Methods For Increasing The Reliability Of The Functioning Of Pipeline Systems

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Abstract

The article is devoted to problem to improve the reliability of the pipeline systems. Traditional ways of improving reliability are considered, among which parametric and structural, and non-traditional (algorithmic and structural-information) methods to improve the reliability of the functioning of pipeline systems are highlighted. Algorithmic methods provide an increase in the reliability of pipeline systems by choosing rational modes of their operation by simulating and optimizing the flow distribution in these systems at the stages of their rational operation, reconstruction and development. Particular attention is paid to the method of improving the design of water supply systems by using regulating capacitances between the zones of the water supply network. The results of simulation modeling of real water supply systems confirmed the feasibility of using interzonal regulating capacitances in the practice of their designing and reconstructing. Using of the considered methods and means in practice allows to increase the reliability and efficiency of pipeline systems functioning.

Keywords 1

reliability, pipeline system, functioning, operation, probability, criterion, modeling, control, structure, regime, efficiency, stream distribution.

1. Introduction

The purpose of this article is to analyze the existing traditional ways of improving reliability of the pipeline systems and the development of non-traditional (algorithmic and structural-information) methods to improve the reliability of the functioning of pipeline systems. Algorithmic methods provide an increase in the reliability of pipeline systems by choosing rational modes of their operation by simulating and optimizing the flow distribution in these systems at the stages of their rational operation, reconstruction and development. Wherein articular attention is paid to the method of improving the design of water supply systems by using regulating capacitances between the zones of the water supply network.

The most important indicator of the pipeline system (PS) is the reliability of its operation. Reliability tasks are solved both in the rational operation of the PS as well as in the control of its development.

The reliability of the pipelines depends not only on the type, material and diameter of the pipes, but also on the design of joints, the quality of their installation, the preparation of the base, the nature of the soils, the impact of transport, fluctuations of internal pressures, corrosion properties of soils, etc. The reliability parameters of such elements are determined only as the result of long-term monitoring of their functioning during the operation, systematic collection and processing of statistical data on all damages and accidents. The greater the observation period is as well as the

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number of homogeneous elements subject to observation (testing), the more accurate reliability indicators will be obtained. Therefore, it is very important to have a complete system for recording accidents and damages of the system elements.

2. Reliability of pipeline systems functioning

Many fundamental scientific works of Abramov N.N., Evdokimov A.G., Tevyashev A.D., Hasilev V.Y., Merenkov V.P., Novitsky N.N. and other scientists [3] in the 70s of the last century are devoted to the problems of improving the reliability of pipeline systems.

When choosing indicators of reliability for certain types of elements, it is necessary to consider which of the two types of items this item should be attributed - to a renewable or non-renewable. Most of the elements of the PS belong to the reparable and renewable types. The quality of functioning of the renewable element is characterized by the ratio of the duration of periods of its operational and nonserviceable conditions.

The main reliability criterion for PS and or its elements is the probability of failure-free operation of the PS or its individual elements (R) during a given duration of operation (T) usually defined as "the probability that there is no failure within the run-to-failure time". Here, the run-to-failure time should be understood as the given duration T of the work of the PS or its element.

The reliability of the system or its individual element can be presented as temporary function (reliability function).

$$p(t)=P(T>t) \tag{1}$$

which for any of its arguments is numerically equal to the probability of the fact that the system will remain operational for a time greater than the value of the argument.

The reliability function p (t) allows:

- using the given reliability of the system (element) P (T) to determine the duration of its failure-free operation;
- using the given duration of the system (element) T to determine the probability of its failure-free operation P (T) during the time period $t \le T$.

The reliability function has three properties:

- p (0) = 1, that is, at the moment of putting into operation the system (element) is in an operational state;
- p (∞) = 0, that is, there are no systems (elements) that could operate indefinitely long;
- p (t2) <p (t1), if t2> t1, that is, p (t) is a monotonically decreasing function and, as a consequence, the reliability of any network (element) falls over time.

Under the condition of absence of the reliability function in the finished form (as a passport item), it can be determined by statistical data on the refusal of the exploited systems (elements) according to the formulas:

$$p(t)=\frac{N-n(t)}{N}=1-\frac{n(t)}{N} \tag{2}$$

Here N - number of elements at the time of their putting into exploitation (t = 0); n (t) is the number of subsystems (elements) that had failures during the time period from 0 to t.

