ANNOTATION

doctoral dissertation
submitted for the degree of Philosophy Doctor (PhD)
by speciality 6D070800-Oil and gas business
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«Elimination of gas leak from the pipeline microcracks without gas pumping termination»

For Kazakhstan, the transit gas potential is of great strategic, geopolitical and economic importance. Therefore, the developing transit capacities of the gas transmission pipeline passing through the territory of the Republic of Kazakhstan is prioritized in the gas companies' operations aiming to ensure the ever-increasing volumes of international natural gas transit and more efficiently use the existing assets of the pipeline system.

The concept for the development of the gas sector of the Republic of Kazakhstan until 2030 specifies the vision and main approaches to the gradual reforming and comprehensive development of the gas sector of the Republic of Kazakhstan.

In order to provide uninterrupted gas supply to consumers and enhance economic performance, gas companies devote special attention to possible risks during transportation. The principal risks while pumping gas are failures of the main gas pipelines which lead to a complete or partial pumping cessation, derange the regular operation of the entire gas pipeline system, and might also cause fires crash, explosions and emissions of the hazardous substances into the environment and human losses.

The reasons for the failure of the main gas pipelines can be different: physical impacts during excavation, due to deviations from safety rules and work execution sequence; corrosion-fatigue failure of pipes as a result of violations during the construction process and/or inadequate control of the technical condition; rupture of joints and opening of pipeline joints due to poor-quality construction and installation work. The most complicated case is leaks from underground gas pipelines, since gas filtration in the ground, its spread from the leakage point and accumulation in underground voids are determined by a large number of factors.

To prevent emergencies and maintain the gas transmission network in operable state, gas companies allocate extensive resources and take a number of measures for preventing and reducing accident rates in main gas pipelines: inspecting the current state of the gas pipelines in due time; determining the volume of natural gas losses and eliminating the defects.

In recent years, the overhaul work scope of the line pipe of the main gas pipelines has grown dramatically.

The principal conditions for the extensive use of a particular repair technique are:

- ensuring the desired level of operating reliability of the site after repair;
- minimum labor inputs for its implementation;
- minimum total cost of the repair operations.

At present in-line techniques for damage repair on gas pipelines without stopping gas pumping are of great interest.

The dissertation proposes a patented machine for in-line repair of the gas pipelines. It is possible to eliminate defects without stopping the product pumping by means of the engineered machine which enables to shorten repair time, significantly reduce labor intensity, repair costs, and enhance repair safety excluding welding operations on the surface of the existing pipeline and, first of all, ensures uninterrupted gas supply to consumers.

Information on the planned scientific and technical level of elaboration, patent research and conclusions. In the course of work, review of literature and patent research in regards to eliminating gas leaks on gas pipelines without stopping gas pumping, choice of modern research methods, programs and methods for determining the volume of gas leaks in non-stationary conditions were carried out.

The dissertation shows the results of the scientific analysis of the current state of a scientific and technical problem and research on forecasting directions for future scientific developments in the context of gas leakage elimination on main gas pipelines, natural gas reduction processes in order to simulate leaks from underground gas pipelines and determine their volume in non-stationary conditions. The novelty of the adopted technical solution is confirmed by the patent of the Republic of Kazakhstan and corresponds to the current level of scientific research.

Information on the metrological support of the dissertation.

The reliability of the obtained results is confirmed by the use of the mathematical model based on the proportional-integral control law of fluid dynamics parameters for simulating gas leaks from the gas pipelines.

Laboratory research in the paper was carried out on the basis of the "Transportation and Storage of Oil and Gas" Department, St. Petersburg Mining University. To obtain experiment data, an experimental plant was used which enables to simulate gas leaks from a pipeline with a transient flow regime into a medium with superatmospheric pressure, as well as to determine their volume by means of dimensional expander. Metrological measurements were carried out on verified check-reading instruments.

General description of the thesis research.

The given dissertation is devoted to create a device for in-line repair of gas pipelines without stopping gas transportation.

Rationale of the research.

Main gas transportation stands at the head of the fuel and energy complex of the state. Ensuring industrial and fire safety of main gas pipelines is a crucial task for gas companies.

Experience has proven that one of the main usability problems of gas pipeline system is defects wherethrough substantial gas volumes are lost.

Natural gas leaks can result in environmental pollution, structural damage, injury and human loss due to combustion or explosion of the gas-air mixture, gas shortfall to consumers and punitive penalties.

To ensure the efficient and safe operation of main gas pipelines, it is necessary to solve the problems of timely detection, leakage elimination and determination of the

natural gas loss volumes.

