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EXPERIMENTAL INVESTIGATION OF TUBE BUNDLE WETTING INFLUENCE ON HEAT TRANSFER INTENSITY IN EVAPORATIVE HEAT EXCHANGER

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Abstract. *Results of a heat transfer experimental investigation in laboratory experimental evaporative heat exchanger (HE in the further text) are presented. Tube bundle is with square arrangement, consisting of 13 pipes with 10 passes, ∅15/13 mm in size, which are connected with collectors. HE is placed into the air channel with dimensions 470×470 mm, through which air flows in counter current direction to the cooling water flow falling over the tube bundle.*
During the experiment the inlet and outlet temperatures of working fluids (tube fluid, falling water and air) were measured. From the air side relative humidity at inlet and outlet was measured.

Key words: *evaporative heat exchanger, heat and mass transfer, experimental results*

1. INTRODUCTION

Evaporative heat exchangers (EHE) are the recuperative tubular apparatuses in which the simultaneous heat and mass transfer is occurring.

Through the bundle tubes of apparatus flows the working fluid which is cooling or condensing, while the cooling water in the form of film flows down around the tubes and the ambient air flowing up exhausts a significant amount of heat from cooling water.

In such kind of apparatuses the cooling water could be recirculated (it is more efficient) or could be discharged from apparatus.

The air flow could be:

- **Natural** – atmospheric evaporative heat exchanger
- **Forced** – evaporative heat exchanger.

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2. PROCESSES OF CHANGE IN STATE OF HUMID AIR BEING IN CONTACT WITH WATER -PHYSICAL MODEL-

Heat exchange in evaporative exchangers consists of the following elementary processes:

- heat transfer between working fluid and inner surface of tube;
- conduction trough the tube wall;
- heat transfer from outer surface of tube to water film;
- simultaneous heat and mass transfer between water film and air stream.

It is also necessary to take into account the fouling resistances at inner and outer tube surfaces.

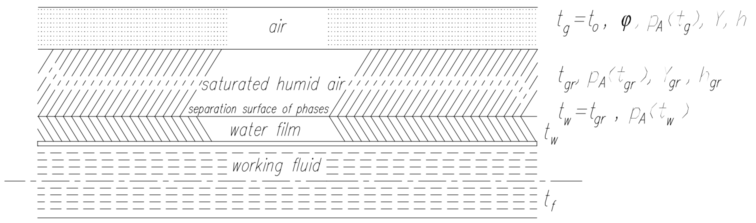

Fig. 1. Physical model of heat and mass transfer

Above the water surface of temperature t_{gr}, being in direct contact with air, one can notice thin layer of air, so called boundary layer which temperature is equal to water surface temperature, and has relative humidity of $\varphi = 1$. Water evaporates, if the partial pressure of water vapor in this layer p''_w is greater than partial pressure of water vapor p_w in bulk of air.

Positive difference of those pressures ($p''_w - p_w > 0$) is proportional to the driving force of evaporation process from the water surface. In the case of negative pressure difference ($p''_w - p_w < 0$) process has an opposite direction; i.e. vapor migrates to the region where its partial pressure is lower, from bulk of air to boundary layer, air in boundary layer being saturated is not able to accept it and as a result the condensation of vapor occurs at water surface.

Heat exchange between water at temperature t_{gr} and air at temperature t_g, is performing through two mechanisms:

1. convection; the specific heat flow rate in the case of convective heat transfer is defined as follows:

$$\dot{q}_k = \frac{\dot{Q}_k}{F} = \alpha(t_{gr} - t_g) \tag{1}$$

where:

$\dot{Q}_k$ – convective heat flux, W

F – heat exchange surface, m^2

α – heat transfer coefficient, W/m^2K

t_{gr} – water surface temperature, ^oC

t_g – bulk air temperature, ^oC

2. evaporation of water or **condensation** of vapor from air, during these processes the humid air absorbs the evaporation heat of water or loses the condensation heat of vapor that condensates at water surface; the realized heat flux $\dot{Q}_w$ is so called ″latent heat flux″.

The specific heat flux realized by evaporation of water, can be defined as:

$$\dot{q}_W = \frac{\dot{Q}_W}{F} = \dot{g}_W r = \beta(x'' - x)r \qquad (2)$$

$\dot{Q}_W$ – heat flux of evaporation or condensation, W

F – heat exchange surface, m^2

$\dot{g}_W$ – specific mass flow rate of vapor evaporated from water surface, kg/m^{2}s

r – evaporation latent heat of water at temperature t_{gr}, J/kg

β – mass transfer coefficient, kg/m^{2}s

x'' – absolute humidity of saturated air in boundary layer, kg/kg

x – absolute humidity in bulk flow of air, kg/kg

The direction of resulting heat flux is determined by the states of humid air and cooling water. The following seven situations are possible.

