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REGULARITIES OF SAFE CONTROL OF PISTON COMPRESSOR UNITS OF MOBILE COMPRESSOR STATIONS

Purpose. Ensuring the optimal mode of gas transportation from local sections of the main gas trunkline (GT), subject to repair (maintenance) and/or shutdown, to existing main gas trunkline based on the calculation, determination, and establishment of rational values of the operating modes of mobile compressor stations during the entire time of gas pumping.

Methodology. The studies are based on existing physical principles and laws that describe the effect of the properties of natural gas and the geometric parameters of pipelines through which gas is pumped on the dynamics of changes in the mass and pressure of the transported gas. The calculation of the change in the mass and pressure of the gas in the gas pipeline from which the gas is pumped is based on a number of existing theoretical and empirical dependencies included in the generally accepted methods for their calculation. Known physical relationships and mathematical models are used to carry out the calculations.

Findings. The "mass" approach to the issue of calculating the gas transportation time is more mathematically accurate than the "volumetric" one. The ratio of the relative mass to the relative gas pressure in a localized section of the main gas pipeline, during the entire pumping time, is a constant value. The use of the values of the quantities obtained at the point of intersection of the graphs of changes in the relative mass and relative pressure of the gas, in the preliminary calculation of the time for pumping gas, or pressure, or mass, or the volume of gas in each time interval, makes it possible to select the optimal rate of building up/reducing gas pressure by compressor units and optimal modes of gas transportation by operating gas pipelines during the operation of mobile compressor stations.

Originality. The proposed approach to calculating and determining the time of gas pumping by mobile compressor stations from local sections of the main gas pipelines subject to repair (maintenance) and/or shutdown to sections of existing main gas pipelines proves that it is advisable to establish stable patterns in the transportation of natural gas using reciprocating compressor units only after modeling in time the change in the mass and pressure of gas in the local section of the main gas pipeline from which the gas is pumped.

Practical value. The proposed approach to optimizing the time of gas pumping by mobile compressor stations makes it possible to increase the level of energy and resource efficiency of gas transmission enterprises, as well as to improve the technical and economic indicators of technologies for repairing the main gas pipelines, compressor stations of main gas pipelines associated with the need to bleed gas from sections of the main (technological) pipelines subject to repair (maintenance) and/or shutdown. Optimization of gas pumping time significantly reduces the time spent by employees of gas transmission enterprises under the influence of hazardous and harmful production factors, thereby reducing the level of relevant risks. Gas emissions and associated risks are reduced by 90 %.

Keywords: *natural gas, gas trunkline, compressor station, gas transportation*

Introduction. The gas transfer technology intended to prevent the natural gas throttling while using mobile compressor station (MCS), is well known in the world. This technology is used during the major overhauls, tests (simulations), other repair and scheduled maintenance works of gas linepipes.

There are several MCS models with multi staged gas compression in piston compressors. These MCS models are produced by COMPEX/OGE/LMF/CAT/AG/ARIEL and other companies [1]. Gas engines from different producers are used as drive units in MCS.

The essence of the mentioned technology is the following: the selected gas trunkline section is sealed at both sides (localization); then the gas is pumped by MCS [2] from the sealed part into the operating part of the same gas trunkline or into another operating gas trunkline.

In compliance with the current legislation, pipeline transport companies are bound by the contract terms to provide nobreak natural gas delivery to consumers. These companies also have to follow existing norms, safety regulations, gas pipelines operating procedures, fire safety rules and natural environment protection rules [3]. Also, natural gas (methane CH_4) is one of the important greenhouse gases.

All these facts force gas transmission providers to create and guarantee appropriate parameters and requirements for natural gas transportation via gas linepipes, requirements for repair/maintenance works at gas trunklines without stopping the natural gas delivery to consumers and without throttling major volumes of natural gas into the external environment.

The research on impact over time of geometric pipe parameters and natural gas thermodynamic parameters (which is transported under the pressure varying from 1 to 75 bar) on gas transportation processes is required for optimization of MCS modes and working conditions.

Ideally, pumping gas out from an isolated section should happen with constant relative mass to relative pressure ratio in the chosen pipeline during the whole period of pumping.

