Testing heat supply networks for heat losses

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Abstract. The scope of operations of the branch where the survey was carried out is: transmission and distribution of heat and heating medium to consumers through heat supply networks, maintaining the proper quality and amount of thermal power and heating medium supplied, ensuring contractual activities with heat consumers, as well as control of compliance with the consumption regimes stipulated by contracts, ensuring payments from consumers for supplied heat and heating medium, development and implementation of measures ensuring maximum efficiency of heat supply activities. The purpose of the work performed is to determine the actual heat losses through the thermal insulation of the surveyed heating networks and to compare them with normative values. The article presents an analysis of materials on the heat supply system; test findings for actual heat losses in a heat supply pipeline; calculation of actual heat losses for each section and their adjustment to average annual operating conditions of the given heat supply network; comparison of calculation results with normative characteristics. The test findings are used in developing the output performance for the «Heat Loss» indicator and in setting of norms for operating heat losses. The heat supply source for the heat pipeline is the CHP-plant. The pipelines are routed above ground on high and low supports, as well as in crawl ways. The thermal insulation of the pipelines is mainly made of 50 mm blankets of mineral wool and is typical for heat supply networks. In overhauls of heat supply networks, polyurethane foam is partly used as thermal insulation.

Keywords. Thermal power, heat losses, heat supply networks, CHP-plant, testing heat supply networks, actual losses, normative losses, thermal insulation.

1 Introduction

The actual operating heat losses are determined experimentally through carrying out thermal tests on the heat supply network. The target of the tests is to determine the heat losses for various types of routing and design of the pipeline insulation that are specific to the heat network in question. Based on the test results, the insulation condition of the tested pipelines under the specific routing operating conditions is assessed [1-4]. The tests were performed for the network sections with the routing type and the insulation design is the characteristic of the given network, which facilitates expansion of the test results to the heating network as a whole [5-9].

The immediate task of testing water-based heating networks is to determine the actual heat losses through the thermal insulation of heat network sections determined for testing under the selected mode and to compare them with normative values of heat losses for the

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same sections of the heat supply network. Determination of heat losses in heat supply networks through thermal insulation is an important practical task. Levelizing of the heat losses at the heating network pipeline section and cylindrical tanks based on the thermal conductivity laws is presented in papers [14-18].

Determination of heat losses based on thermal tests was deduced in accordance with the requirements of RD 34.09.255-97 «Procedural Guidelines for the Determination Thermal Losses in Piped Hot Water Heat Supply Networks». Energy survey of heat supply systems is considered in papers [19-22].

The thermal power and heating medium source are the CHP-plant. The supplied heat is quality and flow rate controlled according to the time-temperature chart of 130 – 65°C with a peak lopping of 115 – 65°C.

The heat supply system is closed. Consumers are connected within a dependent system. The connected maximum hourly load is 2970.71 Gcal/h, including: for heating – 2296.03 Gcal/h; for hot water supply – 674.0 Gcal/h; for process needs – 0.15 Gcal/h.

There are 125 central heating substations (CHS) and 5 transfer pumping stations (TPS) currently in operation. The heat supply networks being currently under lease are 1,381.619 km long in single-pipe enumeration, including: water pipelines – 1375.729 km, comprising 87.348 km derelict ones; steam piping – 5.890 km.

The assumed outdoor temperature for heating engineering is 32 °C.

The heating season lasts 5160 hours, the summer period is 3240 hours and the repair period is 360 hours.

2 Materials and methods

The tests should be carried out on the sections of the heat supply network whose installation type and thermal insulation design are representative features of the given network.

Table 1. Material characteristic of the heat supply network sections under test (in single-pipe enumeration).

Network section	Installation type, design of the thermal insulation	Year of installation or replacement	External diameter, m	Section length, m	Pipeline volume, m ³	Material characteristic, m ²
CHP – downdrop to the duct	Overhead, mineral wool blankets	up to 1990	0.820	1949.0	979.2	1598.2
Downdrop to the duct – TC 6-9	Duct-type, mineral wool blankets	up to 1990	0.820	480.0	241.2	393.6
TC 6-9 – TC 6-13	Duct-type, mineral wool blankets	up to 1990	0.720	1118.0	430.0	805.0
TC 6-13 – TC 6-15	Duct-type, PU foam	2012	0.720	560.0	215.4	403.2
TC 6-15 – TC 6-19	Duct-type, blankets	up to 1990	0.720	662.2	254.6	476.8
TC 6-19 – TC 6-21A	Duct-type, mineral wool blankets	up to 1990	0.630	516.0	145.8	325.1
				5285.2	2266.2	4001.9

Representative are those the sections of the heat supply network which make up at least 20% in the material characteristic of the entire network:

$$\varphi = \frac{M_x}{M_c} = \frac{\sum_x (D_n \cdot L)}{\sum_c (D_n \cdot L)} > 0,2$$

(1)

here M_x – material characteristic for the feeding or return piping of the network summed over all sections with a given installation type and thermal insulation design, m²; M_c – material

characteristic for the feeding or return piping of the network summed over the entire network, m^2 ; D_n – outer pipe diameter within one network section (in the feeding or return pipeline with equal pipe diameters), m; L – length of the network section, m.

