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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

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DETERMINATION OF NATURAL GAS LOSS VALUES BASED ON PHYSICAL SIMULATION OF LEAKAGES FROM THE PIPELINE TO THE MEDIA WITH SUPERATMOSPHERIC PRESSURE USING A VOLUMETRIC-TYPE EXPANDER

Abstract. The operating practice of gas transmission system reflects that one of the major concerns of pipeline companies is through fault, wherethrough considerable amount of gas is lost triggering gas pipeline accidents followed by fires, explosions, and hazardous substances emissions to the environment, which may cause human losses. The gas leak volume depends on varied parameters, particularly the parameters of the defect itself, the operating mode and the ambient medium.

The purpose of the study was to improve methods for determining the natural gas leakage value from pipelines to the media with superatmospheric pressure.

Software-based methods determining the location and gas leak volume enable to keep continuous control and estimate the target values in real time. However, their accuracy depends largely on the equations simplification degree comprised in the used mathematical model. One of the most significant stages in the development of any model is its adaptation based on experimental data.

For obtaining experimental findings, a test installation was exploited, which provides an opportunity to simulate gas leaks from the pipeline under non-steady-state conditions, and define their value by means of a volumetric expander. Based on it, full factorial experiments for two pressure ranges were carried out with subsequent regression analysis of the results and obtaining dependencies of leakage values on pressures at the leak point inside the gas pipeline and in the medium outside of it. Dependencies can be applied to determine the gas leak volume under non-steady-state conditions.

Keywords: leakage, natural gas, gas loss, leak volume, gas pipeline, experimental studies, volumetric-type expander.

Introduction. In order to ensure efficient and safe operation of main gas pipelines, solving timely detection tasks, leakage elimination and determining the natural gas loss value are essential [1].

The most complicated case is the leakage from the buried gas pipelines, since the gas filtration is in the soil, its distribution from the leak point and concentration in the subsurface voids are determined by a great number of factors [2, 3].

Damages to buried gas pipeline occur for the following reasons: physical impact while excavating due to the deviation from safety rules and operational procedures; corrosion damage of metal pipes as a result of violations and/or inadequate control of the technical state during the construction process; joints rupture and stitches opening of pipelines due to the poor construction and installation works [2, 4].

The consequences of natural gas leakage, apart from its loss, are meant to be: structural damage; injuries and human losses due to burning or explosion of the gas-air mixture; financial and economic expenses as a result of gas shortfall to consumers and penalty provisions [5, 6].

At present leakage detection methods can be divided into several types: traditional, hardware and software.

Traditional methods include visual inspection of pipelines.

The hardware examples may include methods fundamentally applying visual, fiber-optic and acoustic devices, samplers, videothermovision survey, wave of pressure detectors and others. However, due to the long mileage of main gas pipelines, the severe climatic conditions and the inaccessibility of substantial amount of linear parts, using most of the described technical facilities seems to be incredibly challenging [7-10].

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 [5, 11-13].

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 [7, 14].

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.

Applied research methods. 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 [15]. 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 were 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 was performed on the basis of the computerized algebra software Wolfram Mathematica 10.0.

Body. In general, the gas filtration model in soil consists of the equations: continuity, filtration under Darcy's law and the state equation and has the following form [16-19]:

$$\begin{cases} \frac{\partial}{\partial t}(\rho_i s_i m_i) + div(p_i \vec{v}_i) = q_i \\ \vec{v}_i = -\frac{k}{\mu} f_i(s)[gradP_i - \rho_i \vec{g}] \\ F(P, T, \rho) \end{cases}$$

The simultaneous equation outlined above is non-linear and difficult to solve; therefore, a simplified linear theory is used to describe the problems of one-dimensional filtration.

