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DETERMINATION OF HEAT TRANSFER COEFFICIENT IN THE PHASE-CHANGE HEAT STORAGE DEVICE

Abstract

This article describes information about the research of the heat transfer coefficient from air to water on the basis of comparison of theoretical calculations with the use of mathematical modeling and experimental studies of small copies of the heat accumulator to operate in the charging mode and discharging process without phase change.

Keywords: heat transfer coefficient, heat accumulator

1. Introduction

Efficient use of heat energy during operation of the heat supply system is impossible without solving the problem of accumulation of heat. The most promising is the use of the phase-change heat storage device, because it provides a high density of stored energy, small changes in temperature and stable temperature at the outlet of the accumulator [1]. Important thermal characteristics of the heat exchanger is the heat transfer coefficient from the working fluid (air) to a heat exchange surface with heat storage material (water). Moreover, one should distinguish between local and overall heat transfer coefficient. The first relates to locally minor part of the surface, the second to the entire heat exchange surface [2].

2. Review of recent sources of research and publications

Similar heat exchange processes which taking place in the heat storage device occurs when fluid flow around the horizontal pipe and when flow of liquid or gas ablution the horizontal plate, calculated according to formulas given in the sources [3, 4] the value of the heat transfer coefficient is in the range of 2.3 W/m°C to 13 W/m°C. In a complete performance description heat transfer processes in this type heat storage device is reduced to a multidimensional nonlinear nonstationary Stefan problem [5, 6], constrained convection in the liquid phase. The nonlinearity of the mathematical model is to change the heat transfer coefficient depending on the mode of movement that takes place in the heat exchanger, changes temperature difference in time between the heat exchange mediums, the direction of circulation of the supply air, that is why its definition with the use of experimental studies is one of the main tasks.

3. Formulation of the problem

The aim of this work is the determination of the heat transfer coefficient from air to water on the basis of comparison of theoretical calculations with the use of mathematical modeling and experimental studies of small copies of the heat accumulator to operate in the charging mode and discharging process without phase change.

4. The basic material and results

For mathematical simulation of transition heat transfer processes inside the heat storage device as the basis used known linear mathematical model [7]. To determine the change of temperature of air and water along the length of the heat accumulator will divide it into sections and make up a system of equations of heat balance for each:

$$\begin{cases} m_w \cdot c_w \cdot \dfrac{dt_w}{dz} + m_{ice} \cdot c_{ice} \cdot \dfrac{dt_{ice}}{dz} + r \cdot \dfrac{dm_{ice}}{dz} = \\ = \alpha_i \cdot F_i \cdot \left(\dfrac{t_{air}^{in} + t_{air}^{out}}{2} - t_i \right) \\ c_{air} \cdot G_{air} \cdot \dfrac{dt_{air}}{dz} = \\ = \alpha_i \cdot F_i \cdot \left(\dfrac{t_{air}^{in} + t_{air}^{out}}{2} - t_i \right) \end{cases} \quad (1)$$

where: m_w – the mass of water in the i-th section of the accumulator, kg; c_w – heat capacity of *air*, kJ/kg·K; m_{ice} – the mass of *ice* in the *i-th* section of the accumulator, kg; c_{ice} – heat capacity of *ice*, kJ/kg·K, $\frac{dt_{ice}}{dz}$ – changes in *ice* temperature over a period of time *dz*; c_{air} – heat capacity of *ice*, kJ/kg·K; $\frac{dt_w}{dz}$ – changes in water temperature over a period of time *dz*, K; α_i – the heat transfer coefficient in the *i-m* section of the battery, W/m²·K; G_{air} – mass flow of supply *air*, kg/s; $\overline{t_{air}} = \frac{t_{air}^{in} + t_{air}^{out}}{2}$ – average temperature of *air* in the accumulator, K; F_i – heat exchange surface area in the *i-th* section of the accumulator, which is in contact with the *air*, m²; t_i – the temperature of the heat exchange surface in the *i-th* section of a heat accumulator, K; *r* – latent heat of melting, kJ/kg; $\frac{dm_{ice}}{dz}$ – change in *ice* mass for the period of time *dz*, kg; $\frac{dt_{air}}{dz}$ – changes in water temperature over a period of time *dz*, K.

