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OPTIMIZATION OF "MATURE" GAS FIELD DEVELOPMENT

The primary problematic issue represented as basic idea of the article is the gradual drop of reservoir pressure, which, following the decrease of pressure gradient between the reservoir and the well head pressure, results in the deterioration of the production rate of the well. This problem was solved by the authors in the following ways: by engaging an additional consumer for the low-pressure gas, by introducing compressors providing for adjustment of pressure at inputs to aggregates. These ways was considered based on a practical example of the "mature" field – Shebelyns`ke gas-condensate field. The algorithm of the drop of pressure evaluation is presented taking into account factors typically attended by withdrawal off the formation of liquid and solid deposits, which accumulate in the gas-gathering system, causing reduction of the hydraulic efficiency and capacity of gas pipelines; which, in its turn, requires further implementation of certain applications for pipeline pigging and utilization of deposits after these operations. It is noteworthy that the question of solving the problem of development of depleted fields shall sooner or later become urgent for the majority of countries engaged in the gas production; therefore, the specialists already regard as a perspective line to substantiate the operation modes for fields of low operating pressure going through the final stage of development. Another important note is that the approach to solving such problematic issues at the final stage of development of a field is of comprehensive and systematic nature, thus combining the major constituents comprising the process of gas extraction and transportation.

Keywords: *gas, production, well, manifold, liquid, deposits, pipeline, specific, volume.*

Problem statement

The issue of energy safety of any country is primarily related to traditional and prudent use of natural resources. The specific feature of using natural resources in Ukraine, in major, is using of gas from gas- and gas condensate fields, and, associated gas from oil fields [1 - 6].

The reliable and failure-proof operation of main energy-consuming enterprises in Ukraine and continuous supply of gas to general consumers are ensured by of natural gas production in amount of no less than 25% of the total annual volume of gas consumption. This explains the issue of even increasing the gas production volumes in Ukraine.

Analysis of recent researches and publications

The task of further stabilizing or increasing of gas production from the active fields becomes particularly urgent considering the fact that the process of year-to-year production of natural gas from the field causes gradual decrease in the volume of gas production throughout the whole life of the field [7 - 10].

The above mentioned task may be solved as implementation of a certain set of applications for each field in particular. Prior to taking a closer look at such actions, we need to consider the results of analysis and systematization of all of the challenging issues, related to operation of "mature" fields (see figure 1). Hereby, "mature" means a field with long operation period and which is at its final stage of development [1 - 3, 10].

Now let us consider the issues from figure 1 in details.

The primary challenging issue is the gradual drop of reservoir pressure, followed by decreasing of pressure gradient between the reservoir and the well head pressure, results in the deterioration of the production rate of the well.

This problem may be solved by decreasing of operating pressure in the wells of the field. The desired result may be achieved by:

- engaging an additional consumer for the low-pressure gas, e.g. by constructing distribution gas pipelines network;
- introducing compressors which provide adjustments of pressure at inputs to aggregates.

These ways allow gradual decreasing of pressure in the well head, while also ensuring stabilization of gas production in the field.

Statement of base material

Supplying of natural gas to consumers constitutes the second challenging issue. Firstly, supplies of natural gas of equity production are supposed to be provided concerning gas consumption in the area of extraction; secondly, the supplies are related to low-pressure gas. In most regions of Ukraine, the value of output pressure at gas fields, where no gas compression is done, ranges within 0.3-1.0 MPa, and, in cases of gas compression at booster compression stations (BCS) implementation – 1.2-2.0 MPa.

The third challenging issue is that the final stage of field operation is characterized by withdrawal of considerable amounts of water and solid deposits from the reservoir, which causes pollution of the cavities of the flow lines, industrial gas pipelines and gas-main pipelines. The main reason for that is increasing of gas velocity; the solution of this problem requires an improvement of operational indices of the separation equipment, and, introduction of new methods for gas pipelines pigging.

Let us now consider the above mentioned challenging issues and solutions for them by using a practical example of the “mature” field. There is an example featuring all the signs peculiar to the final stage of development. It is the Shebelynsky Gas Condensate Field (GCF) that has been under development for over fifty years, yet still keeping the largest residual gas reserves and being the gas field number one in Ukraine. This field includes 24 Gas Treatment Stations (GTS), which gather and treat raw natural gas extracted from a whole park of over 500 wells. The principal diagram of the Shebelynsky GCF is presented in figure 2.

