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COMPARATIVE STUDY OF TURBULENCE PROMOTERS ON PRESSURE LOSS IN HEAT TRANSFER

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ABSTRACT. In this paper was studied the influence of some turbulence promoters (annular or spiral baffles), placed in the inner tube of a double pipe heat exchanger, on the pressure losses of the fluid. These studies were conducted in conjunction with the intention to enhance heat transfer by convection of the fluid that moves through these spaces

Keywords: *baffles, heat exchanger, heat transfer, pressure loss, turbulence promoters*

INTRODUCTION

The turbulence in hydraulic systems significantly influences various processes: frictional pressure losses, heat transfer by convection, absorption and adsorption, drying, dissolution; hydrodynamic regime determines the relationships which allow the calculation of the friction coefficient, partial coefficients of heat and mass transfer [1,2]. At the same fluid flow rate, turbulence increasing can be provided by introducing structures into the flow that can successive modify the state of the contact surface and therefore the speed or direction of flow, thus providing an additional local turbulence. Constructively, these changes consist in making artificial roughness in the form of circular or spiral baffles, ribs, channels, conical surfaces or blades swirling etc [3]. Intensification of convective heat or mass transfer considered effective, will be given along with the disadvantage of increasing hydraulic resistance, which leads to the undesired effect of increasing frictional pressure loss [4,5].

When turbulence promoters are used, optimal solutions are obtained by comparing relative changes of partial transfer coefficients with similar changes of the pressure loss. In the case of using turbulence promoters for the intensification of heat transfer by convection, it was compared the ratio between

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the partial heat transfer coefficients α_i/α_0 with the ratio of frictional pressure losses $\Delta p_i/\Delta p_0$ experimentally determined, under the same conditions [4].

This paper presents the experimental study of frictional pressure losses in a straight pipe, that is part of the tubular heat exchanger, in the presence and absence of turbulence promoters. Were effectively used cylindrical rings located along the length of the tube at different distances, or spirals having the same thickness and winding step equal with the distance between cylindrical rings.

The annulus of the heat exchanger was heated by hot water with known flow rate and temperature, and through the inner tube was ensured the airflow under warming. The determinations are performed both as turbulent and transient flow.

RESULTS AND DISCUSSION

The total heat transfer coefficient K is determined from the energy balance equation:

$$Q_1 = Q_2 + Q_3 = Q_4 \tag{1}$$

$$Q_2 = m_{air} \cdot c_{air} \cdot (\Delta t)_{air} \tag{2}$$

$$Q_4 = K \cdot A \cdot \Delta t_{med} \tag{3}$$

where: Q_1 - heat delivered by the hot fluid (water), W; Q_2 - heat received by the cold fluid (air), W; Q_3 - the lost heat, W; Q_4 - the transmitted heat, W; m_{air} - the air flow rate, $kg \cdot s^{-1}$; c_{air} - specific heat of air to the average temperature, $J \cdot kg^{-1} \cdot K^{-1}$; $(\Delta t)_{air}$ - the temperature differences for air at the heat exchanger extremities, $^\circ C$; Δt_{med} - the average temperature difference between air and water, $^\circ C$. The heat transfer area A was calculated with the relationship $A = \pi \cdot d_{med} \cdot H'$, where d_{med} and H' are the average diameter and the height of the inner pipe ($A = 0.05 m^2$).

The partial heat transfer coefficient for air α_{air} was determined from the values of total heat transfer coefficient K, taking into account the thermal resistance to conduction of the pipe wall ($2.6 \cdot 10^{-6}\ m^2 \cdot K \cdot W^{-1}$) and the partial heat transfer coefficient for water ($\alpha_w = 920 W \cdot m^{-2} \cdot K^{-1}$) analytically calculated in the case of heat transfer in laminar flow through vertical pipes, when the forced movement direction is reversed to the free convection ($Gr \cdot \Pr > 5 \cdot 10^5$) [6], Gr and Pr being Grashof and Prandtl criteria.

In Fig. 1 it is comparatively presented the variation of pressure losses caused by the air flow through the central tube, in the absence, respectively, the presence of annular baffles.

