Digitalization of heat energy accounting as a means of improving the reliability of heat supply

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Annotation The paper considers the issue of improving the reliability of heat networks due to timely detection of deviations of actual operating conditions from the normative-sections of the heat network located in a humid environment, intensifying the processes of external corrosion of metal. The use of the software complex in real time analyzing and notifying about the operating conditions of thermal networks, deviations from the normative values is proposed. A method for automated calculation of normative values of coolant temperature is developed.

1 Introduction

Reliability is a complex property of an object, which, depending on the purpose of this object and the conditions of its operation, can include several single properties.

One of such single properties are survivability and long-eternity of heat networks. The survivability and durability properties of thermal networks are actually provided by three integral components: protection, detection and response. Here an important task is the timely detection of foci of corrosion in the pipelines.

In the conditions of urban development pipelines of heat networks are laid mainly in underground execution. Statistically, the most significant cause of failure of thermal networks is external corrosion of metal, which, in turn, most often leads to the presence of pipelines of thermal networks in a humid environment or simply in water when the channel is flooded or groundwater rises above the occurrence of pipelines laid by a canal-free method.

In turn, the humidity (flooding) of the cover layer of the thermal insulation of the pipelines of the heating network site is caused by factors, the main of which include: surface water leaks through leaky manhole covers, coolant leaks through the seals of valves and compensators, destroyed channel overlaps. At air convection on overlappings of thermal chambers, adjacent parts of the channel, and also on planes of the panel supports having temperature below dew point, there is a condensation of moisture with the subsequent formation of a drop therefore there is a humidification of the heat-insulating designs concentrated in separate places causing corrosion of metal of pipes.

Traditional methods of increasing the reliability of heat networks, such as hydraulic testing of networks for strength and density in the inter-heating period, major repairs and reconstruction of heat networks are not tools for the rapid search for places of humidification of thermal insulation, but only ensure the maintenance of regulatory reliability.

The solution of a problem of increase of reliability of work of thermal networks, preservation of their working capacity and durability should not be limited to replacement, reconstruction, modernization actually worn out, emergency, not passed hydraulic tests of sites of thermal networks.

It is equally important to maintain the regulatory conditions that determine the durability of pipelines during their operation, namely during the heating period.

An indicator indicating the presence of the pipeline in a humid environment can be a decrease in the temperature of the heat carrier at the end of the section below the normative values, as a result of increased losses of thermal energy. The influence of humidification of thermal radiation on the value of heat losses is given in [1,2] and is estimated by increasing the latter by 2-4 times.

For the purpose of operational search of places of increase of humidity of thermal insulation, the decision on development of a software product is offered.

For the development of software required are 2 conditions: 1) the presence of a heat source and consumers metering devices of thermal energy, equipped with means di-station transmission; 2) a system for the automated collection and storage of data.

In accordance with the requirements of [3] in recent years, the number of metering devices for consumers has increased significantly: in the service area of JSC Tatenergo (Kazan, Republic of Tatarstan) today, more than 98% of thermal energy consumption is determined by commercial metering devices, of which more than 60% are equipped with remote data transmission to the

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company's automated data collection system.

The information delivered to the created software product consists of two temperature fields from the source of thermal energy to the consumers: on the supply (T1) and on the return (T2) pipeline.

For automated detection of abnormal operating conditions of pipelines in the online mode, it is necessary to set the temperature range of consumers corresponding to the norm, taking into account the time of passage of the temperature wave. The purpose of the calculation is to provide the possibility of automated determination of the normative temperature of the coolant at the consumer, taking into account the temperature of the coolant at the outlet of the heat source and the normative losses of thermal energy in thermal networks.

Other things being equal (constant coolant flow rate, constant design characteristics of the heat network), the following dependencies are observed:

$$Q_{\text{пот}} = f(T_{\text{тн}}, T_{\text{нв}}), \quad (1)$$

where $Q_{\text{пот}} -$ losses of thermal energy on the site of the heat network, Gcal/h; $T_{\text{тн}} -$ coolant temperature, °C; $T_{\text{нв}} -$ the actual outdoor air temperature, °C.