Analytical research survey. All the factors with both direct and indirect impact on gas pumping influence the MCS choice.

Major influencing factors are safety, economical efficiency, environmental friendliness.

Accordingly, the gas pumping time is the groundwork for industrial safe [4, 5] and energy resource effective [6] approach for MCS choice.

The MCS efficiency is mostly determined by the following factors:

- characteristics of the isolated and operating sections of gas trunkline involved in gas pumping;
- geometric characteristics of pipes of both gas trunkline sections connected to MCS and piping pipes;

- characteristics of piston compressor units of MCS;

- thermodynamic characteristics of natural gas, these should be taken into account while simulating MCS processes.

Gas pumping with MCS should only be done after gas and mass over time simulation of the isolated section of the gas trunkline. It should be noted that pressure value in the isolated section is almost irrelevant for MCS choice due to the wide array of available compressor units with a much broader range of performance capabilities than needed.

By analogy with linear compressor stations, it is clear that working parameters and control parameters of MCS, as well as all the involved calculations, are determined by the working (approved) pressure value in the trunk pipeline, where gas will be pumped into, and by temperature of the pumped gas (it should not be higher than thermal resistance of isolation at the point of MCS connection.

Natural gas pumping technology from the gas trunkline isolated section as a design object should be considered as a set of specific parameters' values of the system, which provides gas transportation process. Regulation of these values fulfills the purpose – with specified resource consumption, specified gas transportation modes, within specified period and with specified quantity.

This concept shows the way to achieve the goal not only with compressor units' parameters, but also with gas pumping (transportation) modes and with industrial control measures.

Purpose. The objective of this work is to research the process of natural gas transportation with the view to maintain the optimal performance during the gas transportation from the gas trunkline section scheduled for repairs (maintenance) and/or disconnection into the operating section of the same gas trunkline (while the scheduled section is sealed off with isolation valves), or into another operating gas trunkline. Optimal performance values are calculated for the whole compressor units operational time during the gas pumping by mobile compressor stations.

Methods. Nowadays, there are following widely used technological schemas of gas transportation with MCS (Figs. 1, 2) [7]. Theoretical, methodological, technological and practical aspects of world-class gas transportation (evacuation) technologies are not shared due to IP protection.

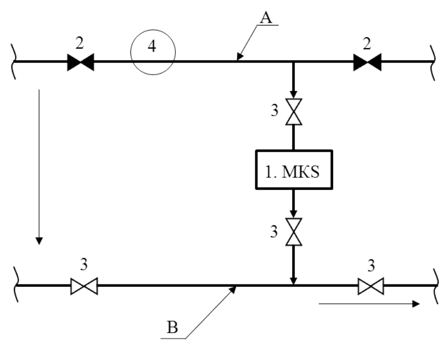

Fig. 1. Parallel scheme, twin gas pipeline:

1 – MCS; 2 – isolation valve set to "sealed"; 3 – isolation valve set to "opened"; 4 – repair works spot; A/B – trunk pipelines; arrows show the direction of gas transportation

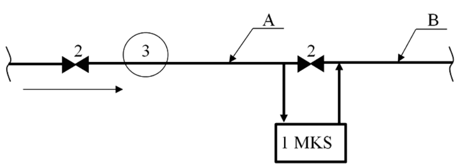

Fig. 2. Serial Scheme, single gas pipeline:

1 – MCS; 2 – isolation valve set to "sealed"; 3 – isolation valve set to "opened"; 4 – repair works spot; A/B – trunk pipelines; arrows show the direction of gas transportation

The Ukrainian technology of natural gas evacuation is not currently applied because of inconsistency in the current legislation in Ukraine.

Ukrtranshaz was the first company in Ukraine who applied the mentioned technology while repairing the gas trunkline Yelets – Kursk – Kyiv in March 2017 [8].

To improve accuracy and optimization of the gas transportation time, as the main criterion for MCS choice and simulation of fluctuation of gas mass and pressure values over time at the isolated section of the trunk pipeline, the calculations have to be made. The calculation algorithm is given below in the article.

