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HEAT CONDUCTION AND HEAT TRANSFER IN TECHNOLOGICAL PROCESSES

STUDY OF THE HEAT-TRANSFER PROCESSES OF TUBULAR ELEMENTS OF GROUND HEAT EXCHANGERS

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In this paper, consideration is given to the efficiency of utilization of the low-potential heat of the ground. Also, the advantages and distinctive features of polyethylene tubes used in vertical tubular elements of heat pumps are described. This paper gives the results of investigation of the heat transfer of tubular elements of ground heat exchangers. The dependences of the temperature distributions in the ground in the vicinity of a tube and the change in the temperature with time in dry and moist grounds are determined.

Keywords: *heat exchanger, polyethylene tube, temperature distribution, ground, moist ground.*

Introduction. The rise in prices for traditional energy carriers causes increasing interest in methods of using renewable sources of energy and, in particular, low-potential thermal energy stored in the surface layers of the earth. An important energy source is low-potential energy scattered in the environment: heat of the ground, of groundwater and geothermal water, of open natural and artificial bodies of water, and of air [1–2].

At a depth larger than 5 m, the ground is characterized by a low but constant temperature, which enables one to consider it as an efficient energy source for heat pumps. This temperature is from 8 to 12^{o}C depending on the climate of the area. A geothermal heat pump requires horizontal and vertical ground heat exchangers on the wells [2].

A horizontal ground heat exchanger is installed near the building at a small depth. The use of such ground heat exchangers is limited by the dimensions of the available area.

A vertical ground heat exchanger efficiently operates in virtually all kinds of geological media, except for the grounds with a low thermal conductivity, e.g., dry sand or dry gravel. Systems with a vertical ground heat exchanger do not require large sites and are independent of the intensity of solar radiation incident on the surface. Systems with ground heat exchangers have enjoyed very wide use [3–5].

A mathematical model has been proposed and an experiment on recovery of geological heat by vertical heat exchangers has been described in [6–8]. The process of freezing of the ground using smooth and ribbed heat pipes has been investigated. However, the authors of the cited works did not use polyethylene tubes for investigation.

In geothermal ground heat exchangers, one currently uses PÉ-63, PÉ-80, and PÉ-100 polyethylene tubes. They differ from steel, copper, and polyvinylchloride tubes by their high adaptability to streamlined production and the possibility of automating production. The use of polyethylene tubes saves materials that are in very short supply; many types of them allow recycling.

The basic advantages of polyethylene tubes are as follows:

1) the high strength and rigidity enable the tubes to withstand an internal pressure up to 1–6 MPa and external loads of the ground alike;

2) resistance to the chemical action of aggressive grounds and chemical agents;

3) the low coefficient of the elastic modulus of the material makes it possible to reduce the maximum value of dynamic pressure during hydraulic shocks;

4) there is no need to insulate pipelines externally from corrosion and to set up electrochemical protection;

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5) flexibility, rigidity, light weight, and high shock resistance facilitate mounting and reduce the cost;

6) the design life of polyethylene tubes is 50 years [9].

Taking into account the above characteristics of polyethylene tubes and the instability of metal tubes to the chemical action of aggressive grounds and chemical agents, we consider it expedient to use polyethylene tubes in creating heat exchangers.

The prime objective of the present work is to study the heat transfer of tubular elements of ground heat exchangers. It is necessary to determine the dependences of the temperature distribution in the ground in the vicinity of the tube, and also to obtain the change in the temperature with time in dry and moist grounds.

Formulation of the Problem. The parameters of a heat-exchange unit of the "ground–water" type for studying heat transfer experimentally are the flow rate of cold fluxes and the temperature differences of the ground cooled with the aid of heat pipes. To conduct the experiment we must develop and create an experimental setup enabling us to determine the basic characteristics of the process of heat transmission and heat transfer. We take the following boundary conditions for the experiment: inlet temperature of cold water $t_{\text{in}} = 9^{\circ}\text{C}$, temperature of the ground on the inlet portion of the sand-filled pipe under study $t_{\text{gr}} = 23^{\circ}\text{C}$, and environmental temperature 23°C.

Experiment. To solve the problem posed, an experimental bench for modeling of the process of heat transfer on heat-removal elements of the heat pipe in "ground–water" systems was erected in the Laboratory of Hydrodynamics and Heat Transfer. A diagram of the experimental bench is shown in Fig. 1.