In accordance with the order of the General Director of "KazTransGas" JSC dated from August 25, 2015 No. 209, the strategic plan "100 steps in the field of gas and gas supply" was approved, in which the 57th step is "Application of new technologies to reduce gas leaks", as well as with the official a letter sent to the Kazakh National Research Technical University named after K.I. Satpayev dated from 27.06.2016. No. 0662-1567, the management of "KazTransGas" JSC requested the development of new technologies to eliminate gas leaks via through holes and microcracks without stopping gas pumping, one of the main objectives of the gas supply system is the need to develop and implement new technical means that enable service life extension of the pipeline system and ensure uninterrupted gas supply to consumers which confirms the rationale of the dissertation topic.

The aim of the dissertation.

The aim of the paper is to develop a device for inline repair of main gas pipelines without stopping gas pumping.

Within the framework of the study, the following objectives were set and solved:

- to analyze the current state of theory, practice, patent materials in the field of eliminating gas leaks on gas pipelines;
- to analyze the main factors affecting the technical condition of longtime operating main gas pipelines;
- to conduct experimental studies on natural gas reduction processes in order to simulate leaks from underground gas pipelines and determine their volumes in transient conditions by means of dimensional expander;
- to elaborate a device for in-line repair of main gas pipelines without stopping gas pumping;
- to conduct analysis of the economic efficiency of applying techniques for in-line repair of gas pipelines without stopping gas transportation.

Problem-solving techniques.

The objectives were solved by carrying out theoretical, experimental and numerical studies, analyzing the results by means of software, analyzing the economic efficiency of the techniques in operation

Scientific novelty:

- application of the mathematical model based on the proportional-integral control law of fluid dynamics parameter for simulating gas leaks from gas pipelines has been substantiated;
- dependences of the gas leakage volume due to the pressure at the defect formation site inside and outside the gas pipeline have been obtained, which can be used to determine the gas leakage volume in transient conditions;
- a device has been designed for in-line repair of the main gas pipelines without stopping gas pumping.

Scientific provisions submitted for defense:

- determining the gas leakage volumes in transient conditions;
- method and technical means of eliminating the gas pipeline damages without stopping gas transportation.

Theoretical and practical significance of the research:

- use of the expander -generating plant for simulating gas leaks from gas pipelines under transient conditions is substantiated, the results of which can be used to determine the volume of gas leaks under transient conditions;
- the patent of the Republic of Kazakhstan for the elaborated device to eliminate leaks on gas pipelines without stopping gas pumping was issued. The use of this technical means enables to dramatically reduce financial costs on repair and restoration work and ensure uninterrupted gas supply to consumers.

Personal contribution

Setting the aim and objectives of research; review and analysis of literature; search and analysis of patents for the repair of gas pipelines; the mathematical model of gas leaks was elaborated taking into account the application of the proportional-integral control law in various stabilization options; theoretical and experimental research; processing and interpretation of the obtained results; elaboration of the device for in-line repair of the gas pipelines.

Approbation

The main findings of the research were reported at the International Satpayev Readings "Scientific heritage of Shakhmardan Yessenov" (Almaty, 2017), the International Scientific Conference "High Technologies and Innovations in Science" (St. Petersburg, 2018), the International Conference Satpayev Readings "Innovative technologies are the key to successful solution of the fundamental and applied problems in the ore and oil and gas sectors of the economy of the Republic of Kazakhstan" (Almaty, 2019), the International Scientific Conference "Science. Research. Practice" (St. Petersburg, 2019), IV International Scientific and Practical Conference "WTO Membership: Prospects for Scientific Research and the International Technology Market" (Vancouver, 2019).

Publications

11 scientific papers have been published on the topic of the dissertation, 3 of which in periodicals approved by the Committee for Control in Education and Science of the Republic of Kazakhstan, 2 in scientific journals included in the Scopus database, 5 scientific abstracts at international conferences, 1 patent of the Republic of Kazakhstan.

The volume and structure of the dissertation. The dissertation is presented on 106 pages of computer text, consists of an introduction, 4 sections, conclusion, bibliography of 97 items, contains 50 figures, 14 tables and annex in the form of additional mathematical calculations.

The main content of the work

Introduction substantiates the rationale of the dissertation topic, formulates the aim and objectives of the research, outlines the scientific novelty and practical significance, the personal contribution of the applicant.

In the first chapter, based on the processing of statistical information on failures on domestic and foreign gas pipelines, the analysis of the key factors affecting their occurrence is given. The reporting data observes the fact that the most common sources provoking the occurrence of emergency situations on gas pipelines are: corrosion, external influences, defects in welded joints, natural impacts.