In order to make aforementioned calculations and simulations, all the initial parameters should be set, and it is mandatory to include the following parameters: MCS efficiency (including values found by brute-force search), working parameters of MCS, geometric parameters of gas trunklines "*A, B*" (Figs. 1, 2) and MCS technological pipelines, and so on. The calculation scope should also be taken into account, specifically the working (approved) pressure values in gas trunkline "*B*" (Figs. 1, 2) and bearable temperature of gas trunkline insulation "*B*" (Figs. 1, 2) at the point of MCS connection.

During the creation of their own simulation model of MCS, the authors assessed the contribution of every aforementioned factor to gas transportation time from isolated section of gas trunkline "*A*" (Figs. 1, 2) DN 1370, L is equal to 25 km of gas trunkline "*B*" (Figs. 1, 2) DN1370, L is without limits, with pressure ranging from 73.92 bar to 1 bar accordingly.

Calculation Algorithm. Set technical characteristics of gas trunklines "*A, B*" (Figs. 1, 2) including the characteristics of bypass piping of the mentioned gas trunklines (Figs. 1, 2) at the points of MCS connection and MCS piping.

The minimum number is set of compressor units of MCS and their volumetric efficiency values (more than or equal to 70 000 Nm^3/h).

Gas constant for the target gas composition is calculated [8].

Natural gas mass at the isolated section of the gas trunkline "*A*" is calculated (Figs. 1, 2) [9].

Natural gas pressure at the isolated section of the gas trunkline "*A*" is calculated (Figs. 1, 2) [9].

Mass efficiency of MCS is calculated. It is advised to use the methodology and the methane thermodynamic state calculator [8] or other special software to calculate the gas compressibility coefficient.

Parameters which characterize the process of gas pumping from the gas trunkline "*A*" (Figs. 1, 2) into the gas trunkline "*B*" are calculated (Figs. 1, 2) [9].

Gas mass flow and gas mass are calculated, when pressure and temperature are equal to their initial values at the isolated section of the gas trunkline "*B*" (Figs. 1, 2) at every pressure decrease interval (using the volumetric efficiency of MCS compressor units from specifications), taking into account the fact that pumped gas is moving, i.e. its properties are changing [9].

Gas transportation time is calculated at target pressure decrease time interval (1 hour or less) using the ratio of pumped gas mass to mass efficiency of MCS.

The general gas transportation time of MCS is calculated by summing the previously received relative values.

The graph is built of linear functions of gas mass variation and gas pressure variation corresponding to target time intervals of gas pumping by MCS.

The graph is built of linear function of gas relative mass variation and gas relative pressure variation corresponding to target time intervals of gas pumping by MCS.

The graph is built of linear function of gas relative mass variation and gas relative pressure variation corresponding to relative time of gas pumping by MCS (Fig. 3).

The parameters are determined of the intersection point of relative mass variation graph and relative pressure variation graph corresponding to relative time of gas pumping by MCS (point of conservation of mass – "SM" at Fig. 4).

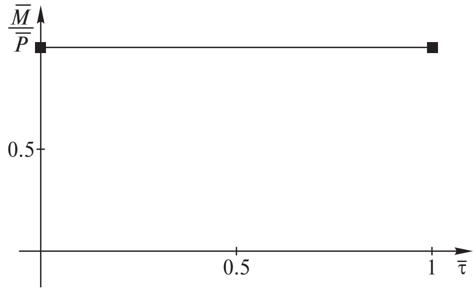

Fig. 3. Graph of correspondence of gas pumping process characteristics:

$\overline{M}$ – relative gas mass; $\overline{P}$ – relative gas pressure; $\overline{\tau}$ – relative gas pumping time

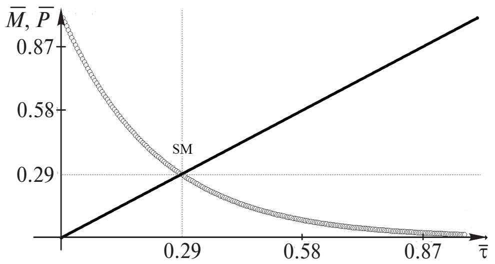

Fig. 4. Graph of relative gas mass variation and relative gas pressure variation during the pumping period:

$\overline{M}$ – relative gas mass; $\overline{P}$ – relative gas pressure; $\overline{\tau}$ – relative gas pumping time

The calculation results are checked. The received data is summarized and analyzed.

