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TECHNIQUE OF ESTIMATION OF THE REFRIGERATING CAPACITY OF SELF-ACTING COOLERS

The technique of definition of refrigerating capacity of self-acting cooling plants applied in areas with a severe climate as devices lowering depth of soils freezing is described. These devices are applied in the struggle with ice, critical shrinkage of the artificial structures and other phenomena connected with ground thawing. The results of experimental measurements obtained by emulation of phenomena occurring in the cooling plant are given.

Keywords: calculation of cooling plant, struggle with ice, Gapeev´s plant, determination of refrigerating capacity, alternative design procedure.

Introduction

Erection of reliable installations on permanently frozen soils is a complicated technical problem.

The most familiar self-acting cooling plants are single-tube, two-tube, multitube, three-tube (curved), multitube and single-tube coolers of S. I. Gapeev developed in design and survey institute “Lengiprotrans”. These coolers use kerosene as a heat transfer agent [1, 2].

In present, experimental-theoretical formula of S. I. Gapeev is used for determinating refrigerating capacity [3]:

$$Q = 24 \cdot \sum \tau \cdot t \cdot \left[V_\kappa - V_\kappa (t^{'} - t^{''}) \cdot \beta \right] \cdot q \cdot \varphi \cdot k^{'} \cdot k^{''}, \quad (1)$$

where $24 \cdot \sum \tau \cdot t$ is the work of the cooler in winter, degree-hour; V_k is the volume of kerosene, litre; $t^{'}$ is the temperature of kerosene in the beginning of the cooler operation; $t^{''}$ is the average elevated temperature of kerosene (in winter); β is the coefficient of kerosene volume measurement; q is the heat capacity of 1 litre of kerosene, degree-hour (depends on design o the cooler), calorie; φ is the coefficient considering the change in specific surface of kerosene cooling in tubes compared to pilot plant (increases with decrease in diameter); $k^{'}$ is the coefficient considering the influence of wind влияние ветра, it is taken to be equal to $1+0.1\sqrt{\omega}$, where ω is the wind speed, m/sec; $k^{''}$ is the coefficient considering the ratio of volume of kerosene in the upper plant (in the air) to the volume of kerosene in the bottom plant (in the ground). It is taken to be equal to

$$\sqrt{\left(\frac{V_в}{M_г}\right)}.$$

It should be note however, that calculation technique of the coolers has hardly been developed. It is based primarily on the use of the results of conducted experiments and correction coefficients whose nature and methods of determination are not clear [4].

In present paper we attempt to consider generalized method of calculation in accordance with environment parameters and cooler capacity.

In the scheme with different diameters of the tubes circulation is sustained through difference in temperature (to be more exact, in specific weights of kerosene) in the right and in the left branches (Fig. 1) [5].

As will be seen from the further consideration, temperature drop

$$\to t_1 \to t_2 \to t_3 \to t_2 \to t_1$$

is rather small. Therefore, average temperature between points

$$t_1 \to t_2 \to t_3$$

can be found from linear law.

Under these assumptions, operational head is equal to

$$p = \frac{\gamma_3 - \gamma_1}{2} \cdot (h + h_1) = \frac{\Delta t \cdot 0.6745 \cdot H}{2}, \tag{2}$$

where 0.6745 is the value of change in kerosene specific weight for 1^0 of temperature change.

Going to the determination of $t_1$and t_3, it is necessary to keep in mind that in this case it is not allowed to use linear dependence for errors to be avoided.