Special attention is given to crack-like defects in the pipeline. The reason for this is that microcracks while merging transform into the larger cracks which form a rapid-growing main crack. The main crack leads to the destruction of the material at the macroscopic level. As a result, the service life of underground gas pipelines under load is reduced severely. The occurrence and development of microcracks is caused by the chemical composition of the soil in which the gas pipeline is laid. Under the corrosive medium and the impact of tension stresses, the birth of crack growth is formed which is called stress-corrosion cracking. This type of destruction for underground main pipelines is dangerous, since the operation process occurs without visible deviation, but only until the crack reaches the critical size followed by an emergency rupture of the gas pipeline.

The consequences of such destruction processes were accidents on gas pipelines in Kazakhstan. Analyzed acts of technical investigation of accidents and failures of collapsed gas pipelines belonging to “Intergas Central Asia” JSC for signs of stress-corrosion cracking demonstrated that brittle cracks were found in the focal area of destruction which were opened during the accident development. The depth and length of the brittle component of the crack is about half of the pipe wall and more than 180 mm, respectively. Calculations showed that the development of the investigated destruction of the main gas pipelines was caused by the presence of such a crack. Based on these evidences, it was found that most of the gas pipelines in Kazakhstan are susceptible to stress-corrosion cracking (Figure 1).

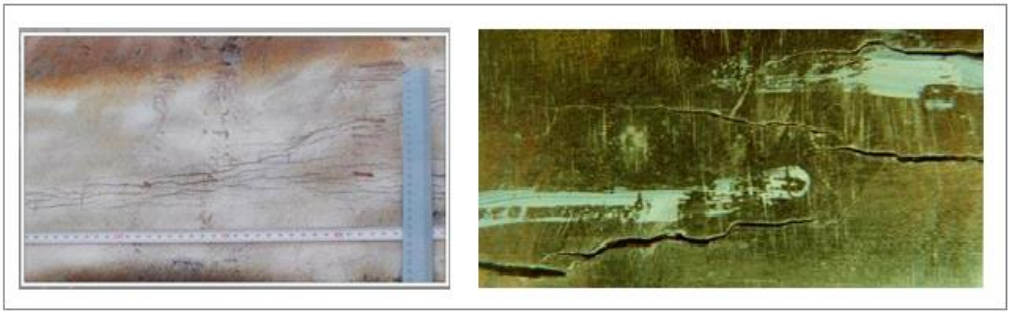

Figure 1 - Development of stress-corrosion cracking on the gas pipeline

There are three main approaches to solve the existing problem. The first approach is to conduct a timely inspection of the current state of gas pipelines, identify and register damages. The second approach is to draw up a clarified algorithm for locating leaks in gas pipelines. The third approach is to assess the reliable operation of gas pipelines with crack-like defects.

In the second chapter, use of the dimensional expander for simulating gas leaks from gas pipelines in transient conditions was substantiated and the technique for determining the volume of natural gas leaks from underground pipelines was proposed.

Software methods enable to keep continuous control, determine the leakage location as well as gas loss values from the pipeline in real time. They are expected to use systems analyzing the deviation obtained from SCADA pumping parameter

systems from the calculations collected by preliminary mathematical modeling of gas flow through the pipeline with the use of statistical data.

The determination accuracy of the location and gas loss values depends on the equations simplification degree applied in the model. The most popular algorithmic methods use simplified gas motion equations in their composition, which enables to increase the speed of their computational solution, although adversely affects the computational accuracy, especially under non-steady-state conditions. Applying dynamic models, which use general gas motion equations in the pipeline and its filtration during propagation in the soil, can improve the computational accuracy of the leak point and the gas loss volume.

However, one of the most important stages in the development of any mathematical model is its adaptation based on experimental data. The given article represents the empirical data to adapt the existing dependencies and models for determining the natural gas leak volume to the media with superatmospheric pressure. In obtaining experimental data, a test installation was used, which enables to simulate gas leakage from the pipeline with non-steady-state mode to the medium with superatmospheric pressure, and determine their value by means of volumetric expander. On the basis of the installation, full factorial experiments were conducted for two pressure ranges of inside and outside the pipeline.

Data collection, visualization and export was carried out on the basis of the SCADA Trace Mode software, data conversion was conducted with Matlab R2017a, regression analysis was performed by means of MS Excel.

Further conversion of collected dependencies were performed on the basis of the computerized algebra software Wolfram Mathematica 10.0.