The calculations performed by the authors are correct according to the law of mass conservation and fully comply with MCS simulation and the concept of gas pumping by MCS technology.

The authors, relying on the simulation results, calculations and their correctness, built graphs of corresponding functions, received parameters' values at intersection point of relative mass variation graph and relative pressure variation graph corresponding to relative time of gas pumping by MCS (point of conservation of mass – "SM at Fig. 4"), summary and analysis of received data, can assume the following:

1. The total number of aforementioned influencing factors can be reduced if geometric parameters of all the pipelines, participating in the process of pumping by MCS from the gas trunkline "*A*" (Figs. 1, 2) into the gas trunkline "*B*" can be merged as an influencing factor.

2. The influencing factor characterized by gas thermodynamic properties at the isolated section of the gas trunkline "*A*" (Figs. 1, 2), and its relative value constantly variates during the whole time of gas pumping. The influence of the factor on MCS gas pumping time is constantly growing.

3. Local resistance of gas flow along the whole length of MCS technological pipelines from point of connection to the isolated section of the gas trunkline "*A*" (Figs. 1, 2) till point of its connection to the gas trunkline "*B*" (Figs. 1, 2) has a minor impact on gas pumping time [10].

4. Graphical interpretation of gas relative mass to gas relative pressure ratio corresponding to target time intervals of gas pumping by MCS (Fig. 3) shows that both simulated and probably real processes of gas pumping by MCS can occur with constant pressure decrease at every time interval at the isolated section of the gas trunkline "*A*" (Figs. 1, 2).

5. Probably, both simulated and real processes of gas pumping by MCS are stationary processes, i.e. their characteristics do not change in time.

6. Possible gas pumping by MCS from the isolated to the operating section of the gas trunklines at set time with constant efficiency of MCS compressor units with constant gas offtake while optimal performance work of compressor unit (compressor station) corresponds to values, received from intersection of relative mass variation graph and relative pressure variation graph during the relative time of gas pumping by MCS (point "SM" in Fig. 4).

Please note that during the MCS simulation, MCS and the gas trunkline are physical systems and the MCS technological schema has only one input and one output, and gas leakage possibility is excluded by standard, and MCS does not require gas accumulation technologically.

It is possible to make an assumption that gas volumetric flow values of MCS will strongly depend on specific placement of MCS and the gas trunkline control instruments, while gas mass and gas mass flows will have constant values at any point of the system.

According to the authors, it is rational to use gas mass and gas mass flow quantities to deduct stable dependencies when it comes to control of MCS piston compressor unit modes based on calculations, that gases do not have fixed volume and try to fill the whole volume, because volumetric flow and gas density are taken into account during the gas mass flow and the gas mass calculation, and in turn because gas compressibility coefficient, gas constant, pressure and molar mass are used during the calculation of gas density.

Taking into account the fact that the main task of MCS control is to ensure safety and gas pumping process efficiency as well as to maintain balance between units' productivity and gas flow, and taking into account conducted calculations of gas pumping time, we propose to use the following equation (1), with a goal in mind to optimize MCS modes control system as stable function

$$\frac{dM_i(\tau)}{dP_i(\tau)} = \text{const}, \quad (1)$$

where $dM_i(\tau)$ is mass of the gas pumped off during the target time interval, kg; $dP_i(\tau)$ is set pressure reduction interval at isolated section of the gas trunkline, bar; τ is gas pumping time, h.

Examples of equation applications (1).