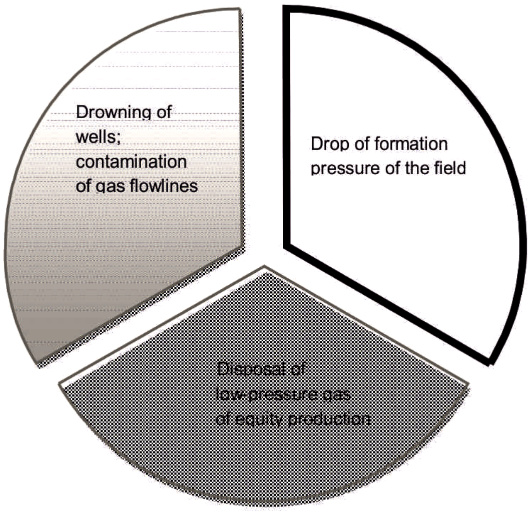

Figure 1. Challenging issues in the exploitation of “mature” fields

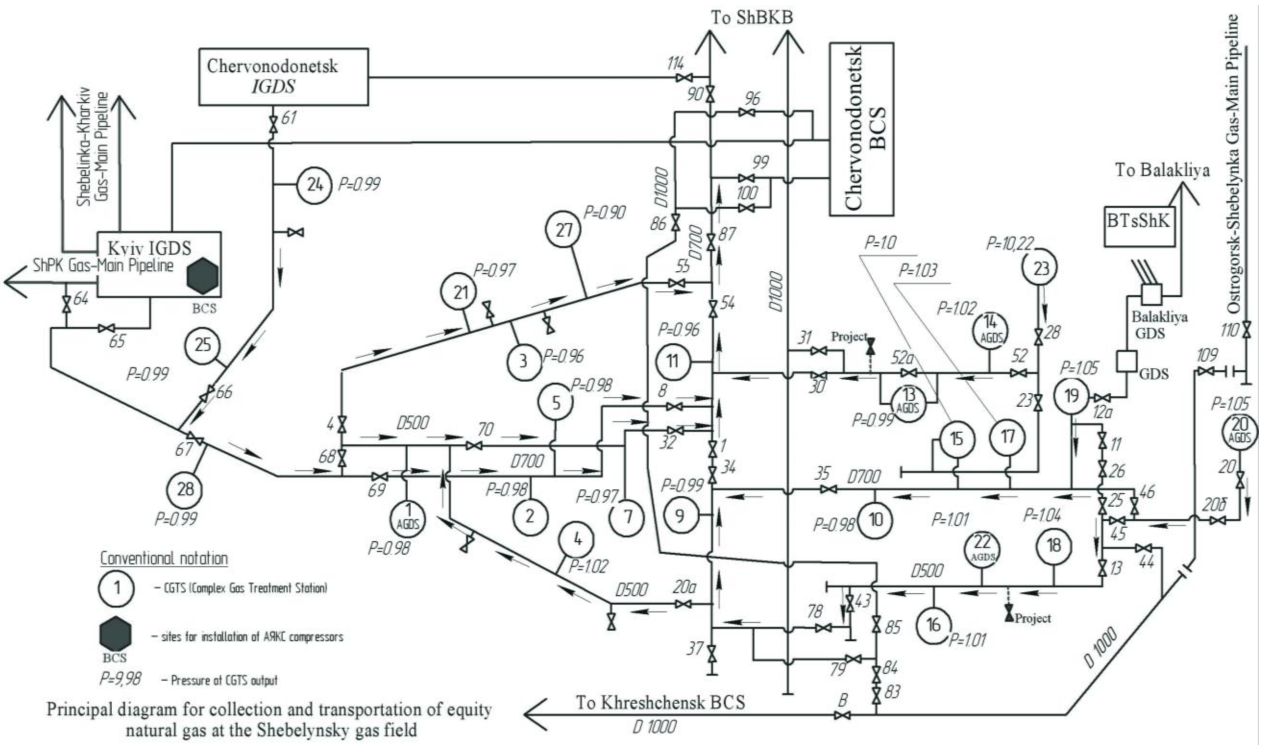

Figure 2. Principal diagram for collection of equity-production gas at the Shebelynsky gas field

The GTSs are connected to each other and to the BCS via a system of trunk lines that comprise a circular gas-collecting system. As for 2016, the operating pressure decreased to 0.65 MPa in the gas-gathering system, and to 0.8 MPa at the well head. Following the first stage of compression at the BCS, the value of pressure does not exceed 1.45 MPa.

