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Investigation of heat transfer in tubular elements of ground heat exchangers

The article discusses the effectiveness of using low-potential heat of the ground. Also describes the advantages and features of polyethylene pipes which are used in vertical heat exchangers in the system heat pumps. The results of investigation of heat transfer tubular elements ground heat exchangers. It is shown the dependence of the heat transfer coefficient heat accepting pipe of heat exchanger on the Reynolds number.

Key words: heat exchanger, polyethylene pipe, heat transfer coefficient, Reynolds number.

Increase in prices for traditional energy sources causes growing interest in methods of use of renewable energy and, in particular, of low potential thermal energy stored in surface layers of the ground. Low potential energy dissipated in the environment is an important source of energy: the heat of the ground, of groundwater, of geothermal water, of open natural and artificial reservoirs, of air [1].

At the depth of more than 5 m the ground is characterized by low but constant temperature, which can be considered as an efficient energy source for heat pumps. This temperature ranges from 8°C to 12°C, depending on local climate. A geothermal heat pump at wells requires horizontal and vertical subsurface heat exchangers.

A horizontal subsurface heat exchanger is installed next to a building at a small depth. The use of such subsurface heat exchangers is limited by the size of available space.

A vertical subsurface heat exchanger works effectively in virtually all types of geological environment except grounds with low thermal conductivity, such as dry sand or dry gravel. Systems with vertical subsurface heat exchangers do not require large area sites and do not depend on the intensity of solar radiation incident on the surface. Systems with vertical subsurface heat exchangers are widely spread [2].

Currently, polyethylene pipe of PE-63, PE-80 and PE-100 brands are used for geothermal ground heat exchangers. They differ from steel, copper and PVC pipes in high technological effectiveness, possibility to automate production. Use of polyethylene pipes saves materials in short supply, many of their types are reusable.

Technical specifications of polyethylene pipes are shown in Table.

Table

Physical and mechanical properties of polyethylene for pipe production

Indicators	Value		
	PE-63	PE-80	PE-100
Density (specific gravity), g/cm^3	0,953-0,959	0,940-0,957	0,952-0,961
Specific elongation at break,%	350-800	350-850	350-681
Tensile yield limit, MPa	20-23	18-23	23-25
Modulus of elasticity in tension, MPa	800	1000	1300-1400
Thermal conductivity coefficient, W/(m·K)	0,38	0,38	0,38
Linear thermal expansion coefficient, mm /(m·K)	0,19	0,18-0,19	0,19
Frangibility temperature, ^{0}C	<-100	<-100	<-100

The main advantages of plastic pipes are the following:

- high strength and toughness of pipes make it possible to withstand the internal pressure up to 1.6 MPa, and the external loads of the ground;
- chemical resistance to corrosive grounds and chemicals;
- low modulus of elasticity of the material makes it possible to reduce the maximum value of the dynamic pressure in case of fluid shocks;

– no need to isolate the external pipeline from corrosion and to install electrochemical protection;

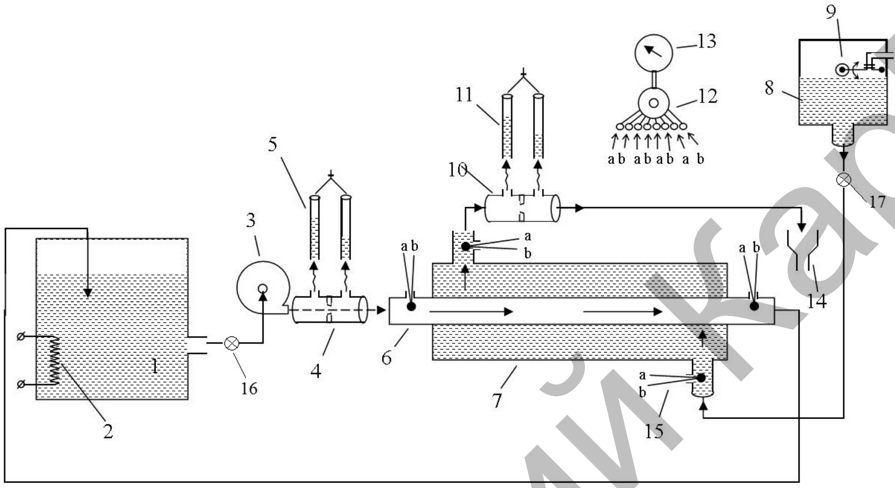
– flexibility, toughness, light weight and high impact strength make it easy to install and reduce costs;

– expected useful life of polyethylene pipelines is 50 years.

Considering the above characteristics of polyethylene pipes and lack of chemical resistance of metal pipes to corrosive grounds and chemicals, we consider it necessary to use PE pipes in making heat exchangers.

The purpose of the work is to study heat transfer of tubular elements of subsurface heat exchangers and to determine dependence of heat transfer coefficient on Reynolds number.

