6. Singh, W. R. The preferential composting of water fern and a reduction of the mobility of potential toxic elements in a rotary drum reactor [Text] / W. R. Singh, A. S. Kalamdhad, J. Singh // Process Safety and Environmental Protection. – 2016. – Vol. 102. – P. 485–494. doi: 10.1016/j.psep.2016.05.002
7. Di Maria, F. Energy production from mechanical biological treatment and Composting plants exploiting solid anaerobic digestion batch: An Italian case study [Text] / F. Di Maria, A. Sordi, C. Micale // Energy Conversion and Management. – 2012. – Vol. 56. – P. 112–120. doi: 10.1016/j.enconman.2011.11.023
8. Kumar Singh, Y. Maturation of primary stabilized compost from rotary drum composter [Text] / Y. Kumar Singh, A. S. Kalamdhad, M. Ali, A. A. Kazmi // Resources, Conservation and Recycling. – 2009. – Vol. 53, Issue 7. – P. 386–392. doi: 10.1016/j.resconrec.2009.02.004
9. Shevchenko, I. Justification of external radius the drum aerator compost mixes [Text] / I. Shevchenko, A. Kovyazin, V. Haritonov // Tekhnichni systemy i tekhnolohiyi tvarynnytstva: Visnyk kharkivs'koho Natsional'noho tekhnichnoho universytetu sil's'koho hospodarstva imeni Petra Vasylenka. – 2013. – Issue 132. – P. 292–296.
10. Shevchenko, I. Teoretycheskoe obosnovanye parametrov aėratora kompostnykh smesey [Text] / I. Shevchenko, A. Kovyazin, V. Haritonov, I. Velychko // Zb. nauk. prats' IMT NAAN «Mekhanizatsiya, ekolohizatsiya ta konvertatsiya biosyrovyny u tvarynnytstvi». – 2012. – Issue 2 (10). – P. 92–109.
11. Pavlenko, S. Novitni tekhnichni zasoby pererobky orhanichnykh vidkhodiv [Text] / S. I. Pavlenko, O. O. Lyashenko, A. A. Povolots'kyi, Yu. A. Filonenko // Visnyk KhNTUSH im. P. Vasylenka «Tekhnichni systemy i tekhnolohiyi tvarynnytstva». – 2013. – Issue 132. – P. 193–200.
12. Pavlenko, S. Monitoring of the market and technical means of production solid organic fertilizer [Text] / S. Pavlenko, V. Dudin, R. Akimenko // Visnyk KhNTUSH im. P. Vasylenka «Tekhnichni systemy i tekhnolohiyi tvarynnytstva». – 2016. – Issue 170. – P. 34–45.

UDC 628.14
DOI: 10.15587/1729-4061.2017.101262

ESTIMATION OF FAILURE-FREE OPERATION OF METAL WATER PIPES

A. Matyash
PhD*
I. Usenko
PhD, Associate Professor*
E-mail: irina__usenko@ukr.net
R. Myagkohlib
PhD, Associate Professor
Department of Heat and Gas Supply, Ventilation and Heat Power Engineering**
E-mail: myagkohlib@gmail.com
S. Kostenko
Assistant*
*Department of hydraulics, water supply and sewerage**
**Poltava National Technical Yuri Kondratyuk University
Pershotravnevyi ave., 24, Poltava, Ukraine, 36011

Досліджено причини відмов та значення питомого параметра потоку відмов металевих водопровідних труб. Аналіз статистичних даних щодо відмов дозволив побудувати залежності питомого параметра потоку відмов від діаметра трубопровода. Виконано порівняльний аналіз отриманих даних та розроблені відповідні висновки та пропозиції. Отримані дані корисні для розрахунків надійності систем водопостачання

Ключеві слова: водопостачання, водопровідні мережі, металеві труби, надійність, безвідмовність, причини відмов труб

Исследованы причины отказов и значения удельного параметра потока отказов металлических водопроводных труб. Анализ статистических данных об отказах позволил построить зависимости удельного параметра потока отказов от диаметра трубопровода. Выполнен сравнительный анализ полученных данных и разработаны соответствующие выводы и предложения. Полученные данные полезны для расчетов надежности систем водоснабжения

Ключевые слова: водоснабжения, водопроводные сети, металлические трубы, надежность, безотказность, причины отказов труб

