Performance Tests for an All-welded Plate Heat Exchanger

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Abstract. Heat transfer and pressure drop in an all-welded plate heat exchanger with ripples have been experimentally investigated in this paper. The ripples were corrugated by the way of special machine. The heat transfer coefficient and pressure drop was experimented, and also calculated by the wall temperature method. The flow of water inside the plate heat exchanger was arranged as a single-pass and countercurrent. The hot water and cold water inlet temperatures were maintained at around 50℃ and 35℃, respectively, while the hot oil and cold water inlet temperatures were got at about 40℃ and 35℃, respectively. It indicated that the overall heat transfer coefficient calculated by wall temperature method fitted the actual value.

Nomenclature

Q_h heat transfer rates of the thermal fluid (kW)
Q_c heat transfer rates of the cold fluid (kW)
u_h flow velocity of the thermal fluid (m/s)
u_c flow velocity of the cold fluid (m/s)
G_h the volume flow of thermal fluid (m^3/h)
G_c the volume flow of cold fluid(m^3/h)
C_{ph} specific heat of the thermal fluid (kJ kg^{-1} K^{-1})
C_{pc} specific heat of the cold fluid (kJ kg^{-1} K^{-1})
T_{h1} inlet temperature of thermal fluid (℃)
T_{h2} outlet temperature of thermal fluid (℃)
T_{c1} inlet temperature of cold fluid (℃)
T_{c2} outlet temperature of thermal fluid (℃)
K the total heat transfer coefficient W/(m^2*k)
A heat transfer area (m^2)
Δt_m the average temperature (℃)
ΔP_h pressure drop of the thermal side (kPa)
ΔP_c pressure drop of the cold side (kPa)
ΔP pressure drop (kPa)
α_h heat transfer coefficient of thermal W/(m^2*k)
α_c heat transfer coefficient of cold W/(m^2*k)

Introduction

Plate heat exchanger as a thermal element with superior heat transfer performance, is widely used in petroleum industry, chemical industry, power industry, mechanical ship industry and other industries. It has great vital significance to research on heat transfer enhancement technology. The plate heat exchangers have the advantages of high transfer efficiency, flexibility, and ease of maintenance and cleaning. But the performance of plate heat exchanger is determined by many factors such as corrugation inclination angle, the flow mechanism of fluid, geometrical parameters, fluid distribution and so on.

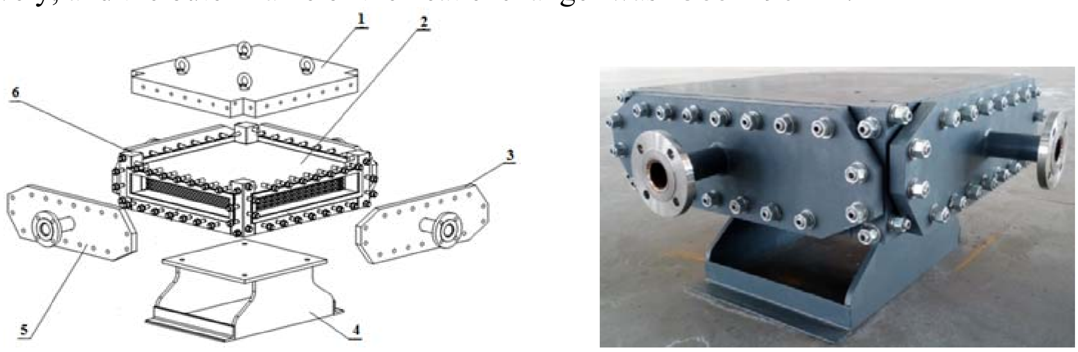
In order to obtain high efficiency, low resistance of the plate heat exchanger, many scholars around the word made a series of studies on the plate heat exchanger. Corrugated inclination angle β of chevron plate heat exchanger was first studied by W. W. Focke [1] who changed the angle and other parameters to improve heat transfer efficiency. Muley and Manglik [2] further studied the different forms of the plate heat exchanger, heat transfer coefficient correlation was amended and area expansion coefficient was also introduced. Reinhard Wurfd [3] studied the steam condenses experiment with different structures of plate heat exchanger, also studied the effect of corrugation inclination angle β for heat transfer and pressure drop in two-phase flow plate heat exchanger. Z. Vlahostergios [4] researched the effect of turbulence intensity on the pressure drop in elliptical tube heat exchanger, the results suggested that increased turbulence intensity lead to decreased pressure drop of the heat exchanger. A A Gholami [5] studied three different baffles and baseline impact on heat transfer and pressure drop in fin tube heat exchanger, the result showed a rectangular wavy fin can significantly improve the heat transfer performance and reduce the pressure drop. The heat transfer and pressure drop was researched by visualization technology under conditions of two-phase coexistence between air and water in the study of Asano [6]. The geometric parameters of plate were also studied as the factors that influence the heat transfer and pressure drop of plate heat exchanger. Bahadır Dogan [7] compared the heat exchanger performance between double and multi-row fin heat exchanger by studying the exchanger side of air, studies showed that in quasi-steady state, the double fin heat exchanger with higher thermal performance and efficiency, and the friction factor is also high. Muley [8] noted the uneven distribution of the fluid in the plate heat exchanger was a major factor that affected the performance of the plate heat exchanger.