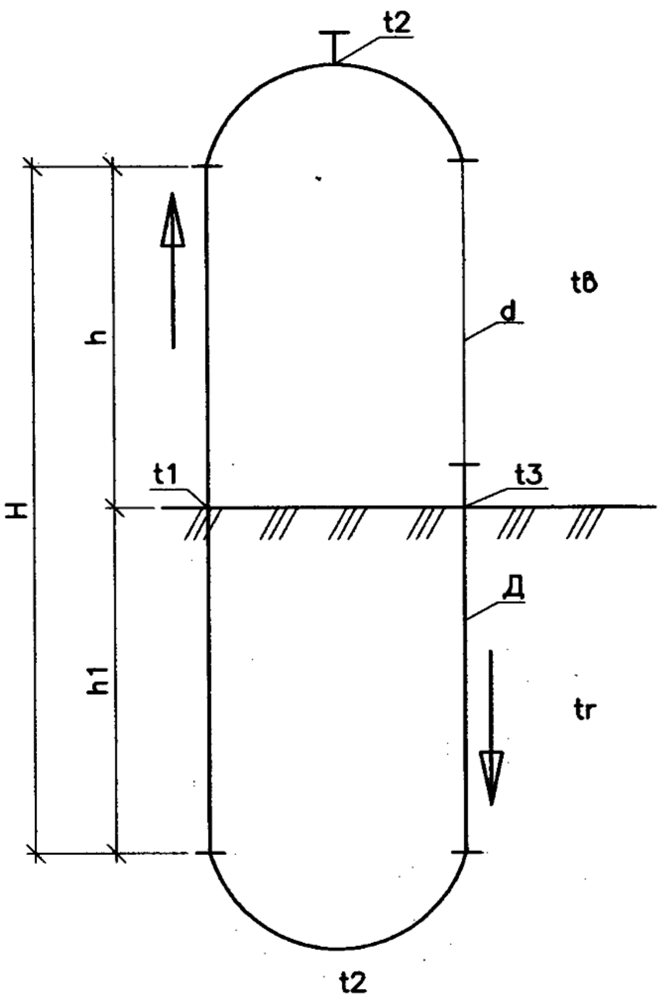

Fig. 1. Calculation scheme of a cooler

At fixed volume of circulation temperatures are computed from the Shukhov (Grasgof) formula:

$$t_1 = t_r + \frac{t_3 - t_r}{\ell^a};\ t_3 = t_{\text{в}} + \frac{t_1 - t_{\text{в}}}{\ell^{\text{в}}}. \tag{3}$$

Rearranging gives:

$$t_3 = t_{\text{в}} \cdot \frac{(1 - \frac{1}{\ell^{\text{в}}})}{1 - \frac{1}{\ell^{(a+\text{в})}}} + t_r \cdot \frac{(\ell^a - 1)^0}{(\ell^{(a+\text{в})} - 1)} = \frac{t_{\text{в}} \cdot (\ell^{(a+\text{в})} - \ell^a) + t_r \cdot (\ell^a - 1)}{\ell^{(a+\text{в})} - 1}. \tag{4}$$

If soil temperature is taken to be equal to t_r =0, formulae become simpler:

$$t_3 = t_{\text{в}} \cdot \frac{t^{(a+\text{в})} - \ell^a}{\ell^{(a+\text{в})} - 1};\ t_1 = \frac{t_3}{\ell^a}. \tag{5}$$

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In these formulae

$$; \, в = \frac{h \cdot (K + K_1)}{W \cdot c} = \frac{K'_в}{W \cdot c}; \qquad (6)$$

where W is the number of circulating kerosene, kg/hour; c is the heat capacity of kerosene, kilocalorie/kg·degree Celsius; t_1, t_3 are temperatures of kerosene in points 1 and 3; $t_в$ is the air temperature; t_r is the soil temperature at a depth of $\frac{h_1}{2}$; K'_r is the total coefficient of heat transfer from ground to the tubes; $K'_в$ is the total coefficient of heat transfer from the tubes to air.

Coefficients K'_r и $K'_в$ depend on many factors. First of all, it depends on tube diameter.

Calculations showed that distance between tubes is equal to $3D$; coefficient of interference is about 0.625 for each tube.