A very important concept, which is included into the definition of many indicators of reliability, is the run-to-failure. The average run-to-failure between failures, i.e., the average time of failure-free work, is its mathematical expectation Tav. (the average "time of life").

Considering the flow of failures as a Poisson flow of events, it is possible to represent the reliability function in the form of exponential dependence

$$p(t)=e^{-\lambda t} \tag{3}$$

where λ is the failure rate (average number of failures per a unit of time).

The parameter of the failure flow λ is related to mathematical expectation of the run-to-failure Tav. inversely proportional to the dependence:

$$\lambda = \frac{1}{T_{cp}} \tag{4}$$

The second important criterion for reliability of the subsystem elements is their reliability, the lifetime of which is the service life, or resource, i.e. the time to the onset of the boundary state at which it is necessary to stop the work of this subsystem or element.

The most applicable private definitions of the concept "resource" are the following:

Medium resource - the mathematical hope of the resource, that is, the average duration of the subsystem (element) work up to a certain state or between capital and medium repairs. Gamma is the percentage resource expressed by the time during which the subsystem or element under consideration reaches the boundary state with a given probability γ [%]. If the property distribution function p (t) is known, then the value of the γ-percentage resource is determined by the expression:

$$\frac{\gamma}{100} = 1 - p(t) \tag{5}$$

The assigned resource determines the operating time of the subsystem (element), after which its operation should be terminated regardless of the state.

For calculating the reliability of successive and parallel subsystems the following formulas are used:

$$P_{serial} = \prod_{i=1}^{n} p_i \tag{6}$$

$$P_{nap} = 1 - \prod_{i=1}^{n}(1 - p_i) \tag{7}$$

where pi - index of reliability of the i-th structural component of the system; n - the total number of components in serial or parallel subsystems, respectively.

The analysis of the models (6) - (7) shows that with the increase in the number of components n in the subsystem, the value P *serial* decreases, and the value P *parallel* increases.

The more complicated the serial subsystem is, the lower its reliability is, and on the other hand, the more complex the parallel subsystem is, the higher its reliability is.

3. Traditional means of increasing the reliability of the functioning of pipeline systems

Among the classical traditional means of increasing the reliability of the operation of pipeline systems as a separate case of complex systems are parametric and structural methods.

3.1. Parametric means

Parametric means provide reduction of the failure rate of individual elements of pipeline systems by planning and conducting preventive maintenance as well as using more reliable elements and their timely reconstruction, modernization and replacement.

The list the main types of failures typical of the PS includes.

Internal failures, that is, the violation of the normal functioning of pipeline systems because of damages and accidents of individual structures or elements of the system are the most widespread. System failures may be caused by breakdowns of such responsible facilities as the facilities for receiving the target product (TP), main pump or compressor stations, as well as the main elements of the PS, namely, pipes and their joints, pumps, electric motors and electrical equipment, shut-off, regulating and safety valves [9-11].

For most of these elements there are some general patterns of their damages (failures) during the period of operation from the moment of putting in service to the onset of the limiting state. At the beginning of this period, various damages are observed relatively continuously, in particular, the defects of mounting and starting-up become evident, the product "adapts" to normal working conditions. Later comes the period of normal operation when damages is rare. The third period is characterized by a new increase in the frequency of damages (the result of aging), which ends with the onset of the boundary state, the elements must be timely replaced with new ones.

Thus, high-quality, strict implementation of the rules of operation, and, in particular, the timely conduct of planned preventive maintenance, is very important for ensuring the reliability of the PS. A well-organized technical service allows predicting the possibility of failure of some products and taking measures to prevent it.

External failures. Very serious consequences for the operation of the PS may be caused by failures of the associated external systems, namely, the natural sources of the target product, the power supply system, and sometimes the system of maintenance. Failure of these systems can lead to very serious violations of the normal functioning of PS, up to complete temporary suspension of the supply of the target product in the condition of appropriate reserves absence.

The failure of the natural source is the greatest danger for the operation of pipeline systems using single source, and can lead to complete failure of such system.

Failures of the power supply system primarily violate the work of the pump and compressor stations of PS and may cause a temporary break in supplying consumers with the target product, as well as cause significant disruptions in the work of a number of structures, where mechanisms and electrical equipment with electric drive, telecontrol and signaling systems are widely used.

3.2. Structural means

Structural means also refer to traditional means of increasing the reliability of piping systems. They are reduced to the change in the original structure of the system by adding additional pipelines. The simplest way is to reserve individual elements (pipelines, pumping units, etc.). The looping of plumbing and regional gas networks can also be attributed to the structural ways to improve the reliability of their operation.

