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THE THERMOPHYSICAL PROCESSES IN GROUND-AIR HEAT EXCHANGERS OF THE GEOTHERMAL VENTILATION SYSTEM

Heat transfer processes that occur when working the ground-air heat exchanger of geothermal ventilation system are considered in this article. The heat balance in the elementary volume of ground-air heat exchanger is proposed on the basis of thermophysical processes. The main factors that affect the process of heat transfer between the outside air and soil was been determined. Initial conditions, which can be used in mathematical and physical modelling of horizontal ground-air heat exchangers for geothermal ventilation systems were selected article presents the experimental study for determining the intensity of radiant energy in the zone irradiated by infrared heaters with their parallel arrangement in relation to the distance between them.

Keywords: **ground-air heat exchanger, geothermal ventilation, heat transfer, heat balance**

INTRODUCTION

Low-grade heat soil is characterized by inexhaustibility and independence from environmental conditions, time of day and year. The main equipment, which allows you to get renewable energy of soil, is ground-air heat exchangers. The ground-air heat exchangers are vertical and horizontal depending on the method of laying in the soil. Vertical heat exchangers are the most common. They do not require large additional areas for their laying. The amount of heat from the ground with increasing depth remains almost unchanged. However, to provide the necessary coolant temperature, the length vertical heat exchanger should be 50÷100 m. This complicates the process of installation. Laying of horizontal ground-air heat exchanger requires no drilling of wells and limitation the length of the heat exchanger.

Describe the thermal processes occurring in horizontal ground-air heat exchanger of the geothermal ventilation system in the cold season.

MAIN MATERIAL

The operating principle of the geothermal ventilation in the cold season is the following. Air, which has a temperature t_{ext}, applied to the input of the ground heat exchanger. Passing through the heat exchanger, the outside air is heated to a temperature t_{inf_1}, taking the heat of the soil through the wall of the heat exchanger. When transferring heat from the ground into the outdoor air through the wall of the heat exchanger occurring the following thermal processes: the heat transfer from the ground to the heat exchanger, heat conduction through the wall of the air pipe and convective heat exchange between the inner wall of the heat exchanger and air in the heat exchanger. Consider the array of ground with horizontal ground-air heat exchanger, which is laid at a depth h. (Fig. 1). The flow of air moving at a constant speed υ in round tube with length l and internal diameter d_{int}.

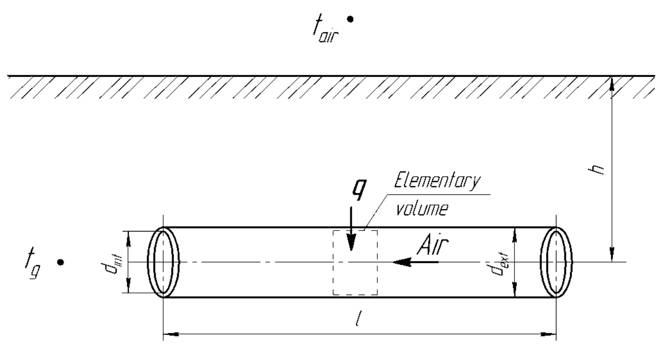

Fig. 1. Scheme of heat flows for elementary volume of the ground-air heat exchanger

The heat balance in the elementary volume of ground-air heat exchanger is viewed by the stationary conditions in this article: the air temperature entering the heat exchanger t_{ext} and soil temperature t_g are accepted constant. Assuming that the temperature change of the radius can be neglected, the heat transfer is carried out only in one direction, namely from the soil to the air in the ground-air heat exchanger. The amount of heat supplied to the air in the heat exchanger Q_{air} should be equal to the heat that comes from the soil Q_g:

$$Q_g = Q_{air} \tag{1}$$

The heat that comes from the soil is defined as:

$$Q_g = q \cdot F = q \cdot \pi d_{ext} l \tag{2}$$

where:
q - specific heat flow through the heat exchanger surface [W/m^2],
F - surface area heat exchanger [m^2].

The heat supplied to the air in the heat exchanger is:

$$Q_{air} = 0.278 \cdot L_{air} \cdot c_{air} \cdot \rho_{air} \cdot \left(t_{inf_1} - t_{air}\right) \tag{3}$$

where:
L_{air} - the amount of air that passes through the ground-air heat exchanger [m^3/h],
c_{air} - the specific isobar heat capacity of the outside air [kJ/(kg·K)],
ρ_{air} - the density of the outside air temperature [kg/m^3],
t_{air} - outside temperature [°C],
t_{inf_1} - supply air temperature at the outlet of the ground-air heat exchanger [°C].