1. Introduction

Water supply networks are the most extended water supply system element, and, therefore, the most vulnerable in terms of reliability. Emergency situations in water supply networks lead to many negative consequences for both utilities companies and consumers of water. On the one hand, damaged sections in the existing water supply networks lead to the loss of a valuable resource – water, and additional financial expenses to eliminate accidents. On the other hand, it causes discontent of the population due to the shortfall of water in required amount to meet their needs in a timely manner. No less distrurbing this issue for industrial enterprises when a break in water supply leads to losses due to unsatisfied demand for products. Given this, consumers of water, both legal entities and physical persons, always put forward requirements regarding the reliability of water supply. These requirements can be formulated differently, but, at present, it is impossible to perform a comparison of the specified requirements to the normative parameters of reliability of water supply. Thus, DBN V.2.5-74:2013 «Water supply. Outdoor networks and facilities» [1] formulates requirements only for the duration of interruptions in water supply (Table 1) and does not indicate the frequency of such interruptions.

Table 1

Categories of centralized water supply systems by reliability or by a degree of water supply provision

Category of the centralized water supply systems	Conditions of system operation by permissible limits		
	Water supply decrease		Break in water supply
	%	time	
1	<30	<3 days	Allowed during period of shutdown of damaged and switching on the reserve system elements <10 min
2	<30	<10 days	Allowed during period of shutdown of damaged and switching on the reserve system elements and the repair <6 hours
3	<30	<15 days	Allowed during period of shutdown of damaged and switching on the reserve system elements and the repair <24 hours

At the same time, in accordance with the Decree of Cabinet of Ministers of Ukraine [2], it is stipulated that: the absence of water for consumers should not last lpnger than 6 hours per day and not oftener than 2 times per month. The given Decree is generic in nature and it does not indicate for which consumers (an individual person or a populated area) these requirements are valid. The above aspects limit working out measures to improve the reliability of water supply system as whole.

2. Literature review and problem statement

At present, the issue of reliability of separate structures of water complex is rather important for both scientists and specialists in the field of water supply. This factor is important because it is directly linked to the efficiency and quality service of water supply to consumers.

Development of methods and techniques for calculating the reliability was addressed by a significant amount of scientific papers. It is proposed to determine the level of reliability for water supply systems by the coefficients of readiness K_R or failure-free operation $K_{F.O.}$ [3]. However, in order to determine a coefficient of readiness, it is necessary to know the average duration of the elimination of breakdown (mean duration of repair). Article [4] proposed an improved classification of consumers and water-supply systems by reliability (Table 2) than that of DBN V.2.5-74:2013 and it establishes regulatory requirements concerning the reliability of water supply as a technological process. The techniques, devised in [3, 4], to calculate reliability of the water supply facilities, make it possible to calculate the quantitative indicators of reliability. This, in turn, allows comparing them to the normative requirements. On the other hand, it is necessary to continue to develop methods and procedures for calculating the reliability of water supply facilities with regard to the specified requirements. Calculations of reliability of separate elements of the water supply systems in [5, 6] are performed based on theoretical principles only. A technique for the calculation of reliability in [7] can only be used for water supply systems with distributed networks. In order to see an actual picture of reliability of metal water pipes, it is necessary to carry out research additionally for each city [8].

Considerable attention of scientists is paid to collecting and analyzing statistical data on failures in water-supply networks. Papers [9, 10] established the causes of failures in water supply pipes and the main factors influencing the reliability of separate structures in the water system of Moscow (Russia) and Babylon (Iraq). Based on the collected statistical data, an analysis of pipeline failures depending on the diameter and material of pipes is conducted (Fig. 1).

Table 2

Classification of consumers and water-supply systems by reliability

No. of entry	Groups and categories of water supply systems	Values of essential and basic reliability indicators		
1	First group Subgroup A – water supply systems of dangerous industries	Maximum probability of failure-free operation during service life max $P(T_l)$		
	Subgroup B – fire protection water supply systems	Maximum coefficient of operational readiness over 3 hours of fire site localization $K_{O.R.}=K_R \cdot P(\tau)$		
2	Second group Centralized water supply systems of populated areas at number of residents	Time to failure T, hours	Average time of operation recovery T_R, hours	Coefficinet of readiness K_R
	town category 1, N≥50 thousand people	T≥2160 hours (3 months)	$T_R \leq 3$ hours	0.99861
	town category 2, 10 thousand people≤N≤50 thousand people	T≥360 hours (0.5 month)	$T_R \leq 6$ hours	0.98361
	settlement category 3, N<10 thousand people	T≥360 hours (0.5 month)	$T_R \leq 24$ hours	0.93750

