Determination of additional factors in assessing the reliability of heat supply systems

I G Akhmetova, A A Kalyutik, A V Fedukhin, O V Derevianko, L R Mukhametova

1Federal State Budgetary Educational Institution of Higher Education “Kazan State Power Engineering University”, Kazan, Krasnoselskaya street, 51
2Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya 29, Saint Petersburg, 195251 Russia
3National Research University «Moscow Power Engineering Institute» Krasnokazarmennaya 14, Moscow, 111250 Russia

Irina_akhmetova@mail.ru

Annotation. As a result of the research, additional factors that significantly influenced the reliability of the consumers’ heat supply were assessed, an assessment of the influence of these factors on the reliability of the operation of the heat network was made. The influence of additional factors is taken into account when developing a new methodology and algorithm for calculating the reliability of consumers’ heat supply; a program for calculating the reliability of consumers’ heat supply was developed.

Determination of factors unaccounted for in the existing methodology

To determine the reliability of heat supply to consumers, the initial data: failure rate and average recovery time of heat pipelines and equipment should be taken into account [1–8].

The actual level of reliability of the heating system should be assessed on the basis of statistical data on failures of the system components.

To assess the reliability of existing and newly developed schemes of heat networks, a technique described in [9,10] is developed, which allows to determine the availability and probability of failure of the heat network on the basis of such initial data as the length, diameter and duration of operation of the pipeline system sections.

The disadvantage of this approach is that the calculations do not take into account a number of factors that directly affect the reliability of the heating system.

The aim of the study was to identify and take into account additional factors, as well as the development of a new method of calculating reliability indicators.

Research problems are the following:
- Determination of additional factors affecting the reliability of heat supply to consumers;
- Assessment of the impact of these factors on the reliability of the heat network;
- Taking into account the influence of these factors in the development of a new method of calculating the reliability of heat supply to consumers;
- Development of the program of reliability indicators calculation for consumer heat supply on
The basis of the new methodology.

It was assumed that the failure rate of the elements of the heat network (in addition to the service life) is influenced by the following factors: the residual thickness of the metal of the pipeline, the previous gusts, the corrosion activity of the soil, the presence of the channel flooding, the material of the pipeline, the presence of intersections with communications, the percentage of failure of the pipeline [7,11–21].

In order to solve the issue of including factors in the new methodology, the analysis of statistical data on gusts in different parts of the heat network of the city of Kazan was carried out [10].

Information on gusts was grouped by a set of factors. The influence on the failure rate of the elements of the heat network was revealed for the following factors: the residual thickness of the metal walls of the pipeline (K1), the presence of previous gusts (K2), the corrosion activity of the soil (K3), the presence of the channel flooding (K4), the presence of intersections with communications (K5). The influence of these factors on the reliability of heat supply of consumers was evaluated [10].

To take into account the factors identified in the existing methodology was introduced the coefficient of additional factors:

\[
K_i = f(K_1; K_2; K_3; K_4; K_5)
\]  

With the calculated values of the coefficient \( K_i \) it is possible to estimate the effect of additional factors on the failure rate of the heat network sections.

The linear dependence of the coefficient of additional factors \( K_i \) on the residual wall thickness of the pipeline metal was revealed during the comparison of the parameters (figure 1):

![Figure 1. Influence of residual wall thickness of the pipeline metal on the coefficient of additional factors \( K_i \)](image)

The next stage was the failure analysis, which includes two additional factors—the thickness of the pipeline metal and the corrosion activity of the soil (figure 2):

![Figure 2. The influence of parameters K1 and K3 on a coefficient by accounting additional factors \( K_i \)](image)
Next analysis was performed, which includes two additional factors—the thickness of the pipeline metal and the presence of the channel flooding (figure 3).

![Figure 3](image1.png)

Figure 3. The influence of parameters K1 and K4 on the coefficient by accounting additional factors Ki

The next sample included parameters—the thickness of the pipeline metal and the presence of intersections with communications.

The functional dependence of the coefficient Ki on the parameters K1 and K5 is shown in figure 4.

![Figure 4](image2.png)

Figure 4. The influence of parameters K1 and K5 on the coefficient by accounting additional factors Ki

The final analysis of failures was combined with five parameters—the thickness of the pipeline metal, the presence of previous gusts at the site, the corrosion activity of the soil, the presence of the channel flooding and the presence of intersections with communications.

The functional dependence of the coefficient Ki on the parameters K1, K2, K3, K4 and K5 is shown in figure 5.

![Figure 5](image3.png)

Figure 5. The influence of parameters K1, K2, K3, K4 and K5 on the coefficient by accounting additional factors Ki
Consideration of the influence of parameters not included in the analysis

The remaining isolated cases of refusal of sections of heating networks (for example, the combination of K1-K2, K1-K3,-K5, etc.) that were not included in the analysis were taken into account using a General functional dependency is built according to the values of the coefficient Ki (figure 6).

