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Design calculation of heat exchangers

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Abstract: In order to take the right amount of energy from an environment with low-potential heat, it is necessary to use very large volumes of this very environment. In order to organize a relatively efficient heat exchange, it will be necessary to move sufficiently large amounts of secondary coolant over very long distances.

Key words: borehole, soil, heat exchange collectors, thermal balance.

The soil is an inexhaustible source of thermal energy. Geothermal heat (ground heat) can be taken away only with the help of heat pumps. Heat pumps that are used to extract ground heat are sometimes called ground pumps. This concept is quite conditional, because the same heat pump can be used both for the extraction of soil heat, and for the extraction of heat from water, and from the air.

When selecting the heat of the Earth, its upper layers are used, located at a depth of up to 100 meters from the surface. From the point of view of heat transfer, this layer of soil is under the influence of the radiant energy of the Sun, radiogenic heat from the deep layers of the Earth, convective heat exchange with atmospheric air and heat transfer due to various mass transfer processes (rain, snowmelt, groundwater.).

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One of the "obvious" advantages of building ground heat exchangers is declared to be an almost "infinite" mass of soil with a relatively stable positive temperature, compared with the amount of heat taken from it for the needs of the consumer.

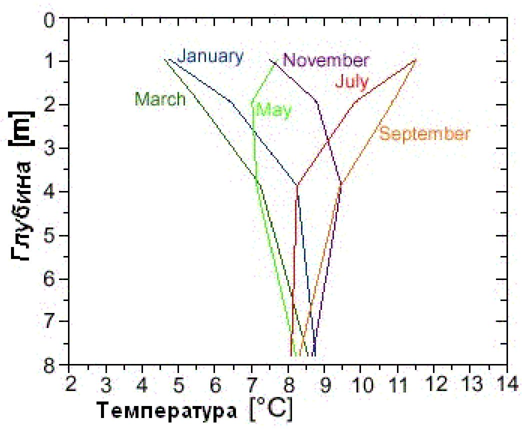

Table 1

Classification of soils by their thermal conductivity

Soil class	l, W/(m*°C)	Type of soil
Very low thermal conductivity	<1	Light clay (15% humidity)
Low thermal conductivity	<1,5	Heavy clay (5% humidity)
Normal thermal conductivity	<2	Heavy clay (15% humidity) Light sand (15% humidity)
High humidity	<2,5	Heavy sand (5% humidity)
Very high thermal conductivity	>2.5	Heavy sand (15% humidity)

Note that the thermal conductivity of the soil is not a constant value throughout the year. It depends on humidity, the aggregate state of moisture in the soil and temperature. Moreover, humidity changes especially strongly when the soil freezes. The thermal conductivity of frozen soils lf is

l_f =1.05…2.1* l th (1)

The value of the amount of radiogenic heat is (for the Central Asian zone) 1-2 W/m2. If it is not known, then 1 W/m^2 is usually accepted.

Fig. 1. Distribution of soil temperatures by depth

There are two main ways to extract geothermal heat – using open and closed circuits. An open circuit is understood as the use of groundwater heat, providing for the delivery of these waters to the surface, the use of their heat and return to the reservoir. A closed circuit is understood as the use of ground heat using intermediate heat exchangers and heat carriers. In turn, systems with closed circuits are distinguished by the type of heat exchangers – horizontal (Fig. 2a) and vertical (Fig. 2b). The device of closed circuits with vertical heat exchangers is more expensive than with horizontal heat exchangers. At the same time, circuits with horizontal heat exchangers occupy large areas, which in some cases can be a very critical condition.

The basis for the calculation of heat exchangers are the equations of heat transfer and thermal balance.

The heat transfer equation has the following form:

$Q = F \cdot k \cdot \Delta t$, (2)

where:

Q – the size of the heat flow, W;

F – working surface area, m^2;

k – heat transfer coefficient;

Δt – the difference between the temperatures of the media at the outlet to the device and at the outlet from it. The value is also called the temperature pressure.

As you can see, the value of F, which is the purpose of the calculation, is determined precisely through the heat transfer equation. Let's derive the formula for determining F:

$F = Q/ k \cdot \Delta t$ (3)

The heat balance equation takes into account the design of the device itself. Considering it, it is possible to determine the values of t1 and t2 for further calculation of F. The equation looks like this:

$Q = G_1 c_{p1}(t_1^{вх}-t_1^{вых}) = G_2 c_{p2}(t_2^{вых}-t_2^{вх})$ (4)

where:

G_1, G_2 – the mass consumption of the heating and heated media, respectively, kg/h;

c_{p1}, c_{p2} – specific heat capacities (accepted according to regulatory data), kJ/kg, ° C.

During the exchange of thermal energy, the carriers change their temperatures, that is, each of them enters the device with one temperature, and exits with another. These values (t_1^{inx}; t_1^{inx} and t_2^{inx}; t_2^{inx}) are the result of a verification calculation, with which the actual temperature parameters of the heat carriers are compared.

For greater clarity, let's present an example of a design calculation of heat transfer.

<u>Initial data:</u>

- The temperature of the heating medium at the inlet t_1^{bx} = 14 ° C;
- The temperature of the heating medium at the outlet t_{1c} = 9 ° C;
- The temperature of the heated media at the input t_2^{inx} = 8 ° C;
- The temperature of the heated media at the output t_{2v} = 12 ° C;
- Mass consumption of the heating carrier G_1 = 14000 kg/h;
- Mass consumption of the heated carrier G_2 = 17,500 kg/h;
- The standard value of the specific heat capacity cp =4.2 kJ/kg/ ° C;
- Heat transfer coefficient k = 6.3 kW/m^2.

1) Let's determine the power of the heat exchanger using the heat balance equation:

$$Q^{вх} = 14000 \cdot 4{,}2 \cdot (14 - 9) = 294000 \text{ KJ / H}$$

$$Q^{вых} = 17500 \cdot 4{,}2 \cdot (12 - 8) = 294000 \text{ KJ / H}$$

$Q_{вх} = Q_{вых}$

The conditions of the thermal balance are fulfilled. Let's convert the resulting value into a unit of measurement of Watts. Provided that 1W = 3.6 kJ/h,

$Q = Q_{вх} = Q_{вых}$ = 294000/3,6 = 81666,7 Вт = 81,7 кВт.

2) Let's determine the pressure value t. It is determined by the formula:

$$\Delta t = \frac{(t_1^{вх} - t_2^{вых}) - (t_1^{вых} - t_2^{вх})}{\ln\frac{t_1^{вх} - t_2^{вых}}{t_1^{вых} - t_2^{вх}}} = \frac{(14 - 12) - (9 - 8)}{\ln\frac{14-12}{9-8}} = 1{,}4$$

3) Let's determine the heat transfer surface area using the heat transfer equation:

F = 81,7/6,3·1,4 = 9,26 $м^2$.

Conclusions. What do we get as a result of the calculation?

To solve this issue, a thermal calculation is performed, that is, the temperatures of the heat carriers at the inlet and outlet of the device are determined. Based on these data, materials are selected for the manufacture of device elements.

In the end, we can say that the working area and the temperature of the media at the inlet and outlet of the device are the main interrelated indicators of the quality of the heat exchanger.

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