Experimental Investigation of Heat Transfer Process in a Perforated Plate Heat Exchanger

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Abstract— **The growing trend for compact heat exchangers has led to many innovative types of surfaces that enhance the rate of heat transfer. One of the types is heat exchangers with perforated plates, known also as Matrix Heat Exchangers, which consists of a series of perforated plates, mutually separated by a series of spacer gaskets. This paper aims to analyze the heat transfer process inside the package of perforated plates depending on their position within the package. Perforated plates observed in the experiment had a circular opening with a diameter to thickens ratio of 1. The openings were 2 mm in diameter in a square arrangement with a step of 3.5 mm between openings. The package of perforated plates was set within the specially constructed air channel at which entrance was a thrust fan with the ability to control the flow. The airflow rates, the temperatures of the hot and cold fluids were measured at the pre-defined locations in the package in order to determine the heat transfer coefficient.**

Keywords- Heat transfer, Heat exchanger, Perforated plate

I. INTRODUCTION

One of the most important properties of heat exchangers, besides their high effectiveness is their compactness, *i.e.* they must accommodate a large heat transfer surface in smaller volume. The need for such a type of heat exchanger units with a high level of compactness led to the invention of perforated plate heat exchangers, also referred to as matrix heat exchangers, by McMation *et al.* [1]. This heat exchangers consist of a package of perforated plates with many flow passages aligned in the direction of flow, allowing high heat transfer in a proper design unit. These exchangers can have very high (up to 6000 m^2/m^3) surface-to-volume ratio [2,3].

The convective heat transfer characteristics of any heat exchanger surface can be determined using the steady-state, transient test techniques and periodic tests [2]. For a steady-state method which was implemented in the research, the temperatures of hot and cold fluids entering and leaving the heat exchanger, as well as flow rates were measured when a steady state was achieved. On the basis of obtained data the heat flux, thus the overall heat transfer coefficient could be determined.

The goal of this paper is to research thermal processes on the airside of an air/water perforated plate heat exchanger based on the steady-state method. The research was conducted over a package of one, two, and three perforated plates with a porosity of 25,6%, and the air flow was ranged from 100 to 300 m^3/h.

A good literature review of perforated plate heat exchangers, types and constructions is given in papers [3,4].

In this research, the perforated plates had the following characteristics

- dimensions (length x with) - 740x145 mm,
- thickness – 2 mm,
- diameter of perforations – 2 mm.

The perforations were in a square arrangement resulting in an overall porosity of 25,6%. The plate was divided into two zones for the cold and hot fluids - the central zone through which hot fluid (water) flows and the peripheral section, through which the cold fluid (air) flows. These zones were separated by a gasket as presented in Fig. 1.

The plates were placed within the experimental chamber, at which entrance was a fan with the possibility to regulate the airflow in the range from 100 to 300 m^3/h. The distance between the plates in the package was set to 5 mm to provide access to the measuring probes (Fig. 2)

Fig. 1 A perforated plate with a gasket

The chamber was attached to the boiler with adjustable power which was the heat source in the experiment. The hot water enters the collector which was over the central zone of the and flows through the central part of the plate and along with the water flow the heat is transferred from the water to the plate.

Exchanged heat is than transferred by conduction through the plate towards the colder peripheral zone of the plate, and it reaches into the contact with the air stream. The heat is then transferred by convection from the plate to the cooler air stream.

For the needs of the experiment on the perforated plate, the series of thermocouples were set. In total 11 thermocouples were attached to the air side of plates – five of them on windward and leeward side of the plate (Fig. 3), while one was used as a control for the estimation of the error. Similarily, the temperatures of air at the inlet and outlet of the chamber were measured by thermocouples.

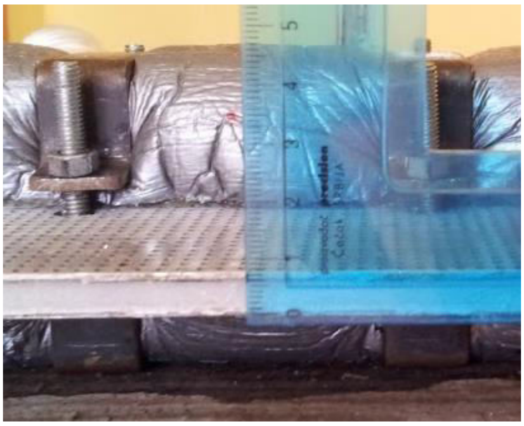

Fig. 2 A package of two perforated plates

Fig. 3 Thermocouples positions on a perforated plate

For the cold end of thermocouples a mixture of water and ice was used. During each experiment, the air flow rate, water flow rate, temperatures at the characteristic points were measured. According to the methodology measurements were conducted during the thermal equilibrium, *i.e.* when the change of the hot fluid temperature(water) was under the 0.1 K [5].

