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EFFECTIVENESS STUDY ON THE SYSTEM FOR GAS GATHERING, TREATMENT AND TRANSPORTATIONS FROM GAS PRODUCTION COMPANY

В роботі приведено результати аналізу стану діючої системи збору, підготовки та транспортування свердловинної продукції Опішнянського, Котелевського та західного склепіння Березівського газоконденсатних родовищ АТ «Укргазвидобування» (м. Київ, Україна). Виявлено основні ускладнення при експлуатації газозбірних мереж на завершальній стадії розробки родовищ і запропоновано заходи щодо нівелювання їх негативного впливу на обсяги видобутку.

На першому етапі досліджень було здійснено польові заміри режимів роботи системи в літній та зимовий період. Експериментально встановлено, що в зимовий період експлуатації процес сепарації газу на сепараційному обладнанні здійснюється якісніше, ніж в літній період експлуатації. Це пов'язано з впливом понижених температур на процес випадання рідкої фази із природного газу.

Основна ідея роботи полягає у впровадженні постійного моніторингу роботи газозбірної системи на предмет виявлення змін термобаричного режиму експлуатації. Такі зміни можуть сигналізувати на високу вірогідність утворення рідинних скупчень, які чинитимуть додатковий гідравлічний опір.

Результати моніторингу зміни тиску, температури, точок роси і композиційного складу природного газу дозволяють провести їх комплексний аналіз та з прийнятною точністю оцінити можливість формування мас рідини на певних ділянках газопровідної системи. Це виключає необхідність підтвердження їх наявності за допомогою приладового обладнання і додаткових людських ресурсів, а також скорочує час не реагування на виникнення проблеми.

Такий підхід буде досить цікавий і для великих міжнародних компаній, оскільки запаси природного газу постійно вичерпуються, а вилучення залишкових запасів газу із виснажених родовищ є привабливою метою для компаній-видобувників. Крім того, застосування простих способів очистки на основі аналізу гідравлічної ефективності трубопроводів дозволяє суттєво скоротити як часові, так і матеріальні ресурси.

Ключові слова: *система збору газу, багатофазний потік, промисловий газопровід, ділянка трубопроводу, гідравлічна ефективність.*

1. Introduction

The deposits of the extracting region of Ukraine have been exploited for quite a long time. The vast majority of them entered the stage of final development in the gas regime for attrition. Consequently, the level of gas production, first of all, will depend on the level of working pressure at the wellhead, the volume of its consumption and the efficiency of the equipment of the facilities of the ground part of the fields where the gas is collected, prepared and transported.

To date, JSC «UkrGasVydobuvannya», Kyiv, Ukraine (further – the Company) has a powerful system for collecting, preparing and transporting gas among gas producing companies in Ukraine. It includes 9272 kilometers of field pipelines (inter-field gas pipelines, trains, gas pipelines for connection, collectors, etc.), More than 2,700 wells, 140 fields, 39 booster compressor stations, 184 complex gas treatment units. The structure of the gas producing company includes three gas industrial departments (GID) ShebelynkaGasVydobuvannya (Donetsk, Kharkiv region), PoltavaGasVydobuvannya and LvivGasVydobuvannya, which carry out the main functions of gas production, preparation and transportation to points of transfer to main gas pipelines. The volume of gas produced by the company in 2017 is 15.25 billion m^3 [1].

Considering the strategy of increasing production «20/20», in recent years, Ukraine has been increasing gas production:

- by exploring new promising gas producing regions;
- increase in the scope of drilling and the commissioning of new wells;
- capital repair of wells;
- reduction of well head pressure to minimum allowable values, taking into account the natural drop in reservoir pressures of fields (operating mode of deposits for «depletion»);
- by establishing wellhead low-pressure booster compressor stations (LPBCS), zero degrees of existing booster compressor stations (BCS), etc.

But on the basis of these methods, with increasing gas production, the problem arises of ensuring as low as possible pressure differences along the gas pipeline route:

- gas pipeline transports gas from the producers to consumers;
- or a gas pipeline (trail) transports gas from the wellhead to the complex gas processing plant (CGPP) or from CGPP to BCS.

The motion of gas-liquid flows in the pipeline cavity can have three structures from annular to cork and stratified, which in any case are characterized by the presence of localized liquid in the lowered and upward sections of

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the gas pipeline. The result is the formation of hydraulic plugs, partially or completely overlapping the cross section of the pipe, which are characterized by the growth of hydraulic resistance and hydrostatic pressure drop.

