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EXPERIMENTAL INVESTIGATION OF THERMAL AND FLUID FLOW PROCESSES IN A PERFORATED PLATE HEAT EXCHANGER

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Abstract: The goal of this paper is to investigate thermal and fluid flow processes in an air/water perforated plate heat exchanger. The experimental investigation was carried out over a single perforated plate which was installed in an experimental chamber and heated by hot water. A fan with the variable flow was connected to the experimental chamber, and the flow rates were varied from 100 up to 360 m^3/h. The thermocouples were attached to the surface of the perforated plate along upwind and downwind side, as well as at the inlet and outlet of the chamber. During each experiment, the readings of thermocouples were recorded alongside with air and water volume flow and temperatures of water at the inlet and outlet of the chamber. On the basis of the experimental results equations for heat transfer and pressure, drops were established. On the end, a comparison was done with other authors.
Keywords: perforated plate, pressure drop, heat transfer

INTRODUCTION

One of the most important properties of heat exchangers, apart of having a high effectiveness is the need to be very compact i.e. they must accommodate a large surface to volume ratio. This helps in controlling the heat exchanger exposure to the surroundings by reducing the exposed surface area. A small mass means also a smaller heat inertia. This requirement is particularly important for small refrigerators operating at liquid helium temperature. The need of attaining high effectiveness and a high level of compactness together in one unit led to the invention of matrix heat exchangers (MHE) by McMation et al. [1]. Matrix heat exchanger consists of a package of perforated plates with a multitude of flow passages aligned in the direction of flow allowing high heat transfer in a proper design unit. This exchanger can have 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 steady state, periodic test and transient test techniques [2]. For a steady-state method, the temperatures of hot and cold fluids entering and leaving the heat exchanger, as well as flow rates are measured, and when steady state is achieved it is possible to determine heat flux, thus overall heat transfer coefficient. In the transient technique method, after the steady state is achieved the temperature of the fluid entering the heat exchanger is suddenly changed. The heat transfer coefficient can be determined from temperature-time history data. The periodic test techniques represent a variation of the transient method in which the temperature of the fluid entering the heat exchanger is continuously varied.

In 1966, an extensive experimental study of convective heat transfer and flow friction based on transient technique was published for eight different perforated surfaces [4].

G. Venkatarathnam and Ragab M. Moheisen give good literature review of MHE, their constructions and Nusselt criteria [3,5]. The goal of this paper is to investigate thermal and fluid flow processes on the air side of an air/water perforated plate heat exchanger. The research was conducted over a single 25,6% porous perforated plate.

EXPERIMENTAL SETUP

Plate sized 740x145 mm, 2 mm thick, with square arranged, 2 mm in diameter, perforations was tested in the experiment. The plate was divided in two sections: central section through which water flows and peripheral section, through which the air flows. Sections were separated by a gasket (Figure 1). The plate was placed in the channel of the experimental chamber, at which entrance was a thrust fan.

As a heating fluid, water was used. The heat source was the boiler with adjustable power. Water enters the collector and flows through the central part of the plate, and along the water flow, heat is transferred from the water to the plate. Exchanged heat is further transferred by conduction through the plate towards the edge of the plate, where it comes into the contact with the air stream. The heat is then transferred by means of convection from the plate to the cooler air stream.

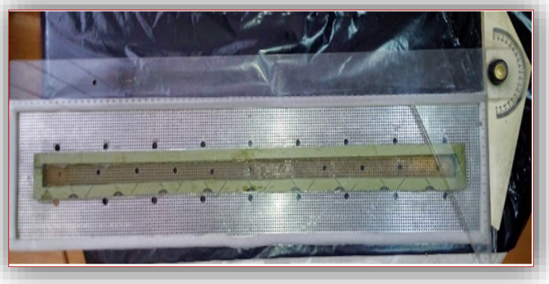

Figure 1. A perforated plate with a gasket

For the needs of the experiment on the perforated plate, the thermocouples were set. In total 11 thermocouples were placed, 5 on each side of the plate (Figure 3,4) and one as control thermocouple for error estimation. Heads of thermocouples were covered with thermal conductive paste in order to ensure thermal contact between thermocouples and plate. Thermocouples were calibrated before the experiment. Also, the temperatures of air at the inlet and outlet of the chamber were measured by thermocouples.

The cold end of thermocouples was obtained as a mixture of water and ice. During each experiment, the air flow, water flow, temperatures at the inlet and outlet of the chamber and the plate temperature were measured. Measurements were conducted when the thermal equilibrium was achieved.