The most popular methods for determining the natural gas leak volume are algorithmic [6, 20, 21] based on the law of mass or volume conservation ($V_y = Q_\phi$) and the formula for pressure variation along the length of the pipeline (figure 1), which is exemplified by solving the following simultaneous equations [20]:

$$\begin{cases} p_в^2 = p_1^2 - 1{,}11 \cdot 10^{-3}\left(\frac{0{,}01}{d} + 2{,}9 \cdot 10^{-2}\frac{d}{Q_y}\right)^{0{,}25}\frac{Q_\phi^2}{d^5} l_\phi \\ V_y = 1090 \cdot f \cdot p_в \end{cases}$$

where p_1 and $p_в$ – 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_y – is a commercial gas rate flowing to the leak point, nm^3/hr; $l_ф$ – is a length of the pipeline from the section beginning to the leak point, m; f – is a damage port-hole area, cm^2; 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 [20].

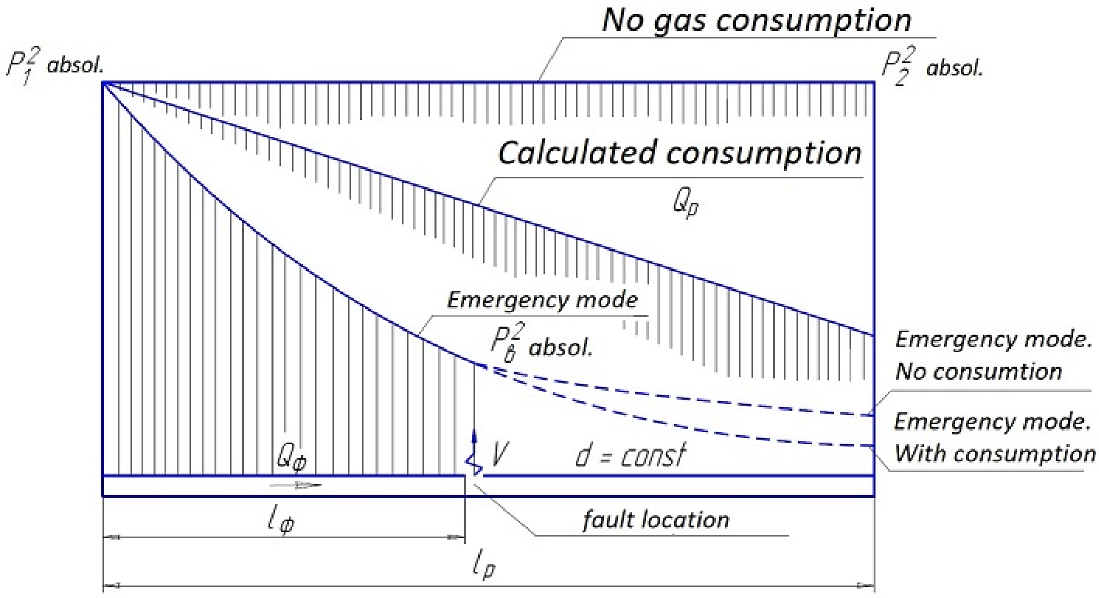

Figure 1 – Pressure variation along the length of the pipeline in the event of an accident [20]

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 2) [15].