Thus, the heat balance in the elementary volume of ground-air heat exchanger that works in geothermal ventilation system can be written as:

$$q \cdot \pi d_{ext} l = 0.278 \cdot L_{air} \cdot c_{air} \cdot \rho_{air} \cdot \left(t_{inf_1} - t_{air}\right) \tag{4}$$

Specific heat flow through a cylindrical surface [W/m^2] can be determined from the equation [1]:

$$q = k\left(t_g - t_{air}\right) \tag{5}$$

where:
t_g - soil temperature on the axis of the laying heat exchanger [°C],
t_{air} - outside temperature [°C],
k - linear (per unit length of the pipeline) heat transfer coefficient [W/(m·K)] is determined from the dependence

$$k = \frac{1}{R_{int} + R_w + R_g} \tag{6}$$

where:
R_{int} - thermal resistance of heat transfer from the inner wall of the heat exchanger to the air transported therein [(m·K)/W],
R_w - thermal resistance of the wall pipe of ground-air heat exchanger [(m·K)/W],
R_g - thermal resistance of heat transfer from the soil to the outer wall of the heat exchanger [(m·K)/W].

Thermal resistance of heat transfer from the inner wall of the heat exchanger to the air transported in it, is determined from the dependence [(m·K)/W]:

$$R_{int} = \frac{1}{\pi \cdot d_{int} \cdot \alpha_{int}} \tag{7}$$

where:
α_{int} - heat transfer coefficient of the inner surface of the heat exchanger [W/(m^2·K)],
d_{int} - the internal diameter of the pipe heat exchanger [m].

Thermal resistance of the pipe wall of ground-air heat exchanger [(m·K)/W] is:

$$R_w = \frac{1}{2\pi \cdot \lambda_w} \ln \frac{d_{ext}}{d_{int}} \tag{8}$$

where:
d_{ext} - the external diameter of the pipe of ground-air heat exchanger [m],
λ_w - coefficient thermal conductivity of material wall heat exchanger [W/(m·K)].

Thermal resistance of heat transfer from the soil to the outer wall of the heat exchanger [(m·K)/W] can be determined by the formula Forhheymer [2] similar as for channel-free laid:

$$R_g = \frac{1}{2\pi \cdot \lambda_g} \ln\left[\frac{2h}{d_{ext}} + \sqrt{\frac{4h^2}{d_{ext}^2} - 1}\right] \tag{9}$$

where:
λ_g - coefficient thermal conductivity of the soil [W/(m·K)],
h - depth laying the pipeline axis [m].

The heat transfer coefficient of the inner surface of the pipe ground-air heat exchanger can be defined as:

$$\alpha_{int} = \frac{Nu \cdot \lambda_{air}}{d_{int}} \tag{10}$$

where:
λ_{air} - coefficient thermal conductivity of air that is transported in the heat exchanger [W/(m·K)],
Nu - Nusselt number.

Nusselt number is determined depending on the flow regime. For air movement within the ground-air heat exchanger and taking into account the physical properties of air Nusselt number is determined by the formula [3]

$$\overline{Nu} = 0.021 \cdot Re^{0.8} \cdot Pr^{0.43} \cdot \varepsilon_t \cdot \overline{\varepsilon_l} \tag{11}$$

where:
$\overline{\varepsilon_l}$ - coefficient that takes into account the effect of hydrodynamic stabilization of flow in the initial area of heat transfer depends on the Reynolds number and value l/d [3],
ε_t - amendment that takes into account the changing physical properties of the medium depending on temperature, determined by the formula:

$$\varepsilon_t = \left(\frac{\overline{T}_{air}}{\overline{T}_w}\right)^m \tag{12}$$

where:
$\overline{T}_{air}$, $\overline{T}_{w}$ - the average temperature respectively of the air inside the heat exchanger and the tube wall [K]; m = 0.4, if $\overline{T}_{air} < \overline{T}_{w}$, m = 0, if $\overline{T}_{air} > \overline{T}_{w}$.

As seen from the formula, process of heat transfer in the ground-air heat exchanger depends on many factors.

Ukraine has no reference or normative documents, which contained calculation of parameters of geothermal ventilation. This complicates the process of selecting the initial conditions for calculating of horizontal ground-air heat exchanger.

For the exploitation conditions of ground-air heat exchanger in Lviv the input heat depending on the length of the heat exchanger is shown in Figure 2. Depth of laying the heat exchanger is 3.5 m, the speed of air inside the tube is 4 m/s [4] external diameter polypropylene tube heat exchanger - 200 mm.