The material characteristic of the sections of heat supply network under test is stated in Table 1.

The basic parameters have been determined through calculation. These are the water temperature in the feeding pipeline and the water flow rate in the initial section of the circulation loop under test. Besides, the expected water temperature in the return piping and make-up water flow rate during the tests has been calculated, as well as the approximate duration of the tests.

Water temperature in the feeding $t_{f,t}$ and return $t_{r,t}$ pipelines of the tested loop has been determined by formulae, $^{\circ}\text{C}$:

$$t_{f,t} = \frac{t_f^{a,a} + t_r^{a,a}}{2} + \frac{\Delta t_t}{2} + t_{e,t} - t_e^{a,a} \quad (2)$$

$$t_{r,t} = t_{f,t} - \Delta t_t = \frac{t_f^{a,a} + t_r^{cp,z}}{2} - \frac{\Delta t_t}{2} + t_{e,t} - t_e^{a,a} \quad (3)$$

here $t_f^{a,a}$ and $t_r^{a,a}$ – annual average water temperatures in the feeding and return pipelines of the network under test, $^{\circ}\text{C}$, calculated as the arithmetic average of the monthly average temperatures for network water determined as per the approved operational temperature diagram at the monthly average ambient air temperatures; $t_{e,t}$ – expected ambient temperature averaged over all sections of the loop during the test, $^{\circ}\text{C}$; $t_e^{a,a}$ – annual average ambient temperature averaged over all sections of the loop, $^{\circ}\text{C}$.

The expected average ambient temperature over all sections of the loop during the tests is determined according to the formula, $^{\circ}\text{C}$:

$$t_{e,t} = \frac{t_{g,t}^{m,a} M_{und} + t_{a,t}^{m,a} M_{ab}}{M_k} \quad (4)$$

here $t_{g,t}^{m,a}$ and $t_{a,t}^{m,a}$ – respectively, the average temperature of the ground at the middle level of the heat pipeline axis and of the ambient air throughout the month of the testing period, $^{\circ}\text{C}$; M_{und} and M_{ab} – material characteristics for the feeding or return pipeline over all sections of underground and above-ground installation, respectively, located within the loop under test, m^2 ; M_k – aggregate material characteristics for the feeding or return pipeline over all loops under test, m^2 .

Calculated water consumption G_t , circulating over the tested loop, is accepted considering the estimated value of heat losses for the loop under the test conditions, which has been calculated by the formula, kcal/h:

$$Q_t = \sum_{ab} (q_{n,f,t} + q_{n,r,t}) \cdot \beta \cdot l + \sum_{und} q_{n,t} \cdot \beta \cdot l \quad (5)$$

here β – local loss factor, considering the heat loss in the valves, supports and compensating pipes. It is applied according to regulation documents for the duct-type underground and above-ground cable installation, depending on the diameter of the nominal bore of the pipelines (150 mm, at the least $\beta = 1.15$). $q_{n,t}$ – specific heat losses of a given heat supply network for each underground pipeline diameter in the thermal test mode, kcal/($m \cdot h$); $q_{n,f,t}$ and $q_{n,r,t}$ – specific heat losses of a given heat supply network in the feeding and return pipeline, respectively, for each diameter of above-ground pipeline in the thermal test mode, kcal/($m \cdot h$).

The specific heat losses for underground and above-ground installations are determined considering the normative values for heat losses in the thermal mode and circulation loop during tests according to formulae, W/m or kcal/($m \cdot h$):

$$q_{f,t} = q_n \frac{t_{f,t}^{a,a} + t_{r,t}^{a,a} - 2t_{g,t}^{m,a}}{t_f^{a,a} + t_r^{a,a} - 2t_g^{a,a}}, \quad (6)$$

$$q_{n.f.t} = q_{n.f} \frac{t_{f.t}^{a.a} - t_{a.t}^{m.a}}{t_f^{a.a} - t_a^{a.a}}, \quad (7)$$

$$q_{n.r.t} = q_{n.r} \frac{t_{r.t}^{a.a} - t_{a.t}^{m.a}}{t_r^{a.a} - t_a^{a.a}}. \quad (8)$$

The values q_n , $q_{n.f}$ and $q_{n.r}$ are adopted according to the norms of heat flow density according to the requirements of Decree of the Ministry of Energy of the Russian Federation № 325 dated December 30, 2008 «On work arrangement in the Ministry of Energy of the Russian Federation on approval of norms of process losses during heat transfer», at average annual temperatures of network water and environment.