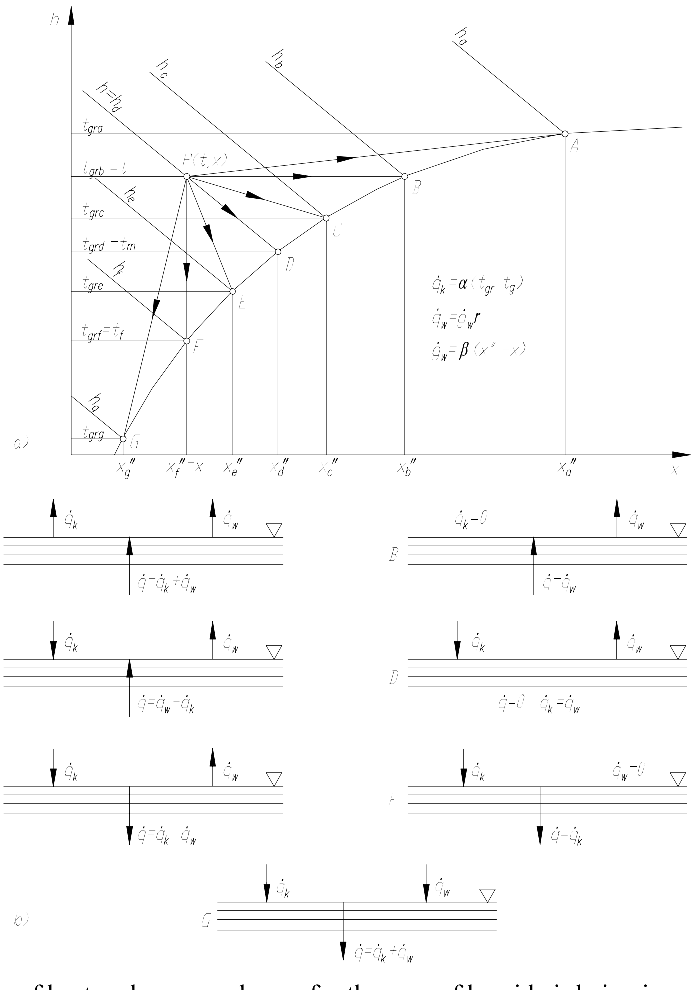

Fig. 2. Process of heat and mass exchange for the case of humid air being in contact with water surface. a) path of the process in h-x diagram, b) direction of heat fluxes

3. EXPERIMENTAL INSTALLATION DESCRIPTION

On the Fig. 3 experimental instalation is schematically presented. Evaporative HE consists of square arranged tube bundle, consisting of 13 pipes in 10 passes, sized ∅15/13 mm, which are connected with collectors. Horizontal distance between pipes is 36mm, and vertical pitch is 60mm. HE is settled in the air channel with dimensions 470×470 mm, through which air flows counter of the cooling water flow spreading over the tube bundle. Tubeside fluid is heated in the electrical boiler, and transported into the EHE with a circulation pump. Spray jet of the cooling water, transported from the local water supply, is spreading over the EHE tube bundle and collecting into the reservoir. Forced air flow countercurrent to the cooling water direction is provided with the centrifugal ventilator, while water drops removal with the air flow is prevented with the droplet eliminator.

Tubeside and cooling water flows are measured using the TA-STAD throtling valve and CBI acquisition system. Air flow is determined on the standard orifice pressure drop data base using the TESTO 454 measuring system.

Tubeside fluid and cooling water temperatures are measured on the all measuring points using the chromel – allumel thermocouples. Air parameters are determined with TESTO 454 measuring system using humidity/temperature measuring probe.