The gas field is located in the Eastern industrial region of Ukraine featuring a branched system of gas-main pipelines and a large number of consumers (figure 3).

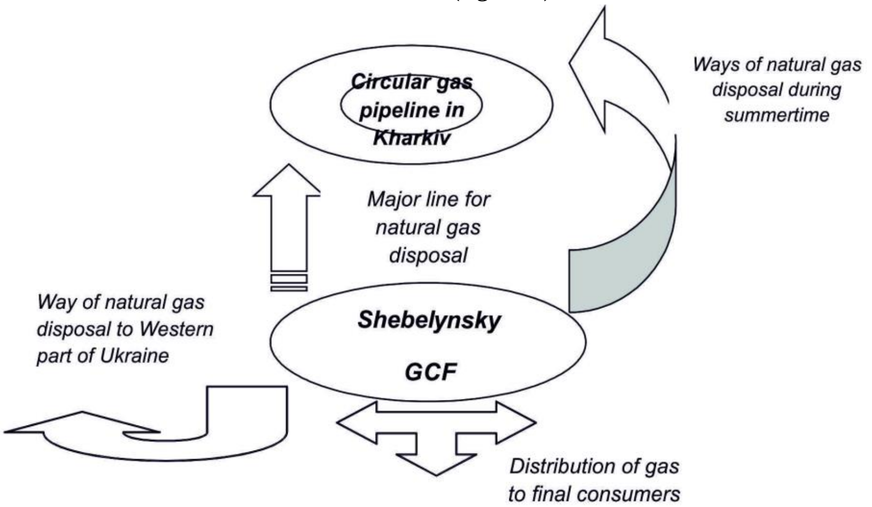

Figure 3. Natural gas disposal from the field scheme

The general algorithm for solving the problem of further exploitation of the gas field is presented in figure 4 below.

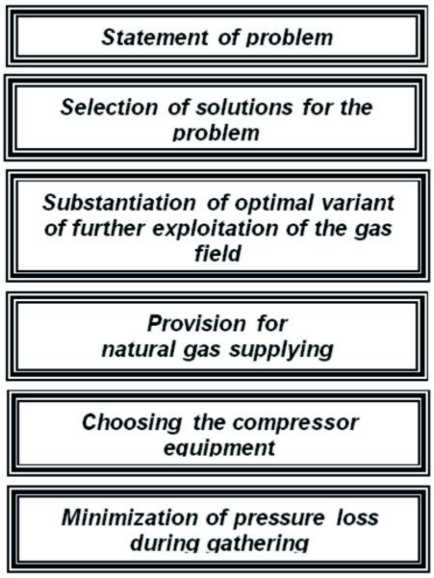

Figure 4. Algorithm of evaluations

Particularly for the Shebelynsky GCF, the algorithm shall be presented as follows (see figure 5).