The most popular methods for determining the natural gas leak volume are algorithmic based on the law of mass or volume conservation ($V_{\text{у}} = Q_{\text{ф}}$) and the formula for pressure variation along the length of the pipeline (Figure 2), which is exemplified by solving the following simultaneous equations:

$$\begin{cases} p_{\text{в}}^2 = p_1^2 - 1{,}11 \cdot 10^{-3} \left(\frac{0{,}01}{d} + 2{,}9 \cdot 10^{-2} \frac{d}{Q_{\Phi}}\right)^{0{,}25} \frac{Q_{\text{ф}}^2}{d^5} l_{\text{ф}}, \\ V_{\text{у}} = 1090 \cdot f \cdot p_{\text{в}} \end{cases}$$

where p_1 and $p_{\text{в}}$ – are, respectively, the absolute gas pressure at the beginning of the pipeline section and at the leak point, MPa; d - is an inner pipeline diameter, cm; $Q_{\text{у}}$ – is a commercial gas rate flowing to the leak point, m^3/hr; $l_{\text{ф}}$ – is a length of the pipeline from the section beginning to the leak point, m; f – is a damage port-hole area, cm2; 1090 – is a numerical coefficient considering the reduction of existing values, sound velocity in the medium and the coefficient of irregularity in the gas velocity distribution through the cross section of the port-hole.

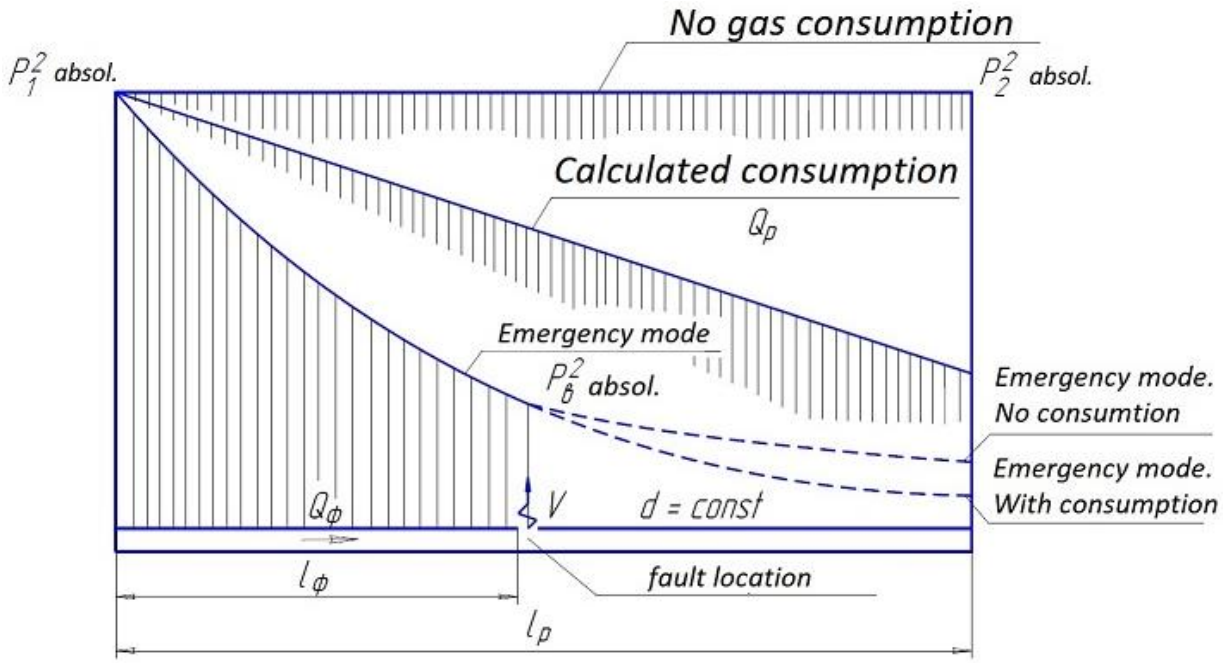

Figure 2 – Pressure variation along the length of the pipeline in the event of an accident

The purpose of the work was to obtain dependencies of the gas loss values from the pressure at the leak point inside the pipeline and in the medium outside of it. Experimental data were obtained on the basis of the installation which has an adjustable volumetric-type expander inward (Figure 3).

Figure 3 represents the complete diagram of the multifunctional test installation, including the elements that are out of use during the experimental procedure for this performance.