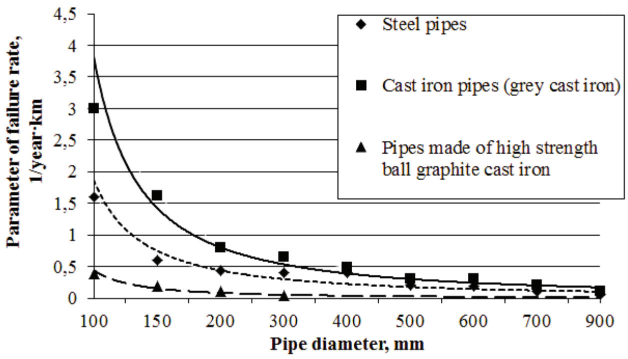

Fig. 1. Dependence of specific parameter of failure rate on the pipe diameter

However, using these results of reliability of water supply pipes for other cities is difficult. When obtaining reliable results for reliability in other localities, there are a number of local factors: water corrosion, operation quality of water supply networks, geological conditions and others.

It is a relevant task to model failures of water supply system structures depending on the many influences: period of operation, a change in pressure in a water supply network, maintenance of systems, human factor, and others. Articles of scientists [11, 12] presented analyses and methods that make it possible to establish causal relationships of failures in the form of a «failure matrix tree». Assessing the reliability of water supply system as a renewable technical system made it possible to build statistical models of failure intensity considering time and to display graphically in the form of a reliability curve [13]. Any theoretical research [11–13] should be verified by practical experiment. For this purpose, it is necessary to analyze the types of failures in separate facilities of water supply system. Paper [14] conducted a detailed analysis of failures of metal pipes under the influence of corrosion. However, the practice of exploiting the pipelines suggests that the causes of failure in pipelines may be due to a number of other reasons.

Theoretical methods of calculating the reliability are based on the existing mathematical models of the process of functioning of renewable elements. However, in order to verify theoretical hypotheses about the failures and renewal of separate elements, it is necessary to collect statistical data based on the operational practice. Practical methods are based on statistical data on reliability of the elements obtained during operation. Therefore, the more statistical data on operation the better results of calculating the reliability of water supply facilities.

3. The aim and tasks of research

The aim of present work is to evaluate reliability of water supply pipes on the example of water supply system in the city of Kremenchuk, Poltava oblast (Ukraine).

To accomplish the set aim, the following tasks had to be solved:

– to define the main factors that lead to the failures of metal water pipes (qualitative analysis);

– to calculate basic indicators of failure-free operation of metal water pipes (quantitative analysis);

– to determine the dependences of parameter of failure rate on the diameter of pipes based on statistical data on the damages of metal pipes.

4. Materials and methods for examining the failure-free operation of metal water pipes

4. 1. Materials and methods for examining the failures of metal water pipes

In order to perform research into evaluation of reliability of metal water pipes, we used information on the damages of water supply networks of the examined object. A local «Vodokanal» registers information about the failures of water system elements at the end of each day by the foremen of respective stations and submits these data to a unified database. To evaluate a failure-free operation of pipes in the sections of water networks, we have collected and processed statistical data from the city of Kremenchuk, Poltava oblast (Ukraine). We employed data on the damages to metal pipes with a diameter of 50...300 mm over 7 years. Prior to combining statistical data into the general sample, we verified separate samples on deviation from the accepted law of distribution of the observation results.

In order to process and analyze obtained statistical data on failures of metal water pipes, we applied the following methods:

– mathematical statistics in the analysis of statistical data on the damages to metal pipes;

– theory of reliability when performing qualitative and quantitative analysis of failure-free operation of water supply networks.

4. 2. Analysis of statistical data on the failures of metal water pipes

4. 2. 1. Plan of check tests

In the theory of reliability [15], when choosing possible plans of check tests, the number of elements (N) is taken into account that undergo the test, duration of the test (t) and character of the test:

– test with a renewal (V) is the test in which every failed element is replaced with the new one;

– test without a renewal (B) is the test in which the element that failed during examination is not replaced.

Time of completing the tests can be assigned in various ways:

T – plans, under which tests are carried out within the assigned time T;

r – plans, under which tests are conducted prior to the occurrence of the r-th failure;

(r, T) – plans, under which tests are carried out either to the time t_r of the occurrence of the r-th failure, if $t_r < T$, or to the time T, if $t_r > T$:

1. [N, B, T] – the plan, under which N elements are put to test; elements that failed are renewed (B); the test is conducted to the previously specified time T.