The scheme of the experimental setup is illustrated in the Fig. 4. During the experimental research the following hypothesis were introduced:

1. The first perforated plate in the package of two perforated plates operates same as the first plate in the package of two or more plates;
2. The second (ending) perforated plate in the package of two perforated plates operates same as the last plate in the package of two or more plates;
3. The second (middle) perforated plate in the package of three perforated plates operates as the inner perforated plates in the package of three or more perforated plates.

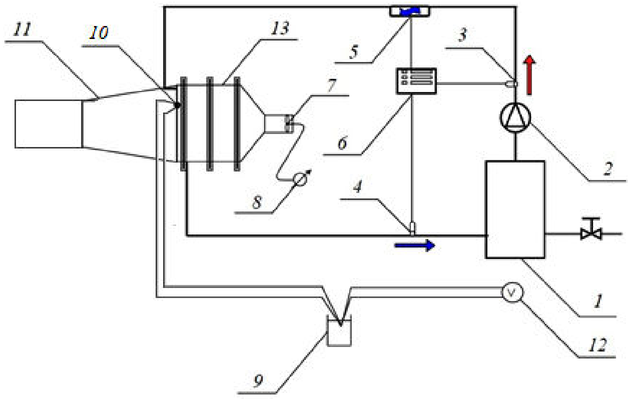

Fig. 4 Experimental setup: 1 – boiler, 2 – circulator pump, 3,4 – pt temperature probes, 5 – flow meter for water, 6 – acqusition unit, 7 – fan, 8 – fan speed control, 9 – thermocouples cold end, 10 – thermocouples, 11 – Air flow meter, 12 – voltmeter, 13 – experimental chamber

II. THE RESULTS AND DISCUSION

The experimental results of the perforated plate temperature fields on the windward and the leeward sides have been presented in the Fig. 5 to 6.

Further, the averaged air temperature in the package of perforated plates is presented in the Fig. 7 and 8.

The convective heat transfer rate $\dot{Q}_w$ from the water side is equal to

$$\dot{Q}_w = \rho_w \cdot \dot{V}_w \cdot c_w \cdot \Delta T_w. \quad (1)$$

while, similarly the heat transfer rate of air side is equal to

$$\dot{Q}_L = \rho_L \cdot \dot{V}_L \cdot c_p \cdot \Delta T_L. \quad (2)$$

The heat transfer rate for the perforated plate was determined as the average value of water and air side transfered heat as

$$\dot{Q}_{av} = \frac{\dot{Q}_L + \dot{Q}_w}{2} \quad (3)$$

and the measurement error is calculated as

$$\varepsilon = \frac{\sqrt{(\dot{Q}_{av} - \dot{Q}_L)^2 + (\dot{Q}_{av} - \dot{Q}_w)^2}}{\dot{Q}_{av}}. \quad (4)$$

For the analysis of results, only measurements with errors of 10% of lower were used. The heat transfer coefficient is defined as follows:

$$\alpha = \frac{\dot{Q}_{av}}{A \cdot \Delta T} \quad (5)$$

where ΔT is the difference between the average air temperature (between windward and leeward) and the average value of perforated plate temperature, while A is the overall heat exchanger surface on the airside.