The emergence of various plate heat exchangers [9-12] greatly broadened the application field of plate heat exchanger. The plate structure of all welded plate reactor was a complex network port, which can effectively promote the fluid turbulence. In this paper, the heat transfer and pressure drop of an all-welded plate heat exchanger was investigated.

Experimental

Heat exchanger

Fig. 1 showed that the schematic diagram and entities picture of the test all-welded plate heat exchanger. The all-welded plate heat exchanger comprised of a series of plates welded together to form cassettes which were stacked one on top of another to provide channels for flowing fluids to exchange heat. Two sheet frames with inlet, two sheet frames with outlet, a top cover and a bottom cover with foundation enclosed the stacked cassettes. The all-welded plate heat exchanger, with the heat transfer area of $4.5m^2$, contained 11 plates, where provided 5 channels for thermal fluids and 5 channels for cold fluids. The corrugation depth and corrugation pitch were 4mm and 14mm, respectively, and the outer frame of the heat exchanger was 1388×496mm.



1 top cover; 2 stacked cassettes; 3 sheet frame with inlet;
4 bottom cover with foundation; 5 sheet frame with outlet; 6 stand column
Fig. 1 Schematic diagram and entities picture of the test all-welded plate heat exchanger

Test process.

The heat transfer performance and pressure drop were investigated with water-water and water-thermal oil (LONTHERM-60) as heat transfer fluids, respectively. The temperature was measured by Pt100 thermocouples, and the flow rate of fluids was measured by turbine flow-meters. Cold and thermal heat transfer fluids were flowed in full countercurrent type.

Data processing formula.

The average heat transfer rate

$$Q = \frac{Q_c + Q_h}{2} \quad (1)$$

$$Q_h = G_h \cdot \rho_h \cdot C_{ph} \cdot (t_{h1} - t_{h2}) \quad (2)$$

$$Q_c = G_c \cdot \rho_c \cdot C_{pc} \cdot (t_{c2} - t_{c1}) \quad (3)$$

$$K_1 = \frac{Q_c}{A \times \Delta t_m} \quad (4)$$

Wall temperature method to calculate the overall heat transfer coefficient

First, the heat transfer coefficient of cold side and the thermal side were calculated, and then use the formula (9) to calculate the overall heat transfer coefficient.

$$q = \alpha_h (t_{mh} - t_{wh}) \quad (5)$$

$$q = \frac{\lambda (t_{wh} - t_{wc})}{\delta} \quad (6)$$

$$\alpha_h = \frac{q}{t_{mh} - t_{wh}} \quad (7)$$

$$\alpha_c = \frac{q}{t_{wc} - t_{mc}} \quad (8)$$

$$\frac{1}{K_2} = \frac{1}{\alpha_c} + \frac{1}{\alpha_h} \quad (9)$$

Results and discussion

The study of heat transfer coefficient and pressure drop in water-to-water

Table 1 showed that the experimental results at constant flow rate of thermal and cold fluid in water-to-water. From Table 1, the heat transfer coefficient that calculated by the wall temperature method and experimentally measured was compared, the relative error of heat transfer coefficient was also calculated. The date showed that the use of wall temperature method to calculate heat transfer coefficient was basically consistent with the actual test.