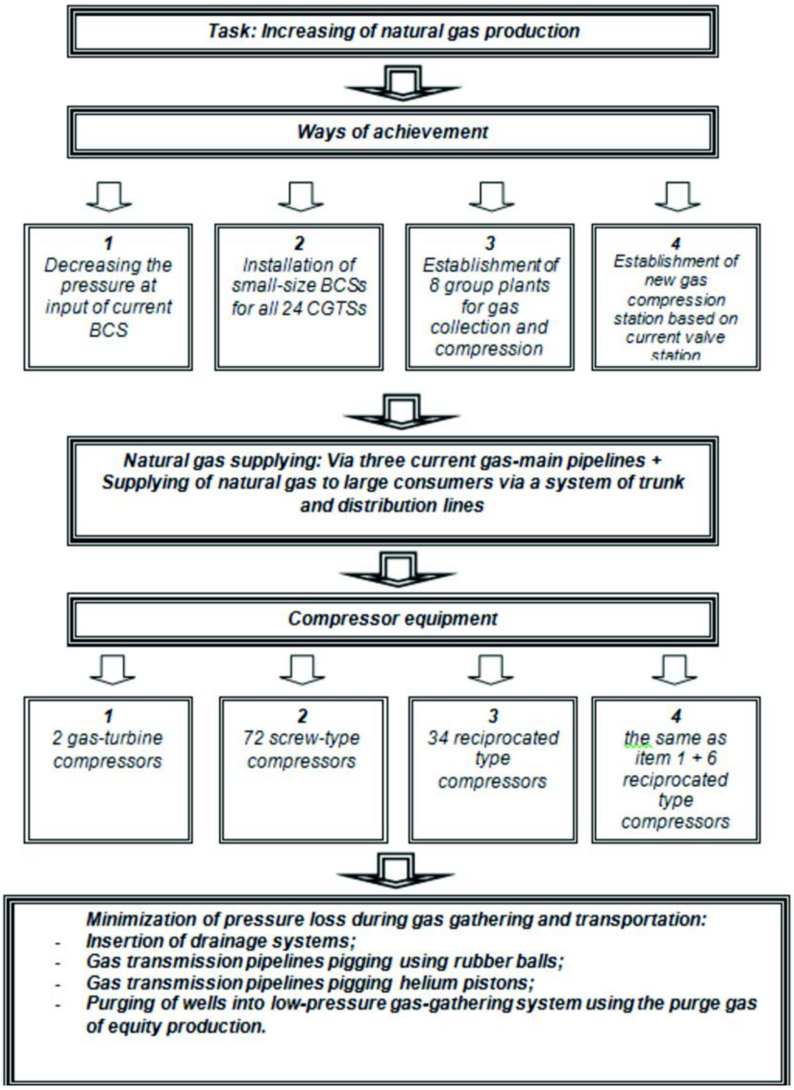

Figure 5. Algorithm of evaluations for Shebelynsky GCF

The optimum variant for development of the gas field was selected through work-back calculation of the pressure loss at various points of the field, e.g. the flowline, GTS, branch and trunk lines, BCS , also making allowance for changes in system loading. Thus, the overall pressure loss shall be calculated according to the equation below [11]:

$$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4 + \Delta P_5 , \qquad (1)$$

here are: ΔP_1 – pressure loss in the flowline, MPa; ΔP_2 – pressure loss in GTS, MPa; ΔP_3 – pressure loss in brunch lines, MPa; ΔP_4 – pressure loss in main trunk line, MPa; ΔP_5 – pressure loss in BCS, MPa.

The pressure at well head is calculated on the basis of a certain value of pressure at the input of a check point:

$$P = P_{ct} + \Delta P , \qquad (2)$$

here are: P – pressure at the well head, MPa; P_{ct} – pressure at the check point.

It is clear, that the closer the check point is to the well head the fewer constituents are calculated in equation 1; so, the lower level of pressure can be attained at a particular group of wells in the field.

The major factors determining hydraulic resistance in the gas pipelines are the roughness of internal walls and the volume of liquid deposits in the internal cavity, of the pipes. The volume of liquid deposits in the pipeline and the changes of pressure related to fluctuation of roughness throughout the period of production, are included into the value of Efficiency Factor E, which is a ratio between the actual and the maximum gas-flow rate (volumetric or mass). Thus, the actual gas-flow rate in the pipeline is defined as a product of the maximum flow rate by the Efficiency Factor E. The operational estimation of the actual hydraulic resistance and contamination level of a gas pipeline section is based on prior periodic determining of the efficiency factor E using the actual parameters of the mode, and the following dependence:

$$E = \frac{Q_a}{Q_{th}} , \qquad (3)$$

here are: Q_a - actual volumetric gas-flow rate in a pipeline defined on the basis of measurement data; Q_{th} - maximum volumetric gas-flow rate in a pipeline calculated according to normative procedures and on the basis of actual data.

The reservoir parameters are calculated based on the dependence of nonlinear filtration:

$$P_{fm}^2 - P_{bh}^2 = a \cdot q + b \cdot q^2 , \quad (4)$$

here are: a, b - filtration resistance factors of the wells, determined by well testing; P_{fm}, P_{bh} - absolute reservoir pressure and bottom-hole (well bore) pressure, MPa; q - flow rate of well, thousand m^3/day.