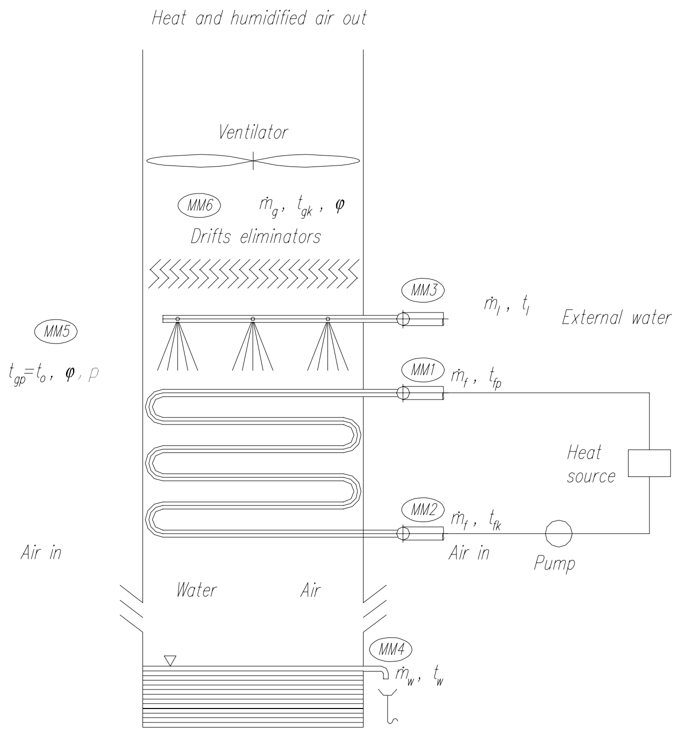

Fig. 3. Schematic layout of experimental installation

Fig 4. Photos of experimental installation

4. PRESENTATION OF EXPERIMENTAL RESULTS

In the experimental results shown in this paper working fluid mass flow was keeped constant at value ($\dot{m}_f = 0.8 kg/s$). By pressure drop regulation on the standard measuring diaphragm, humid air mass flow and inlet temperature were keeped on three different values:

$\dot{m}_g = (0.8;1.1;1.25) kg/s$, ($t_{f1} = 37;47;57^o C$). For each of these regimes amount of the cooling water brought into the process from the local water supply through system of nozzles was varied in the range: $\dot{m}_l = (0.06;0.09;0.12) kg/s$. Graphical presentation of heat exchanged in the EHE over the water spreading density dependence are shown on the Fig 5-7.