The bench consists of two circuits: 1) the internal circuit with the heat-removal tube of the heat pump and 2) the external circuit of the heat-transfer portion with sand. The internal circuit consists of a thermostat, an orifice plate, a heat-removal portion, and a differential manometer. The outside diameter of the heat-pump′s heat-removal tube is 32 mm and the thickness is 3.5 mm. Thermocouples are installed in the beginning and at the end of the tube under study. The external circuit incorporates a heat-transfer portion with ground in the form of a cylinder of diameter 600 mm. Also, the system includes the switch of thermocouples, the thermocouples, the potentiometer for the thermocouples′ emf, and the cock for control of the rate of flow of the heat-transfer agent.

Experimental Procedure. Cold water from the tank enters the heat-removal tube of the heat pump. The water temperature is monitored with the thermostat which maintains a temperature of 9°C. The flow rate of the cold water is controlled by the cock, and the differential manometer shows the velocity of the liquid entering the heat-removal tube at the center of a 5-m-long cylindrical module filled with ground. The liquid velocity in the measuring tube ranges within 0.045–0.072 m/s. Copper-constantan thermocouples are used to measure the difference of the temperatures of the cooled liquid and the ground in the tubes.

From the experimental data obtained, we determined the heat-transfer parameters and constructed the plots shown in Fig. 2.

Figure 2 gives the changes in the temperature for different radial distances. It can be seen from the plot that, at the closest distance of 1.6–5 cm, the temperature curves run in parallel at different moisture contents of the ground. With a change of 14 cm in the cylinder′s diameter, the temperature grows and becomes equal to the environmental temperature at a certain instant of time.

To more qualitatively evaluate the effect of heat transfer of the ground with different moisture contents, we created another experimental bench. Here, the tube was placed in a cylindrical vessel with a diameter of 100 mm. The vessel simulated a well, which was first filled with dry ground and thereafter moistened at different mass concentrations of water.

Figure 3 gives a laboratory setup.

The mass concentrations of water in the sand amounted to 10, 25, and 50%. To monitor the temperatures we installed thermocouples, which were fastened to the rule at different distances from the tube surface. They showed the temperature distribution in the ground and in the vicinity of the tube. The experiments were conducted on the portion where we observed hydrodynamic stabilization of the liquid.

Figure 4 and 5 show the investigation results. It can be seen in Fig. 4 that the temperatures in the ground decrease with distance from the tube surface. It is well known that thermal conductivity sharply grows with the moisture content of the ground, since the thermal conductivity of the air displaced from the pores of the rock by the water is approximately 30 times smaller than the thermal conductivity of water.

Figure 5 plots the temperatures of grounds with different moisture contents versus time. In dry ground, the temperature changes by 4°C within an hour, whereas in moist ground, by only $1\text{–}2^{\circ}\text{C}$. It follows that a moist ground enhances heat removal.

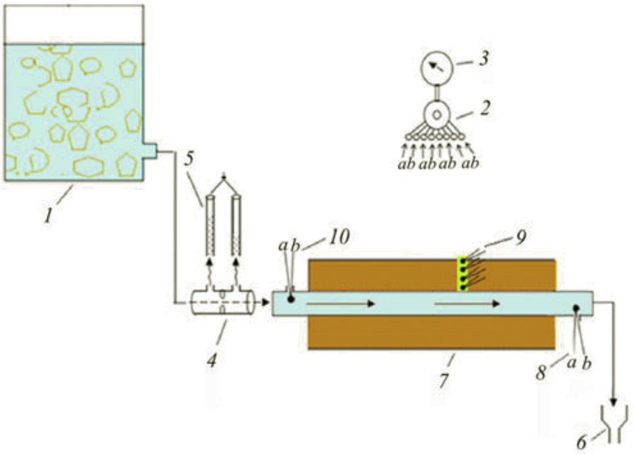

Fig. 1. Experimental bench for modeling of heat-transfer processes in heat-removal elements of a heat pump for "ground–water" systems: 1) thermostat; 2) switch of thermocouples; 3) potentiometer to measure the thermocouples′ emf; 4) orifice plate of the heat-removal portion; 5) differential manometer; 6) outlet pipe of the municipal sewer; 7) heat-transfer portion with sand; 8, 9, and 10) thermocouples (a and b are thermocouple connectors).