The flow of gas in well is calculated as per the following formula:

$$P_M = \sqrt{P_{bh} \cdot e^{-2 \cdot S} - 1{,}377 \cdot \lambda \cdot \frac{z^2 - T^2 \cdot \left(1 - e^{-2 \cdot S}\right) \cdot q^2}{d^5}} , \quad (5)$$

(MPa),

here are: d - internal diameter of well, mm; P_M - absolute pressure at the well head, MPa; P_{bh} - absolute pressure at bottom-hole of well, MPa; P_{fm} - absolute reservoir pressure, MPa; λ - hydraulic resistance factor; z - gas compression factor; T – absolute temperature of gas, K; q - flow rate of well, thousand m^3/day;

S - coefficient to be defined by the formula: $S = 0{,}03415 \cdot \frac{\Delta \cdot L}{z \cdot T}$; Δ - gas specific gravity.

The parameters of operation of flow lines are calculated using the dependence of gas flow in gas transmission pipelines indicated below:

$$q = 3{,}26 \cdot 10^{-7} \cdot d^{2,5} \cdot \sqrt{\frac{P_1^2 - P_2^2}{\lambda \cdot z \cdot \Delta \cdot T \cdot L}} \cdot 10^3 , \quad (6)$$

thousand m^3/day,

here are: d - internal diameter of gas pipeline, mm; P_1, P_2 - absolute gas pressure at start and end of gas pipeline, MPa; λ - hydraulic resistance factor; z - gas compression factor; T – absolute temperature of gas, K; L - length of gas pipeline, km.

As it is seen from the above described approach, the closer is the compressor to the well head, the lower is the gas loss caused by friction pressure and by local resistance, ensuring the lower value of pressure at the well head and allowing for increase of gas extraction volumes.

With that said, the next question is whether it is expedient to install compressor equipment at each well head, or at each GTS (which is suggested in the statement above) to minimize the pressure loss at the stage of gas collection prior to compression.

Let us consider the histogram presented in figure 6 below.

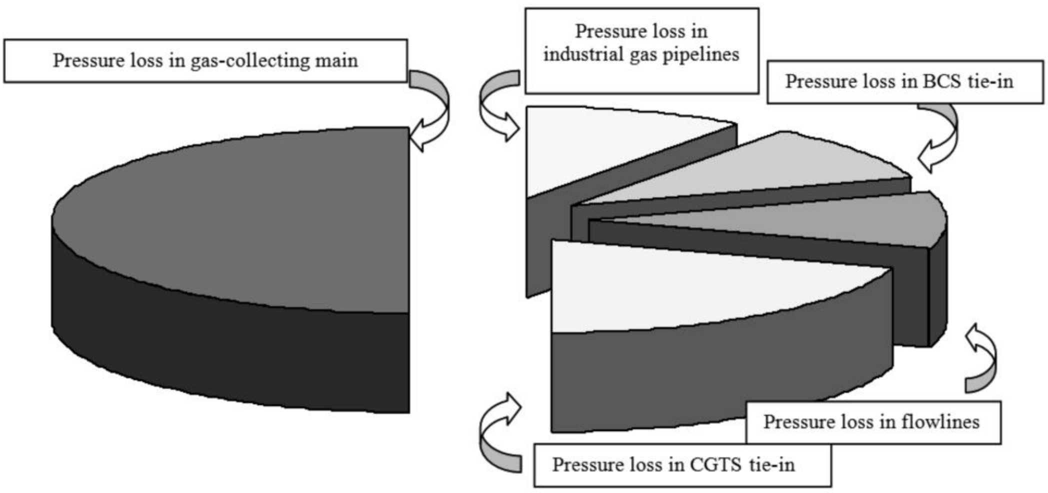

Figure 6. Histogram of distribution of pressure loss at gathering, treatment and transportation systems at the Shebelynsky gas field

As it is seen from figure 6, the major part of pressure loss occurs in the gas brunches, main trunk line and the tie-in of the BCS currently in use. Therefore, should the question of further development of the gas field be solved using Ways 1 and 4 of figure 5, this would necessarily entangle more than one half greater loss of pressure at gas gathering and, as the result, lower value of gas extraction volumes.