In turn:

$$T_{\text{тн}} = f(T_{\text{нв}}) \quad (2)$$

In accordance with [2] the temperature of the coolant in the supply and return pipeline of the heat network, as well as after the mixing unit of the consumer, depending on the outside air temperature are determined by the formulas:

$$t_1 = \left(1 + u_{\text{р}}\right) * t_3 - u_{\text{р}} * t_2 \quad (3)$$

$$t_3 = t_{\text{в}} + 0{,}5 * \left(t_{3\text{р}} - t_{2\text{р}}\right) * \frac{t_{\text{в}} - t_{\text{н}}}{t_{\text{в}} - t_{\text{нр}}} + 0{,}5 * \left(t_{3\text{р}} + t_{2\text{р}} + 2 * t_{\text{в}}\right) * \left(\frac{t_{\text{в}} - t_{\text{н}}}{t_{\text{в}} - t_{\text{нр}}}\right)^{\frac{1}{1+n}} \quad (4)$$

$$t_2 = t_3 - \left(t_{3\text{р}} - t_{2\text{р}}\right) * \frac{t_{\text{в}} - t_{\text{н}}}{t_{\text{в}} - t_{\text{нр}}} \quad (5)$$

where $t_1, t_2, t_3 -$ the temperature of the coolant in the supply, return pipeline of the heat network, after the mixing unit at the input of the consumer at the temperature of the outside air corresponding to $t_{\text{н}}$, °C; $u_{\text{р}} -$ the estimated coefficient of mixing; $t_{\text{в}} -$ estimated indoor air temperature, °C; $t_{\text{нр}} -$ estimated outdoor temperature for heating, °C; index "p" refers to the parameters for the calculation conditions.

In thermal networks of JSC Tatenergo (Kazan) the temperature chart of 135/65°C is applied, the table of temperatures is given on Fig. 1.

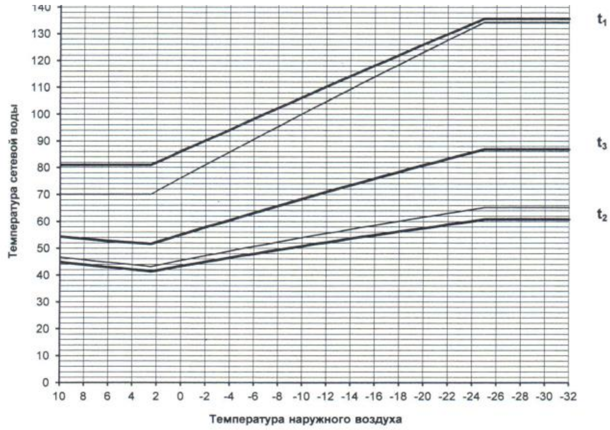

Fig.1-Temperature chart of thermal networks of JSC "Tatenergo", Kazan

The method of calculating the value of normative heat losses in the proper state of thermal insulation and normal operating conditions of thermal networks is given in [4].

The standards of technological losses include losses and costs of energy resources caused by the technical condition of heat pipelines and equipment and technical solutions for reliable provision of consumers with heat energy and the creation of safe operating conditions of heat networks, namely: losses and costs of the coolant (steam, condensate, water) within the established norms; losses of thermal energy by heat transfer through heat-insulating structures of heat pipelines and with losses and costs of the coolant.

Determination of standard technological losses of thermal energy, Gcal, caused by losses of the heat carrier, is made according to the formula:

$$Q_{\text{у.н}} = m_{\text{у.н}} * \rho_o * \text{c} * [b\tau_1 + (1-b)\tau_2 - \tau_{\text{х}}] * n * 10^{-6} (6)$$

where $m_{\text{у.н}}$ - rate of coolant losses due to leakage, m³/h; ρ_o - the density of the coolant at the average temperature of the coolant in the supply and return pipelines of the heat network, kg/m³; b - share of mass flow rate of coolant lost by the supply pipeline of the heat network; τ_1 и τ_2 - average values of coolant temperature in the supply and return pipelines of the heat network according to the temperature schedule of heat load regulation, °C; $\tau_{\text{х}}$ - the average annual value of the temperature of the source water supplied to the heat supply source and used to feed the heat network, °C; c - specific heat of the coolant, kcal/kg °C; n - duration of functioning of heat networks, h.