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

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

Simillarily the heat transfer rate to air side is equal to

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

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

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

and the error of measurement is calculated as

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

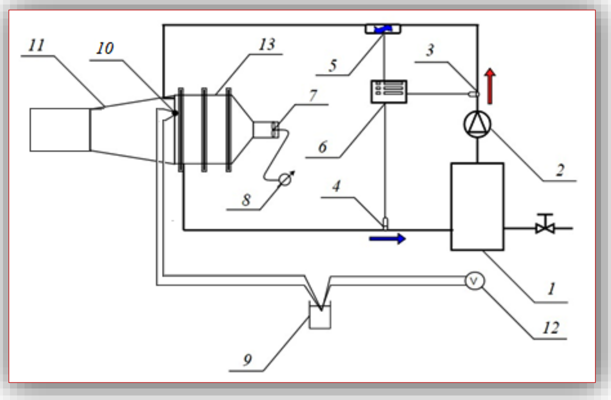

Figure 2. Experimental setup: 1 – boiler, 2 – pump, 3,4 – pt probes, 5 – ultra sonic water flow meter,6 – aqusition unit, 7 – fan unit, 8 – fan speed control, 9 – cold end of thermocouples, 10 – thermocouples,11 – Alonre balometer, 12 – milivoltmeter, 13 - chamber

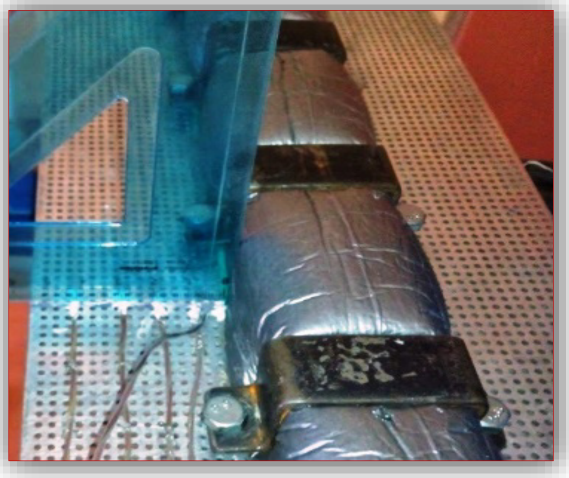

Figure 4. Thermocouples positions on the perforated plate

In the analysis, only measurements with error less than 10% were used. For the measurement of air flow pressure drop through the perforated plate, the measuring system TESTO 454 with 0638 1447 probe was used. For the pressure drop range of 80 hPa.

The accuracy of measuring the pressure drop is ±0,3Pa or ±0.5% of measured value. Measurement accuracy is therefore for a minimal and maximal pressure drop

$$\varepsilon_{pmin} = \frac{\delta p}{\Delta p} = \frac{0,3}{2,3} = 13,04\% \quad (5)$$

$$\varepsilon_{pmin} = \frac{\delta p}{\Delta p} = \frac{0,3}{13,43} = 2,23\% \quad (6)$$

RESULTS AND DISCUSION

The heat transfer coefficient α is defined as

$$\alpha = \frac{\dot{Q}_{av}}{A\Delta T}, \quad (7)$$

where ΔT is the difference between the average air temperature on the inlet and outlet of the chamber and the average value of perforated plate temperature and A is the overall heat exchager surface on the air side. The Nusselt number is defined as

$$Nu = \frac{\alpha p}{\lambda}, \quad (8)$$

where p is the pitch between perforations and λ is the thermal conductivity. On the Figure 5 are presented results of obtained heat transfer coefficient Nusselt number. If the Reynolds number is determined as

$$Re = \frac{\rho w_0 p}{\mu}, \quad (8)$$

where w_0 represents free stream velocity, and μ and ρ are fluid density and dynamic viscosity. If the Nusselt number dependence is written as

$$Nu = CRe^n Pr^{1/3}, \quad (9)$$

(where Prandtl number for air is Pr = 0,7), the Nusselt number is then

$$Nu = 1{,}188 Re^{0{,}524} Pr^{1/3}. \quad (10)$$

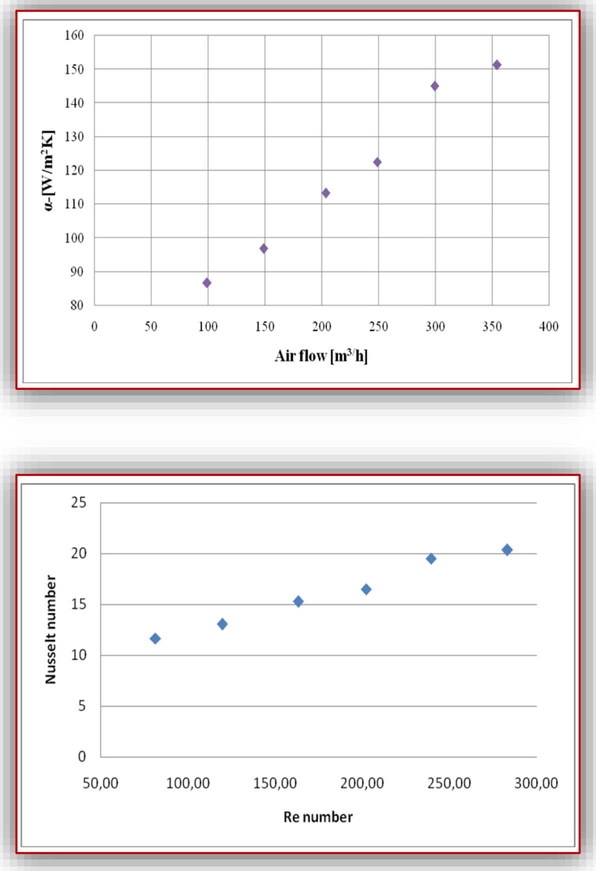

Figure 5. Heat transfer coefficient in the function of air flow and Nusselt number in the function of Reynolds number