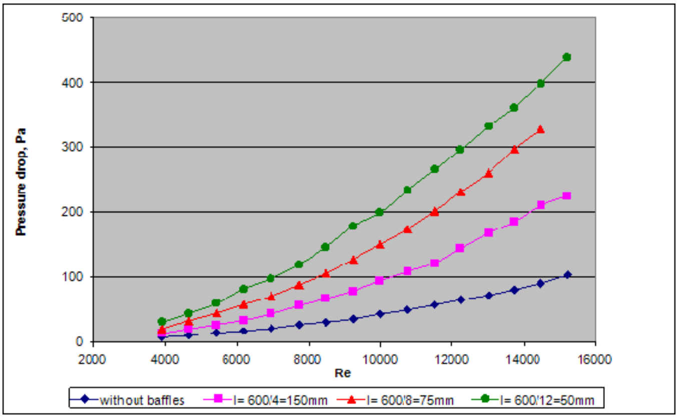

Figure 1. The dependence between the pressure losses and the air hydrodynamic regime, in the presence of annular baffles

It is observed that the presence of annular baffles leads to the pressure losses increasing in the inner tube, the increase is even greater than their number grows.

In the case of annular baffles absence, for the inner tube was analytically calculated the frictional pressure loss. Thus, in Fig.2 it is comparatively presented the evolution of the calculated and experimentally determined pressure losses, as a function of the air hydrodynamic flow regime. It was found a very good correlation of the pairs of values corresponding to the same hydrodynamic regime.

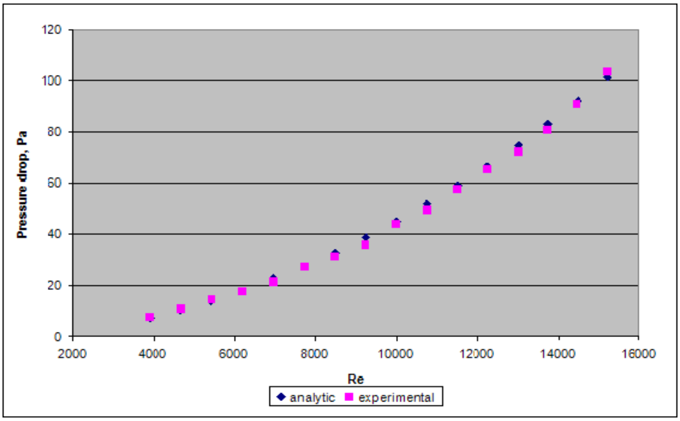

Figure 2. The dependence between the pressure losses and the hydrodynamic regime ($\Delta P = f(\mathrm{Re})$), in the absence of annular baffles

In Table 1 are presented the equations which show the dependence $\Delta P = f(\mathrm{Re})$. It was observed that in all cases the exponent of Re tends to 2, suggesting the correlation with the dynamic pressure $\Delta P_{din} = \rho \cdot w^2/2$.

Table 1. The dependence $\Delta P = f(\mathrm{Re})$ for annular baffles

Number of annular baffles and their step	**Equation** $\Delta P = f(\mathrm{Re})$	**r²**
-	$0.85 \cdot 10^{-6} \cdot \mathrm{Re}^{1.98}$	0.9984
4 ($l = 600/4 = 150\ mm$)	$0.28 \cdot 10^{-6} \cdot \mathrm{Re}^{2.13}$	0.9992
8 ($l = 600/8 = 75\ mm$)	$1.56 \cdot 10^{-6} \cdot \mathrm{Re}^{2.00}$	0.9955
12 ($l = 600/12 = 50\ mm$)	$3.70 \cdot 10^{-6} \cdot \mathrm{Re}^{1.93}$	0.9995

In Fig. 3a, b is shown the variation of pressure loss through the inner tube in the presence of spiral type turbulence promoters.To obtain an unified expression for the pressure losses values, it was proceeded to the reporting of the experimentally determined values to the inner tube length.