The first equation in system (1) is the thermal balance of the water, and the second is the termal balance of the air. To calculate this problem using digital methods, it is necessary to divide the storage tank into n layers with equal mass of heat storage material, which are arranged along the flow of air. For modeling the processes of charging and discharging, and to apply in practice mathematical models are collected pilot plant and conducted a series of experimental measurements.

To measure the temperature in the heat accumulator are used electronic temperature sensors with the output values of the temperature on the digital display (the measurement accuracy 0.1 K), for measuring air velocity – microanemometer. From the equations of thermal balance of the heat storage device define the formulas which allows to find the average temperature of the air and changes in water temperature for the *i-th* layer using the method of finite differences [8]:

$$\overline{t_{air}} = \frac{2 \cdot c_{air} \cdot G_{air} \cdot t_{air}^{in} / z + \alpha_i \cdot F_i \cdot t_i}{\alpha_i \cdot F_i + 2 \cdot c_{air} \cdot G_{air} / z} \quad (2)$$

$$\Delta t_w = \frac{\alpha_i \cdot F_i \cdot (t_{air} - t_i)}{m_w \cdot c_w / z} \quad (3)$$

Basic characteristics of accumulator:

1) overall dimensions:
   a × b × h = 600 × 600 × 1150 mm;
2) mass of heat storage material (water) – 98 kg;
3) cross-sectional area – 0.04 m²;
4) size of heat transfer surface – 2.26 m²;
5) equivalent diameter for the passage of air – 16,4 mm;
6) diameter of the duct for inflow of air – 100 mm.

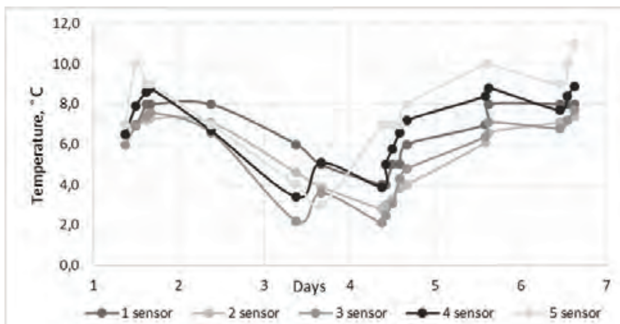

Fig. 1. Graph of the temperature distribution in heat storage device with a daily changing temperature of outdoor supply air (experimental data)

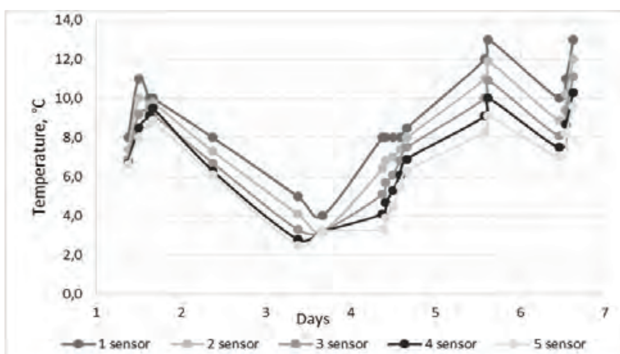

Fig. 2. Graph of the temperature distribution in heat storage device with a daily changing temperature of outdoor supply air (mathematical modeling)

The experiment was conducted in February duration of six days. The temperature of the air which flow to the accumulator was equal and changed as the outdoor air temperature. From the graphs it is seen that in the heat storage device alternate the processes of charge and discharge, the range of temperature fluctuations is 4÷5°C.

The temperature distribution in the accumulator calculated for different values of heat transfer coefficients and determined the average deviation [8, 9] of theoretical temperature values from experimental. The heat transfer coefficient can be determined from the conditions of equality of this deviation to zero.