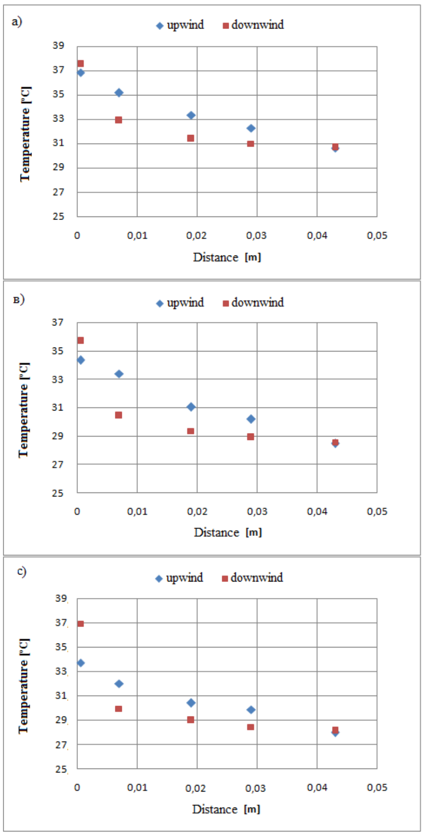

Fig. 5 Windward and leeward temperature profile over a single perforated plate for the following air flow rates a) 100 m^3/h, b) 200 m^3/h and c) 300 m^3/h

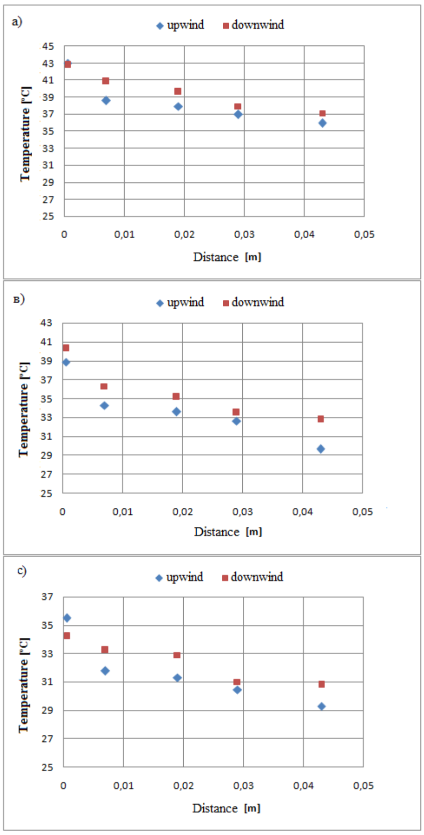

Fig. 6 Windward and leeward temperature profile over the second perforated plate in the package of three plates for the following airflow rates a) 100 m^3/h, b) 200 m^3/h and c) 300 m^3/h

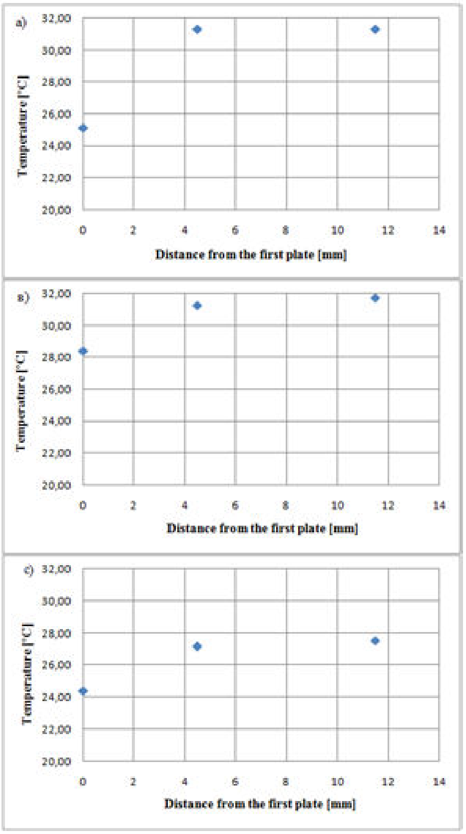

Fig. 7 The average air temperatures for the package of two plates for the following airflow rates a) 100 m^3/h, b) 200 m^3/h and c) 300 m^3/h

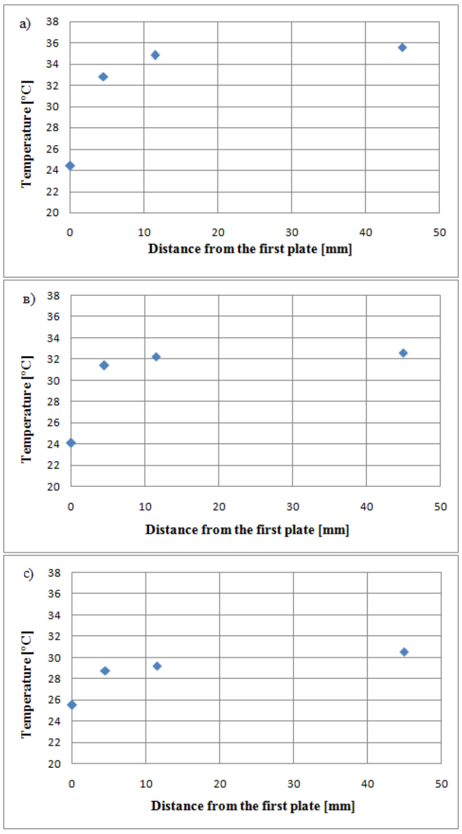

Fig. 8 The average temperatures of air for the package of three plates for the following airflow rates a) 100 m^3/h, b) 200 m^3/h and c) 300 m^3/h