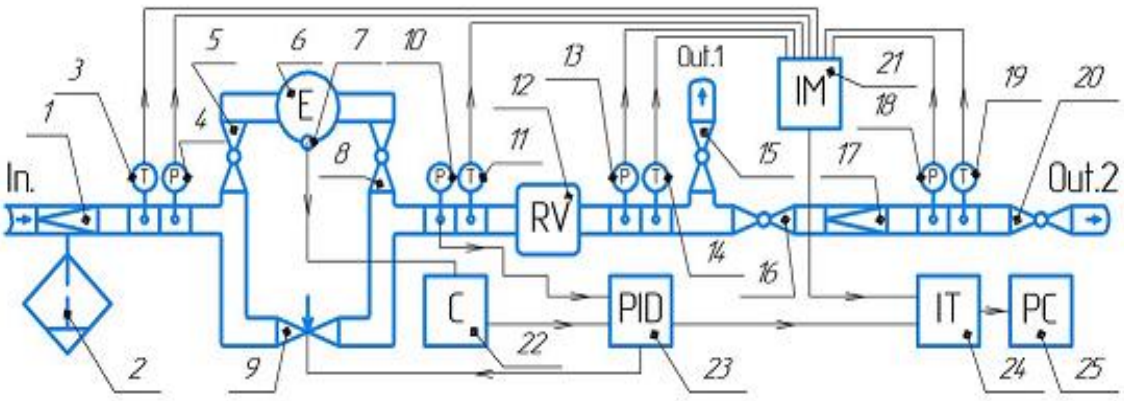

Figure 3 – Test installation diagram

Full two-factor experiments were carried out for three-level factors taking into account the effect of their interactions for two pressure ranges (Table 1). Since natural gas in the filtration conditions is under pressure not exceeding 100 kPag, the pressure range in the medium beyond the pipeline p_2 was chosen from 45 to 125 kPag. The pressure range at the leak point inside the pipeline p_1 is based on the engineering constraints of the installation.

Table 1 - Experiment Factor Levels

Factor	**The factor levels on a natural scale**	
	1	**2**
p_1, kPag	300	400
	350	450
	400	500
p_2, kPag	45	85
	65	105
	85	125

The results of the conducting and processing the obtained data have become dependencies of the expander rotor speed on pressures inside and outside of the pipeline at the leak point $\omega^3(p_1, p_2)$, on the basis of which, target dependencies of the gas loss values were obtained by applying the predeveloped method of calculating basic parameters of the volumetric expansion machine, $V(p_1, p_2)$, the visualization of which is represented in Figures 4 - 5.

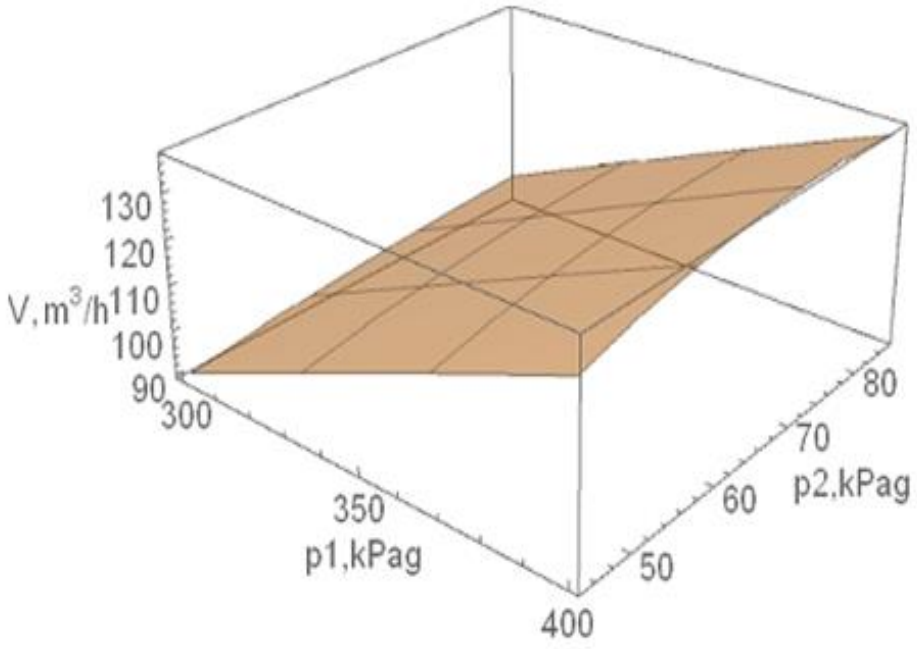

Figure 4 – Dependency visualization of the reduced volume of hourly leakage on pressures at the leak point from the pipeline and in the external medium for the first pressure range