The primary causes of increased pressure losses during gas transportation are:

– decrease in operating pressure at a constant volume of pumping, which affects the loss of pressure on friction;

– formation of a certain amount of contamination in the cavity of the pipe, forming additional local hydraulic supports.

In addition, it should be noted that the presence of local resistances in the pipeline entails a change in the temperature regime, prompting the precipitation of heavy fractions from the two-phase flow. The role of such local resistances can play themselves liquid accumulations in the lowered places of the pipeline.

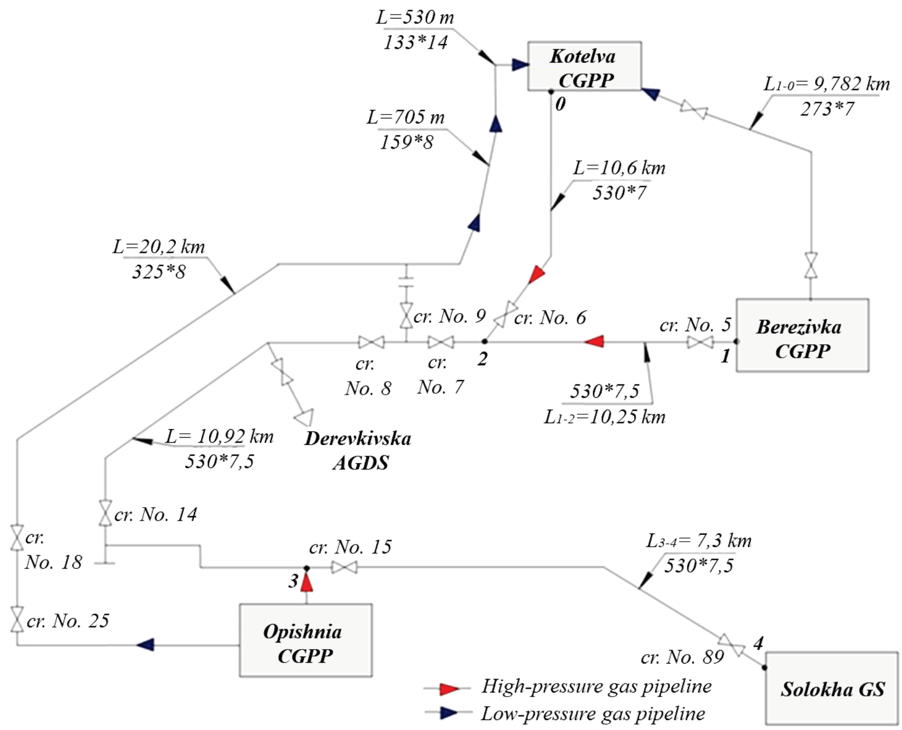

Fig. 1. The layout of the system between the industrial gas pipelines connecting Berezivka CGPP, Kotelva CGPP, Opishnia CGPP of GPU «PoltavaGasVydobuvannia» and transport gas to the complex preparation in the Solokha GS

In turn, complete gas separation is a complex technological operation and is associated with large capital investments, which will significantly increase the cost of gas. So, the gas enters the gas pipeline will contain a certain amount of liquid will be suspended in the gas stream in the form of minute drops.

Considering the fact that the history of the extraction of fuel resources of Ukraine begins at the beginning of the last century, as a result of which the vast majority of the explored deposits are at the final stage of operation and have an increased liquid factor. And also taking into account the program for increasing our own production and the value of each extracted cubic meter of gas, now the coordinated work of the system «reservoir-well-train-CGPP-trunk gas pipeline» remains an urgent issue. And also ensuring its functioning with minimal expenses for transportation and providing capacity on the present modes.

2. The object of research and its technological audit

The object of research is the system between the industrial gas pipelines of the Kotelva group of deposits, it collects gas from the Berezivka, Kotelva and Opishnia gas treatment plants of the gas industry department and transports gas to the complex training for Solokha's main facilities by:

– low-pressure gas pipelines for supplying gas from low-pressure wells without compressing the gas of the Opisnia gas processing plant and the Berezivka CGPP (operating pressure within 8–12 atm);

– high-pressure gas pipelines for gas supply from high-pressure wells of Berezivka, Kotelva and Opishnia gas condensate fields (GCF) and compressed gas at the BCS of the Opishnia and Kotelva CGPPs (Fig. 1) [2].