The average water temperatures in the test mode in the feeding and return pipelines of the tested loop, respectively, are determined according to formulae, °C:

$$t_{f.t}^{a.a} = \frac{t_f^{a.a} + t_r^{a.a}}{2} + \frac{\Delta t_t}{4} + t_{e.t} - t_e^{a.a} \quad (9)$$

$$t_{r.t}^{a.a} = \frac{t_f^{a.a} + t_r^{a.a}}{2} - \frac{\Delta t_t}{4} + t_{e.t} - t_e^{a.a} \quad (10)$$

The rated water flow in the circulation loop assigned for the test period is determined by the formula, t/h:

$$G_t = \frac{Q_t}{c \cdot \Delta t_t} \cdot 10^{-3} \quad (11)$$

here c – specific heat capacity of the grid water, assumed to be 1.0 kcal/(kg· °C).

The estimated hourly grid make-up during the tests is assumed as 0.5 % of the aggregate pipeline capacity within the tested circulation loop.

The expected time of the water flow through the tested circulating loop is determined by the formula, h:

$$\tau_\kappa = \frac{V \cdot \rho \cdot 10^{-3}}{G_t} \quad (12)$$

here V – aggregate pipeline volume of the tested loop, m³; G_t – rated water consumption during the test, t/h; ρ – water density in the tested loop at the average water temperature.

Actual heat losses in the feeding and return pipelines for each section of the tested loop are determined by formulae, kcal/h:

$$Q_{f.t} = c \cdot (G_c - \frac{G_f}{4}) \cdot (t_f^n - t_f^k) \cdot 10^3 \quad (13)$$

$$Q_{r.t} = c \cdot (G_c - \frac{3G_f}{4}) \cdot (t_r^n - t_r^k) \cdot 10^3 \quad (14)$$

here G_c – average flow rate of the grid water in the feeding pipeline at the outlet of the CHP plant, t/h; G_f – average make-up water flow rate, t/h; t_f^n and t_f^f – average water temperatures at both ends of the feeding pipeline in the section, °C; t_f^k and t_r^k – average water temperatures at both ends of the feeding pipeline in the section, °C.

3 Results

Tests of the main pipelines from the CHP plant to the thermal chamber TC 6-21A were carried out in the period of June 18 till June 20. The temperature wave travel over the tested loop amounted to 25 hours and 40 minutes.

The average temperature of the grid water at the exit from the CHP unit was 73.8 °C, with the inlet temperature being 61.4 °C. The water temperature at the end of the section at the

circulation jumper in TC 6-21 was 67.6 °C. Inside the thermal chamber TC 6-9 $t_l = 70.7$ °C, $t_l = 64.5$ °C.

Within the temperature wave mode, the maximum temperature of the grid water in the feeding pipeline at the outlet of the boiler plant was 85.2 °C.

The average temperature of the ambient air within the testing period made up $t_n^{m.t} = 16.0$ °C, ground temperature at the middle laying depth made up $t_g^{m.t} = 5.0$ °C.

The average flow rate of network water in the feeding pipeline at the outlet of the CHP plant was 84.6 t/h, and the flow rate of make-up water was 6.0 t/h.

Resulting from the instrumental measurements during the test:
 $t_a^{a.a} = 4.6$ °C; $t_n^{m.t} = 16.0$ °C; $t_f^{a.a} = 79.1$ °C; $t_r^{a.a} = 48.9$ °C; $G_c = 84,6$ t/h; $G_f = 6.0$ t/h; $t_f^n = 73.8$ °C (CHP); $t_f = 70.7$ °C (TC 6-9); $t_f^k = 67.6$ °C (TC 6-21A); $t_r^n = 67.6$ °C (TC 6-21A); $t_r = 64.5$ °C (TC 6-9); $t_r^k = 61.4$ °C (CHP).

4 Discussion

The calculation findings of actual losses are summed up in Table 2.

Table 2. Calculation findings of actual losses.