Hence,

$$K'_r = 1.25 \cdot K_r.$$

It is known that coefficient of heat transfer for vertical cylinder is expressed by the formula

$$K_r = \frac{2 \cdot \Pi \cdot h \cdot \lambda}{\ell_n \cdot \frac{2 \cdot h}{\tau}}, \qquad (7)$$

where h is the height of the cylinder; τ is the radius of the cylinder; λ is the heat conductivity of the ground.

Going to the determination of $K'_в$, it is necessary to note that value of $K'_в$ depends first of all on wind speed and is determined by the formula (for one tube)

$$K'_в = h \cdot (K + K_1); \; K = \alpha; \; K_1 = \alpha_1, \qquad (8)$$

$$\alpha = 11.9 \cdot (\nu \cdot d)^{0.6} + 9.4 \cdot d, \text{ kilocalorie /m·hour·degree Celsius}, \qquad (9)$$

where ν is the wind speed, m/sec.

In connection with high thermal inertia in the ground average wind speeds in winter (during 8 months) should be entered into calculation.

Mutual interference of the tubes is not taken into consideration when calculating air section because of small value of the radiation component.

To determine the amount of circulating air and, therefore, the amount of the heat, we need to define hydraulic characteristic of the plant:

$$\mu = (\frac{\lambda}{d} \cdot L + \Sigma \cdot \xi) . \tag{10}$$

Subsequent calculation, as well as experimental data of Gapeev have shown that kerosene movement mode in tubes is laminar (Fig. 2).

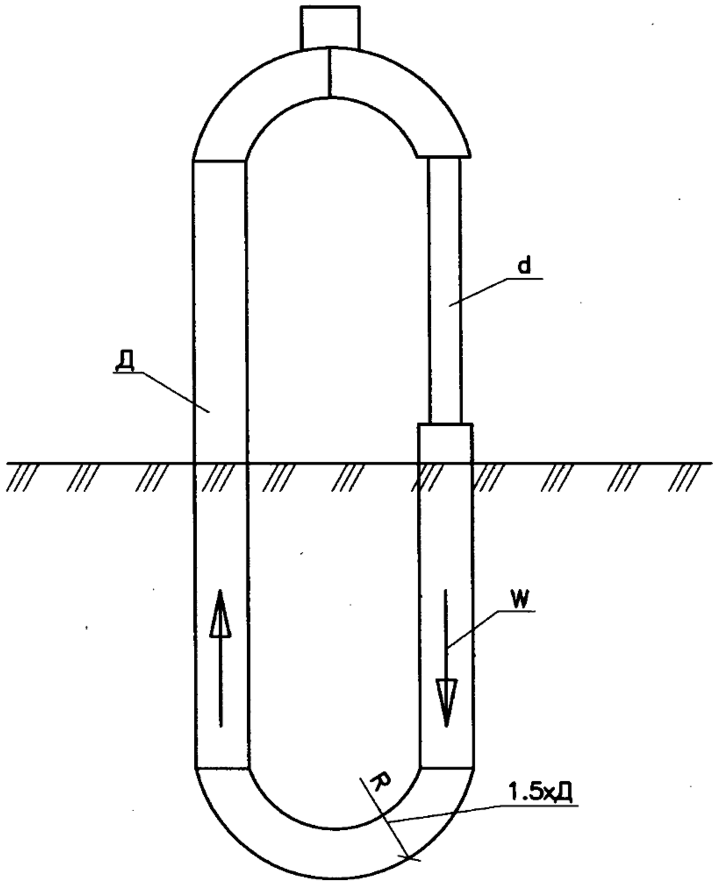

Fig. 2. Design of two-tube cooler

Hence,

$$P = (\frac{\lambda}{Д} \cdot L + \Sigma\xi) \cdot \frac{\varpi^2}{2g} \cdot \gamma = \left[\frac{\lambda}{Д} \cdot 2 \cdot (h_1 + h) + \Sigma\xi \right] \cdot \frac{\varpi^2}{2 \cdot g} \cdot \gamma . \tag{11}$$