The gas industry department of PoltavaGasVydobuvannya in its structure has five oil, gas and condensate production units (OGCPU): Mashev, Solokha, Gadyach, Yablunivsk and Krasnokutsk. The extraction, collection and preparation of gas for transportation are carried out at the above-mentioned OGCPUs with subsequent transfer to the main gas pipelines. The length of industrial and inter-industrial gas pipelines of the «PoltavaGasVydobuvannia» is 3,939,572 km. The volume of gas produced by this gas industry department is more than 5.8 billion cubic meters of natural gas, as of 2017, which was 40 % of the Company's total natural gas production [1].

The existing system for collecting, preparing and transporting gas was commissioned in the 1960s and 1970s and, accordingly, is designed for significantly different operating modes. At the moment, taking into account the natural drop in well head pressure, as well as the increased moisture content of the gas, the quality of natural gas preparation is clearly decreasing due to the inefficient operation of the collection and preparation system in the existing operating modes.

The presence of liquid in the cavity of the gas pipeline is one of the factors that significantly reduce the efficiency of the gas production system. In the conditions of operation of industrial gas pipelines, it is very important to determine the volume of liquid in their cavities, since its presence negatively affects the operation of all components of the gas production system.

3. The aim and objectives of research

The aim of research is assessing the possibility of self-cleaning the system between industrial gas pipelines by introducing a set of measures to increase the linear gas velocities sufficient to provide fluid contamination between differently oriented areas in space based on monitoring the hydraulic state.

To achieve this aim, it is necessary to perform the following tasks:

1. To investigate the operation modes and hydraulic state of the system of industrial gas pipelines of the Kotelva group of deposits («PoltavaGasVydobuvannia») and process, systematize and analyze the data.

2. To assess the hydraulic efficiency of operation of the system of industrial gas pipelines and thermobaric and high-speed operation in winter and summer.

3. To determine the natural liquid traps and the volume of contaminants.

4. To make an assessment of the reliability of the gas pipeline system in terms of the occurrence of massive emissions and the formation of hydrates.

5. To simulate the decrease in the wellhead pressure of the Kotelva group of deposits.

4. Research of existing solutions of the problem

The efficiency of gas collection and transportation systems from the fields of a gas producing company depends on the hydraulic state of the aggregate sections of the linear part of the gas pipelines (industrial, between industry and others). Therefore, it is necessary to carry out periodic monitoring of the hydraulic state in order to evaluate the actual hydraulic characteristics (determination of pressure drops, actual coefficients of hydraulic resistance of the site and hydraulic efficiency, approximate amount of contamination). Since deviations from the nominal operating mode indicate the formation of two-phase currents, which significantly reduces the efficiency and reliability of the system operation.

As of the 80–90's, in the last century, much attention is paid to the research of a two-phase flow. The models of gas and liquid flow in the pipes have been developed, new methods have been developed for determining the amount of liquid in the cavity of the gas pipeline and methods for extracting liquid from the gas pipeline, and devices for removing liquid have been modernized. One of these methods is the method of creating a pulsed regime of the working gas flow (the method of high-velocity gas flow) [3]. Outside of Ukraine, much attention has now been paid to cleaning the internal cavity of the gas pipeline by passing purification devices of various designs. Methods have been developed for cleaning the cavity of loops and gas lines with gel pistons [4] and surface-active substances [5], as well as methods for refined calculations of the hydraulic state of gas-condensate gas pipelines [6, 7]. In addition, due to the creation of modernized separation equipment, the gas cleaning in the fields is significantly improved. As for Ukraine, today the only normative document regulating the procedure for performing hydraulic calculations is VSN 51.1–85 [8], which provisions and own development of specialists of the Ukrainian Scientific Research Institute of Natural Gases (UkrNDIGas) (Kharkiv) are laid in creation of a software-calculation complex «Control of massive emissions of liquid from the cavity of the gas pipeline». This complex consists of three interrelated programs: hydraulic efficiency, the volume of contamination and hydrate formation, on the basis of which the calculations presented in [9] are performed. All hydraulic calculations of gas pipelines are made in accordance with the requirements [8, 10].