The standard technological consumption of thermal energy for filling new sections of pipelines and after planned repairs, Gcal, is determined by the formula:

$$Q_{\text{зап}} = 1{,}5 * V_{\text{тр.з}} * \rho_o * \text{c} * [\tau_{\text{зап}} - \tau_{\text{х}}] * 10^{-6}, \quad (7)$$

where $V_{\text{тр.з}}$ - capacity of the filled pipelines of the heat networks operated by the heat network organization, m³; ρ_o - density of water used for filling, kg/m³; $\tau_{\text{зап}}$ - temperature of water used for filling, °C; $\tau_{\text{х}}$ - the temperature of the source water supplied to the heat energy source "x" during the filling period, °C.

Normative technological losses of thermal energy with drains from devices of automatic regulation and protection, Gcal, are defined by the formula:

$$Q_{\text{а.н}} = G_{\text{а.н}} * \rho_o * \text{c} * [\tau_{\text{сл}} - \tau_{\text{х}}] * 10^{-6}, \quad (8)$$

where $G_{\text{а.н}}$ - annual loss of coolant as a result of draining, m³; ρ_o - average annual density of the coolant depending on the place of installation of automatic devices, kg/m³; $\tau_{\text{сл}}$ и $\tau_{\text{х}}$- the temperature of the drained coolant and the source water supplied to the heat supply source during the draining period, °C.

The analysis of these formulas leads to the conclusion that under constant operating conditions, the value of thermal energy losses caused by losses and costs of the coolant is directly dependent on the temperature of the coolant.

Determination of normative technological losses of thermal energy by heat transfer through heat-insulating constructions of pipelines is made on the basis of values of hourly heat losses depending on year of design of heat pipelines, Gcal:

$$\text{Q}_{\text{из.н.год}} = \sum(\text{q}_{\text{из.н}} * \text{L} * \text{Бета}) * n * 10^{-6} \quad (9)$$

where $\text{q}_{\text{из.н}} -$ specific hourly heat losses by pipelines of each diameter determined by recalculation of tabular values of norms of hourly heat losses on average seasonal operating conditions, kcal/hm; $\text{L} -$ the length of the pipe section thermal networks, m; Бета - the coefficient of local heat losses, which takes into account the thermal losses of shut-off and other valves, compensators and supports (is applied 1.2 at the diameter of pipelines up to 150 mm and 1.15 - at the diameter of 150 mm and more, as well as at all diameters of pipelines without channel laying, regardless of the year of design).

Thus, the change in the value of heat losses for a particular section of the heat network during the heating period is associated only with a change in the temperature of the coolant, due to a change in the temperature of the outside air.

The temperature of the coolant at the end of the heat network section, °C at the normative value of heat losses:

$$t_{\text{к}} = t_{\text{н}} - \frac{Q_{\text{пот}}}{G*n}, \quad (10)$$

where $\text{t}_{\text{н}} -$ coolant temperature at the beginning of the phase °C; $\text{Q}_{\text{пот}} -$ the value of the normative heat losses, converted to the actual temperature of the coolant at the beginning of the site, Gcal; $\text{G} -$ design flow rate of the heat carrier on a site of a heat network, m³/h.

The value of the calculated coolant flow rate for each section is taken according to the results of hydraulic calculation.