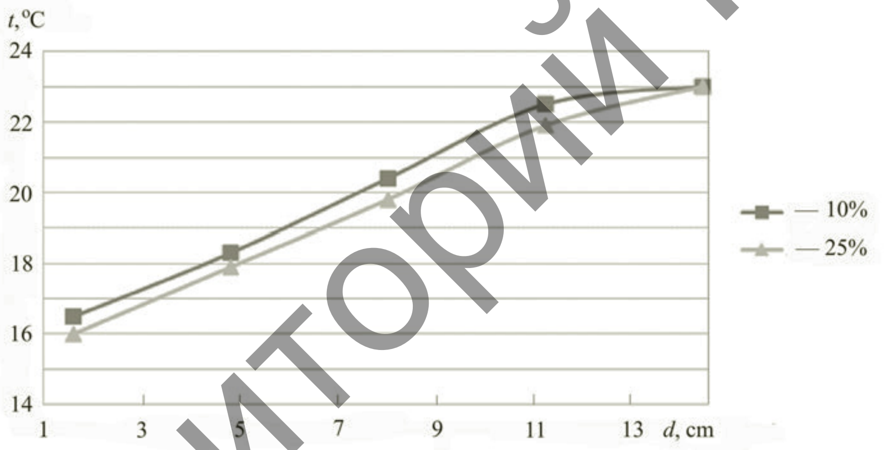

Fig. 2. Temperature of the ground with a varying moisture content vs. outer tube diameter.

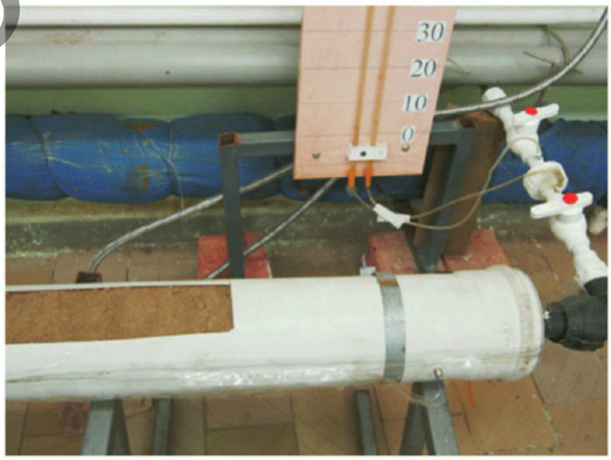

Fig. 3. Laboratory setup for a more qualitative evaluation of the effect of heat transfer of the ground.

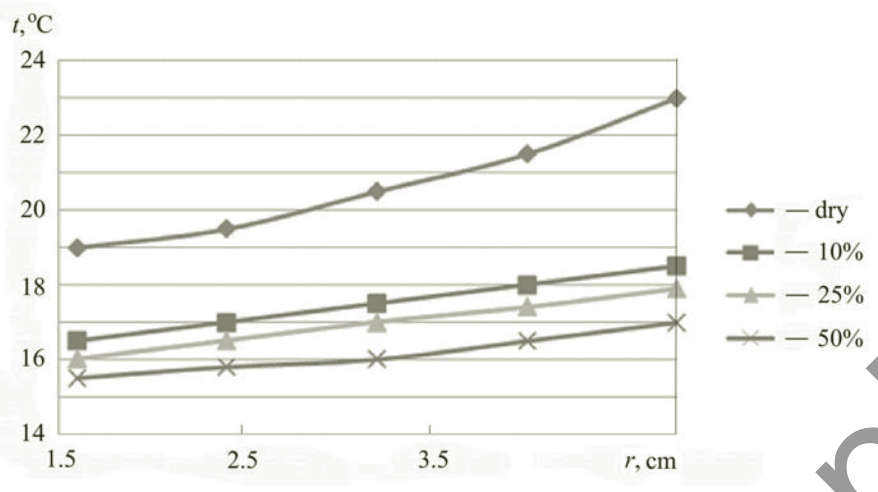

Fig. 4. Temperature distribution in the ground with a varying moisture content in the vicinity of the tube.

