HEAT TRANSFER AND HYDRODYNAMIC RESISTANCE OF GASEOUS PLATE HEAT EXCHANGERS TYPE "DIFFUSER-CONFUSER".

BY

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ABSTRACT:

This paper presents an experimental investigation of heat transfer and hydrodynamic resistance of gaseous plate heat exchangers type diffuser-confuser. The test section was a slotted channel and consisted of two horizontally located heated copper plates with dimensions 1000 x 200 x 15mm. The diffusers flare angle was 12° and lengths of diffusers and confusers were 8 and 4 mm respectively. Symmetric and asymmetric channels were studied with different heights during turbulent motion of air. The heat transfer data for these channels shows that intensification of heat transfer is gained with moderate growth of resistance. Some correlations are obtained for calculating the heat transfer coefficient and the hydrodynamic resistance.

NOMENCLATURE:

a	length of diffusers
B	Width of channels
C	length of confusers
d	hydraulic equivalent diameter
K_N	power ratio
K_Q	heat transfer coefficient ratio
K_h	area ratio
ℓ	length of channel
Pr	Prandtl number
Re	Reynolds number

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St Stanton number
W mean velocity of air
γ flare angle of diffusers
ζ Coefficient of friction.
ψ angle of slots inclination to the flow direction
ν Kinematic viscosity

INTRODUCTION:

Plate heat exchangers are used extensively in the food, chemical, oil-chemical and other industries according to a number of their properties (they are compact, easy in use, have high degree of heat transfer). But in the existing constructions intensification of heat transfer is gained with considerable growth of hydrodynamic resistance, which limits their use for heating (cooling) gaseous heat carriers (coolants). Meanwhile, lately the use of gaseous heat carriers is considerably increasing, especially of air.

In the work [1] it is shown that with turbulent motion of air along the slotted channel representing a successive alternation of flat diffusers and confusers, there appear favourable hydrodynamic conditions allowing to intensify heat transfer with moderate increase of resistance. One of the most efficient surfaces of this kind is an asymmetric channel with the angle of flare of diffusers being γ = 12°, length of diffuser parts b = 40 mm, length of confuser parts C = 20 mm., distance between flat and shaped plates at inlet to diffusers a = 47.7 mm. But this surface is less compact as compared with surfaces made of lattice-flow plates [2,3] where the average distance between plates a is approximately 5 mm.