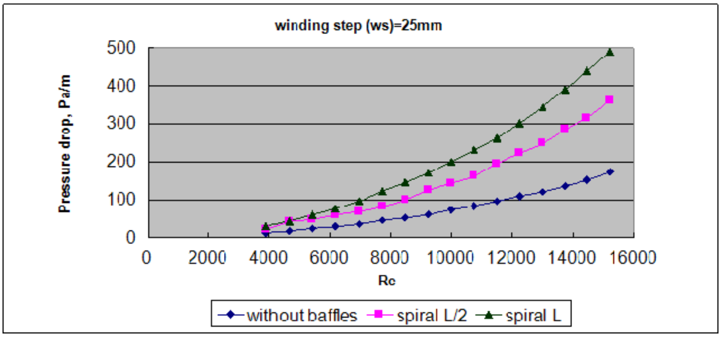

Fig. 3a

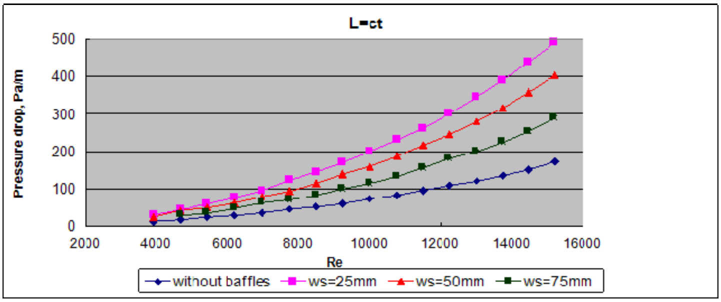

Fig. 3b

Figure 3a,b. The dependence $\Delta P = f(\mathrm{Re})$ for: a) spires with different lengths; b) spires with different winding steps

As you can notice, determinations were made intentionally to higher or less values than 10^4, to include both turbulent and transient flow. The experimental results lead to different values of the slope of these lines, Table 2.

Table 2. The slope of $\Delta P = f(\mathrm{Re})$ lines

Type of turbulence promoters	Characteristics of promoters	Slope	
		Re<10^4	Re>10^4
Pipe without baffles	-	0.0058	0.0117
Annular baffles	Baffles number		
	4	0.0132	0.0272
	8	0.0208	0.0416
	12	0.0281	0.0455
Spire with winding step 25mm	Spire length		
	L/2	0.0191	0.0433
	L	0.0277	0.0587
Spire with winding step 50mm	L	0.0217	0.0481
Spire with winding step 75mm	L	0.0161	0.0339

Based on these experimental measurements were calculated the ratios between pressure losses caused by the presence of promoters compared with their absence ($\Delta p_i / \Delta p_0$). These results were correlated with the ratios of received heats by the air (Q_i / Q_0) in the same constructive and functional conditions, in order to conclude the overall beneficial effect for heat transfer intensification, Table 3.

Table 3. The average increasing of the received heat and pressure losses in the presence of turbulence promoters

Promoters type	$\Delta p_i / \Delta p_0$		Q_i / Q_0	
	Re<10^4	Re>10^4	Re<10^4	Re>10^4
4 annular baffles	2.09	2.00	1.74	1.70
8 annular baffles	3.24	3.57	2.00	2.24
Spire with length L/2	1.88	2.05	1.48	1.66
Spire with length L	2.62	2.82	1.68	1.75

CONCLUSIONS

It was found the amplification effect due to the increasing of annular baffles number and the decreasing of spire winding step, on the pressure losses. This is illustrated by the upward curves and the increasing slope as a function of the hydrodynamic regime. The increasing of spires length has the same amplifying effect.

The growth ratio of pressure losses is higher than that of the received heats. Thus, for the range $\mathrm{Re} \in (1 \div 1.5) \cdot 10^4$, the halving of rings step leads to an increase of 78.5% of the pressure losses compared to a 31.8% increase of the received heats, respectively of partial heat transfer coefficient for air. Instead, to the doubling of the spire length the pressure losses are lower but the received heats decrease substantially (37.6% and 5.4%, respectively).

The intensification of heat transfer needs to be limited by the rapidly increasing of the pressure losses with an unfavorable effect on energy balance.

EXPERIMENTAL SECTION

The heat exchanger used is made of pipes with the following dimensions: the copper inner pipe -diameter $d = 28x1\ mm$, height $H^{'} = 600\ mm$, the outer pipe – diameter $D = 49x1.5\ mm$, height $H = 580\ mm$. The turbulence promoters of the inner pipe were rings with dimension $25x2\ mm$ placed at different distances or spires with different winding step and lengths. Both types of promoters were made of copper with 2x 2.5 mm section.

The heat exchanger is vertically positioned. The air enters on the base of the inner pipe where is ensured its flow regulation and measurement. The heat required for the air warming is delivered by the hot water circulating through the annulus and is transmitted through the cylindrical surface of tubular wall. The air temperature was measured with thermometers placed at the top an bottom of the pipe.

The hot water from the annulus is provided by a thermostat and moves upward, being recycled with a rate flow of 0.145 $m^3 \cdot h^{-1}$. Its temperature was measured both at the entrance and exit of the annulus, the water cooling has not been greater than 1ºC. Determinations were performed at air flow rates from 5 to 20 $m^3 \cdot h^{-1}$, leading to mass rates between 3 and 12 $kg \cdot m^{-2} \cdot s^{-1}$.

The pressure loss caused by air flow through the central tube was measured with an inclined-tube manometer.

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