2. [N, B, r] – the plan, under which N elements are put to test; elements that failed are renewed (B); the test is held until the occurence of the r-th failure.

3. [N, B, (T, r)] – the plan, under which N elements are put to test; elements that failed are renewed (B); tests are carried out either to the time t_r of the occurrence of the r-th failure, if $t_r < T$, or to the time T, if $t_r > T$.

4. [N, B, T] – the plan, under which N elements are put to test; elements that failed are not renewed (B); tests are carried out to the specified time T.

5. [N, B, r] – the plan, under which N elements are put to test; elements that failed are not renewed (B); tests are carried out to the time of the occurrence of the r-th failure.

6. [N, B, (T, r)] – the plan, under which N elements are put to test; elements that failed are not renewed (B); tests are carried out either to the time t_r of the occurrence of the r-th failure, if $t_r < T$, or to the time T, if $t_r > T$.

Water pipes relate to the renewable elements; observation period to obtain statistical data made up 7 years. Given the above, we selected the first check test plan [N, B, T].

4. 2. 2. General characteristic of statistical data

Generalized statistical data on the damages of metal water pipes are given in Table 3.

Table 3

General statistical data on the damages of metal water pipes in the city of Kremenchuk, Poltava oblast (Ukraine)

Pipe sections of the network	Diameter D, mm	Total length of analyzed pipes, L, km	Number of registered damages in the sections of network, n
Cast iron (grey iron)	50	0.400	15
	100	14.490	398
	150	12.110	234
	200	9.920	174
	250	11.095	96
	300	12.760	98
	Total	60.775	1015
Steel	50	1.0500	40
	100	9.979	177
	150	4.3900	64
	200	1.1410	14
	250	5.5000	57
	300	6.6800	63
	Total	28.74	415

Study into the failures in water-supply networks of the examined object revealed that over the total length of cast-iron water pipes of 60.775 km, the number of failures reached 1015, and in the steel water pipes of length 28.74 km – 415.

5. Results of examining the failure-free operation of metal water supply pipes

5. 1. Qualitative analysis of the damage to pipes

An analysis of statistical data allowed us to highlight the main types of damage to the metal water pipes (Fig. 2). For the cast-iron pipes:

– cement outlet from bell joints – 68 %;
– transverse fractures – 19 %;
– corrosion – 9 %;
– damaged by excavation equipment – 4 %.

For the steel pipes:

– transverse fistulas – 71 %;
– breach of welds – 18 %;
– corrosion – 7 %;
– damaged by excavation equipment – 4 %.

For the cast-iron pipes, the largest damage is done by the cement outlet from bell joints (68 %). For the steel pipelines, the biggest factor in failures is the transverse fistulas (71 %).

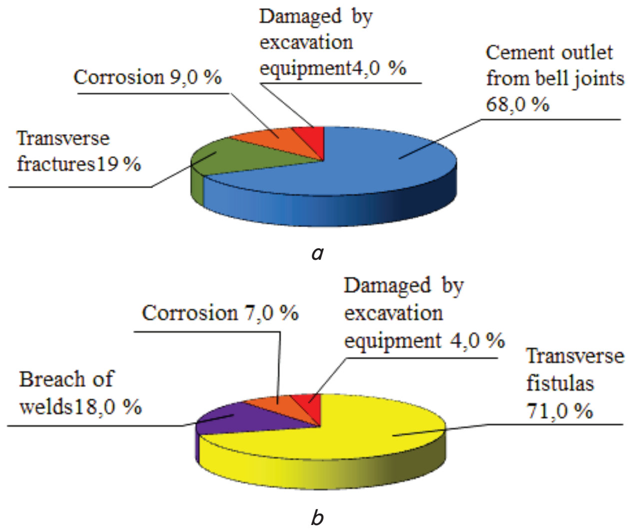

Fig. 2. Types of damage to metal water pipes in the city of Kremenchuk (Ukraine): *a* – cast iron pipe (grey cast iron); *b* – steel pipes

5. 2. Quantitative analysis of the damage to pipes

As the main indicator of failure-free operation of metal water pipes we accepted the mean time to failure T and the magnitude inverse to it – the average value of failure rate parameter ω. In order to calculate reliability of failure-free operation in the sections of water network, it is necessary to apply a specific parameter of failure rate ω_0 – this is a failure rate parameter relative to 1 km of a pipeline. To calculate the mean value of specific failure rate ω_0, we applied formula:

$$\omega_0 = \frac{n}{t \cdot \sum L}, \qquad (1)$$

where n is the number of failures of section of a water network; t is the duration of observation; ΣL is the total length of sections of the water network of corresponding diameter, km.