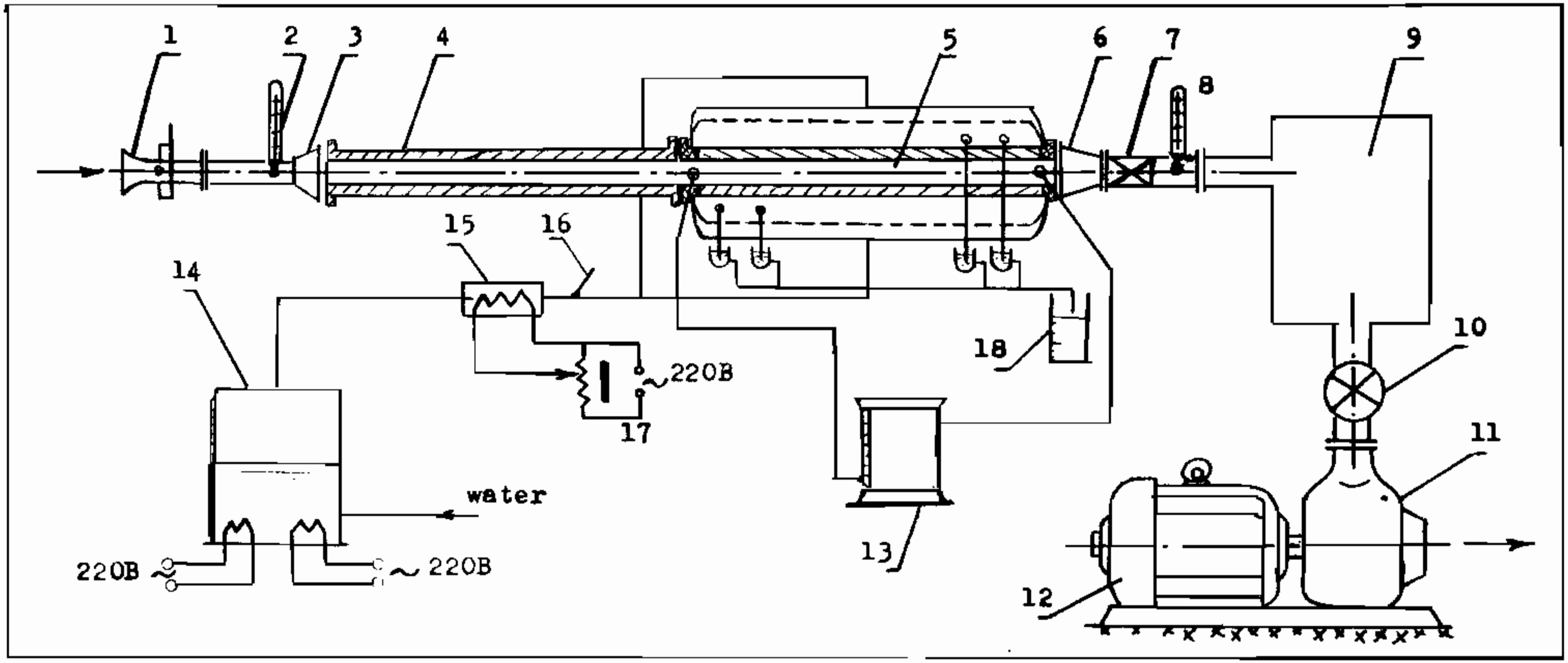

Fig.(1): Layout of experimental wind tunnel

1- Collector, 2,8 and 16- thermometers, 3 and 6-connections, 4-unheated straight channel, 5- test section, 7- mixting secting part, 9- damping chamber, 10- discharge control valve, 11- compressor, 12- electric motor, 13- differential manometer, 14- atomspheric pressure boiler, 15- superheater, 17- transformer, 18- collector for condensing steam.

The present paper is devoted to study on the basis of work [1] a compact plate exchanger with symmetric and asymmetric channels type "diffuser-confuser" for heating (cooling) the air.

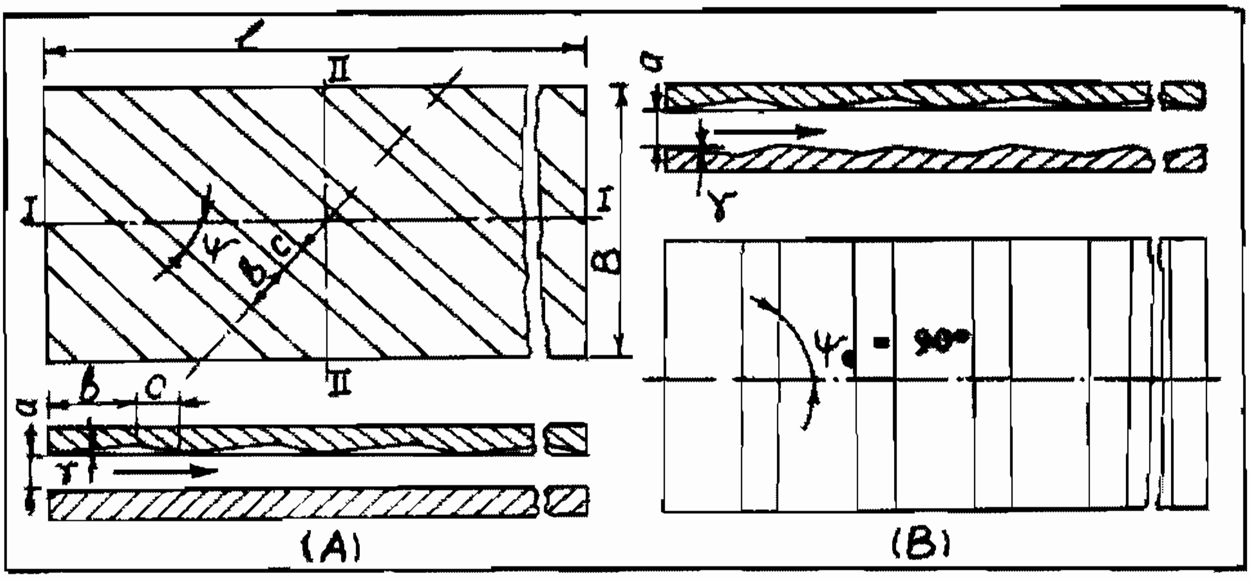

Fig.(2) Layout of channel's type "diffuser-confuser".
A- Asymmetric channel with flat and shaped surfaces.
B- Symmetric and asymmetric channels with two shaped surfaces.

Experimental Rig and Measurements:

The experimental installation presented an open wind tunnel Fig.(1). The air passed through a small unheated section of hydrodynamic stabilization 1000 mm. long (4), then entered a working section (5) behind which was placed a flow damper. The heating medium was superheated by 2-3°C steam at atmospheric pressure.