To achieve this goal, an experimental stand for modeling heat transfer processes in heat pulling elements of a heat pump was assembled in the laboratory of hydrodynamics and heat transfer. A principal scheme of the setup is shown in Figure 1.



1 — a tank with a heat carrier; *2* — an electric heating unit; *3* — a circulation pump; *4* — a measuring orifice of the heat pulling section; *5*, *11* — differential manometres; *6* — a heat pulling pipe of the heat pump; *7* — a heat transfer section with a liquid heat carrier; *8* — a tank with cold tap water; *9* — float with water level control; *10* — a measuring orifice of the heat transfer section; *12* — thermocouple switch; *13* — potentiometer for measuring the EMF of thermocouples; *14* — municipal sewer spill pipe, *15* — thermocouples; *16, 17* — heat carrier flow control valves.

Figure 1. An experimental stand for modeling heat transfer processes in heat pulling elements of a heat pump

The stand consists of two systems: 1) the inner system with a heat pulling pipe of the heat pump; 2) the outer system of a heat transfer section with a heat transfer liquid. The inner system with a heat pulling pipe of the heat pump consists of a tank with a heat carrier, an electric heating unit, a circulation pump, a measuring orifice of the heat pulling section and a differential manometer. The outer diameter of a heat pulling pipe of the heat pump is 32 mm, the thickness of the pipe is 3.5 mm. At both ends of the experimental pipe thermocouples are installed. The outer system comprises a vessel with water having a water level controller; a heat transfer section in the form of a cylinder with the diameter of 100 mm, filled with heat transfer liquid. The system also includes a thermocouple switch, thermocouples, a potentiometer for measuring the EMF of the thermocouples and heat carrier flow control valves.

The plant operates as follows. Hot water is heated by an electrical heating element in the tank to the temperature of 40 °C. The water temperature is controlled by a thermostat. The heated water from the tank through the circulation pump is supplied to the heat pulling pipe of the heat pump. A mode switch for low and maximum flow rate is installed on the pump. The hot heat carrier flow rate is controlled with a valve, and a differential manometre shows the flow rate of the liquid incoming into the heat pulling pipe of the heat pump. After passing the heat pulling pipe of the heat pump, the hot water flows back into the tank. Controlled with the float, cold water from the water supply system flows into intertubular space of the heat transfer area. After passing the intertubular space, the water passes through the flow rate meter and is discharged into the sewer. For measuring the temperature difference of the heating and heated fluids, copper-constantan thermocouples are installed in the heat pulling pipe of the heat pump and the heat transfer section with heat transfer fluid. The potentiometer for measuring the EMF of the thermocouples is connected to the thermocouple.

At the plant for the study of heat transfer, the parameters (flow rates, temperatures) of hot and cold flows were experimentally investigated, the principal characteristics of the heat transfer process (heat load Q and mean temperature difference t_m) were calculated, the values of the coefficients of heat transfer from the hot flow to the wall and from the wall to the cold flow were determined.

Based on the experimental data, similarity criteria of heat transfer and water flow regimes in the pipe were determined. Water flow regime similarities (Reynolds number) were determined by the formula (1), and the similarities of heat transfer (Nusselt number) were determined by the formula (2).

$$Re = \frac{\omega \cdot d_{\text{э}}}{\nu}; \tag{1}$$

$$Nu = \frac{\alpha d_{\text{э}}}{\lambda}, \tag{2}$$

where ω — is a mean linear flow rate, ν — is a dynamic viscosity coefficient; λ — is a heat conduction coefficient of liquid; d_e is an equivalent diameter of the flow defining its geometry [3–5].

On the basis of the determined similarity criteria, the dependence of Nusselt number on Reynolds number was graphed, it is presented in Figure 2.

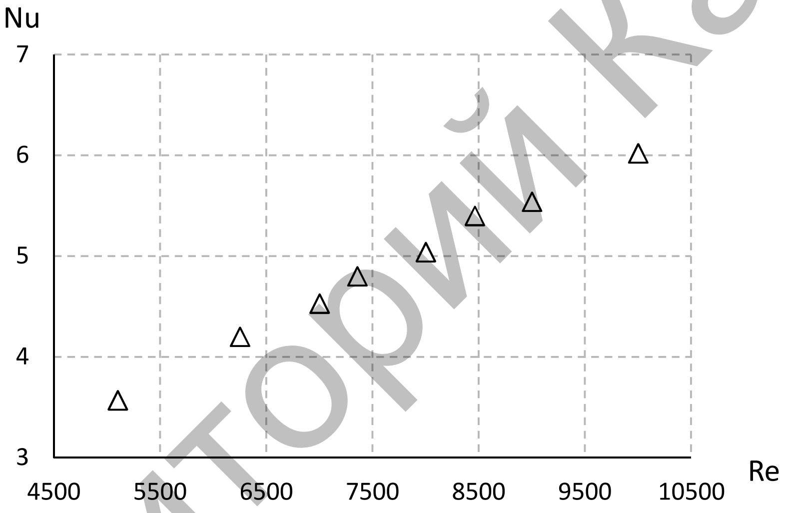


Figure 2. Dependence of Nusselt number on Reynolds number

Figure 2 shows that the rise of Nusselt criterion is directly proportional to the rise of Reynolds number. This is due to the fact that when the moving flow speed increases, in the pipe the flow turbulence grows and the boundary layer thickness between the flow and the walls of the tube decreases. Reduction in the thickness of the boundary layer improves the heat transfer process.