The next question to solve is concerned the expediency of investing finances into a project of further development of the gas field including the idea of installing compressor equipment at each CGTS (Way 2), or establishing group plants for gas collection and compression (Way 3). Let us consider the data of table 1 below related to the economic efficiency and expediency of such projects.

Table 1. Calculation of cost effectiveness of the four Ways of development for the gas field

Project	Additional gain of gas production compared to basic version, %	Object for capital investment	Pay-off period
Way 1 – Modernization of the current BCS	27	Additional compressor equipment, reconstruction of BCS tie-in and separation equipment	Three years
Way 2 – Installation of BCS at each GTS	40	Installation of 72 screw-type compressors; re-equipment of current GTSs	None
Way 3 – Establishment of group plants for gas collection and compression	38	Installation of plants on the basis of objects currently in use; installation of 34 aggregates	Four years
Way 4 – Establishment of additional central processing facility for gas treatment and compression	31	Reconstruction of current BCS; installation of new plant for gas processing and compression; installation of 6 additional reciprocated type aggregates	Four years

Table 1 shows that the most necessary and economically expedient line for development of the gas field is according to Way 3.

The set of technological and economical calculations has been performed by using licensed software complexes developed under the database management systems VisualFoxPro and SQL. The accuracy of output data used in the calculations is based on constant operational monitoring of BCS and GTS in the gas field; monitoring of hydraulic state of the system of pipelines for gas extraction and collection; monitoring of the operation modes of flowlines and wells.

It is noteworthy that solving the problem of development of depleted fields shall sooner or later become urgent for the majority of countries engaged in the gas production. Therefore, the specialists already regard as a perspective line to substantiate the operation modes for fields of low operating pressure going through the final stage of development. Another important note is that the approach to solving such challenging issues, at the final stage of development of a field, is of comprehensive and systematic nature, thus, combining the major constituents which compose the process of gas extraction and transportation, namely:

- Extraction and gathering of natural gas from wells at the GTS;
- Natural gas treatment; operation modes of separation equipment;
- Transportation and supplying of natural gas via a system of trunk lines and gas transmission pipelines;
- Compression of gas at BCS; selection of optimal operation modes for equipment [12].

Conclusions

The final stage of development of gas fields is characterized by the drop of pressure at the well head and by overall decline of gas production volumes. That raises an important issue how to select the appropriate site to locate the BCS relative to the gas-collecting network, type of gas pumping units, and the number of those units in the course of further increase.

The drop of pressure is typically attended by liquid and solid deposits withdrawal off the formation. They accumulate in the gas-gathering system, causing reduction of the hydraulic efficiency and capacity of gas pipelines; this, in its turn, requires further implementation of certain applications for pipeline pigging and utilization of deposits after these operations.

Another important issue relates to the optimization of transportation of low-pressure gas via gas transmission pipelines to consumers (which use their own gas distribution network), imposing certain requirements to the transportation modes and quality of gas, and defining the effect of irregularity in gas consumption during the summer and winter periods of the year.

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ОПТИМІЗАЦІЯ ШЛЯХІВ ДОРОЗРОБКИ РОДОВИЩ НА ЗАВЕРШАЛЬНІЙ СТАДІЇ ЕКСПЛУАТАЦІЇ

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Розроблено та реалізовано для практичних цілей математичну модель динаміки обсягів видобутку газу для родовищ на завершальній стадії розробки, оцінено вплив утворення рідинних пробок в ліфтових трубах свердловини та в порожнині її шлейфа на режими роботи системи «свердловина – шлейф – установка збору».

Ключові слова: газ, видобуток, свердловина, шлейф, рідина, відкладення, газопровід, питомий, об'єм.

ОПТИМИЗАЦИЯ МЕТОДОВ РАЗРАБОТКИ МЕСТОРОЖДЕНИЙ НА ЗАВЕРШАЮЩЕЙ СТАДИИ ЭКСПЛУАТАЦИИ

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Разработано и реализовано для практических целей математическую модель динамики объемов добычи газа для месторождений на завершающей стадии разработки, оценено влияние образования жидкостных пробок в лифтовых трубах скважины и в полости ее шлейфа на режимы работы системы «скважина – шлейф – установка сбора».

Ключевые слова: газ, добыча, скважина, шлейф, жидкость, отложения, газопровод, удельный, объем.