Therefore, solving the problem of analyzing the operating modes of the gas gathering and gas transmission system, identifying problem areas in terms of deteriorating hydraulic efficiency, and justifying the feasibility of implementing measures for cleaning gas pipelines is a promising issue.

When solving the problem of cleaning the gas pipeline, it is necessary to find out the causes of liquid ingress and quantity. This will make it possible to monitor any changes in the operation process and make a timely decision about the time of the cleaning. It should also be noted that the amount of contamination in gas pipelines, calculated theoretically, differs from the experimental one. Therefore, this problem requires detailed study.

In addition, attention should be paid to the differences in the approach to cleaning the internal cavity of field pipelines. In accordance with the requirements of regulatory documents, the decision to clean this type of pipeline is taken solely on the basis of an internal pipe inspection [11], in fact it is impossible to carry out in Ukrainian specific conditions detailed in [12].

Nevertheless, it should be noted that in all conditions, a multiphase medium will form in the cavity of the pipelines. This medium is considered relatively immobile in the conditions of exploitation of mature deposits, or it constantly changes its shape when localized in lowered areas, subject to changes in the thermobaric operating regime [13]. Although, on the other hand, the problem of the behavior of multi-phase media under conditions of changing the thermobaric operating conditions of the pipeline is mainly considered for oil pipelines and collector threads collecting oil, taking into account the possibility of formation of both paraffin deposits [14] and resins [15, 16].

The processes of proliferation and formation of liquid clusters in gas gathering networks are more specific. Such contamination is more mobile when the main pollutant is gas condensate, and more resistant to localization at the final stage of field development, when it will be formed exclusively from water fractions with only traces of condensate. In any case, experts recommend conducting a comprehensive survey of pipeline sections where liquid accumulation is possible [17].

It is shown in [18] that in order to prevent the accumulation of liquid contaminants in the pipeline cavity in the ascending sections of the pipelines, measures were taken to replace large-diameter plumes with smaller ones. Accordingly, these measures were carried out with the goal of providing the minimum necessary gas velocities to ensure the delivery of liquid to the CGPP.

In the absence of clear regulatory guidance on how to carry out such diagnostics, the analysis of hydraulic efficiency should be considered a fairly simple and economical method, despite its significant error and the need to carry out quite often.

5. Methods of research

To study the dynamics of the hydraulic efficiency coefficient between industrial gas pipelines in the framework of this work, the actual technological parameters are measured in separate sections. In order to assess the effect of changing the ambient temperature on the hydraulic efficiency coefficient, the measurements are carried out during the winter and summer periods of operation.

Table 1, 2 presents the output data of the system between industrial gas pipelines, collects gas from the CGPP and transports gas to the integrated preparation of the Solokha GS.

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Table 1

The data of hydraulic efficiency of the system between industrial gas pipelines connecting Berezivka CGPP, Kotelva CGPP, Opishnia CGPP of «PoltavaGasVydobuvannia» and transport gas for the integrated preparation of Solokha GS in winter operation

Pipeline section number	Initial pressure, kgf/cm^2 (at)	Final pressure, kgf/cm^2 (at)	Initial temperature, °C	Final temperature, °C	Gas consumption, thousand m^3/day	Gas density at standard conditions, kg/m^3	Dew-point temperature, °C	Technical specifications			Year of commissioning	Commissioning
								Length, km	*D*, mm	Wall thickness, mm		
1	27.94	26.47	16.37	3.3	623.33	0.783	0	10.25	530	7.5	1992	–
2	26.47	26.16	3.3	3.2	1748.0	0.783	0	10.92	530	7.5	1992	Associated gas sampling at Derevky automatic gas distribution station (AGDS)
3	26.61	26.47	11.0	3.3	1124.68	0.783	0	10.6	530	7	1992	–
4	26.16	25.54	3.2	3.1	2232.24	0.783	–2.3	7.3	530	7.5	1972	–
Supply of low-pressure well gas												
5	9.68	8.44	3.47	3.3	148.6	0.783	0	20.2	228 eq.		1979	–
6	9.6	8.75	-2.07	3.3	90.00	0.783	0	9.782	273	7	2012	–

Table 2

The data of hydraulic efficiency of the system between industrial gas pipelines connecting Berezivka CGPP, Kotelva CGPP, Opishnia CGPP of «PoltavaGasVydobuvannia» and transport gas for the integrated preparation of Solokha GS in summer operation