The working section was formed by two horizontal copper plates (1000 x 200 x 15 mm) with flat and shaped surfaces. The shaped surface was made by milling on the surface a successive row of slots ($\gamma = 12°$, $b = 8$ mm, C = 4 mm).

The slots are inclined to the direction of the flow by an angle ψ = 30, 45, 60 and 90° (Fig. 2-A). Plates with shaped and flat surfaces formed a slotted channel which in the flow direction presented a successive alternation of flat asymmetric diffusers with expersion angle and confusers with relation δ : C = 2:1. The values of δ , C, and γ depend on the angle ψ and shown in Table (1)

ψ	Sec. I-I			Sec. II-II		
	γ	δ,mm	C,mm	γ	δ, mm	C,mm
30°	6° 04′	16	8	10° 26′	9,24	4,62
45°	8° 33′	11,30	5,65	8° 33′	11,3	5,65
60°	10° 26′	9,24	4,62	6° 04′	16	8
90°	12° -	8	4	0		-

Geometrical characteristics of the shaped sunfaces were chosen in accordance with recommendations of work [1] with a scale 1:5. Overall dimensions of plates approximately correspond to the dimensions of the most frequently used type of lattice-flow plates [2,3]. We have studied channels with hight a = 9,5 and 4,9 mm which were selected from the conditions of the scale change and preserving the compactness obtained in real heat exchangers. The relative width of channel B/a varied from 21 to 41 and relative length ℓ/a from 111 to 205.

The temperature of air at the inlet and at the outlet from the working section was measured after mixing by a mercury thermometer with scale division of 0,1°C. The temperature of the surface of copper plates was considered to be equal to the saturation temperature of the steam.

The air consumption was measured with the help of a special aerodynamic collector with diameter of 50 mm which was placed at the inlet of the wind tunnel. The pressure difference in the collector and in the working section was measured by manometer with scale division of 0,01 kg/m^2. The heat flow was estimated according to air consumption and was controlled by the amount of collected condensate. The unbalance did not exceed 8 - 11%.

Experimental data analysis and discussion:

During the analysis of the experimental data the characteristic speed W was considered in the cross section of a height a which equalled to half-sum of the channel height at inlet to the diffuser sections and at outlet from them. As a characteristic length we considered the hydraulic equivalent diameter $d = 2a$. The physical properties of air were chosen according to its average temperature which was estimated as a difference between the surface temperature and average logarithmic temperature difference.

As the standard channel we consider the channel with constant cross section (a = 9 and 4,6 mm). The preliminary experiments proved that for standard channel the heat transfer coefficient is approximately 10% higher than that follows from the well known relation for air

$$Nu = 0{,}018\ Re^{0{,}80}\ , \qquad (1)$$

where $Re = \frac{wd}{\nu}$.

The resistance at adiabatic conditions follows from Blasius equation

$$\zeta = 0{,}3164\ Re^{-0{,}25} \qquad (2)$$

The resistance is approximately 30% higher than that obtained from relation (1) under heating case.

Figure (3) shows the heat transfer and resistance of channels with a = 9,5 mm and ψ = 30, 45, 60, and 90° (curves 2, 3, 4 and 5). In all cases the heat transfer and resistance are higher than that for the flat channel (curve 1). We noticed stratification of experimental points along the angle ψ . With increasing angle ψ the heat transfer and resistance increase. But intensification of heat transfer can be gained with moderate growth ofresistance.

Decreasing the height of the channel a from 9,5 to 4,9 mm as shown in Fig.(4), the resistance approximately increased by 20%. Heat transfer intensity in this case was the same.

The experimental results of heat transfer and resistance for channels with hight a = 9,5 mm can be described by the following generalized equations:

$$St\ Pr^{2/3} = 0{,}028(1 - 0{,}0228 \cos 2\psi)\ R^{-0{,}2} \qquad (3)$$

$$\zeta = 0{,}27(1 - 0{,}1 \cos 6\psi) R^{-0.2(1-0.005\psi)} \qquad (4)$$

which are correct within the range $5.10^3 < Re < 4.10^4$ and ψ in degrees.

There is a possibility to increase the effect of the pressure gradient on the flow by replacing the plate with flat surface by the plate with shaped surface which was made by milling a successive row of slots on the flat surface (γ = 12°, b = 8 mm, C = 4 mm), the generating line of which made an angle with the direction of the flow ψ_o=90°. The composition of plates with ψ= 30, 45, 60 and 90° respectively with plate of ψ_o = 90 at a height a = 9,5 mm allowed to obtain different channels with shaped surfaces Fig.(2-B).