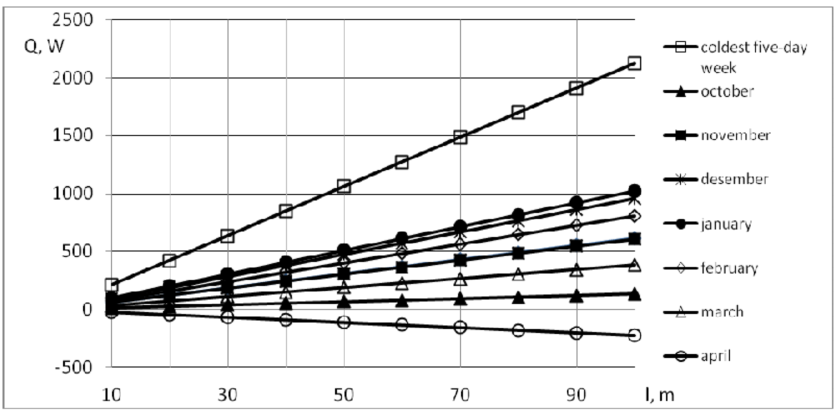

Fig. 2. The heat input from the soil to the air through the wall of horizontal ground-air heat exchanger

As shown in Figure 2, the heat input from soil to air increases with increasing length of the heat exchanger and by lowering the ambient temperature. In April the ground-air heat exchanger can't operate for heating outside air of the system geothermal ventilation, because soil temperature this month is less than the average air temperature in April. To the resulting amount of heat coming from the ground to the air, in Figure 3, the temperature of the soil after the heat exchanger t_{inf_1} is determined from the dependence (3).

The amount of air that passes through the soil heat exchanger [m^3/h] can be determined by known cross-sectional area of the heat exchanger and air velocity in it:

$$L_{air} = 3600 \cdot \frac{\pi \cdot d_{int}^2}{4} \cdot \upsilon \qquad (13)$$

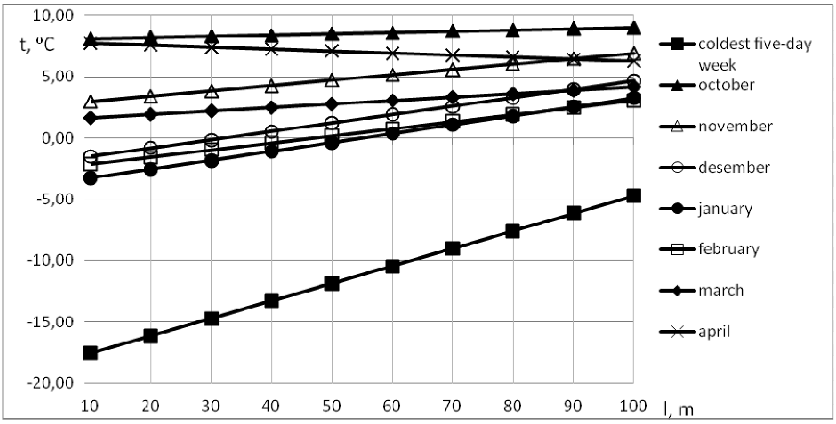

Fig. 3. The dependence of temperature on output of the horizontal ground-air heat exchanger from length of the heat exchanger

Figure 3 shows the temperature dependence of the output from ground-air heat exchanger depending on the length of the heat exchanger for different values of the outside temperature.

As shown in Figure 3, the temperature at the outlet of the heat exchanger while increasing its length and ambient temperature is increases, except April.

CONCLUSIONS

The heat transfer processes that occur when working the ground-air heat exchanger of geothermal system ventilation, are described. The main factors that affect the process of heat transfer between soil and outside air are soil temperature, soil thermal conductivity, temperature and speed of the outside air, the diameter and length of the heat exchanger, the thermal conductivity of the material of the heat exchanger. Based on thermal processes the heat balance in the elementary volume of ground-air heat exchanger are described. The initial conditions which can be used in mathematical and physical modelling of horizontal ground heat exchangers for geothermal ventilation systems are selected.

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PROCESY CIEPLNO-FIZYCZNE W GRUNTOWYM WYMIENNIKU CIEPŁA GEOTERMALNEGO SYSTEMU WENTYLACJI

W artykule rozpatrzono procesy wymiany ciepła zachodzące podczas pracy w gruntowym wymienniku ciepła geotermalnego systemu wentylacji. Na podstawie procesów cieplno-fizycznych zaproponowano model bilansu cieplnego w elementarnej objętości gruntowego wymiennika ciepła. Określono główne czynniki, które wpływają na proces wymiany ciepła między gruntem i powietrzem zewnętrznym. Wyznaczono warunki początkowe, które mogą być wykorzystane przy matematycznym i fizycznym modelowaniu poziomych gruntowych wymienników ciepła w systemach wentylacji geotermalnej.

Słowa kluczowe: **wymiennik ciepła ziemia-powietrze, wentylacja geotermalna, bilans cieplny, wymiana ciepła**