Pipeline section number	Initial pressure, kgf/cm^2 (at)	Final pressure, kgf/cm^2 (at)	Initial temperature, °C	Final temperature, °C	Gas consumption, thousand m^3/day	Gas density at standard conditions, kg/m^3	Dew-point temperature, °C	Technical specifications			Year of commissioning	Commissioning
								Length, km	*D*, mm	Wall thickness, mm		
1	31.15	31.06	19.26	13.8	726.453	0.771	13.8	10.25	530	7.5	1992	–
2	31.06	30.29	13.8	12.9	1814.973	0.771	12.9	10.92	530	7.5	1992	Associated gas sampling at Derevky automatic gas distribution station (AGDS)
3	31.72	31.06	33.01	13.8	1088.520	0.779	13.8	10.6	530	7	1992	–
4	30.54	29.01	12.9	12.7	2255.234	0.757	12.7	7.3	530	7.5	1972	–
Supply of low-pressure well gas												
5	11.38	9.84	27.35	13.8	161.577	0.771	13.8	20.2	228 eq.		1979	–
6	At the time of the research, the gas pipeline did not work							9.782	273	7	2012	–

The study is based on the measurement of process parameters at the control points of the following sections between industrial gas pipelines:

– High-pressure:

1 – «Berezivka CGPP – crane (cr.) No. 6 connection point (c. p.) Kotelva CGPP»;

2 – «cr. No. 6 c. p. of Kotelva CGPP – c. p. of Opishnia CGPP»;

3 – «Kotelva CGPP – crane No. 6 c. p. to the gas pipeline Berezivka CGPP – c. p. of Opishnia CGPP»;

4 – «Opishnia CGPP – Solokha GS».

– Low-pressure:

5 – «Opishnia CGPP – Kotelva CGPP»;

6 – «Berezivka – Kotelva CGPP».

6. Research results

The results of calculating the hydraulic efficiency of the system between industrial gas pipelines are carried out on the basis of technological measurements during the winter and summer period of operation. The results include the determination of excessive pressure losses, the estimation of the operating speed regime, the calculation of the indicative volume of contaminants, and the verification of the conditions for the passage of the volley process of liquid discharges and the conditions for the formation of hydrates, which present in Tables 3, 4 [2].

From the results of calculating the hydraulic efficiency of the system between industrial gas pipelines during the winter operation period (Table 3), it can be seen that the section of the Berezivka CGPP – c. p. of Kotelva CGPP (cr. No. 6) is contaminated (excess pressure loss is 1.39 kgf/cm^2 (94.5 %), V_{cont}=29.9 m^3, E=23.5 %) and requires constant monitoring of the accumulation of liquids and the introduction of clean-up measures.

The site of the low-pressure gas pipeline Berezivka CGPP – Kotelva CGPP is also contaminated. Excess pressure loss is 0.78 kgf/cm^2 (92 %), V_{cont}=5.21 m^3; E=30.47 %) with a high probability of redistribution of pollutants (due to volley ejection) through a gas pipeline. This requires constant monitoring of the hydraulic state.

Table 3

Calculation results of hydraulic efficiency of the system between industrial gas pipelines connecting Berezivka CGPP, Kotelva CGPP, Opishnia CGPP of «PoltavaGasVydobuvannia» and transport gas for the integrated preparation of Solokha GS in winter operation