Figure 6. General functional dependence in all cases bounce sections of a heating system

Table 1. Functions of influence of additional parameters

| №  | The presence of the factors | Functional dependence          |
|----|----------------------------|--------------------------------|
| 1  | K1                         | $K_i = 0.00673 \cdot K1 + 0.954$ |
| 2  | K1, K3                     | $K_i = 0.00664 \cdot K1 + 0.964$ |
| 3  | K1, K4                     | $K_i = 0.00494 \cdot K1 + 0.949$ |
| 4  | K1, K5                     | $K_i = 0.00641 \cdot K1 + 0.973$ |
| 5  | K1, K2, K3, K4, K5         | $K_i = 0.00689 \cdot K1 + 0.905$ |
| 6  | A combination of factors different from options 1-5 | $K_i = 0.00704 \cdot K1 + 0.918$ |

Figure 7 compares the theoretical and experimental values of the coefficient of additional factors $K_i$.

Figure 7. Theoretical and experimental values of the coefficients taking into account additional factors $K_i$

Conclusion

As can be seen from the graph, the deviation of theoretical values from the experimental data is not so significant – the average error does not exceed 1.13%. Therefore, the obtained functional dependences can be used to calculate the reliability of heat supply to consumers.

Acknowledgments

The work was supported by the Ministry of Education and Science of the Russian Federation on
fundamental scientific research (Agreement No. №13.6994.2017/БЧ) «Development of a methodology for determining the reliability of a heat supply system to improve energy efficiency».

References
[1] Gorshkov A and Murgul V 2018 Calculation of Heat Energy Consumption by a Typical Historical Building with a Courtyard Adv. Intell. Syst. Comput. 692 577–91
[2] Kostenko V A, Gafiyatullina N M, Semchuk A A and Kukolev M I 2016 Geothermal heat pump in the passive house concept Mag. Civ. Eng. 68 18–25
[3] Nefedova A, Bykova J, Kosov S and Petrichenko M 2015 Selection of individual automatic heat supply unit of ecomatic LLC vol 117(Elsevier Ltd)pp 1102–11
[4] Borodinecs A, Zemitis J, Sorokins J, Baranova D V and Sovetnikov D O 2016 Renovation need for apartment buildings in Latvia Mag. Civ. Eng. 68 58–64
[5] Akhmetova I, Chichirova N and Derevianko O 2017 Revisiting heat losses calculation at district heating network Int. J. Civ. Eng. Technol. 8 694–702
[6] Murgul V 2016 Assessment of the Energy - Efficient Modernization of Residential Historical Buildings in Kiev vol 73(EDP Sciences)
[7] Strogonov K, Fedyukhin A, Stepanova T and Derevianko O 2018 Estimation of Practical Significance for Application of Composite Pipes in Heat and Polyurethane Materials Adv. Intell. Syst. Comput. 692 1024–35
[8] Soldatenko V S, Smagin V A, Gusenitsa Y N, Gera V I and Soldatenko T N 2017 The method of calculation for the period of checking utility systems Mag. Civ. Eng. 70 72–83
[9] Akhmetova I G and Mukhametova L R 2017 Innovative development of the regional economy Innovative clusters in the digital economy: theory and practice Proc. of the Scientific and practical conference with international participation (Saint Petersburg, May 17-22)
[10] Akhmetova I G and Chichirova N D 2016 Evolution of Thermal Insulation Type Impact on the Value of Regulatory Heat Losses in Heat and Power Systems J. Eng. Appl. Sci. 11 2946–9
[11] Kiselev V G 1999 Information and engineering support of pipeline electrochemical protection (Saint Petersburg: SPbGUVRK)
[12] Turichin G, Kuznetsov M, Sokolov M and Salminen A 2015 Hybrid Laser Arc Welding of X80 Steel: Influence of Welding Speed and Preheating on the Microstructure and Mechanical Properties vol 78(Elsevier B.V.)pp 35–44
[13] Muravyeva L and Vatin N 2016 Elaboration of the Method for Safety Assessment of Subsea Pipeline with Longitudinal Buckling Adv. Civ. Eng. 2016
[14] Silva C C, De Assis J T, Philippov S and Farias J P 2016 Residual stress, microstructure and hardness of thin-walled low-carbon steel pipes welded manually Mater. Res. 19 1215–25
[15] Kondrat’ev S Y and Shvetsov O V 2018 Technological and Operational Features of Drill Pipes from Aluminum Alloys 2024 and 1953 Met. Sci. Heat Treat. 1–7
[16] Davydov V V, Myazin N S, Logunov S E and Fadeenko V B 2018 A Contactless Method for Testing Inner Walls of Pipelines Russ. J. Nondestruct. Test. 54 213–21
[17] Gritskievich M S and Garbaruk A V 2017 Influence of upstream pipe bends on the turbulent heat and mass transfer in T-junctions vol 891(Institute of Physics Publishing)
[18] Muravyeva L V 2017 Simulation modeling in pipeline safety assessment (CRC Press/Balkema) pp 213–8
[19] Loktionova E A and Miftakhova D R 2017 Fluid filtration in the clogged pressure pipelines Mag. Civ. Eng. 76 214–24
[20] Kitanin É L, Smirnov Y A and Lebedev M E 2016 Development of Flow and Heat Transfer During Filling a Pipeline with Water at the Pipe Wall Temperature Below the Freezing Point J. Eng. Phys. Thermophys. 89 808–14
[21] Vasilyev A, Rudskoy A, Kolbasnikov N, Sokolov S and Sokolov D 2012 Physical and mathematical modeling of austenite microstructure evolution processes developing in linke pipe steels under hot rolling 706–709 2836–41