Specialists in water suply [4, 8] adopted a statistical hypothesis of exponential distribution of time to failure T per 1 km of a pipeline. An analysis of statistical data on water supply of the examined object was conducted during a fixed period and the received values of specific failure rate parameter ω_0 were random. Interval estimations for the specific failure rate parameter were calculated by the following formulas:

– the lower interval estimation of failure rate parameter:

$$\omega_0^{lower} = \frac{\omega_0}{r_1}; \qquad (2)$$

– the upper interval estimation of failure rate parameter:

$$\omega_0^{upper} = \frac{\omega_0}{r_2}, \qquad (3)$$

where r_1, r_2 are the coefficients to determine the interval estimates in the case of exponential distribution, which are accepted in accordance with [16] for confidence probability $\gamma = 0.95$.

Results of calculations are given in Table 4.

Table 4

Calculation of interval estimates for specific failure rate parameter ω_0

Network sections pipes	Diameter D, mm	Sample size n	Confidence probability γ	Coefficients for determining the interval estimates		Specific failure rate parameter ω_0, 1/year·km		
				lower r_1	upper r_2	mean value	interval estimate: lower	interval estimate: upper
Cast iron (grey iron)	50	15	0.95	1.4	0.74	5.36	3.83	7.24
	100	398		1.09	0.918	3.92	3.60	4.27
	150	234		1.15	0.87	2.76	2.40	3.17
	200	174		1.19	0.85	2.51	2.11	2.95
	250	96		1.23	0.822	1.24	1.00	1.50
	300	98		1.225	0.824	1.10	0.90	1.33
Steel	50	40	0.95	1.33	0.755	5.44	4.09	7.21
	100	177		1.16	0.868	2.53	2.18	2.92
	150	64		1.28	0.79	2.08	1.63	2.64
	200	14		1.4	0.74	1.75	1.25	2.37
	250	57		1.32	0.77	1.48	1.12	1.92
	300	63		1.4	0.738	1.35	0.96	1.83

The weighted average value of specific failure rate parameter ω_0 regardless of diameter is calculated by formula:

$$\omega_0^{mid} = \frac{\omega_{01}L_1 + \omega_{02}L_2 + \ldots + \omega_{0n}L_n}{L_1 + L_2 + \ldots + L_n}. \quad (4)$$

The weighted average value of specific failure rate parameter ω_0 regardless of diameter for a water supply system of the examined object is

$\omega_0^{mid} = 2.98$ 1/year·km for the cast iron pipes;

$\omega_0^{mid} = 2.06$ 1/year·km for the steel pipes.

5. 3. Analytical dependences for the failure-free operation of metal pipes

As shown by an analysis of statistical data (Table 4), specific failure rate parameter of metal pipes decreases with increasing diameter. This allowed us to evaluate and predict the level of reliability of metal water pipes depending on a diameter.

As a result of mathematical processing of statistical data, we received dependences of specific failure rate parameter ω_0 on the pipe diameter. Construction of functions based on statistical data is conducted using the «Microsoft Excel SR-1» software.

Dependence graphs of specific failure rate parameter ω_0 on the pipe diameter are shown in Fig. 3, 4.