Example 1. With set time of gas pumping from the isolated section of the gas trunkline "*A*" into the gas trunkline "*B*" (Figs. 1, 2) $\tau_1 = 96$ h, from initial pressure $P_a = 100$ bar till excess pressure which is less than or equal to 1 bar, we receive parameters from the point "SM" (Fig. 4)

$$P_i = P_a \cdot \overline{P} = 100 \cdot 0.29 = 29.00;$$

$$\tau = 0.29 \cdot \tau_1 = 0.29 \cdot 96 = 27.84.$$

Optimal pressure increase/decrease rate in the gas trunkline by the compressor (station) is equal to

$$\frac{dp}{d\tau} = 1.04166666666667.$$

Example 2. With the set time of gas pumping from the isolated section of the gas trunkline "*A*" into the gas trunkline "*B*" (Figs. 1, 2) $\tau_1 = 72$ h, from initial pressure $P_a = 75$ bar till excess pressure which is less than or equal to 1 bar, we receive parameters from the point "SM" (Fig. 4)

$$P_i = P_a \cdot \overline{P} = 75 \cdot 0.29 = 21.75;$$

$$\tau = 0.29 \cdot \tau_1 = 0.29 \cdot 72 = 20.88.$$

Optimal pressure increase/decrease rate in the gas trunkline by the compressor (station) is equal to

$$\frac{dp}{d\tau} = 1.04166666666667.$$

Example 3. With the set time of gas pumping from the isolated section of the gas trunkline "*A*" into the gas trunkline "*B*" (Figs. 1, 2) $\tau_1 = 48$ h, from initial pressure $P_a = 55$ bar till excess pressure which is less than or equal to 1 bar, we obtain parameters from the point "SM" (Fig. 4)

$$P_i = P_a \cdot \overline{P} = 55 \cdot 0.29 = 15.95;$$

$$\tau = 0.29 \cdot \tau_1 = 0.29 \cdot 48 = 13.92.$$

Optimal pressure increase/decrease rate in the gas trunkline by the compressor (station) is equal to

$$\frac{dp}{d\tau} = 1.145833333333333.$$

The efficiency of MCS compressor unit should be chosen depending on geometric parameters of the isolated section of the gas trunkline.

The chosen concept shows the opportunity to influence the issues of gas pumping time optimization not only by MCS compressor units' characteristics but also by gas transport modes in the operating gas trunklines.

Looking at the text above, we can make a conclusion that the function of gas pumping time by MCS from initial pressure in the gas trunkline "*A, B*" (Figs. 1, 2) has the direct correlation, i.e. the lower the initial pressure is, the less time MCS requires to pump the gas from the gas trunkline "*A*" (Figs. 1, 2) into the gas trunkline "*B*" (Figs. 1, 2).

First use of MCS in Ukraine. Gas Transmission System Operator of Ukraine started the experimental use of MCS in the first quarter of 2017, which allowed minimizing the number of natural gas emissions into the atmosphere and pumping them into the gas-proof system during the repair works on gas linepipe.

1.3 million cubic meters of natural gas were saved during the first use of MCS, which costs something like 10 million UAH.

"A few years ago, we were forced to dump the gas right into the air, but today, thanks to the modern equipment with which Ukrtranshaz is supplied, we return everything back into the gas transmission system", explains the chief engineer of Yahotynskyi LPMGP Mykhailo Prymak, who was the chief of fireworks during the repair works of trunk pipeline Yelets – Kursk – Kyiv D 1200 mm.

MCS was doing gas pumping with a two-step four-cylinder compressor with internal combustion engine working on natural gas.

MCS manufactured in Austria, LMF model P-Pack 750, has the efficiency of 64.5 Nm^3/h [12].

Andrii Havryliak, the linear service chief at Yahotynskyi LPMGP, said that this machine can be used during the coldest times – "Working temperature is in diapason from –20 to +40° Celsius".

The technology of performing various repair works at gas trunkline objects, involved with depressurization of gas linepipes, including defect correction of gas linepipes, replacement of isolation valves, capital repair works, forces gas transmission providers to spend gas on production and technological works every year.

Taking into account quite high price for natural gas, gas transmission system operator of Ukraine of those days (SC "Ukrtranshaz") made a decision to use MCS.

The preliminary calculations show that the use of MCS will reduce gas consumption by 15 million cubic meters yearly, and with today's prices for natural gas it is over 10 million UAH [8, 13].

Successful cases of MCS application in the world. Gas saving works are done all over the world. For example, there were works at 13 objects of the gas transmission branch of Gazprom (RF). The first company who used that technology was "Gazprom Transgaz Ugorsk" (November 2019). Pelim LPMGP was able to save 2.7 million m^3 gas with that technology. Nowadays, Gazprom saved over 310 mln·m^3 of gas [15], which is more than 2 billion UAH.