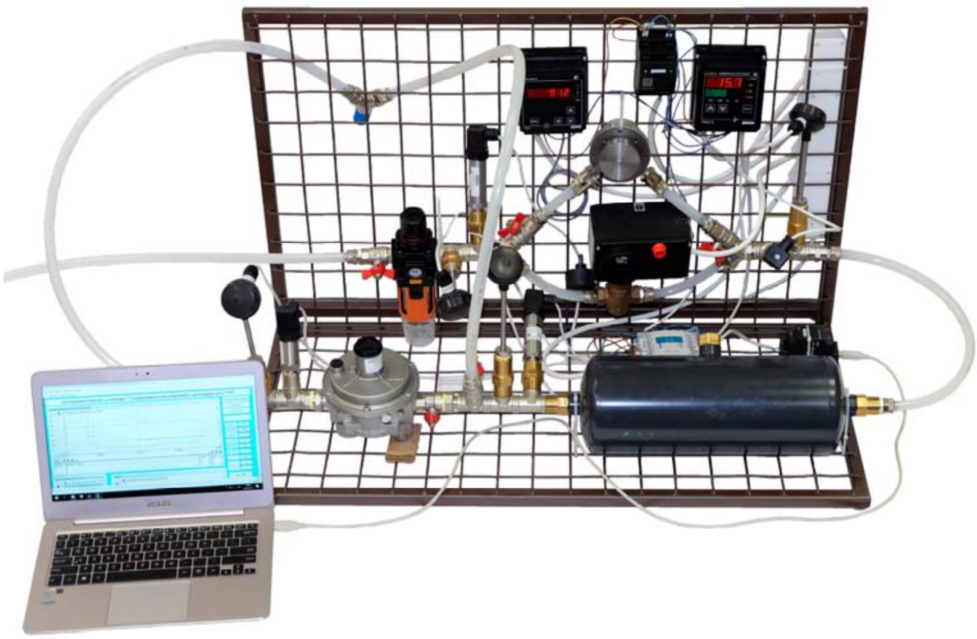

Figure 2 – Test installation

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.

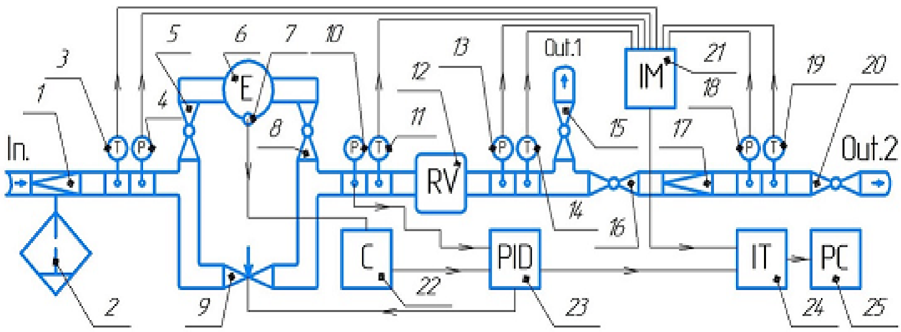

Figure 3 – Test installation diagram

The installation operates in the following manner. After compression by the volume compressor, air gets into pressure regulator 1 and filter separator 2. Nextly, temperature and pressure value measurement is performed by sensors 3 and 4, afterwards the gas flow is divided into two parts proportionally to the rate of opening of the electric control valve 9. One part passes through the volumetric expander 6, which has a contactless frequency sensor 7 fixed on it. The other, respectively, goes through the control valve 9. After the previously separated flows are linked by sensors 10 and 11, pressure and temperature of blended gas stream are measured, further it passes through the receiver 12, and its pressure and temperature are measured once again by sensors 13 and 14. Then, when the tap valve is closed 16, gas is released to the atmosphere by the tap valve 15.

Modeling (maintenance of) a certain pressure in the medium outside the pipeline is in the following way. A signal from pressure sensor 10 is set up to the inlet of the proportional-integral differential controller (PI controller) 23. Depending on the pressure deviation rate for the expander from the programmed constraint, the PI controller 23 sends a guiding signal on the rate of opening of the control valve 9 to its electric driver.

The pressure and temperature transducer readings, frequency sensor 7 and the signal of the rate of opening of the control valve 9 collected by the input module 21 are transmitted via the interface converter 24 to the personal computer 25, where the obtained data are visualized by means of SCADA Trace Mode and exported for further processing. The data collected using SCADA Trace Mode, due to their sizable volume, are exported to TXT or XML file, and then processed using MATLAB R2017a.

Full two-factor experiments were carried out for three-level factors taking into account the effect of their interactions for two pressure ranges (table). Since natural gas in the filtration conditions is under pressure not exceeding 100 kPag [16], 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.

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

Results. 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 $\omega^{э}(p_1, p_2)$, 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 [22, 23], $V(p_1, p_2)$, the visualization of which is represented in figures 4, 5.

