Simulation of geothermal pump

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Abstract. The use of geothermal pumps allows one to reduce the load on the energy complex. For practice it is interesting for the conditions of a moderate climate, to reveal the most effective means of the organization of heat pump installations. The paper describes the main features of the use of heat pumps. The mathematical simulation of the geothermal circuit is given. The work of geothermal contours of different types is investigated. The efficiency of using a dead-end coaxial probe in a heat pump unit with direct boiling of the refrigerant is inferior to a U-shaped heat exchanger from standard pipes. The results of the paper can be useful in the development of prospective sources, using geothermal energy.

1. Introduction
The use of geothermal pumps makes it possible to significantly reduce, and sometimes fully compensate for the load on the energy complex and in conditions of middle latitudes in a flat type of terrain. In some cases, this type of energy is promising compared to others [1,2]. In our time, various functional schemes for the use of geothermal resources have already been developed [3,4]. Many of them are still a theory, many have already been put on stream production and are actively introduced into technology abroad. But at the same time, in Russia, this method of energy supply is now used quite rarely in Central Russia. Many factors - from high capital costs to lack of experience in the design and operation of heat pump installations-are an obstacle to implementation. But one of the main is the lack of an integrated approach to the organization of heat pump systems for temperate climate [5,6]. The effectiveness of the geothermal heat pump is directly determined by the properties of the soil, the characteristics of the solutions used, the type of heat exchangers and other factors, and therefore for the wide implementation requires more significant improvements, both in technical terms and in theory [7-9].

The purpose of the paper is to consider the operation of the geothermal pump in a temperate climate, to identify the most effective means of organizing heat pump installations [10,11].

The research problems: investigation of the organization of collection of low-potential thermal energy; mathematical simulation of the geothermal circuit.

2. The main features of heat pumps use
On the economic side of the consideration, the cost of a heat pump for a long service life is comparable to gas systems, which at current prices for natural fuel remain the most economical type of energy. Another advantage of geothermal-based heat pumps is the compactness in the organization,
which adds to the attractiveness of installations in the density of modern buildings. Nowadays, patents have been developed for the organization of heat collection collectors as a structural element of the bearing structures of buildings [12].

The functional scheme of the heat pump with direct boiling of the coolant in the geothermal device (vapor compression type) includes the following main elements:

- geothermal circuit—serves to transfer heat from the earth's layer to the circulating thermal agent. The configuration, depth of laying, the material of the heat exchanger is selected in each case individually depending on the required thermal power, temperature, geological realities of the area and others. In the context of the use of freon as a heat agent, the geothermal circuit is aimed at changing the aggregate state of the latter.

- compressor—increases the pressure of gaseous freon. With increasing pressure, the temperature of condensation of freon increases, which makes it possible to organize further high-temperature heat exchange.

- condenser—heat exchanger designed to transfer the heat released after the condensation of freon to another coolant, mainly water, for further use in technological purposes.

- throttle body—a throttling device designed to reduce the pressure of freon to the calculated evaporation temperature.

To analyze the operation of the heat pump it is convenient to use p, h-charts.

There are certain advantages to this heat pump scheme: 1) Polyfunctionality. This combination can be used in different modes: heating; hot water and heating; heat and cold supply. 2) Adjustability. Depending on the energy demand, the plant's capacity can be changed by the partial use of geothermal heat exchangers. 3) Efficiency when working in binary modes. An additional advantage of the use of geothermal heat pump is the absence of costs for air conditioning. Moreover, when the cooling ring is included in the General scheme of the heat pump, the vapor freon before the compressor passes into an overheated state, which allows to reduce the cost of compression in the compressor, and thus reduce operating costs. Moreover, with increased needs in the cold, for the warm period of the year is likely to complete the overlap of the valves of thermal circuits. In this case, air conditioning is compensated by the need for heat supply at minimum operating costs.

The heat pump can act as a primary heater of the heat carrier for heating needs, or as the main one, provided that the heating of the premises is possible with a coolant with a low-temperature characteristic. Certainly, tendencies of the last years on active introduction of floor heating, heat fans on low-temperature heat carrier allow to say with confidence that these systems will find wide application in structure of modern technologies of microclimate provision.

The specific design of the heat pump must be selected for the requirements of the individual object.