Then

$$\varpi = 4.43 \sqrt{\frac{p}{\frac{\lambda}{Д} \cdot 2H + \Sigma\xi) \cdot \gamma}} = \frac{1.82}{\sqrt{\gamma}} \cdot \sqrt{\frac{\Delta t}{\frac{\lambda}{Д} + \frac{\Sigma\xi}{2 \cdot H}}} . \tag{12}$$

The following initial conditions were taken:

- calculation plant was made from tubes of diameter 76/89, of size h=2.0 m; h_1=4.0 m;
- air temperature $t_в$ = -21 ^{0}C;
- wind speed v = 4 m/sec;
- ground temperature $t_г$ = 0 ^{0}C.

We obtain heat capacity of the plant T = 182.30 kilocalorie/hour (763.30 kilojoules).

To support the calculations and to study the processes in the cooler during its operation, we have developed pilot plant simulating the working section of the single-tube cooler.

The pilot plant was modeled on the basis of cylindrical container made of transparent glass to observe the processes going on in it. This cylinder reconstitutes part of the single-tube cooler (Fig. 3).

To reconstruct circulation in the system, we have made two sections: cooling section and freezing section. In cooling section, ground needed for freezing is emulated. To simulate this situation, we heated the circulating liquid to obtain temperature difference in points t_1 and t_2 . In freezing section, atmospheric air is emulated in areas with severe climate (in winter). To simulate this situation, we cooled the circulating liquid in this section. This helps to reconstruct natural conditions of cooler operation.

To analyze temperature characteristics in points t_1 and t_2, as well as to record the data, we used two-channel measuring instrument: regulator of TPM 202 type in combination with input transducers (temperature transducers). The temperature is measured to 1 decimal place with data retention on PC.

The circulation speed is measured with motion indicator which is moved by circulating flows.

Refrigerating capacity is the cooler occurs in several stages:

1. Rated circulating volume is determined:

$$Q = \varpi \cdot 3600 \cdot V .$$

2. Temperature difference Δt in points t_1 and t_2 is determined.

3. Speed of kerosene circulation is determined:

$$\varpi = \frac{L}{t} .$$

4. Heat capacity of the plant is determined:

$$T = W_c \cdot \Delta t$$

($W_c = Q \cdot \rho \cdot c$, where ρ is the density of kerosene; c is the heat capacity of kerosene).