In turn, the dependence of the value of heat losses on the temperature of the coolant is determined by the formulas (6)-(9) and the method of least squares:

$$\text{Q}_{\text{пот}} = \text{f}(\text{ t}_{\text{н}}) = Q^{max}_{\text{пот}} * \frac{\left(-3{,}85+0{,}77*t^{\text{ф}}_{\text{тн}}\right)+\left(37{,}57+0{,}46*t^{\text{ф}}_{\text{тн}}\right)}{100*2} * n \quad (11)$$

where $Q^{max}_{\text{пот}} -$ the calculated maximum value of heat losses on the site of the heat network at the calculated outdoor temperature for heating, taken by calculation in accordance with [4], Gcal/h; $t^{\text{ф}}_{\text{тн}}$- the actual temperature of the coolant at the beginning of the site at the current time, °C.

During the heating season, the temperature of the coolant varies depending on the temperature of the outside air. The temperature change of the coolant at the end of the section occurs with a delay in relation to the temperature change at the beginning of the section for the time of the temperature wave.

The formula takes the form:

$$\text{t}_{\text{к}} = t^{\text{ф}}_{\text{тн}} - Q^{max}_{\text{пот}} * \frac{\left(33{,}72+0{,}3542*t^{\text{ф}}_{\text{тн}}\right)}{200*G} \pm \Delta\text{t}^{\tau}_{\text{н}} \quad (12)$$

where $\Delta\text{t}^{\tau}_{\text{н}} -$ the temperature difference of the coolant at the beginning of the section taking into account the time of passage of the temperature wave, $G -$ coolant flow rate on the site, taken according to the hydraulic calculation, m³/h.

The time of passage of the temperature wave is determined by the statistical data of the actual temperature distribution of the heat carrier at different points of the studied heat network in Fig. 2, table. 1.

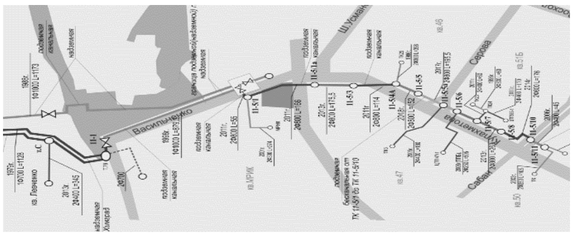

Fig.2-Scheme of the investigated section of the heating network

Table 1. Calculation of the coolant passage time (by fixing the passage of the temperature wave in time) from P-16

Measuring point	The transit time of the coolant, min.
Usmanov street, 33	58,3
Usmanov street, 33/1	35,1
Usmanov street, 33/2	59
Serov street, 6/1	45,66
Kulakhmetova street, 22	49,2
Baccalaureate street, 44a	54,09
Batyrshina street, 16	124,7
Batyrshina street, 22	225,1
Saban street, 7a	57,6

2 Description of digital product units (modules)

Schematically, a digital product can be divided into blocks (modules), each of which will perform a specific task.

Block 1. Input parameters of the heat carrier from a source of thermal energy and in points of release of thermal energy to consumers.

The source of thermal energy is understood as an element of the heating network (CHP, boiler room, heat chamber, etc.), which is the reference point of the initial temperature of the coolant T1 in relation to which the program analysis of thermal energy losses (deviations of the coolant temperature from the normalized value) is performed.

In terms of collecting the parameters of the coolant: thermal insights CHP, thermal insights boiler room, pavilions of heat networks; heat chamber; an observation chamber; grips heating; objects consumers.

Input parameter: coolant temperature in the supply (T1) and return (T2) pipelines of the heat network.

Discreteness of automated parameters collection: depending on the type and scale of the heat supply system, but at least 1 RA-per day.

The array of input parameters is stored on the server of the system for remote collection of thermal energy parameter readings with connection to the consumer's heat supply facility (indicating the address of the facility).

Block 2. Interface of input parameters with objects of heat supply on the map of the district of heat networks.

The block provides an interactive map of heat supply facilities in the district of heat networks with reference to it: sources of heat energy, control devices for measuring the parameters of heat transfer in individual elements of the heat network, subscriber facilities.

Block 3. Analysis of the deviation of the current input parameters from the norm, assessment of the reliability of heat supply to consumers with the construction of a mathematical model of the parameters of the heating system (Fig.3).