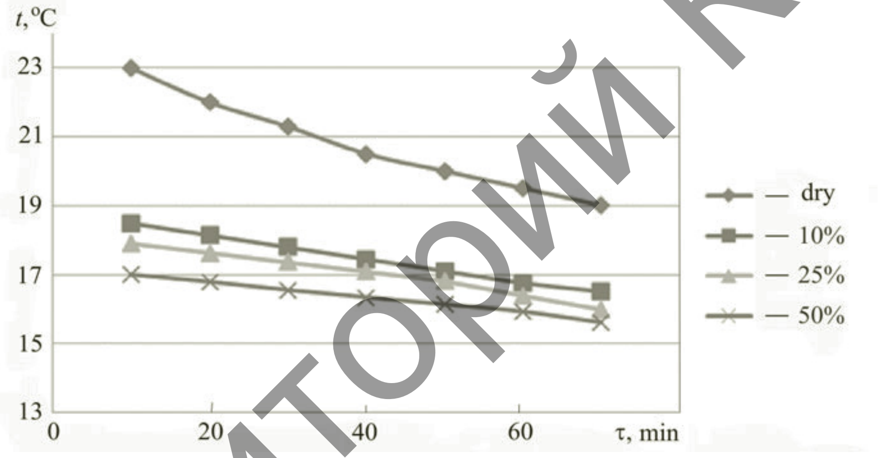

Fig. 5. Change in the temperature of the grounds with different moisture contents with time.

Conclusions. Since there are no standard heat exchangers for extraction of heat from the ground at present, such systems must be designed for each concrete object separately. It should be noted that thermophysically the ground is a rather complicated system. By experimental bench investigations, the authors of the present work have obtained the dependences of the change in the temperature of dry and moist grounds with time, and also the temperature distribution in the ground in the vicinity of polyethylene tubes used as heat-removal elements of heat pumps. The conducted experiments have confirmed that the change in the temperature in dry ground will be larger than that in moist ground. This enables one to use moist ground as a filler of wells of ground heat exchangers.

REFERENCES

1. G. P. Vasil′ev, Use of the low-potential energy of the ground of the earth′s surface layers for heat and cold supply of a building, *Teploénergetika*, No. 2, 31–35 (1994).
2. E. S. Bondar′ and P. V. Kalugin, Heat pump: an energy-efficient component of air-conditioning systems, *Élektron. Zh. Énergoserv. Komp. "Ékologicheskie Sistemy,"* No. 5 (2008).
3. K. Kussaiynov, N. N. Shuyushbayeva, G. M. Shaimerdenova, G. A. Bulkairova, and D. A. Ospanova, Electro-hydraulic pulse technology of drilling wells for installation of heat exchange elements of heat pumps, *Life Sci. J.*, **11**, No. 11, 469–472 (2014).

4. K. Kusaiynov, K. M. Turdybekov, Zh. A. Kuzhukhanova, and K. K. Sadenova, Electro-pulse technology of production of heat exchangers for extraction of heat from the ground at shallow depths, *Vestn. Karagandinsk. Univ*., *Ser. Fiz.*, No. 2 (66), 31–36 (2012).
5. K. Kussaiynov, S. E. Sakipova, N. N. Shuyushbayeva, B. A. Ahmadiev, and J. A. Kuzhuhanova, Electro-pulse technology of production heat exchangers for extracting the heat from the ground at shallow depths, *Eurasian Phys. Tech. J.*, **9**, No. 2 (18), 19–23 (2012).
6. A. I. Nakorchevskii, N. A. Nedbailo, and B. I. Basok, Experimental Investigation of Transient Processes in Ground Accumulation of Heat, *Proc. IV Russian Nat. Conf. on Heat Transfer*, Vol. 7 (2007), pp. 290–293.
7. E. N. Vasil′ev, V. A. Derevyanko, and A. V. Makukha, Investigation of the Process of Freezing of the Ground Using Heat Pipes, *Proc. IV Russian Nat. Conf. on Heat Transfer*, Vol. 7 (2007), pp. 175–178.
8. Thomas Grab, Thomas Storch, Sebastian Braune, and Ulrich Gross, Performance of geothermal heat pipe using propane, *VIII Minsk Int. Seminar "Heat Pipes, Heat Pumps, Refrigerators, Power Sources*," Minsk, Belarus, September 12–15, 2011.
9. G. M. Shaimerdenova, N. N. Shuyushbayeva, Zh. G. Nurgalieva, and N. N. Omarov, Investigation of the Heat Transfer of Tubular Elements of Ground Heat Exchangers, *Int. Scientific-Technical Conf. "Energy Efficiency–2014*," Minsk, Belarus, October 14–16 (2014), pp. 146–150.