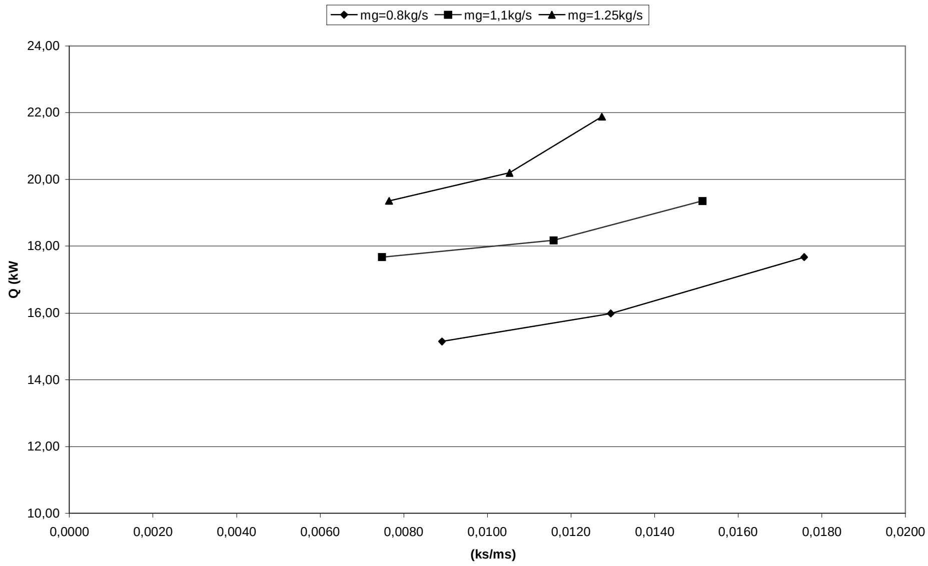

Fig 5. HE's heat power over water spreading density dependence, t_{f1}=37^{o}C

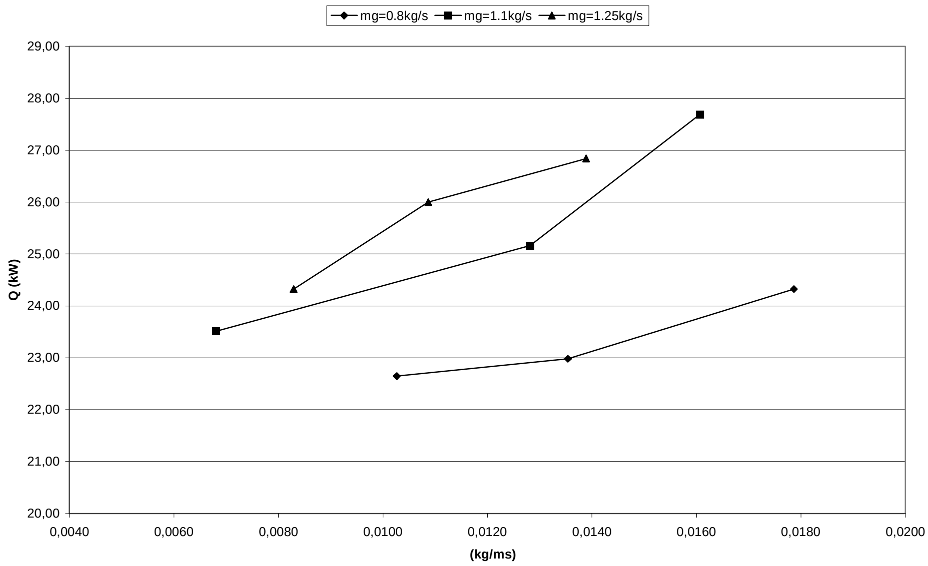

Fig 6. HE's heat power over water spreading density dependence, t_{f1}= 47^{o}C

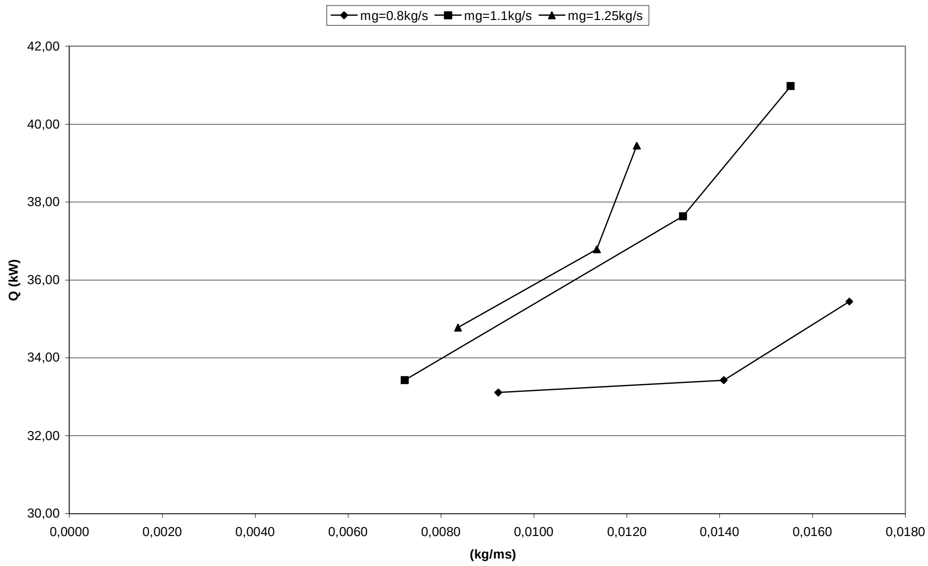

Fig 7. HE's heat power over water spreading density dependence, t_{f1}=57°C

5. Discussion of the results

At the evaporative HE cooling water is heated by taking the heat from the working fluid, and after reaching the evaporation temperature, a part of water evaporates. A part of the cooling water which is carried with the air flow in the form of fine droplets, but only to the droplet eliminator, which is getting this amount of water into the process.

With experimental results analysis presented in this paper one can notice that amount of tube bundle vetting has significant influence on the heat exchange intensity at EHE.

With increase of water spreading density over the tube bundle for the same air flow HE's heat power also increases.

Also, increase of the air flow intensify the heat and mass exchange process, which can be noticed in the HE's heat power increase.

From the fig 5-7 one can notice that, although the amount of cooling water brought into the process through nozzles was kept constant, spreading density (HE's hydraulical load) is different for different air flows, because with increase of air flow bigger part of water goes to the air channel walls – stays iddle.

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ANALIZA UTICAJA KVAŠENJA CEVNOG SNOPA NA INTENZITET RAZMENE TOPLOTE KOD OROŠAVAJUĆIH RAZMENJIVAČA TOPLOTE

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U ovom radu prikazani su rezultati eksperimentalnog istraživanja prenosa toplote u laboratorijskom eksperimentalnom evaporativnom orošavajućem razmenjivaču toplote (u daljem tekstu RT). Cevni snop RT je u kvadratnom rasporedu, a sastoji se od 13 cevnih zmija sa po 10 redova cevi, dimenzija ∅15/13mm, koje su međusobno spojene kolektorima. RT smešten je u vazdušni kanal dimenzija 470x470mm kroz koji prinudno struji vazduh u suprotnom smeru od smera vode koja se razliva preko cevnog snopa.

Istraživanjima prikazanim u radu ispitivan je uticaj kvašenja cevnog snopa na intenzitet razmene toplote. U tom smislu menjana je količina vode koja se razliva preko cevnog snopa RT dok su ostali parametri održavani na stalnim vrednostima.

U toku svakog eksperimenta merene su početne i krajnje temperature radnog fluida, vode koja se razliva i vazduha koji struji, kao i protoci svih procesnih fluida.