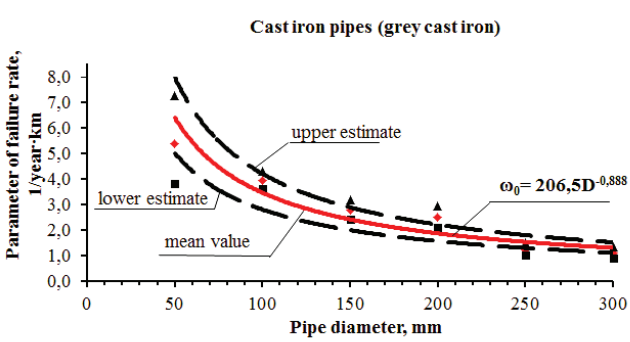

Fig. 3. Analytical dependence $\omega_0 = f(D)$ for the cast iron pipes

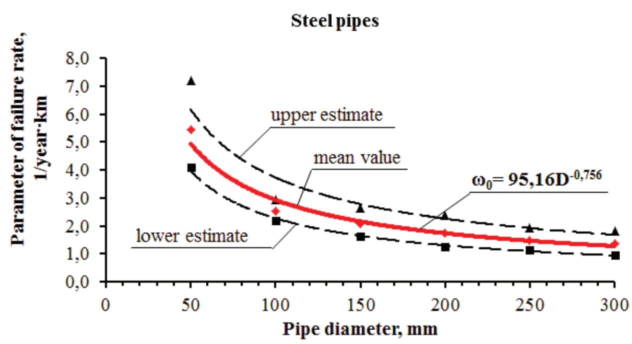

Fig. 4. Analytical dependence $\omega_0 = f(D)$ for the steel pipes

The obtained analytical functions for the mean values of specific failure rate parameter ω_0^{mid} for a water supply network of the examined object take the form:

– for the cast iron pipes $\omega_0^{mid} = 206.5D^{-0.888}$;

– for the steel pipes $\omega_0^{mid} = 95.16D^{-0.756}$,

where D is the pipe diameter in mm.

6. Discussion of results of examining the failure-free operation of metal water pipes

6. 1. A comparative analysis of causes of damage to water pipes

Determining the main factors of failures of water supply metal pipes is the actual direction of research into reliability on the territory of Ukraine. Condition of water-supply pipelines is characterized by a high percentage of deterioration (over 90 %) and low rates of renewal of water supply networks.

The main causes of failures in metal pipes of water supply networks (Fig. 2) allowed us to establish that the dominant factors are the following:

– for the cast iron (grey iron) pipes – transverse fractures and cement outlet from bell joints;

– for the steel pipes – transverse fistulas, and damage of welded joints.

The results obtained on the causes of failures of the cast-iron and steel water pipes do not disagree with data from the articles of known foreign authors [17, 18]. According to [17, 18], based on statistical data of accidents from five water supply companies, the physical and environmental factors that lead to failures in water-supply networks were established. An analysis of basic damage made it possible to categorize and isolate the main types of damage that are similar to those explored in Ukraine:

– for the cast-iron pipes (grey cast iron): longitudinal crack and pitting corrosion;

– for the steel pipes: transverse fistulas.

As a result of quantitative analysis of statistical data on failures of water metal pipes we obtained numerical values and interval estimates for specific failure rate parameter in a range of diameters D=50...300. We also received weighted average values of failure rate parameter ω_0 regardless of diameter for the water supply system in the city of Kremenchuk by formula (4). An analysis of published studies by other authors [9, 19] allowed us to perform a comparison of failure-free operation of water supply pipes by specific failure rate parameter ω_0. Comparison is represented by diagrams (Fig. 5), which show a significant difference in the reliability of pipes in different countries. Comparison to [9, 19] reveals that the failure-free operation of Ukrainian metal water pipes is much lower than that in Sweden and Germany and about 2 times lower than that in Poland.

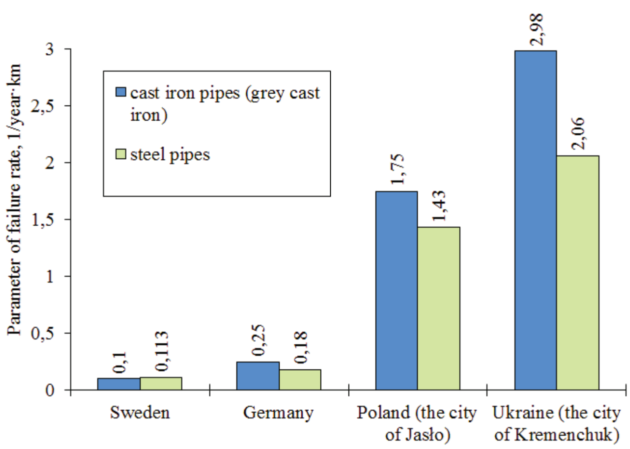

Fig. 5. Comparison of the failure free operation of pipes by the parameter of failure rate

An analysis of statistical data on failures allowed us to build dependences $\omega_0=f(D)$ and subsequently predict the failure free operation of water supply networks for other assortments of metal pipes. Fig. 6, 7 show analytical dependence graphs for the city of Kremenchuk (Ukraine) and other cities from foreign countries [9, 10]. The obtained dependences confirmed a known fact that with an increase in the diameter of metal pipes, specific failure rate parameter decreases. However, analytical dependences take different forms for the specified cities. This can be caused by either insufficient accuracy of registering the damage or there are local operational factors, which are different in the indicated cities (pressures in network pipes, soils, hydrogeological conditions, etc.).