Pipeline section number	Checking the baric operating pressure					Velocity mode	Hydraulic operation mode				Condition of hydrates formation in the period of research	Conclusion on the operation of the system
	Initial pressure, kgf/cm^2 (at)	Final pressure, kgf/cm^2 (at)	Differential pressure, kgf/cm^2 (at)	Excessive pressure drop due to contamination, kgf/cm^2	Conclusion	Gas velocity, m/s / Conclusion	Hydraulic efficiency of the gas pipeline,%	Estimated volume of contamination, m^3	Critical amount of contamination, m^3	Probability of massive emission of liquid / Conclusion		
1	27.94	26.47	1.47	1.39	Virtually all pressure losses are caused by the presence of liquid in the cavity of the pipeline	1.14 The gas velocity facilitates the precipitation of liquid from the gas stream	23.5	29.9	30.3	99 % Essential probability of redistribution of water masses with decreasing working pressure	Performed	The section is contaminated, requires cleaning, constant monitoring of the accumulation of liquid, hydrates formation at temperatures below 7.6 °C
2	26.47	26.16	0.31	0.0	There are no excessive pressure losses	3.22 The increase in gas velocities makes it possible to prevent gravitational sedimentation	96.75	0	0	Absent Gas pipeline is clean	Performed	The gas pipeline section is clean, does not require cleaning, of hydrates formation at a temperature below 7.27 °C
3	26.61	26.47	0.14	0.02	Excessive pressure loss is negligible	2.04 The gas velocity facilitates the precipitation of liquid from the gas stream	92.25	5.26	37.07	14.2 % Low probability of massive emission of liquid	Performed	The hydraulic state of the section is satisfactory, it does not require cleaning, hydrates formation at a temperature below 7.35 °C
4	26.16	25.54	0.62	0.01	Excessive pressure loss is negligible	4.20 Gas velocities are sufficient for the redistribution of liquid masses	99.33	0	12.85	Absent Massive fluid emissions are not predicted	Performed	The gas pipeline section is clean, hydrates formation at a temperature below 7.09 °C
5	9.68	8.44	1.24	0.22	Excessive pressure loss is negligible	3.97 Gas velocities are sufficient to transfer liquid in a drip state	90.84	1.84	8.34	22 % Low probability of massive emission of liquid	Absent	The hydraulic condition of the section is satisfactory, it requires constant monitoring of the of liquid accumulation
6	9.6	8.75	0.85	0.78	Virtually all pressure losses are caused by the presence of liquid in the cavity of the pipeline	1.82 The gas velocity facilitates the precipitation of liquid from the gas stream	30.47	5.21	7.11	73 % High probability of massive emission of liquid	Performed	The section is contaminated, requires cleaning, constant monitoring of fluid accumulation

On all sections of high-pressure and low-pressure gas pipelines, except for the gas pipeline Opishnia CGPP – Kotelva CGPP, hydrate formation conditions are met.

Low-pressure gas pipeline Opishnia CGPP – Kotelva CGPP works with optimal pressure losses, caused mainly by local resistance (diameter transitions) and minor liquid contamination.

The research results, in the summer period of operation (Table 4), indicate that the section of the high-pressure gas pipeline of c. p. of Kotelva CGPP (No. 6) – Opishnia CGPP has a small degree of contamination (excess pressure loss is 0.24 atm, V_{cont}=8.54 m^3, E=82.58 %). It has been experimentally confirmed that the site requires constant monitoring of the accumulation of liquid [2].

The most contaminated are such sections of the gas pipeline system:

– a section of the high-pressure gas pipeline Kotelva CGPP – c. p. to the Berezivka CGPP – Opishnia CGPP, the excess pressure loss is 0.49 atm, V_{cont}=22.33 m^3; E=51.27 %), requires cleaning and constant monitoring of the hydraulic state;

– a section of the high-pressure gas pipeline Opishnia CGPP – Solokha GS, the excess pressure loss is 0.99 atm, V_{cont}=11.14 m^3; E=64.33 %) with a high

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probability of redistribution of pollutants (due to massive emission) through the gas pipeline, requires cleaning and constant monitoring of the hydraulic state.

Low-pressure gas pipeline Opishnia UKPG – Kotelvaya USP works with optimal pressure losses, caused mainly by local resistance (diameter transitions) and minor liquid contamination.

The site of the low-pressure gas pipeline Opishnia CGPP – Kotelva CGPP at the time of the research did not work.

On all sections of high-pressure and low-pressure gas pipelines, the conditions for hydrate formation are absent.

In addition, it should be noted that, compared with the winter period, pressure losses from 0.44 atm to 0.09 atm have decreased in the section of the CGPP – c. p. of CGPP (crane No. 6). This is due to the self-cleaning of the section and the redistribution of liquid to neighboring areas due to increased loading.

On the basis of the analysis of the research results carried out during the different periods of operation, it should be noted that in the winter (at low ambient temperatures) the gas separation process at the gas pre-treatment facilities is more qualitative. So, the gas that enters the pipeline during winter operation is less voluminous and the total amount of condensed liquid phase is less compared to the summer period of operation. This condition is experimentally confirmed by the studies carried out in this paper, since the hydraulic efficiency coefficient in the sections of this gas gathering unit and the estimated amounts of contamination in the cavity pipelines are significantly less than in the summer period of operation.