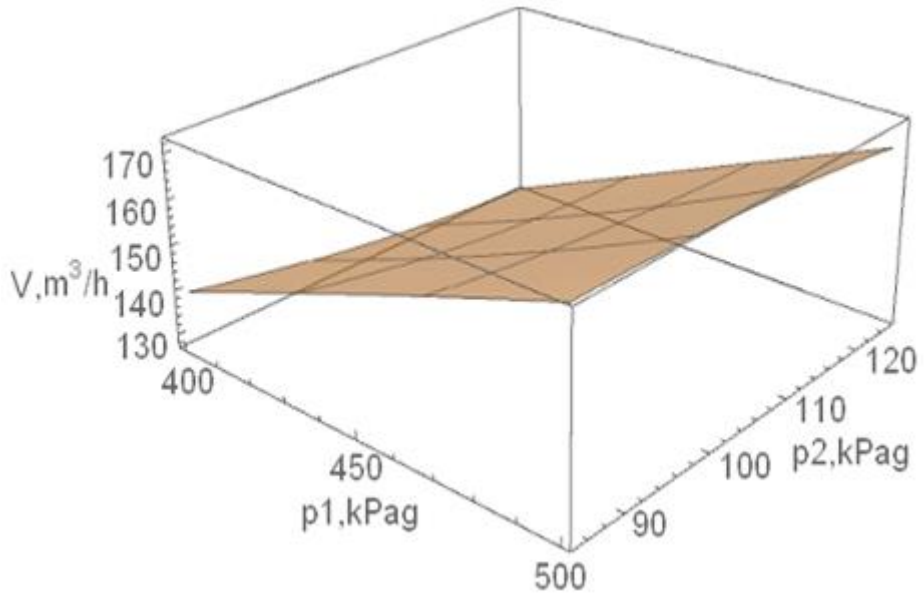

Figure 5 – Dependency visualization of the reduced volume of the hourly leakage on the pressure at the leak point from the pipeline and in the external medium for the second pressure range

The abovementioned dependencies can be used to determine the leakage value under unsteady-state conditions for a certain time t in accordance with the following equation

$$V_{\text{сум}} = \int_{t_1}^{t_2} V(p_1^t, p_2^t)dt$$

where p_1^t and p_2^t – are, respectively, the functions of pressure variation inside the pipeline and in the gas filtration medium with time t; t_1 and t_2 – are, respectively, the time points of the beginning and end measurement.

By means of the test installation, simulating gas leaks from the pipeline to the media with superatmospheric pressure was carried out. Based on the experimental findings, the dependencies of the leakage value on the pressure at leak point inside the pipeline and in the medium outside of it for two ranges were obtained. Dependencies can be applied to determine the gas leak volume under non-steady-state conditions.

The third chapter provides a patent review of methods and technical means for in-line repair of gas pipeline damages without stopping gas pumping. The in-line machine has been elaborated to eliminate defects in a gas pipeline under gas pressure.

Accident-free operation and lengthening the life of supports of main pipelines mainly depend on timely and high-quality repairs.

Optimal planning and rational use of material and technical resources of the repair and construction industry are becoming important.

As shown by the quantitative and qualitative analysis of the existing repair system, the efficiency of the overhaul of line pipe of the main gas pipelines can be achieved only by comprehensive consideration on optimization problems in

engineering, technology, organization and management of repair and construction operations.

Successful implementation of the large volume work both for the construction and overhaul of main gas pipelines is impossible without the introduction of the most sense technology and perfect organization of work ensuring their high rates. It is very important to choose the most effective technological scheme for the production of repair work taking with respect to available equipment.

Primarily, it seems necessary to analyze the existing techniques of repairing gas pipelines.

Currently, gas transportation companies are increasingly repairing gas pipelines without interrupting gas transportation.

There are two ways to eliminate through defects on gas pipelines without stopping pumping: external and in-line.

The external technique includes repairing technology of the gas pipeline with cutting out the defective area, composite-coupling technologies, pipe clips, hold-down clamps, overlapping welded overlays.

The method of repairing the existing gas pipeline with composite couplings includes installation of two steel parts of the sleeve joint, the diameter of which is larger than the diameter of the pipe being repaired which is connected in such a way that the damaged section is completely enclosed. The resulting annular gap between the gas pipeline and the sleeve joint is filled with a composite material (Figure 6).

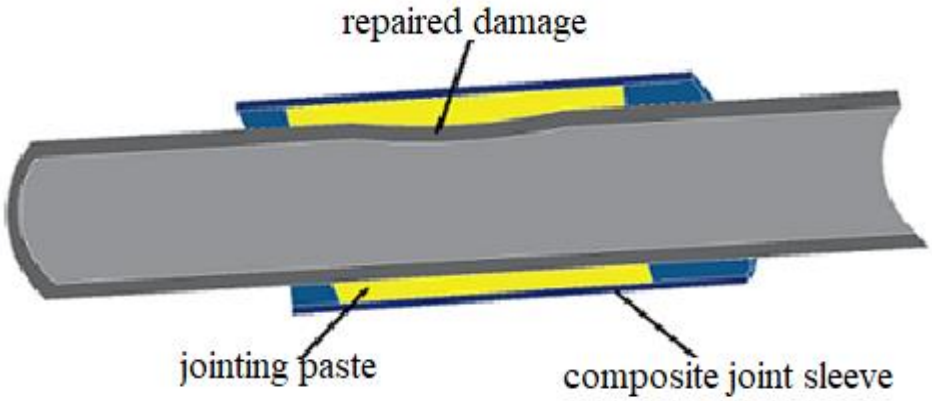

Figure 6 - Composite joint sleeve

Devices for eliminating damage on gas pipelines without stopping the product pumping have simpler designs outside, but require excavating a trench which increases time for repairs and funding.