Obtained dependences of the specific failure rate parameter on the diameter of pipes (Fig. 6, 7) allow us to easily perform calculations of reliability of pipe lines for other assortments of diameters of pipes.

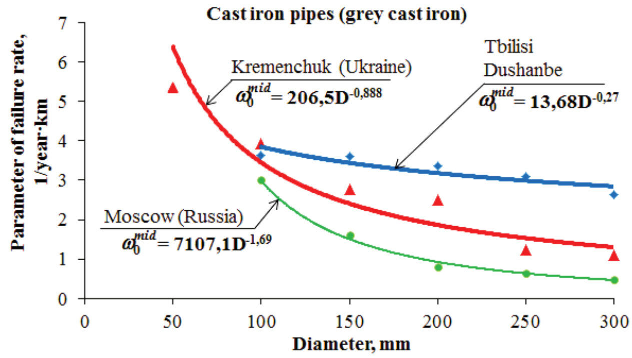

Fig. 6. Analytical dependences $\omega_0=f(D)$ for the cast iron pipes

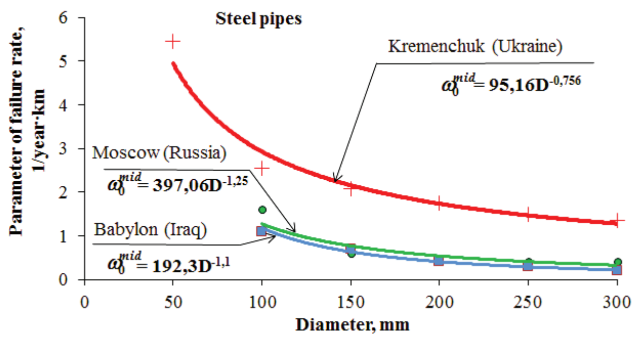

Fig. 7. Analytical dependences $\omega_0=f(D)$ for the steel pipes

7. Conclusions

1. An analysis by the methods of mathematical statistics of data on the failures of metal water pipes in the city of Kremenchuk, Poltava oblast (Ukraine) confirmed the fact that with an increase in the diameter of metal pipes, specific failure rate parameter decreases.

2. Conducted statistical analysis allowed us to isolate the main types of damage to the metal water pipes. For the cast-iron pipes:

– cement outlet from joints – 68 %;

– transverse fractures – 19 %;

– corrosion – 9 %;

– damaged by excavation equipment – 4 %.

For the steel pipes:

– transverse fistulas – 71 %;

– breach of welded joints – 18 %;

– corrosion – 7 %;

– damaged by excavation equipment – 4 %.

3. Analytical dependences obtained for the mean value of specific failure rate parameter of metal pipes take the following form:

– the cast-iron pipes (grey cast iron)

$$\omega_0^{mid}=206.5D^{-0.888} \text{ 1/year·km};$$

– the steel pipes

$$\omega_0^{mid}=95.16D^{-0.756} \text{ 1/year·km},$$

where D is the pipe diameter in mm.

The obtained dependences allow us to calculate the frequency of failures in the sections of a network D=50...300.

4. Generalized mean values of specific failure rate parameter ω_0^{mid} regardless of diameter for the city of Kremenchuk, Poltava oblast (Ukraine) make up:

– for the cast-iron pipes (grey cast iron)

$$\omega_0^{mid} = 2.98 \ \ 1/\text{year}\cdot\text{km};$$

– for the steel pipes

$$\omega_0^{mid} = 2.06 \ \ 1/\text{year}\cdot\text{km}.$$

5. A comparison we performed to foreign data reveals that the failure free operation of Ukrainian metal water pipes (cast-iron pipes – 2.98 1/year·km, steel pipes – 2.06 1/year·km) is much lower than that in the Western European countries:

– Poland (cast iron pipes – 1.75 1/year·km, steel pipes – 1.43 1/year·km);

– Germany (cast iron pipes – 0.25 1/year·km, steel pipes – 0.18 1/year·km);

– Sweden (cast iron pipes – 0.1 1/year·km, steel pipes – 0.113 1/year·km).