In general, the reliable work of most pipeline systems is based on the redundancy of their elements. The pipelines are designed to pass the maximum target product, at pumping stations (for water supply and drainage systems), reserving of pump units is foreseen [8], and to ensure the continuity of the power supply of electric motors, powering is carried out from two independent sources of power supply. At least two pipelines are usually laid from each pumping station.

3.3. Non-traditional methods

Among the variety of PS elements, most important for the reliability of the functioning of these systems, of course, are main pipelines and pumping stations. Indicators of reliability of these elements (for example, run-to-failure) depend not only on the abovementioned reasons (the quality of the material, joints and others), but also on the mode of operation of these elements (the pressure under which the element is located, the speed of the target product movement, its contents, hydraulic strikes, etc.).

When organizing the distribution of the target product in pipeline systems (for example, by reconstructing the system) in such a way as to reduce the total supernormal pressure in the network, it is possible to significantly reduce the number of accidents over a fixed period of time T. The same effect can be achieved by a deliberate increase the pipelines' capacity and, consequently, pipeline systems as a whole by replacing pipes (or by laying additional parallel pipelines) with a weak capacity for pipes of a higher diameter.

Moreover, accidents can be reduced not only by upgrading the system and increasing its throughput, focusing on peak loads in the system in terms of target product flows, but also by rationally organizing the supply of the target product and reducing these peak loads by using local systems with regulating capacitances that accept the target product at a reduced demand for it and return it during peak periods.

The methods that increase the reliability of pipeline systems by a rational control of the distribution of the target product at the stages of operational control, reconstruction and projecting are called non-traditional [1, 2].

Conditionally, these methods can be divided into the following four groups:

- algorithmic (information) methods that increase the reliability of pipeline systems by choosing rational modes of their operation by simulation modeling as well as optimize the flow distribution in these systems at the stages of their rational exploitation, reconstruction and development [1, 2, 4-7];
- the methods of the levels interconnection that assume such an organization of the system structure in which its individual levels or zones are interconnected through accumulation reservoirs or pressure regulators [3, 6, 7];
- structural-algorithmic (structural-information) methods that allow to choose the structure and parameters of PS sections in such a way that in case of failure of its separate element or even a part of the system, most consumers will have an access to the target product through the pipes having a normal capacity. In such a case, the reliability of the system functioning in its truncated version is evaluated using computer simulation modeling. For example, the availability of a low-pressure ring for the water supply system of the city, which is served by the water supply stations and which supplies with water the reservoirs of the pumping stations operating on the urban water supply network dramatically increases the reliability of this network functioning and its survivability [6];
- alternative approaches that are based on lowering (or at least not increasing) the loading of main pipeline systems by using various alternative solutions.

Algorithmic methods provide an increase in the reliability of pipeline systems by choosing rational modes of their operation by simulating and optimizing the flow distribution in these systems at the stages of their rational operation, reconstruction and development.

Let's take a closer look at the following unconventional methods.

A significant increase in the reliability of WSS operation can be achieved by improving the principles and methods of their design and reconstruction. One of the main such principles is the need to design WSS with manageability in mind. At the same time, improving the quality and efficiency of the WSS operation can be achieved by improving the design of both its elements and the WSS as a whole.

When designing a WSS, it is necessary to determine the number and location of individual subsystems, its structure, as well as the parameters and variables of each of the subsystems in such a way as to ensure the supply of water to all consumers in the required quantities and under specified pressures. The design should be carried out taking into account the stochastic nature of the processes of water consumption, the dynamics of the system development, reliability and high probability of emergency situations (emergency shutdown, natural disaster, etc.).

All this leads to the need to design water supply systems that have the property of controllability of flow distribution, i.e. the network should include various active and passive regulators, backup water sources and communication lines that provide a reserve of network bandwidth. Obviously, the option that costs less will be preferable.

The designed water supply networks should also have a hierarchical structure, the individual levels of which would be decoupled through regulating devices.

The reliability of the functioning of water supply systems can also be improved by improving their design methods. Consider method for improving the design of WSS by using regulating capacitances between zones of the water supply network.

In order to ensure reliability requirements, water supply networks are designed as ring networks and are divided into levels, which are designed separately. However, in the process of practical implementation, the city water supply network loses its multi-level nature, because levels are usually not decoupled between themselves by decoupling elements, which leads to a significant complication of design and control tasks.