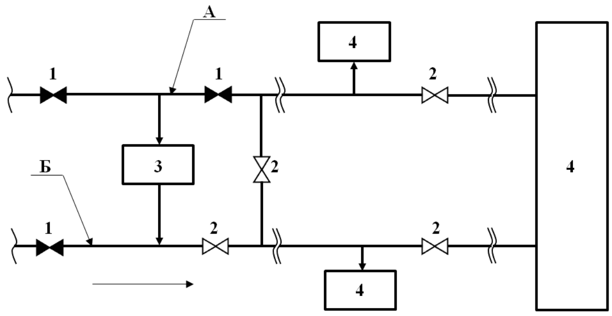

Fig. 5. Scheme of gas removal:

1 – isolation valve set to "sealed"; 2 – isolation valve set to "opened"; 3 – MCS; 4 – consumer (manufacturer, city, village, district, etc.) A/B – trunk pipelines; arrows show the direction of gas transportation

Conclusions.

1. Stable dependencies were found within issues of control, setting and optimizing modes of MCS piston compressor units, and these dependencies are repeatable. Equation (1) allows us to develop an optimal algorithm for regulating the parameters of the units (stations)

2. A fairly simple method for calculation of time required for piston MCS to pump gas with a set rate of gas offtake from an isolated section of gas trunkline was proposed.

3. A simple method was proposed for calculation and optimization of required time for natural gas pumping by MCS, which implements the general concept of technology, specifically it was proposed to influence the gas pumping not only with MCS parameters, but also with gas transportation modes of operating gas linepipes; main restricting factors were presented.

4. The main factor was discovered which influences the choice of MCS piston compressor units – an ability of the unit to maintain the calculated gas offtake rate within the whole period of gas pumping.

5. A simple method was proposed to calculate pressure values at the isolated section of the gas trunkline within set intervals of MCS gas pumping time.

6. It is proved that it is possible to pump gas with MCS units from isolated sections into operating sections of gas linepipes at the set time with stable efficiency of MCS compressor units in time, constant gas offtake, while optimal modes of compressor unit (compressor station) correspond to the values obtained at the point of intersection of relative mass variation graph and relative pressure variation graph within the relative gas pumping time.

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Закономірності безпечного регулювання поршневих компресорних агрегатів мобільних компресорних станцій

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Мета. Забезпечення оптимального режиму транспортування газу з локальних ділянок магістральних газопроводів (МГ), що підлягають ремонту (технічному обслуговуванню) та/або відключенню, до діючих магістральних газопроводів на основі розрахунку, визначення, встановлення раціональних значень режимів роботи мобільних компресорних станцій протягом усього часу перекачування газу.

Методика. Дослідження базувалися на існуючих фізичних принципах і законах, що описують вплив властивостей природного газу й геометричних параметрів трубопроводів, по яких перекачується газ, на динаміку зміни маси й тиску газу, що транспортується. Розрахунок зміни маси й тиску газу в газопроводі, з якого перекачується газ, базувався на низці існуючих теоретичних і емпіричних залежностей, що входять до загальноприйнятих методів їх розрахунку. Для виконання розрахунків використовувалися відомі фізичні залежності й математичні моделі.

Результати. «Масовий» підхід до питання розрахунку часу перекачування газу є більш математично точним, ніж «об'ємний». Відношення відносної маси до відносного тиску газу в локалізованій ділянці магістрального газопроводу, протягом усього часу перекачування, є постійною величиною. Застосування значень величин, отриманих у точці перетину графіків зміни відносної маси й відносного тиску газу, при попередньому розрахунку часу перекачування газу, або тиску, або маси, або обсягу газу в кожному інтервалі часу, дає можливість підібрати оптимальну швидкість підйому/зниження тиску газу компресорними установками та оптимальні режими транспортування газу діючими газопроводами під час роботи мобільних компресорних станцій.