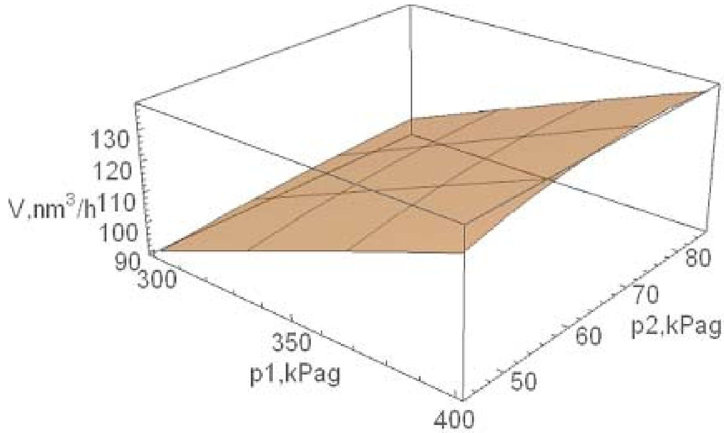

Figure 4 – Dependency visualization of the reduced volume of hourly leakage on pressures at the leak point from the pipeline and in the external medium for the first pressure range

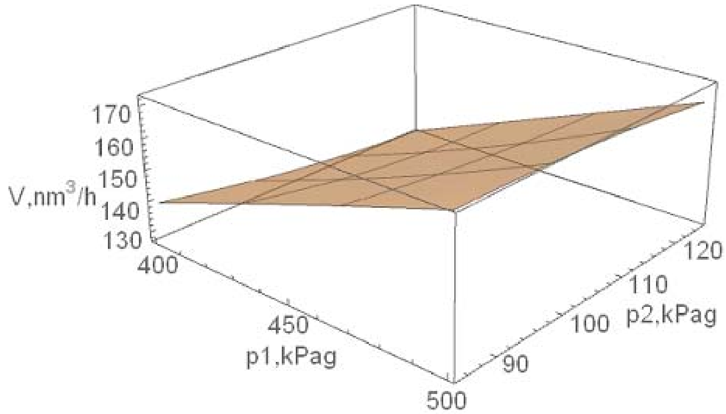

Figure 5 – Dependency visualization of the reduced volume of the hourly leakage on the pressure at the leak point from the pipeline and in the external medium for the second pressure range

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

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

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.

For instance, for the first pressure range (see above) when the pressure variation at the leak point inside the pipeline, according to the following law

$$p_1^t = \left(1 - \sin\left(\frac{2\pi \cdot t}{8760}\right)\right) \cdot p_1^{t_1},$$

where $p_1^{t_1}$ – is a pressure at zero time t_1 equals to 350 kPag, with constant outlet pressure at the level of 65 kPag in an hour the leakage value will be 102.125 nm^3. With $p_1^{t_1} = 450$ kPag and $p_2 = 105$ kPag for the second pressure range is 135.578 nm^3.

Conclusion. 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.

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КӨЛЕМДІК ТҮРДЕГІ ДЕТАНДЕРДІ ПАЙДАЛАНА ОТЫРЫП, АТМОСФЕРАЛЫҚ ҚЫСЫМНАН ЖОҒАРЫ ОРТАҒА ҚҰБЫРӨТКІЗГІШТІҢ ШЫҒЫНЫН ФИЗИКАЛЫҚ МОДЕЛЬДЕУ НЕГІЗІНДЕ ТАБИҒИ ГАЗДЫҢ ЖОҒАЛУ ШАМАЛАРЫН АНЫҚТАУ

Аннотация. Газ тасымалдау жүйесінің нысандарын пайдалану тәжірибесі көрсеткендей, газ компанияларының басты проблемаларының бірі газдың едәуір көлемін өтпелі ақаулар арқылы жоғалту болып табылады, бұл өрт, жарылыс және қоршаған ортаға зиянды заттардың шығарылуына алып келетін газ құбырларындағы аварияларға әкеп соғады, бұл адам құрбандығына әкелуі мүмкін. Газдың шығын көлемі әртүрлі параметрлерге, атап айтқанда ақаудың өзінің параметрлеріне, пайдалану режимі мен қоршаған ортаға байланысты.