The results of experiments are shown on Fig. 3 (curves 6, 7 ,8 and 9) . The heat ransfer and resistance of channels with two shaped channels are higher than that of channels with one shaped surface. The experimental results can be expressed by the following generalized equations:

$$St\ Pr^{2/3} = 0{,}039(1 - 0{,}148 \cos 2\psi)\ Re^{-0.2} \qquad (5)$$

$$\zeta = 0{,}279\ (1 - 0{,}2339 \cos 2\psi)\ Re^{-0.1} \qquad (6)$$

which are correct within the range $5.10^3 < Re < 4.10^4$.

Figure (5) shows equations 3 and 5 which express the effect of angle ψ on heat transfer for different velocities of air for channels type"diffuser-confuser" with one or two shaped surfaces. The maximum deviation of equation (3) from the data which are given in Fig.(3) not more than 5%. In case of channels with two shaped surfaces the maximum deviation about 8%.

Hydrodynamic resistance relations (4) and (6) are shown in Fig.(6). In case of channels with two shaped surfaces equation(6) shows a good agreement with the experimental results given in Fig.(4). In case of channels with one shaped and one flat surfaces the maximum deviation of equation(5) from the experimental results is about 5%.

The comparative evaluation of efficiency of channels type "diffuser-confuser" was conducted ac rding to the methods[4,5]. The efficiency is quantitatively characterized by coefficients K_Q, K_N, K_R, which represent corresponding relations of heat flows (with the same power spent for moving the coolant and the same areas), powers (with the same heat flows and the same areas); areas (with the same heat flows and the same powers) for the studied channels and the standard one.

The comparison shows that all the studied channels in investigated range of Re have a bigger efficiency than the flat channel. The most efficient channels were found to be the symmetric channel with height 9.5 mm and ψ_o = 90°, and asymmetric channel with two shaped surfaces with height 9.5 mm and ψ/ψ_o = 60/90°. For these channels the efficiency, for example, at Re = 10^4 (comparing with flat channel) is characterized by the following data: K_Q = 1.55 and 1.64, K_N = 0,22 and 0,14 and K_W = 0.55 and 0.51 for symmetric channel with ψ_o = 90° and height 9.5 mm and asymmetric channel with ψ/ψ_o = 60/90° and same height. These coefficients weakly depend on Reynold's number, Re. The channels with two shaped surfaces are more efficient than channels with one shaped plate. At Re = 10^4 the asymmetric channel with one shaped plate with ψ_o = 90° and hieght a = 9,5 mm has the following data: K_Q = 1.3, K_N = 0,40, K_W = 0.70. When the channel hieght decreases the efficiency of diffuser-confuser channels also decreases.

It might be expected that increase of height over 9.5 mm within a certain range would lead to the increase of efficiency of diffuser-confuser channels. But determination of optimum distance between the plates requires special investigation and is outside the scope of the present study which is limited by definite values of height which are chosen from the compactness conditions.

The obtained experimental results can be used for designing plate heat exchangers with the surface type "diffuser-confuser". The most perspective is the symmetric channel with γ = 12°, b = 8 mm, C = 4 mm, ψ_o = 90° and hight 9.5 mm, also asymmetric channel: ψ/ψ_o = 60/90° and γ = 12°, b = 8 mm, C = 4 mm and asymmetric channel with ψ_o = 90° and γ = 12°, b = 8 mm, C = 4 mm.