The lack of decoupling between levels leads to a strong dependence between them, large errors between the calculations of individual levels, if they were carried out on the assumption of their independence, and most importantly, to a sharp complication of the problem of WSS operational control.

Thus, the multi-level nature of water supply networks is clearly visible only at the design stage. In the process of practical implementation, it is impossible to consider such networks as hierarchical from the point of view of control, because the levels are highly interconnected, and the WSS of the city is a single inseparable system, which is difficult to control.

Design and control tasks become easier if any individual layer can be pick out from the overall network. This can be achieved by decoupling existing levels through various adjustable elements. They are such passive-active regulating capacitances of water supply networks as reservoirs, water columns, water towers.

The considered methods for improving the design of WSS require the mandatory partitioning of the network structure into zones. Zoning has a number of advantages: it allows you to reduce excess free pressure in the network, reduce the cost of electricity for lifting water, reduce the total capacity of pumping stations, and therefore reduce operating costs.

The introduction of additional interzonal reserve-regulating capacitances into the original water supply system and their inclusion in the system allows:

- to attract water reserves of those zones in which there are excess water, as well as water reserves of interzonal reserve-regulating capacitances, to regulate the unevenness of water consumption;
- create additional reserve water reserves in interzonal reserve-regulating capacitances by accumulating excess water in them from zones with low water consumption.

This achieves the goal of improving the design of the WSS, as improves the satisfaction of the water needs of the system's subscribers.

To evaluate the effectiveness of methods to improve the WSS considered in [3, 6], the developed [6, 7] simulation model of the technological processes of the WSS functioning together with pumping stations and regulating capacitances was used at any given time interval.

The introduction of interzonal regulating capacitances into the water supply system can significantly improve the quality of its functioning in the time interval [0,T].

The presence of interzonal regulating capacitances in the water supply system makes it possible to reduce the ranges of change in the operating parameters of pumping stations, contributes to a better supply of water to consumers under pressure at the standard level, reduces excess pressure in the network and, as a result, reduces the probability of emergencies in the network.

The studies carried out by simulation modeling have shown that the introduction of interzonal regulating capacitances into the WSS can significantly improve the quality of its operation, reduce the cost of electricity and the total water supply to the network, reduce excess pressure in the network, as a result of which unproductive costs and leakages in the network are reduced, and the probability of emergency situations are reduced too. In addition, the presence of regulating capacitances in the WSS makes it possible to stabilize the operating modes of pumping stations by reducing the ranges of change in their regime parameters and increasing the efficiency of their operation.

4. Conclusions

According to the proposed non-traditional methods described, the following conclusions can be drawn.

1. Accounting for controllability in the design and reconstruction of water supply systems makes it possible to increase the reliability and efficiency of their operation, as well as the duration of networks operation.

2. The introduction of interzonal regulating capacitances into the practice of designing and reconstructing water supply systems can significantly improve the quality of water supply to consumers through the use of the internal reserves of the system.

3. The water supply system proposed using the considered design methods is characterized by the following advantages:

- by the ability to use the water reserves of those zones in which there is an excess of water, as well as the water reserves of interzonal reserve-regulating capacitances, to regulate the unevenness of water consumption;
- by reduction of excess total pressure in ring water supply networks, which helps to reduce water leakage;
- by a decrease in the range of change in the value of hydraulic resistance, which makes it possible to stabilize the operating modes of all pumping stations of the system and increase the efficiency of their work;
- by increasing the survivability of the system due to the fact that the failure of one of the chains, including a low-pressure pipeline, a zonal reserve-regulating capacitance with a controlled pumping station connected by a conduit to one of the zones, does not cause a disruption in the functioning of the water supply system, because in this case, the corresponding zone of the system will be supplied with water from the nearest interzonal reserve-regulating capacitance;
- by reducing the requirements for the throughput of low-pressure pipelines and ring water supply networks.

4. The results of simulation modeling of real water supply systems confirmed the feasibility of using interzonal regulating capacitances in the practice of their designing and reconstructing [6].

These advantages make it possible to use in practice these methods for improving the design and reconstruction of water supply system and, as a result, to provide a real increase in the reliability and efficiency of their operation during operation. On the whole using of the considered methods and means in practice allows to increase the reliability and efficiency of real pipeline systems functioning.

Conducted practical studies of a large number of real pipeline systems by simulation confirmed the effectiveness of the ways under consideration.

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