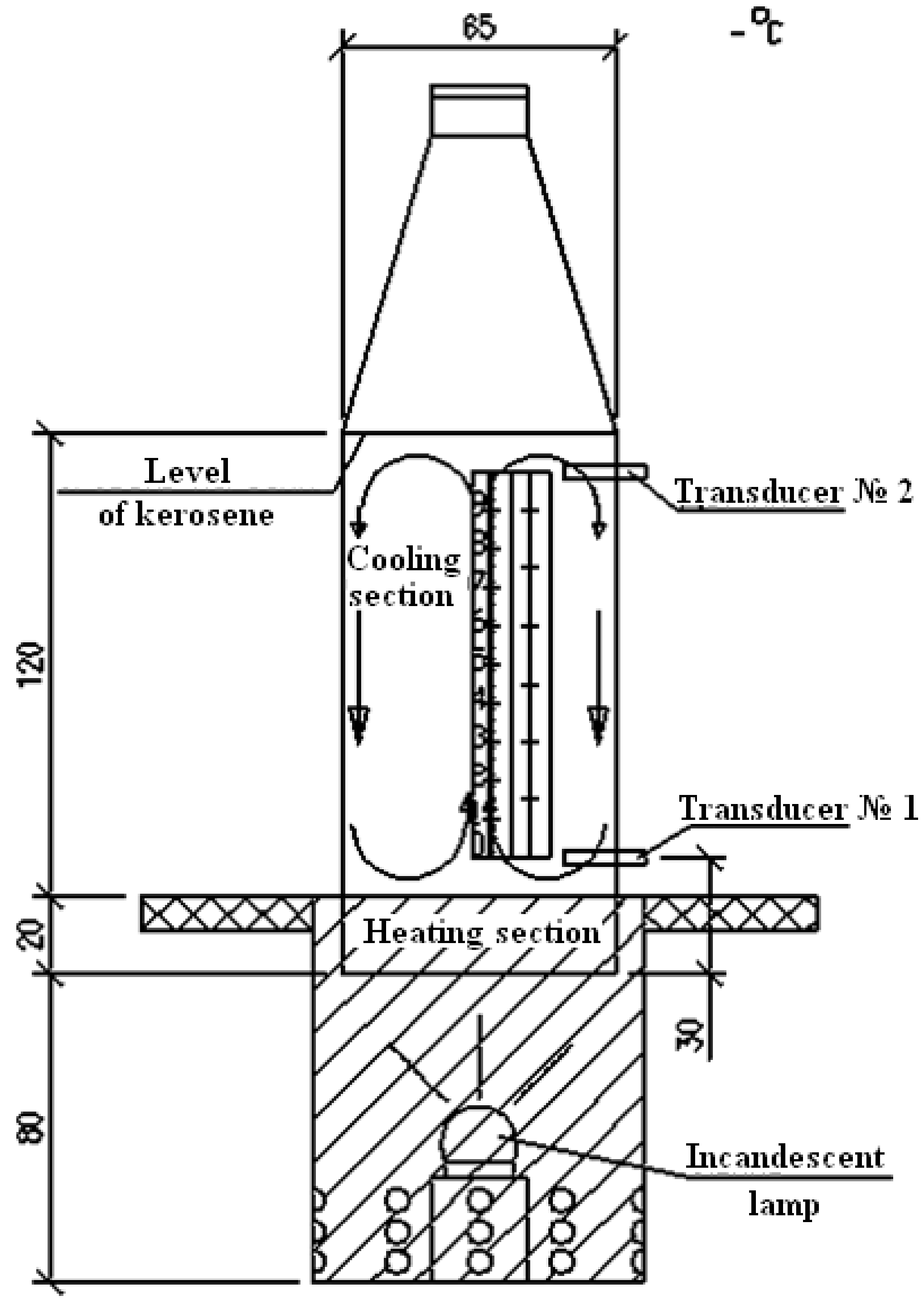

Fig. 3. Design of experimental plant

Comparison of theoretical and experimental data and their reduction to one equivalent result in the following:

– heat productivity of the system during first observation is

173.224 kilocalories /hour
(725.20 kilojoules);

– heat productivity of the system during second observation is

194,163 kilocalories /hour
(812.90 kilojoules);

– heat productivity of the system during third observation is

190.991 kilocalories/hour
(799.60 kilojoules).

Comparing the results with rated heat productivity obtained earlier (763.30 kilojoules) we obtain data similar to experimental ones (725.20 kilojoules; 812.90 kilojoules; 799.60 kilojoules).

Small discrepancies can be attributed to the simple method of conversion of the single-tube experimental system to the two-tube rated one. In addition, errors involving visual control of the experimental plant are possible.

Summary

The technique of estimation of the refrigerating capacity of self-acting coolers was obtained and proved experimentally.

This technique is proposed as an alternative to experimental and theoretical method of Gapeev.

References

1. Gapeev, S. I. Use of the natural cold in road construction. Moscow, 1951. 34 pp.

2. Gapeev, S. I. Recommended measures and experimental researches on cooling of permafrost soils for the purpose of their strengthening and increase of the upper bound of bedding. Circular № 22. Leningrad, 1957. 2 pp.

3. Gapeev, S. I. Guidance on designing, construction and operation of artificial structures of highways on waterways with ice. Moscow, 1989. 112 pp.

4. Gapeev, S. I. Strengthening of frozen bases by cooling. Moscow, 1983. 23 pp.