3. Mathematical modeling of geothermal circuit

When considering vertical geothermal heat pumps, a special role is given to the organization of the ground heat exchanger. This component of the system largely determines the efficiency of the system as a whole and is the most expensive part of the heat pump. Among the elementary units of the geothermal scheme, the most common are ground heat exchangers made of single, made in the form of coaxial and U-shaped pipes [13] (Figure 1). The U-shaped heat exchanger contains two parallel tubes connected at the bottom. One or two (less often – three) pairs of such pipes are located in one well. The advantage of this scheme is the relatively low cost of production. Coaxial heat exchanger—the simplest coaxial heat exchanger is two pipes of different diameters. A smaller diameter pipe is located inside another pipe. Coaxial heat exchangers can be more complex configurations.

U-shaped type of pipe form the basis of most existing systems, the extent of which range from the microclimate of private houses to the village. The second type of heat exchanger tubes has become widely used in the last decade, in particular in Iceland, Germany, France, with some progress being made, in some cases in increasing the efficiency of the system to 10-37 %. This statistics is achieved in the study of brine heat pumps.
In order to identify the trends of freon boiling in geothermal heat exchangers of various types, we will conduct an analytical analysis of changes in the main parameters of the working medium: the degree of dryness and pressure on the basis of the energy balance for the coaxial dead-end and standard U-shaped probes [14]. When considering a geothermal heat pump, the energy is given to the working medium by the heat exchange of the ground heat exchanger and the ground. The process of real heat transfer is complex and non-stationary. Non-stationary heat transfer is characterized by the variability of the thermal process in substances, which is characterized by a change in temperature over time space. The process of heat transfer is a value that depends on many factors.

Stationary heat transfer is a process of heat transfer characterized by constant parameters over time, flowing through a separating barrier between media with different temperatures. Stationary heat exchange is established at long-term maintenance of temperatures of surfaces constant that by and large in view of dependence of system, is an assumption and idealization of process. However, under certain parameters in the consideration of the process as stationary for a relatively short period of time allows to obtain important specific knowledge applicable in practical calculations.

To study the dynamics of the pressure change, we use the following dependence of the pressure change during the movement of the coolant

\[ P = P_t + dP_g + dP \]  

where \( P_t \) - technological pressure, that is, the pressure required for the process, Pa; \( dP_g \) – change of the gravitational pressure, Pa; \( dP \) – pressure loss on the friction in the system, Pa.

\[ dP = \lambda \frac{\ell V^2}{d 2g} \]  

where \( \lambda \) is the coefficient of friction loss along the length; depending on the flow regime, calculated in accordance with [15]: \( \ell \) is the length of the medium displacement section, m; \( d \) is the channel diameter, m; \( V \) is the medium velocity, m/s.

The change of the gravitational pressure in the zones occurs according to [16].

\[ dP_g = gh d \rho \]  

where \( h \) is the height change when you move the coolant fluid; \( g \) - acceleration of free fall, m/s\(^2\); \( d \rho \) is the density change of the coolant when you move, kg/m\(^3\).

The degree of dryness of the steam-water mixture is a characteristic of its state and depends on the internal energy at a given pressure. In turn, the internal energy is in direct connection with the heat flow and is determined from the first law of energy conservation.
\[ dE = dQ + dA \]  

where \( dQ \) - the amount of energy supplied, W; \( dA \) - the work of the system against external forces, W.

Heat flow from the ground to the coolant in relation to engineering practice is calculated quite accurately by means of the equation of the form [6]

\[ dQ = K \left( T_g - T_p \right) dx \]

where \( T_g \) - current soil temperature, K; \( T_p \) - current solution temperature, K; \( K \) - heat transfer coefficient, W/(m\(^2\)K);

The heat transfer coefficient at a heat flow through a separating wall from one medium to another is usually determined by the expression [17]

\[ K = \frac{1}{d_2 H + \sum \frac{d_k}{\lambda_k} + \frac{1}{\alpha}} \]

where \( d_2 \) - the outer diameter of the pipeline, m; \( H \) - the distance from the surface of the pipe to the soil layer, in which the temperature gradient tends to zero, m; \( \lambda_g \) - the coefficient of thermal conductivity of the soil, W/(m\(\cdot\)K); \( d_k \) - layer thickness, m; \( \lambda_k \) - the coefficient of thermal conductivity of the layer, W/(m\(\cdot\)K); \( \alpha \) - the coefficient of heat transfer by convection, W/(m\(^2\)K).