At present in-line techniques of eliminating defects on existing gas pipelines are of our main interest.

One of these invention is a robotic centre which includes means for moving, inspecting and repairing damaged sections of the pipeline. The device is moved in the pipeline by means of two toroidal elastic retainer located in front and behind the centre downstream with the flow. Upon reaching the place of damage, the walls of the pipeline tightly seal this area by expanding the elastic retainer of the device which are located

along the outer boundary of the damaged, repaired area, and the flow is directed through a temporary pipeline formed by the device.

The disadvantage of this device is the use of two allowable zones: liquid and gas which complicates the design, in addition, the use of inflatable elastic sealing elements considerably reduces the reliability of the device, since the resulting rugosity on the inner surface of gas pipelines during the long-life operation can lead to mechanical damage.

The reliable device for in-line repair of gas pipelines has been developed which ensures the implementation of repair work on defective areas within integrity damage of the pipeline without stopping gas pumping (Figure 7).

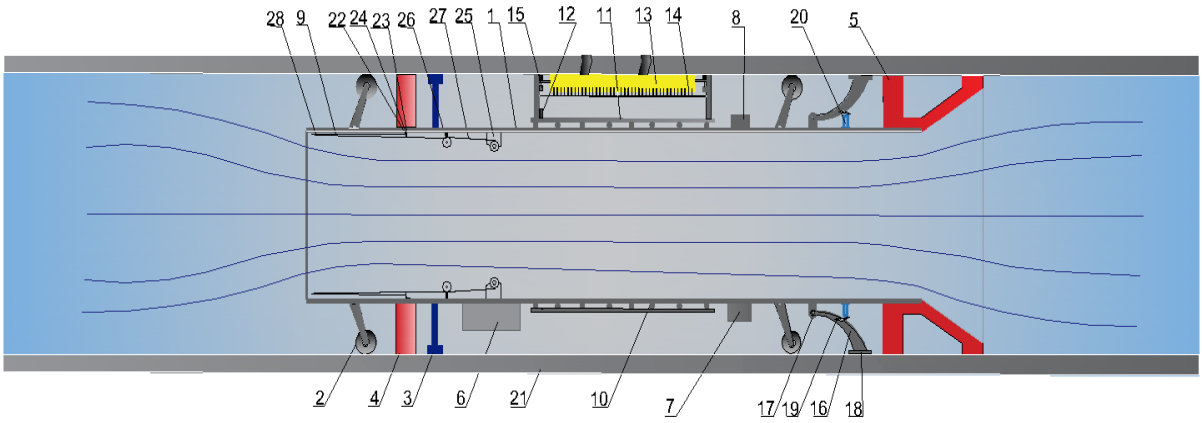

Figure 7 - Assembled representation of the device with an open petal mechanism
1-body-frame, 2-wheels, 3-leak detector, 4- sleeve gasket, 5- socket end, 6-accumulator, 7-generator, 8-processor, 9-petal mechanism dampers, 10-bearings, 11-cylinder, 12- electric engine, 13-drum, 14-injectors, 15- holding-down clamp, 16-rod, 17,22-articulated joint, 18-brake pads, 19-foot step, 20-jack, 21- main gasline, 23-angle plate, 24- spring, 25-geared engine, 26-block, 27-cable, 28-damper ears

The device for in-line repair of gas pipelines including sealing means, a leak detector, a repair unit, an accumulator and a control device under the utility model has a cylindrical body with spring-loaded support wheels, the sealing means are made in the form of a cuff in the front part of the device and a bellmouth/socket end in the end part, a unit repair work is equipped with an electric engine and is made in the form of a drum mounted outside the housing with a clamping device, the drum is fixed on a cylinder located on bearings, the repair work unit is equipped with injectors for supplying sealing material to the drum surface, a petal mechanism for regulating the speed of movement is installed inside the body-frame in its front part connected to a gearbox, while the device is equipped with a generator, processor, brake mechanism.

The device is launched into the launching and receiving chamber of tubing broach and moves inside the existing gas pipeline on spring-loaded wheels which reduce the contact pressure of the cuffs on the pipeline walls which leads to more uniform movement of the device jerk-free. Under the influence of the hydraulic pressure of the gas, the device moves inside the main gas pipeline to a predetermined

location. The location of the device is determined using a leak detector. The speed of movement of the device is regulated by a petal mechanism. When the petal mechanism is opened, a passage for the gas flow is created, the gas-dynamic resistance of the device to the gas flow is eliminated, the speed of the device slows down and thus the device does not create significant additional hindrances to the operating mode of gas transportation. The location of the device is corrected using a leak detection detector. The device takes a position in the damaged area. When the leakage sensor is triggered under the control of the processor, a layer of sealant is applied to the drum surface by means of injectors, the drum moves to the inner surface of the gas pipeline and the polymer layer is applied in a circular direction. After sealing, the drum returns to its original position. The device remains in place until the applied layer has completely polymerized. After completing the repair work, the device turns off the braking device, closes the petal mechanism and begins to move along the pipeline. Then the device is removed from the pipeline.