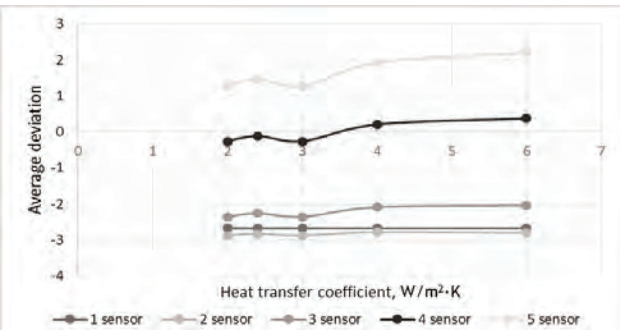

Fig. 3. Determination of the heat transfer coefficient with daily temperature change of supply air

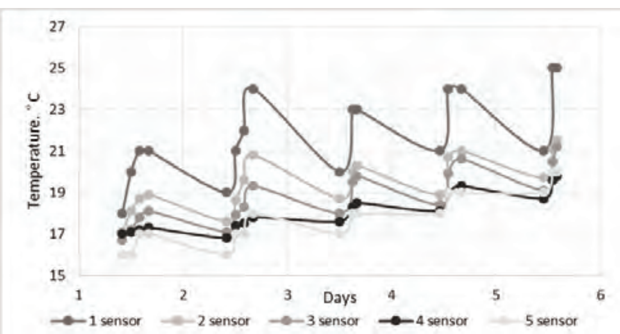

Fig. 4. Graph of the temperature distribution in heat storage device with using additional heat source (experimental data)

Also conducted a series of experimental studies for the mode of operation using artificial sources of heat (inside the supply air duct was installed electric incandescent lamp) to get more stable temperature of the air which entering to the heat accumulator. For the five day period of studies temperature in the heat storage device has changed to 7÷7.5°C.

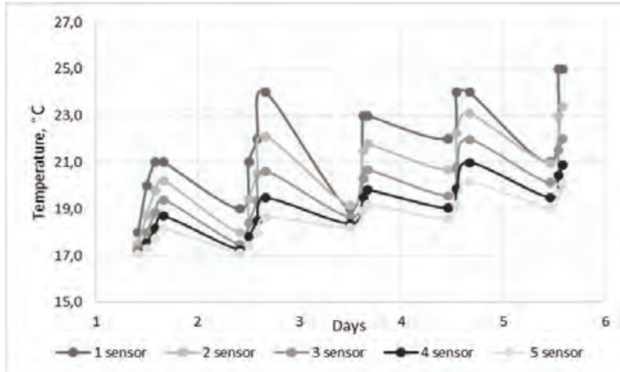

Fig. 5. Graph of the temperature distribution in heat storage device with using additional heat source (mathematical modeling)

Heat transfer coefficient is affected by the speed and direction of air movement, temperature difference and hydrodynamic conditions of the heat exchange process.

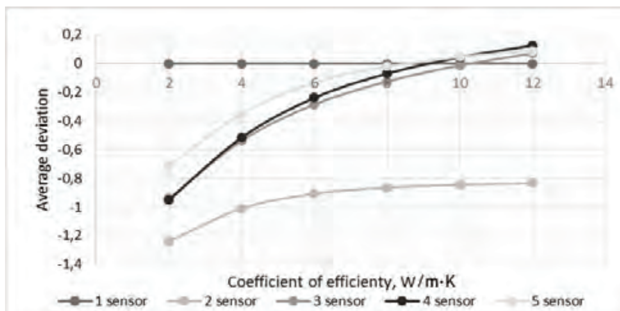

Fig. 6. Determination of the heat transfer coefficient with using additional heat source

Most precisely it is possible to determine the heat transfer coefficient by analyzing the average deviation of air temperatures in the locations of the sensors 3, 4 and 5.

5. Conclusions

1. Compiled non-stationary mathematical model for determining the temperature distribution in the cross sections of the phase-change heat storage device.
2. Made experimental researches of heat exchange processes in the heat storage device and theoretical calculations using mathematical models.
3. On the basis of the obtained theoretical and experimental temperature distributions calculated their average deviation and the coefficient of heat transfer: for the mode of work with the daily change of temperature it is 3.5 W/m°C, for the mode of charging with the use of artificial sources of energy it is 9.5-10 W/m°C.

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