Жұмыстың мақсаты атмосфералық қысымдардан жоғары ортаға табиғи газдың құбырөткізгіштен шығу шамасын анықтайтын әдістерді жетілдіру болды.

Газ шығынының көлемі мен орнын анықтаудың бағдарламалық тәсілдері үздіксіз бақылау жүргізуге және нақты уақытта ізделінетін мәндерді есептеуге мүмкіндік береді. Алайда, олардың дәлдігі көп жағдайда қолданылатын математикалық модельдің құрамына кіретін теңдеулерді оңайлату дәрежесіне байланысты. Қандай да бір модельді әзірлеудің маңызды кезеңдерінің бірі оның эксперименттік деректер негізінде бейімдеу болып табылады.

Тәжірибелік деректерді алу үшін стационарлық емес жағдайларда құбырөткізгіштен газдың шығуын моделдеуге, сондай-ақ көлемді детандердің көмегімен олардың шамасын анықтауға мүмкіндік беретін эксперименттік қондырғы қолданылды. Соның негізінде екі қысым диапазоны үшін толық факторлық эксперименттер жүргізілді, кейін олардың нәтижелерін регрессиялық талдау және газ құбырының ішінде және оның сыртындағы ортаға шығу орнында шығын шамасының қысымдардан тәуелділігін алу. Бұл тәуелділік стационарлық емес жағдайларда газдың шығын көлемін анықтау үшін қолданылуы мүмкін.

Түйін сөздер: шығын, табиғи газ, газ жоғалту, шығын көлемі, газ құбыры, тәжірибелік зерттеулер, көлемдік түрдегі детандер.

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ОПРЕДЕЛЕНИЕ ВЕЛИЧИН ПОТЕРЬ ПРИРОДНОГО ГАЗА НА ОСНОВЕ ФИЗИЧЕСКОГО МОДЕЛИРОВАНИЯ УТЕЧЕК ИЗ ТРУБОПРОВОДА В СРЕДЫ С ДАВЛЕНИЯМИ ВЫШЕ АТМОСФЕРНОГО С ИСПОЛЬЗОВАНИЕМ ДЕТАНДЕРА ОБЪЁМНОГО ТИПА

Аннотация. Практика эксплуатации объектов газотранспортной системы показывает, что одной из главных проблем газовых компаний являютя сквозные дефекты, через которые теряются значительные объемы газа, что приводит к авариям на газопроводах, сопровождающиеся пожарами, взрывами и выбросами вредных веществ в окружающую среду, что может привести к человеческим жертвам. Объем утечки газа зависит от различных параметров, в частности параметров самого дефекта, режима эксплуатации и окружающей среды.

Целью работы было совершенствование методов определения величины утечек природного газа из трубопроводов в среды с давлениями выше атмосферного.

Программные способы определения местоположения и объёма утечки газа позволяют вести непрерывный контроль и в реальном времени рассчитывать искомые значения. Однако, их точность во многом зависит от степени упрощения уравнений, входящих в состав используемой математической модели. Одним из важнейших этапов разработки какой-либо модели является её адаптация на основе экспериментальных данных.

Для получения опытных данных была использована экспериментальная установка, которая позволяет моделировать утечки газа из трубопровода в нестационарных условиях, а также определять их величину с помощью объёмного детандера. На её основе были проведены полные факторные эксперименты для двух диапазонов давлений с последующим регрессионным анализом их результатов и получением зависимостей величины утечек от давлений в месте утечки внутри газопровода и в среде снаружи него. Зависимости могут быть применены для определения объёмов утечек газа в нестационарных условиях.

Ключевые слова: утечка, природный газ, потери газа, объём утечки, газопровод, экспериментальные исследования, детандер объёмного типа.

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