In this manner, it is feasible to determine the heat transfer coefficients for every perforated plate depending on the airflow rate and its position in the package (Fig. 9). The overall heat transfer coefficient for the package of *n* perforated plates could be calculated as

$$\alpha = \frac{\sum_{i=1}^{n} \alpha_i A_i}{\sum_{i=1}^{n} A_i} \qquad (6)$$

thus, when the number of perforated plates increases, the heat transfer coefficient tends to the value of the inner (middle) plate. The experiments have shown that for the package of 7 or more plates the overall heat transfer does not change significantly.

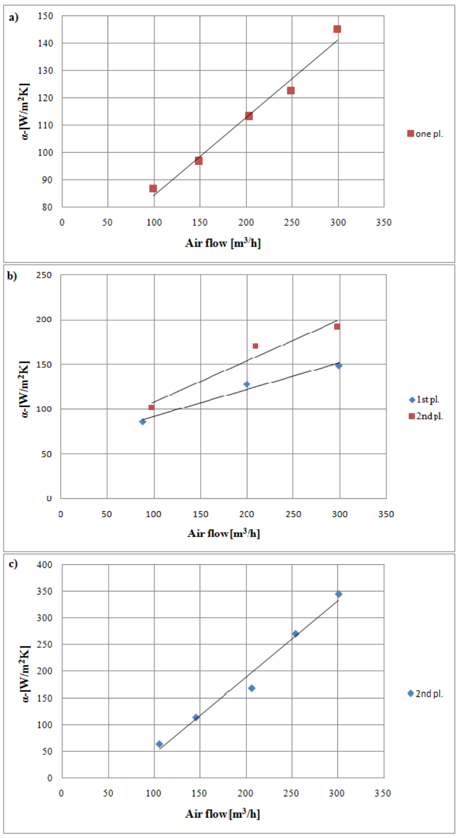

Fig. 9 The heat transfer coefficient in the function of air flow for the package of a) one perforated plate b) the first and the second perforated plate in the package of two perforated plates c) the second plate in the package of three perforated plates

III. Conclusions

In this paper an experimental instalation and the results of the experimental research of the perforated plate heat exchanger heat taransfer proces have been presented. A fan with the variable flow was connected to the experimental chamber in which was set a package of one, two, or three perforated plates, and the flow rates were varied from 100 up to 300 m^3/h. For the needs of the experiment, thermocouples were attached to the perforated plate, as well as at the inlet and the outlet of the chamber to determine air temperatures. On the basis of the measurements, heat transfer coefficients for the perforated plates depending on air flow and plate position in the package were derived.

References

[1] H. O. McMahon, R. J. Bowen, G. A. Bleye Jr, "A Perforated Plate Heat Exchanger," Trans ASME, vol. 72, pp. 623-632, 1950.

[2] K. Krishnakumar, G. Venkataratham, "Transient Testing of Perforated Plate Matrix Heat Exchangers," Cryogenics, vol. 43, no. 2, pp. 101-109, 2003.

[3] G. Venkataratham, S. Sarangi, "Matrix Heat Exchangers and their Application in Cryogenic System," Cryogenics, vol. 30, pp. 907-918, 1990.

[4] Ragab, M. M. Transport Phenomena in Fluid Dynamics: Matrix Heat Exchangers and their Applications in Energy Systems, Report No. Afrl-rx-ty-tr-2010-0053, Air Force Research Laboratory Materials and Manufacturing Directorate, Tyndall Air Force Base, Panama City, USA, 2009.

[5] M. Bukurov, S. Bikić, S. Ilin, M. Đurđević, G. Dragutinović, "Heat Exchangers with Perforated Plates," Journal on Processing and Energy in Agriculture, vol. 15, pp. 179-182, 2011.