Further the mathematical relationships between the similarities are defined (3), the logarithmic relationship between Nusselt number and Reynolds number is plotted, the exponent of power is determined and the coefficient of proportionality is calculated.

The relationship between similarity criteria is represented in the form of power functions

$$Nu = c \cdot Re^n Pr^m.$$

The Prandtl number of the heat carrier remains constant in the experiment, so Nusselt number depends only on Reynolds number

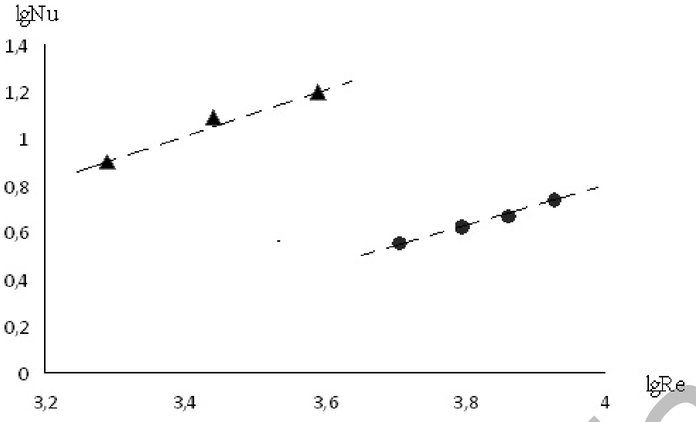
$$Nu = c \cdot Re^n. \tag{3}$$

Taking the logarithm, we obtain

$$\lg Nu = \lg c + n \lg \mathrm{Re}. \tag{4}$$

From the equation (4) we obtain a function $\lg Nu = f(\lg Re)$, which is presented in Figure 3 as a plot.

The graph shows that the exponent of power n is equal to the slope of the straight line to the abscissa axis i.e. $n = tg\varphi = \frac{a}{b}$. A comparative graph is plotted based on the results of Mikheev and processing of the experiment (fig. 3).



▲ — based on the results of the experiment of Mikheev, ● — based on processed data of the author

Figure 3. Graph establishing the dependence of Nusselt number on Reynolds number

The constant c is determined from the equation (5)

$$c = \frac{Nu}{Re^n} \tag{5}$$

satisfied by any point on the line.

Thus, it was found out that the exponent of power is equal to 0.8, and the proportionality constant is 0.0038. Substituting the calculated numerical data in equation (3), we obtain (6):

$$Nu = 0,0038 \cdot Re^{0,8}. \tag{6}$$

By experimental studies at the stand the authors determined universal dependence for mean heat transfer of polyethylene pipes used as heat pulling elements of heat pumps. It was established, that the dependence of Nusselt number on the Reynolds number is linear in a logarithmic scale; the coefficient of slope of the line n that is the exponent of power of Reynolds number, is equal to 0,8. The proportionality coefficient is $c = 0,0038$. Comparing with the experimental data of other researchers shows qualitative agreement, the slope of the line is also 0.8. The numerical values of the proportionality coefficients depending on used material, are different. For metal tubes $c = 0.025$, and for polyethylene pipes under study, it is by 3.7 times less that is due to the poor thermal conductivity of the heat transfer wall.

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Жер асты жылуалмастырғыштарының құбырлық элементтеріндегі жылуалмасуды зерттеу

Мақалада жерастының төменгі потенциалды жылуын пайдаланудың тиімділігі туралы айтылған. Сонымен қатар жылу сорғылары жүйелерінде вертикаль жылуалмастырғыштарда қолданылатын полиэтилен құбырлардың ерекшеліктері мен артықшылықтары қарастырылды. Жер асты жылуалмастырғыштарының құбырлық элементтеріндегі жылуалмасуды зерттеудің нәтижелері келтірілген. Жылу сорғыларындағы жылу тартқыш құбырлардың жылу беру коэффициентінің Рейнольдс санына тәуелділігі анықталды.

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Исследование теплообмена трубчатых элементов грунтовых теплообменников

В статье рассмотрена эффективность использования низкопотенциальной теплоты грунта. Также описаны преимущества и особенности полиэтиленовых труб, используемых в вертикальных теплообменниках в системе тепловых насосов. Приведены результаты исследования теплообмена трубчатых элементов грунтовых теплообменников. Определена зависимость коэффициента теплоотдачи теплосъемной трубы теплового насоса от числа Рейнольдса.

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