Наукова новизна. Запропонований підхід до розрахунку й визначення часу перекачування газу мобільними компресорними станціями з локальних ділянок магістральних газопроводів, що підлягають ремонту (технічному обслуговуванню) та/або відключенню, до ділянок діючих магістральних газопроводів доводить, що виведення стійких закономірностей у питаннях транспортування природного газу із застосуванням поршневих компресорних агрегатів доцільно здійснювати тільки після моделювання в часі зміни маси й тиску газу в локальній ділянці магістрального газопроводу, з якого перекачується газ.

Практична значимість. Запропонований підхід до оптимізації часу перекачування газу мобільними компресорними станціями дозволяє підвищити рівень енерго- й ресурсоефективності газотранспортних підприємств, а також підвищити техніко-економічні показники технологій робіт з ремонту МГ, компресорних станцій МГ, пов'язаних із необхідністю стравлювання газу з ділянок магістральних (технологічних) трубопроводів, що підлягають ремонту (технічному обслуговуванню) та/або відключенню. Оптимізація часу перекачування газу значно скорочує час перебування працівників газотранспортних підприємств під дією небезпечних і шкідливих виробничих факторів, чим знижує рівень відповідних ризиків. Кількість викидів газу та пов'язані з цим ризики знижуються на 90 %.

Ключові слова: *природний газ, магістральний газопровід, компресорна станція, транспорт газу*

Закономерности безопасного регулирования поршневых компрессорных агрегатов мобильных компрессорных станций

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Цель. Обеспечение оптимального режима транспортировки газа из локальных участков магистральных газопроводов (МГ), подлежащих ремонту (техническому обслуживанию) и/или отключению, в действующие магистральные газопроводы на основе расчета, определения, установления рациональных значений режимов работы мобильных компрессорных станций в течение всего времени перекачки газа.

Методика. Исследования базировались на существующих физических принципах и законах, которые описывают влияние свойств природного газа и геометрических параметров трубопроводов, по которым перекачивается газ, на динамику изменения массы и давления транспортируемого газа. Расчет изменения массы и давления газа в газопроводе, из которого перекачивается газ, базировался на ряде существующих теоретических и эмпирических зависимостей, входящих в общепринятые методы

их расчета. Для выполнения расчетов использовались известные физические зависимости и математические модели.

Результаты. «Массовый» подход к вопросу расчета времени перекачки газа является более математически точным, чем «объемный». Отношение относительной массы к относительному давлению газа в локализованном участке магистрального газопровода, в течение всего времени перекачки, является постоянной величиной. Применение значений величин, полученных в точке пересечения графиков изменения относительной массы и относительного давления газа, при предварительном расчете времени перекачки газа, или давления, или массы, или объема газа в каждом интервале времени, дает возможность подобрать оптимальную скорость подъема/снижения давления газа компрессорными установками и оптимальные режимы транспортировки газа действующими газопроводами во время работы мобильных компрессорных станций.

Научная новизна. Предложенный подход к расчету и определению времени перекачки газа мобильными компрессорными станциями из локальных участков магистральных газопроводов, подлежащих ремонту (техническому обслуживанию) и/или отключению, в участки действующих магистральных газопроводов доказывает, что выведение устойчивых закономерностей в вопросах транспортировки природного газа с применением поршневых компрессорных агрегатов целесообразно осуществлять только после моделирования во времени изменения массы и давления газа в локальном участке магистрального газопровода, из которого перекачивается газ.

Практическая значимость. Предложенный подход к оптимизации времени перекачки газа мобильными компрессорными станциями позволяет повысить уровень энерго- и ресурсоэффективности газотранспортных предприятий, а также повысить технико-экономические показатели технологий работ по ремонту МГ, компрессорных станций МГ, связанных с необходимостью стравливания газа из участков магистральных (технологических) трубопроводов, подлежащих ремонту (техническому обслуживанию) и/или отключению. Оптимизация времени перекачки газа значительно сокращает время пребывания работников газотранспортных предприятий под действием опасных и вредных производственных факторов, чем снижает уровень соответствующих рисков. Количество выбросов газа и связанные с этим риски снижаются на 90 %.

Ключевые слова: *природный газ, магистральный газопровод, компрессорная станция, транспорт газа*

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