Table 1 Experimental results at constant flow rate of thermal and cold fluid in water-to-water

N	u_h m/s	T_{h1} ℃	T_{c1} ℃	T_{h2} ℃	T_{c2} ℃	ΔP_h kPa	ΔP_c kPa	Q_h kW	Q_c kW	K_1 W/(m^2*k)	K_2 W/(m^2*k)	error 10^{-3}
1	0.2	43.76	13.04	30.11	26.81	3.65	6.35	102.23	103.13	1341.39	1341.43	0.7455
2	0.3	48.63	29.50	39.71	38.47	6.64	8.44	100.73	100.50	2194.77	2195.28	0.4556
3	0.4	44.05	31.51	37.92	37.90	13.70	10.37	91.44	95.34	3305.45	3304.67	0.3025
4	0.5	50.81	33.85	42.07	42.49	22.59	15.33	163.22	161.71	4366.70	4365.58	0.2290
5	0.6	50.21	34.87	42.11	43.09	31.67	19.45	181.11	184.21	5650.55	5653.36	0.1770
6	0.7	49.71	35.31	41.86	43.21	42.65	24.39	204.66	205.74	6988.81	6988.50	0.1431
7	0.8	49.99	35.79	42.03	43.83	57.58	31.40	236.80	240.05	8537.43	8545.70	0.1171
8	0.9	49.60	36.15	41.91	43.86	67.64	37.32	249.74	250.70	9674.60	9670.34	0.1034
9	0.8	50.33	36.58	42.69	44.35	56.63	31.34	227.88	231.23	8437.69	8438.75	0.1185
10	0.7	50.94	36.83	43.25	44.50	42.65	24.41	200.79	200.88	6946.72	6940.90	0.1440
11	0.6	50.27	36.79	43.10	43.90	32.67	20.32	161.59	159.66	5635.10	5630.04	0.1775
12	0.5	50.17	36.68	43.31	43.49	22.59	14.31	128.11	127.55	4268.64	4268.47	0.2343
13	0.4	52.26	36.48	44.66	43.98	13.70	9.35	113.94	111.00	3037.45	3036.86	0.3292
14	0.3	50.21	36.60	43.97	42.81	6.63	8.40	70.08	69.94	2107.02	2106.67	0.4746
15	0.2	52.41	36.48	45.60	43.03	3.66	6.32	51.41	49.47	1211.95	1211.77	0.8251

The change of heat transfer coefficient with flow rate was shown in Fig. 2, which showed that the heat transfer coefficient increased with the increasing flow rate. With the increasing flow rate, the turbulent fluid level increased. Dot dither and mixing occurred, so the heat transfer coefficient increased. The change of pressure drop with the flow rate was shown in Fig. 3. With the increased of flow rate, a corresponding increase in the frictional resistance, the pressure drop also increased.

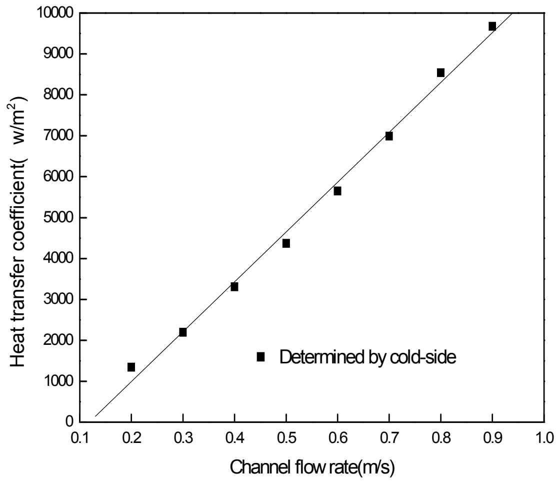


Fig. 2 Test relation curves of heat transfer coefficient and the velocity (water-to-water)

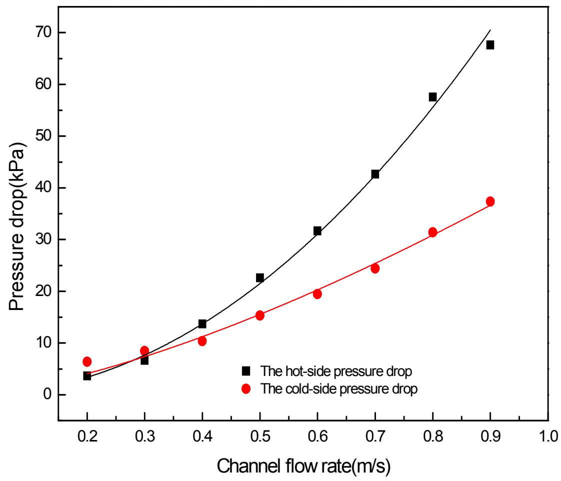


Fig. 3 Test relation curve of pressure drop and the velocity (water-to-water)

The study of heat transfer coefficient and pressure drop in oil-to-water

Table 2 showed that the experimental results at constant flow rate of cold fluid in oil-water. From Table 2, the overall heat transfer coefficient that calculated by the wall temperature method and experimentally measured was compared, the error was also calculated. The result showed that the calculated heat transfer coefficient was basically consistent with the actual test value.