Network section	Estimated flow rate for grid water, <i>t/h</i>	Water temperature at the beginning and end of the section, °C, <i>t_ft_r</i>		Actual heat losses, kcal/h
Feeding pipeline				
CHP – downdrop to the duct	83.1	73.8	71.4	199440
Downdrop to the duct – TC 6-9	83.1	71.4	70.7	58170
TC 6-9 – TC 6-13	83.1	70.7	69.2	124650
TC 6-13 – TC 6-15	83.1	69.2	69.0	16620
TC 6-15 – TC 6-19	83.1	69.0	68.1	74790
TC 6-19 – TC 6-21A	83.1	68.1	67.6	41550
Return pipeline				
TC 6-21 – TC 6-19	80.1	67.6	67.1	40050
TC 6-19 – TC 6-15	80.1	67.1	66.2	72090
TC 6-15 – TC 6-13	80.1	66.2	66.0	16020
TC 6-13 – TC 6-9	80.1	66.0	64.5	120150
TC 6-9 – downdrop to the duct	80.1	64.5	63.8	56070
Downdrop to the duct – CHP-2	80.1	63.8	61.4	192240

The actual heat losses for all tested sections of the heat supply network are converted to the annual average operating conditions using the formulae, kcal/h:

$$Q_{n.t}^{a.a} = \frac{Q_{f.t}(t_f^{a.a} - t_g^{a.a}) + Q_{r.t}(t_r^{a.a} - t_g^{a.a})}{\frac{1}{4}(t_f^n + t_f^k + t_r^n + t_r^k) - t_{g.t}}$$

(15)

for underground routing sections, total of the feeding and return pipelines:

$$Q_{n.f.t}^{a.a} = \frac{Q_{f.t}(t_f^{a.a} - t_a^{a.a})}{\frac{1}{2}(t_f^n + t_f^k) - t_{a.t}}, \quad Q_{n.r.t}^{a.a} = \frac{Q_{r.t}(t_r^{a.a} - t_a^{a.a})}{\frac{1}{2}(t_r^n + t_r^k) - t_{a.t}}$$

(16)

here $t_{g.t}$ and $t_{a.t}$ – ground temperature and ambient temperature, average for the testing period, °C.

Values of average annual heat losses by standards for the tested sections of a given heat supply network are determined according to formulae, kcal/h:

- for underground routing sections: $Q_n^{a.a} = \Sigma \beta \cdot q_n \cdot L$;
- for above-ground routing sections: $Q_{n.f}^{a.a} = \Sigma \beta \cdot q_{n.f} \cdot L$ and $Q_{n.r}^{a.a} = \Sigma \beta \cdot q_{n.r} \cdot L$.

The ratios of actual to norm-defined heat losses are determined by formulae:

- for underground routing sections $K = \frac{Q_{n,t}^{a,a}}{Q_n^{a,a}};$

- for above-ground routing sections $K_f = \frac{Q_{n,f,t}^{a,a}}{Q_{n,f}^{a,a}}$ and $K_r = \frac{Q_{n,r,t}^{a,a}}{Q_{n,r}^{a,a}}.$

The calculation findings for average annual heat losses are summed up in Table 3.

Table 3. Calculation findings for average annual heat losses.

Normative losses, Diameter, (year of routing) $l, m \beta q, kcal/m \cdot h Q_n, kcal/h$					Remarks
CHP - TC 6-9					
800 (above-ground before 1990)	974.5	1.15	173.76	194728	Feeding pipeline
800 (above-ground before 1990)	974.5	1.15	134.08	150260	Return pipeline
800 (duct-type before 1990)	240.0	1.15	323.24	89214	
TC 6-9 – TC 6-21A					
700 (duct-type before 1990)	559.0	1.15	289.68	186221	
700 (duct-type before 2012)	280.0	1.15	115.36	37146	
700 (duct-type before 1990)	331.1	1.15	289.68	110300	
600 (duct-type before 1990)	258.0	1.15	262.12	61192	
Total				829061	

5 Conclusions

The comparison results for heat losses during the tests are stated in Table 4.

Table 4. Comparison results for heat losses during the tests.

Network section	Actual heat losses corrected to average annual conditions, kcal/h	Norm-defined heat losses corrected to average annual conditions, kcal/h	Ratio of actual to norm-defined heat losses, K
CHP – dropdown to the duct	262514	194728	1.35
	182752	150260	1.22
Dropdown to the duct – TC 6-9	108177	89214	1.21
TC 6-9 – TC 6-13	231808	186221	1.24
TC 6-13 – TC 6-15	30908	37146	0.83
TC 6-15 – TC 6-19	139085	110300	1.26
TC 6-19 – TC 6-21A	77269	61192	1.26

Following the result of heat supply network testing and finding processing, the actual heat losses exceed the norm-defined values by 1.21÷1.35 times, except for the section TC 6-13- TC 6-15. To reduce heat losses in heat supply networks, it is recommended to restore the partially destroyed thermal insulation of pipelines and fittings. When overhauling heat supply networks, use of the latest insulation materials, such as polyurethane foam, is recommended.

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