References

1. SBC V.2.5-74: 2013. Water. External networks and facilities. The main provisions of design [Text]. – Kyiv: Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine, 2013. – 281 p.
2. Rules provision of centralized heating, hot and cold water and sanitation [Text]. – Cabinet of Ministers of Ukraine, 2005. – No. 630.
3. Tkachuk, O. A. Hydraulic calculations of existing water pipes [Text] / O. A. Tkachuk // Water and sanitation. – 2008. – Issue 2. – P. 2–6.
4. Novokhatniy, V. G. Reliability feeding-distribution complex water systems [Text] / V. G. Novokhatniy // Scientific Herald building. – 2008. – Issue 48. – P. 215–218.
5. Novokhatniy, V. The reliability of conduits of systems of water supply [Text] / V. Novokhatniy, S. Kostenko // MOTROL. Commission of motorization and energetics in agriculture. – 2013. – Vol. 15, Issue 6. – P. 101–108.
6. Novokhatniy, V. The reliability of cooling water recycling systems [Text] / V. Novokhatniy, S. Kostenko // MOTROL. Commission of motorization and energetics in agriculture. – 2014. – Vol. 16, Issue 6. – P. 77–84.
7. Matyash, A. The reliability of water supply for small settlements [Text] / A. Matyash, V. Novokhatniy, S. Kostenko // MOTROL. Commission of motorization and energetics in agriculture. – 2015. – Vol. 17, Issue 6. – P. 95–102.
8. Novokhatniy, V. G. Reliability water pipes according to the operation [Text] / V. G. Novokhatniy, A. V. Matyash // Scientific Herald building. – 2009. – Issue 51. – P. 136–140.
9. Orlov, V. A. Reconstruction of pipeline systems [Text]: uch. pos. / V. A. Orlov, S. V. Hramenkov, O. G. Primin. – Moscow: Association of Construction Universities (ASB), 2008. – 280 p.
10. Svintsov, A. P. Assessment of the reliability of pipelines for water supply and sanitation in the cities of Iraq [Text] / A. P. Svintsov, Al-Kharami Tami // Bulletin of the PFUR. – 2011. – Issue 2. – P. 5–10.
11. Tchorzewska-Cieslak, B. Failure scenarios in water supply system by means of fault tree analysis [Text] / B. Tchorzewska-Cieslak, K. Boryczko, M. Eid // Advances in Safety, Reliability and Risk Management. – 2011. – P. 2492–2499. doi: 10.1201/b11433-354
12. Boryczko, K. Analysis of risk and failure scenarios in water supply system [Text] / K. Boryczko, R. Janusz, B. Tchorzewska-Cieslak // Journal of Polish Safety and Reliability Association Summer Safety and Reliability Seminars. – 2014. – Vol. 5, Issue 2. – P. 11–18.
13. Faidaee, M. J. Estimation of Failure Probability in Water Pipes Network Using Statistical Model [Text] / M. J. Faidaee, R. Tabat // World Applied Sciences Journal. – 2010. – Vol. 11, Issue 9. – P. 1157–1163.
14. Forsyth, P. Codified methods to analyse the failures of water pipelines: A Review [Text] / P. Forsyth, D. Robert, P. Rajeev, C. Li, J. Kodikara // Proceedings of the 8th Australasian Congress on Applied Mechanics 2014 (ACAM 8). – 2014. – P. 529–539.
15. UIS 8647:2016. Reliability engineering. Evaluation and forecasting reliability test results and (or) use in a small bounce Statistics [Text]. – Kyiv: Institute of Mathematical Machines and Systems of National Academy of Ukraine, 2016. – 54 p.
16. Volodarsky, E. T. Statistical block of the data [Text]: uch. pos. / E. T. Volodarsky, L. O. Kosheva; National Aviation University. – Kyiv: NAU, 2008. – 308 p.
17. Rajeev, P. Factors contributing to large diameter water pipe failure [Text] / P. Rajeev, J. Kodikara, D. Robert, P. Zeman, B. Rajani // Water asset management international. – 2014. – P. 9–14.
18. Rajeev, P. Factors contributing to large diameter water pipe failure as evident from failure inspection [Text] / P. Rajeev, J. Kodikara, D. Robert, P. Zeman, B. Rajani // Strategic Asset Management of Water and Wastewater Infrastructure: Leading Edge Strategic Asset Management (LESAM13). – 2013. – Available at: http://www.criticalpipes.com/wp-content/uploads/2013/09/JKodikara.pdf
19. Szpak, D. Assessment of the failure rate of water supply system in terms of safety of critical infrastructure [Text] / D. Szpak, B. Tchyrzewska-Cieslak // Chemik. – 2014. – Vol. 68, Issue 10. – P. 862–867.