The change of heat transfer coefficient with velocity can be shown in Fig. 4, the heat transfer coefficient increased with the increased of channel flow rate. Heat transfer resistance is mainly concentrated in the boundary layer, the temperature boundary layer thinning with the increase of flow velocity, heat transfer rate increased, heat transfer coefficient also increased. The change of pressure drop with the flow rate was shown in Fig. 5. With the increasing flow rate, the pressure drop increased.

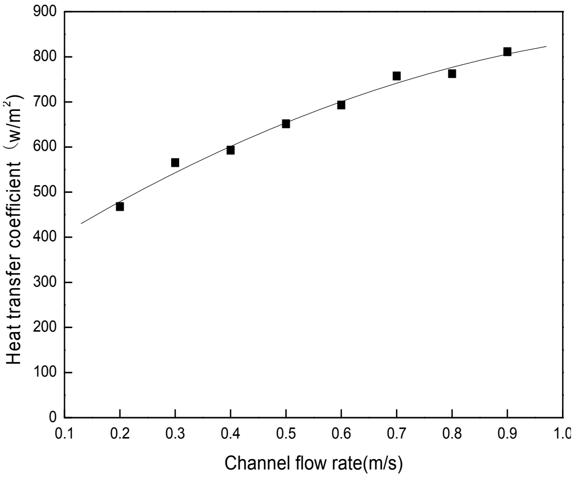


Fig. 4 The test curve of heat transfer coefficient and the velocity (oil-to-water)

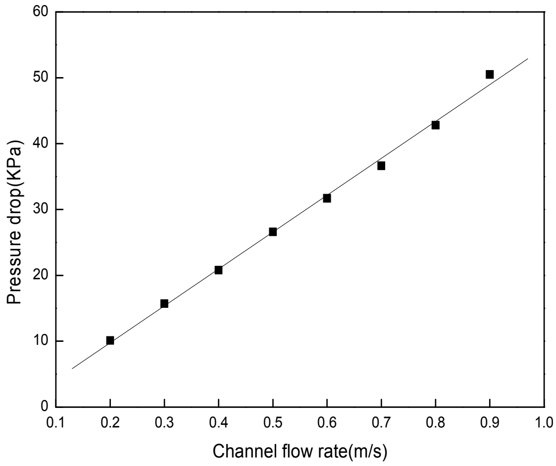


Fig. 5 The test curve of pressure drop and the velocity (oil-to-water)

Table 2 Experimental results at constant flow rate of cold fluid in oil-water

N	u_h	u_c	T_{h1}	T_{c1}	T_{h2}	T_{c2}	ΔP_h	ΔP_c	Q_h	Q_c	K_1	K_2	Error
	m/s	m/s	℃	℃	℃	℃	kPa	kPa	kW	kW	W/(m²*k)	W/(m²*k)	
1	0.2	0.5	46.71	33.78	40.50	34.82	10.13	15.35	19.49	18.68	468.05	455.79	2.6902
2	0.3	0.5	41.68	33.89	38.43	34.65	15.72	15.35	14.22	14.75	565.27	556.42	1.5906
3	0.4	0.5	41.56	33.85	38.96	34.70	20.81	15.35	15.99	15.75	593.12	589.25	0.6566
4	0.5	0.5	41.50	33.67	39.15	34.66	26.62	15.35	18.41	17.57	651.39	648.99	0.3698
5	0.6	0.5	41.76	33.49	39.55	34.60	31.7	15.35	20.80	20.37	693.09	692.05	0.1504
6	0.7	0.5	41.55	33.24	39.37	34.42	36.63	15.35	22.07	23.06	757.55	756.33	0.1618
7	0.8	0.5	41.97	32.73	39.90	34.13	42.81	15.35	26.15	25.31	762.52	761.86	0.0863
8	0.9	0.5	41.64	33.89	39.88	35.13	50.5	15.35	23.23	22.36	811.41	810.49	0.1136

Conclusions

Heat transfer and pressure drop in an all-welded plate heat exchanger with ripples have been experimentally investigated in this paper. The ripples were corrugated by the way of special machine. The heat transfer coefficient and pressure drop was experimented, and also calculated by the wall temperature method. The overall heat transfer coefficient calculated by wall temperature method fitted the actual value.

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