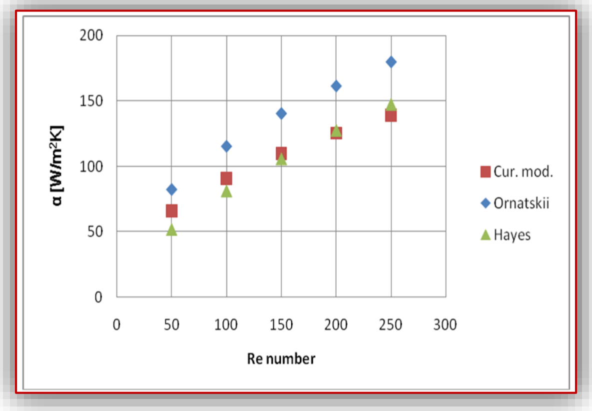

Figure 6. Comparison of results for heat transfer coefficient

The results for pressure drop through the plate with and without water collector are presented on the Figure 7. The general relation for the pressure drop was found in the form

$$\Delta p = \xi \rho \frac{w_0^2}{2} \quad (11)$$

where the ξ represents fluid friction and for observed plate it is equal to 43,7. The results are in good correspondence with results of Idel'chik presented on the Figure 8 [8].

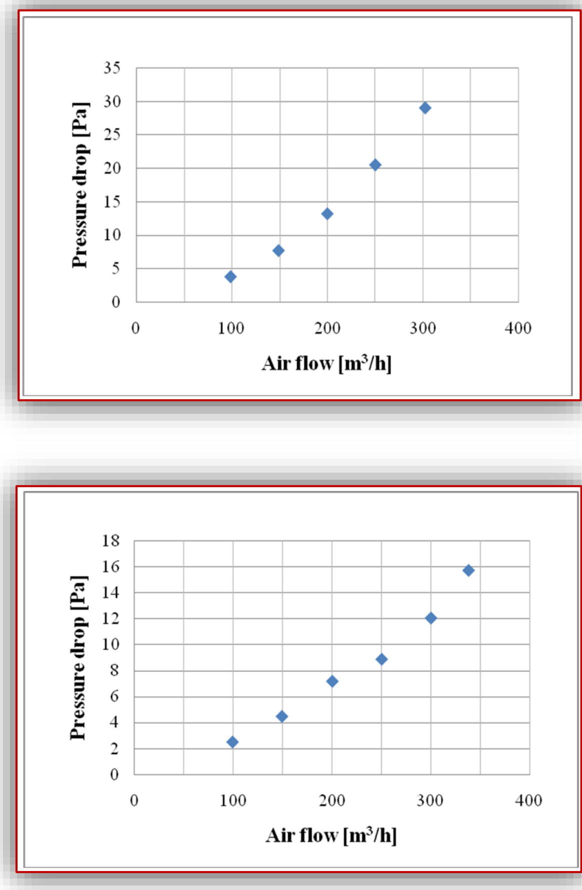

Figure 7. Pressure drop for the plate with water collector (left) and without it (right)

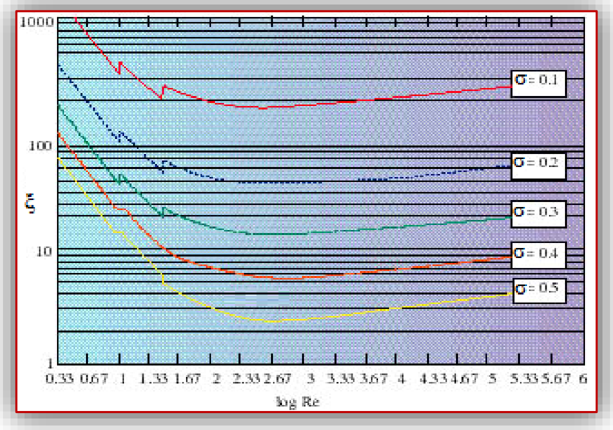

Figure 8. Pressure drop for a perforated plate by Idel'chik

CONCLUSIONS

In this paper an experimental setup and its results for the research of perforated plate heat exchanger have been presented. A perforated plate which was installed in an experimental chamber and heated by hot water. A fan with the variable flow was connected to the experimental chamber, and the flow rates were varied from 100 up to 360 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, a criteria equation for Nusselt number was derived. Also, the air pressure drop was measured during the experiments. The results for Nusselt number and air pressure drop shows favorable agreement between existing Nusselt correlations for heat transfer for the perforated plate.

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