The proposed device decreases financial costs, shortens the time of repair and restoration work, reduces labor intensity and ensures uninterrupted gas supply to consumers.

The fourth chapter analyzes the economic efficiency of the applied techniques for in-line repair of gas pipelines.

Under the terms of the legislation, if the crack depth of the stress corrosion cracking is more than 50% of the gas pipeline wall thickness, then the defect is considered inadmissible regardless of its length, which requires its mandatory elimination. A singular defective pipe is subject to complete or partial replacement if the overall characteristic length of the stress corrosion cracking defects exceeds 30% of the pipe length.

Replacement pipes is carried out on a disconnected and completely gas-free section of the pipeline which requires large financial costs. In organizational and economic terms, the complexity of the problem lies in the large amount of repair and restoration works:

- localizing the defective section of the gas pipeline on the ground, determining the location of the third-party organization communications;
- removing the fertile layer in the right-of-way;
- excavating the pit at the location of the defect, removing insulation and identifying the defect;
- preparing the section of the main gas pipeline to repair;
- carrying out repair work;
- reclaming.

While performing every technological operation for the drilling of main gas pipelines, there is a significant number of forced downtime of special equipment and personnel waiting for their turn which increases the unit cost of repair work.

The only economically feasible way out of this challenging situation is to acquire advanced technologies and search non-standard, fundamentally new techniques and means of repair without interrupting the pumping of natural gas.

One of these techniques is the in-line repair of sections of main pipelines with special devices, the movement of which along the linear part is carried out under the

impact of internal pressure difference, similar to in-line flaw detectors and cleaning pigs.

The economic effect of the use of such a device was analyzed using the example of the 3rd string of the Kazakhstan-China gas pipeline, designed to ensure the transportation of natural gas from the territory of Uzbekistan and Turkmenistan, as well as the supply of Kazakhstani gas from the Beineu-Bozoi-Shymkent gas pipeline for consumption to the southern regions of Kazakhstan and for export to the PRC (Figure 8).

Figure 8 – The map of the main gas pipeline “Kazakhstan-China”

The gas pipeline has the necessary launcher-receiver units of pollution control facilities in sufficient quantity for the service of the device for in-line repair.

Savings, in comparison with repair methods requiring stopping pumping and excavation, were determined as average total costs:

1) on work replacing the defective area;
2) on depleted and purge gas;
3) on gas shortfall.

The repair of the main gas pipeline with in-line devices is advanced due to the possibility of eliminating defective areas with no need for releasing gas into the atmosphere and stop pumping.

The costs on in-line repairs are much less which indicates the economic efficiency of using this repair technique.

Further developments on this topic will be carried out in the direction of specifying the organizational-technical measures related to the service of the device.

Brief summary with regard to findings of the study.

In the dissertation, the analysis of ways to eliminate natural gas leakage from gas pipelines is conducted. Experimental studies of gas reduction processes have been carried out in order to simulate leaks from underground gas pipelines and determine

their volumes in non-stationary conditions by means of dimensional expander. The patent of the Republic of Kazakhstan was obtained on the device for in-line repair of main gas pipelines without stopping gas pumping. Also, according to the objectives set, the following were done:

1. The main factors influencing the technical condition of long-term operating main gas pipelines in Kazakhstan have been determined.

2. The algorithm for locating leaks in underground gas pipelines has been developed on the basis of research results taking into account the implementation of the mathematical model. The boundaries of gas contamination area for two phases of the unsteady gas filtration process have been defined.

3. The algorithm for assessing the safety of main gas pipelines by calculating the probability of failure-free operation based on a probabilistic-deterministic model has been implemented.

4. The use of expander devices for simulating gas leaks from gas pipelines in stationary and non-stationary conditions has been substantiated.

5. The mathematical model of gas leaks from a defective gas pipeline has been developed taking into account the use of a proportional-integral control law in various stabilization options.

6. Gas leaks from a pipeline with a non-steady flow regime were simulated.

7. Dependences of leak volumes on pressures at the point of leakage inside the gas pipeline and in the environment outside it were obtained for two ranges which can be used to determine the volumes of gas leaks in non-stationary conditions.

8. The in-line machine has been elaborated to eliminate gas leaks from defects and microcracks on high-pressure gas pipelines without stopping gas pumping.

9. The cost-effectiveness analysis using the in-line technique of repairing gas pipelines without stopping gas pumping was conducted by way of example of the third string of the Kazakhstan-China gas pipeline.