The coefficient of heat perception by convection in the boiling of the coolant in the pipes in the conditions of forced movement is determined by its physical properties depending on [18]

\[ \alpha = b \frac{\lambda^2 \left( T_s - T_{boil} \right)^2 \rho}{\mu \sigma_{boil}} \]

where \( \lambda \) is the coefficient of thermal conductivity of the coolant, W/(m\(\cdot\)K); \( T_s \) is the temperature of the pipe wall, K; \( T_{boil} \) is the boiling point of the coolant, K; \( \rho \) is the density of the coolant, kg/m\(^3\); \( \mu \) is the dynamic viscosity coefficient, Pa\(\cdot\)s; \( \sigma \) is the surface tension coefficient, n/m; \( b \) is the dimensionless function calculated in accordance with [19].

For the flow of a moving liquid (gas), the work of the medium against external forces in the General case when moving from position 1 to position 2 has the form [19]

\[ dA = G \left( \frac{p_2 - p_1}{\rho_1} \right) + G \left( \frac{V_2^2 - V_1^2}{2} \right) + Gg (h_2 - h_1) + A + A_{fr} \]

where \( G \)-mass flow of the moving medium, kg/s; \( p_1, p_2 \)-pressure in the flow for positions 1 and 2, respectively, Pa; \( \rho_1, \rho_2 \)-density of the moving medium for positions 1 and 2, kg/m\(^3\); \( V_1, V_2 \)-speed of the moving medium for positions 1 and 2, respectively, m/s; \( h_1, h_2 \)-the relative height of the flow of the medium for positions 1 and 2, m; \( A \)-work performed by the working medium, J; \( A_{fr} \)-work flow to overcome the friction force, J [18].

4. Mathematical modeling of geothermal circuit

It is possible to trace the process of evaporation of the coolant by studying the change in its internal energy using the expression (4) and preliminary determination of the amount of energy supplied, as well as the operation of the system against external forces according to the dependencies (5) and (8).

To analyze the efficiency of the above mentioned probes, we place them in equal design conditions from the point of view of the environment, temperature field, cross-section areas and use one circuit
for each design of the geothermal heat exchanger, which is 70 meters deep. As parameters of soil the selected soil conditions in the city of Lipetsk. As a coolant, we use ammonia with the initial parameters: the recommended technological pressure is 0.35 MPa, the initial temperature is -18 °C; the flow rate is 0.25 kg/s. Tubes for U-shaped heat exchanger is adopted steel reinforced diameter 55×6 mm coaxial – steel reinforced outer pipe diameter mm 95×6 mm polypropylene and an inner diameter of 66×13 mm. In the analysis introduces the assumption of absence of heat flow through the inner tube of the coaxial heat exchanger. The calculation takes into account the basic temperature parameters of the soil on the basis of geological data for the city of Lipetsk. In view of the complexity of the heat exchange process in the earth's circuit, for the possibility of calculating the type and humidity of the soil constant throughout the length of the heat exchanger. It is also taken into account that the space between the soil and the heat exchanger is filled with a heat-conducting solution (bentonite). The dynamics of changes in the main parameters of the refrigerant steam flows is shown in the diagrams shown in Figure 2.

![Figure 2](image)

**Figure 2.** a) Demonstration of pressure changes in heat exchangers for different types, b) Demonstration of changes in the degree of dryness in heat exchangers for various types, where 1 - operation of U-shaped heat exchanger, 2 - operation of the dead-end heat exchanger from coaxial pipes.

The diagrams show that the efficiency of using a dead-end coaxial probe in a heat pump unit with direct boiling of the refrigerant is inferior to a U-shaped heat exchanger from standard pipes. This is particularly evident in the output values of the degree of dryness of steam-water systems, where the efficiency reaches 12%. Despite the fact that the area of contact of pipes with the ground in the two versions are equal, the heat-absorbing ability of the refrigerant and the flow energy costs for performing work against external forces reduce the efficiency of the dead-end coaxial heat exchanger.

5. **Conclusions**
1. In direct boiling geothermal plants, U-shaped heat exchangers perform better than coaxial ones in similar operating conditions.
2. The amount of energy obtained by freon in the heat exchanger and expressed as an indicator of the degree of dryness, in the case of U-shaped heat exchanger reaches an efficiency of 12% in comparison with the coaxial.
3. Based on mathematical modeling of freon boiling in heat exchange processes in geothermal heat circuit, the advantage of using a U-shaped heat exchanger over a coaxial in such systems is shown.

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