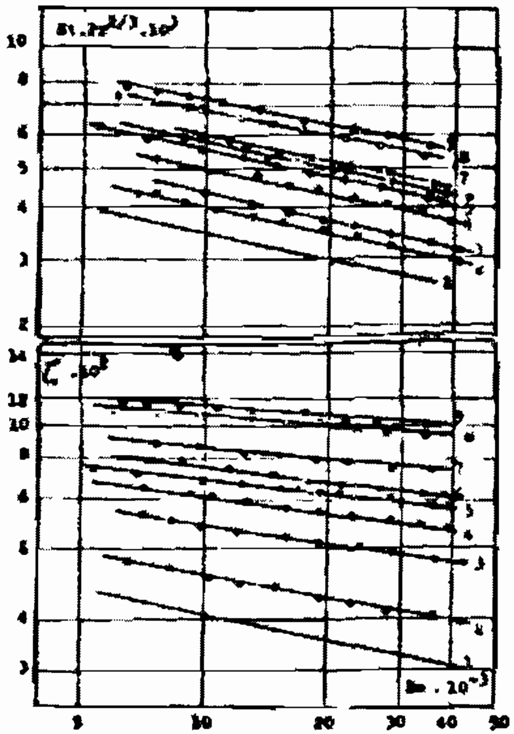

Fig.(3): Heat transfer and resistance channels of plate heat exchangers type diffuser-confuser.
1- flat channel
2,3,4&5- channels with one shaped surface (with height δ = 9,5 mm, ψ = 30,45,60, & 90°).
6,7,8&9-channels with two shaped surfaces (with height δ = 9,5 mm, ψ_1/ψ_2 = 30/90, 45/90, 60/90 90/90°).

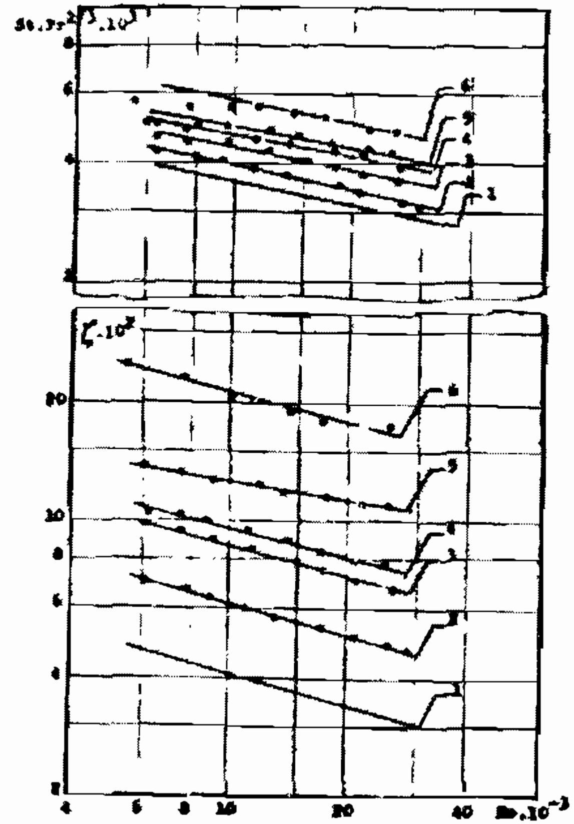

Fig.(4) Heat transfer and hydrodynamic resistance channels of plate heat exchangers type "diffuser-confuser"
1- flat channel
2,3,4&5- channels with one shaped surface (with hight δ = 4,5 mm and ψ = 30,45,60 and 90°
6- symmetrical shaped channel (with δ = 4,5 mm, ψ = 90°).

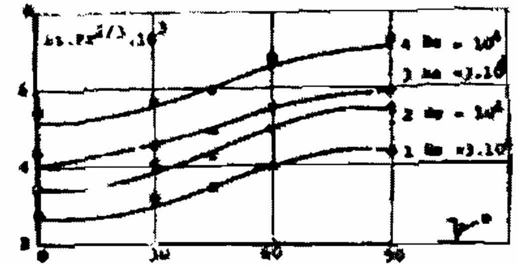

Fig.(5): Effect of angle ψ on heat transfer for channels type diffuser-confuser
1 and 2 channels with one shaped surface.
3 and 4 channels with two shaped surfaces.

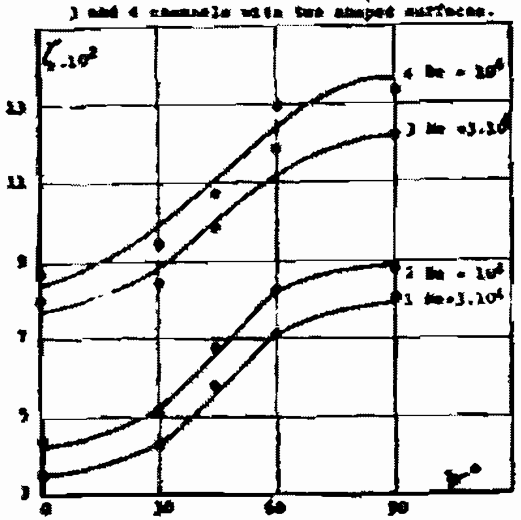

Fig.(6): Effect of angle ψ on heat transfer for channels type diffuser-confuser
1 and 2 channels with one shaped surface.
3 and 4 channels with two shaped surfaces.

To provide the rigidity of the construction and the necessary value of the height a the plates should be furnished by longitudinal ribs.

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