The analysis of deviation of current input parameters from norm is made on each object of heat supply of consumers.

The analysis is based on the fact that during transportation of the coolant from thermal energy source to the object of a heat supply of consumers inevitably, technological losses of heating energy, resulting in reducing the temperature TEP of monocytes. The rate of decrease in the coolant temperature is calculated based on the level of normalized values of heat energy losses in the supply lines of the heating network through the insulation constructions of pipelines with a constant flow rate of the coolant in the network.

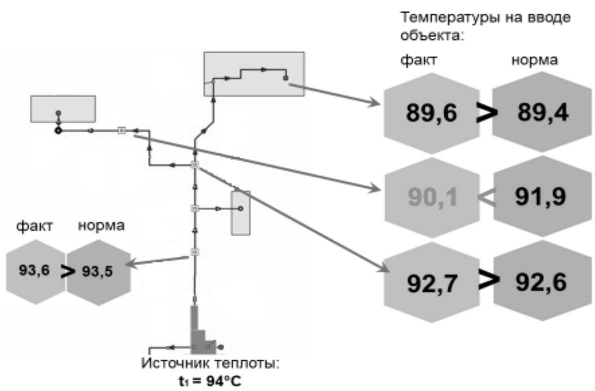

Fig.3-Scheme of analysis of deviation of the current input parameters from the norm

To group the set of obtained values of deviations of the actual temperature of the coolant from its normalized value, a dimensionless parameter φ is introduced, showing the materiality of the temperature deviation, determined by the formula:

$$\varphi = \left(t_к^ф - t_к\right)/\mu \tag{13}$$

where $t_к^ф$ – actual coolant temperature at the end of the section, °C, μ - the coefficient of materiality of the deviation is numerically equal to the number of degrees Celsius, the deviation by the value of which is significant.

The following groups of object States are possible, presented in the table. 2.

Table 2. Verification of object States

Value φ	Condition heat supply
$\varphi \geq 0$	there is no violation of the thermal insulation layer
$-1 \leq \varphi < 0$	violation of the thermal insulation layer is available
$-2 \leq \varphi < -1$	humidification of the thermal insulation layer
$-\frac{t_к}{\mu} \leq \varphi < -2$	strong wetting of the thermal insulation layer

Block 4. Visualization of information on points of formation of excess losses of heat energy, indicators of reliability of heat supply of consumers and a problem site of a heating system

Each object in the interactive map should be displayed as a dynamically changing color element, for example,

- for the layer T1 according to the decrease of φ from black to red;

- for layer T2 in ascending order from green to yellow.

Visualization is provided on an Interactive map of the district heating networks with reference to the objects of heat supply.

For personnel shall be provided the opportunity to work in the "Interactive map" Kazan: by clicking courses-set on a necessary element of the thermal network to obtain necessary information in the current mode according to the actual parameters of the heat carrier on selected sections of heat networks collected with the con-monitoring of meters installed at the collectors of stations on the borders of the sections of teplovogo, the power districts, blocks, heat chambers, facilities, and regulatory parameters.

Block 5. Data archiving and reporting on sections of the heating system, where the parameters of the coolant

This block contains the statistics of the coolant parameters, data analysis parameters of the coolant and arose from the standing in heat networks and for a lot of consumers.

3 Conclusion

The task of timely identification of sections of pipelines of heat networks, which are in abnormal operating conditions, with the subsequent elimination of the threat of reliability is an urgent task for heat supply organizations.

It is proposed to introduce a software package, which, based on the readings of heat energy metering devices at consumers and at the source of heat energy, will allow real-time detection of abnormal operating conditions – humidification of pipelines of the heat network.

The method of determination of standard temperatures of the heat carrier at consumers is developed.

Application of the digital product allows to increase reliability of heat supply of consumers by timely identification of places of humidification of thermal insulation, and also can be used for preparation of the plan of pits of networks in the inter-heating period for research of degree of a thinning of pipelines of a heating system.

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