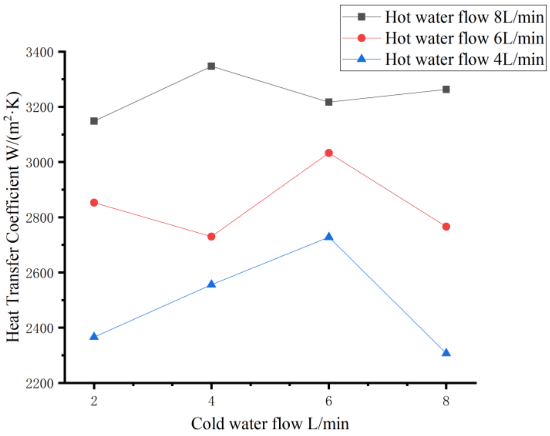

Figure 4 Depicts the heat transfer coefficient of plate heat exchangers under countercurrent flow

5 The Conclusion of Data Analysis

(1) In the realm of thermal dynamics, it is a well-established phenomenon that in instances where the flow rates of hot water and cold water are disparate, counterflow operation typically exhibits a higher heat transfer efficiency compared to cocurrent operation. This superiority stems from the counterflow arrangement, wherein the direction of heat conduction opposes that of fluid flow. Consequently, this configuration facilitates a more thorough transfer of heat to the opposing fluid, thereby enhancing overall heat transfer efficiency.

(2) Optimal performance under cocurrent operation is observed when both hot and cold water flow rates are maintained at 4.0L/min. However, as the hot water flow rate escalates to 6.0L/min, the heat transfer efficiency exhibits an incremental rise with an increase in the cold water flow rate. Upon further escalation of the hot water flow rate to 8.0L/min, the heat transfer efficiency attains its zenith at a cold water

flow rate of 6.0L/min. Experimentally, it has been substantiated that the pinnacle of overall heat transfer efficiency in cocurrent operation is achieved at a hot water flow rate of 8.0L/min concomitant with a cold water flow rate of 6.0L/min. Conversely, under counterflow operation conditions, optimal heat transfer efficiency is solely realized at a hot water flow rate of 6.0L/min.

(3) Experimental observations elucidate that within cocurrent operation, the heat transfer coefficient exhibits a gradual augmentation in tandem with escalating flow rates of both hot and cold water. In contrast, counterflow operation typically manifests a higher heat transfer coefficient than its cocurrent counterpart. Nevertheless, an intriguing deviation arises as the cold water flow rate surpasses a certain threshold; rather than a continued ascent, the heat transfer coefficient undergoes a diminution.

6 Conclusion

Through calculation and analysis, it was determined that counterflow operation yields the most favorable outcomes in heat exchanger operation. This superiority primarily stems from the oppositional alignment between heat conduction and fluid flow direction in counterflow operation. Such a configuration facilitates more comprehensive heat transfer to the opposing fluid, thereby optimizing the overall heat transfer efficiency of the exchanger. Generally, counterflow exhibits heightened heat transfer efficiency, often resulting in a higher outlet temperature for the hot water compared to the cold water outlet temperature in counterflow experiments.

Fund Projects: Yingkou Institute of Technology campus level research project--- Development of food additive supercritical extraction equipment and fluid transmission system research.

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