The corresponding increase in the temperature of gas separation affects the drop in the coefficients of hydraulic efficiency and a significant increase in the amount of contamination in the summer. Subsequently, the gas enters the gas pipelines, where its temperature decreases, resulting in favorable thermodynamic conditions for phase transformations, the result of which is the accumulation of liquid contaminants in the cavity pipelines. These contaminations accumulate in the lowered sections of the pipeline in the form of slugs, can be redistributed while moving along the ascending sections of the pipeline route profile. This leads to the creation of excessive fluctuations, and eventually the complete overlapping of the section of the pipeline in the natural gas trap following the movement of the gas.

Table 4

Calculation results of hydraulic efficiency of the system between industrial gas pipelines connecting Berezivka CGPP, Kotelva CGPP, Opishnia CGPP of «PoltavaGasVydobuvannia» and transport gas for the integrated preparation of Solokha GS in summer operation

Pipeline section number	Checking the baric operating pressure					Velocity mode	Hydraulic operation mode				Condition of hydrates formation in the period of research	Conclusion on the operation of the system
	Initial pressure, kgf/cm^2 (at)	Final pressure, kgf/cm^2 (at)	Differential pressure, kgf/cm^2 (at)	Excessive pressure drop due to contamination, kgf/cm^2	Conclusion	Gas velocity, m/s Conclusion	Hydraulic efficiency of the gas pipeline,%	Estimated volume of contamination, m^3	Critical amount of contamination, m^3	Probability of massive emission of liquid Conclusion		
1	31.15	31.06	0.09	0.02	The pressure losses do not exert any influence on the CGPP operation mode	1.19 The gas velocity facilitates the precipitation of liquid from the gas stream	95	–	–	– –	Absent	There is no significant influence of pressure loss on the operation mode of the gas pipeline. Gas pipeline is clean
2	31.06	30.29	0.77	0.24	Some pressure losses are caused by the presence of liquid	3.23 Gas velocities are sufficient for the redistribution of liquid masses	82.58	8.54	19.67	43 % Low probability of massive emission of liquid	Absent	Pipeline section is moderately contaminated and requires constant monitoring of the accumulation of liquid
3	31.72	31.06	0.66	0.49	Some pressure losses are caused by the presence of liquid	1.81 The gas velocity facilitates the precipitation of liquid from the gas stream	51.27	22.33	35.86	62 % Low probability of massive emission of liquid	Absent	Pipeline section is contaminated and requires constant monitoring of the accumulation of liquid
4	30.54	29.01	1.53	0.99	Some pressure losses are caused by the presence of liquid	4.17 Gas velocities are sufficient for the redistribution of liquid masses	64.33	11.14	13.45	83 % High probability of massive emission of liquid	Absent	Pipeline section is contaminated and requires constant monitoring of the accumulation of liquid
5	11.38	9.84	1.54	0	There are no excessive pressure losses	3.96 Gas velocities are sufficient for the redistribution of liquid masses	100	0	0	– Gas pipeline is clean	Absent	The gas pipeline section is clean, no cleaning is required
6	At the time of the research, the gas pipeline did not work											

When accumulation of contaminants accumulates, the working pressure in the gas pipeline begins to pulsate with a sudden drop below the condensation pressure or an increase above the evaporation pressure of the liquid phase, which, in such cases, changes into a gaseous phase and vice versa. Taking into account the continuous inflow of the liquid phase into the cavity of the pipelines, the accumulation of the critical volume leads to a redistribution of the liquid phase, which results in volley emissions to the process equipment at the outlet of the pipeline.

Such cumulative effect of the mechanical supply of liquid to the cavity of pipelines and phase transformations forms various structures of motion of the gas-liquid mixture along the length of the pipeline, depending on the speed mode of operation. It is clearly noted that in sections 1, 6 in the winter operation period, the gas flow rate contributes to the accumulation of liquid droplets in the lower part of the gas pipeline, «ascending areas». Whereas at the sections 2, 3, 4, 5, during the winter operation period, the gas flow rate contributes to the fact that most of the liquid is collected in a reduced section of the gas pipeline with a wave-like distribution of phases and subsequent displacement into the «ascending areas» in the form of a plug during «massive emission». The efficiency of the system during the summer period of operation is characterized by slightly different values, since in all parts of the system the gas flow rate facilitates the passage of the above process. It should be noted that the efficiency of gas pipelines, in the winter and summer period of operation, varies within the limits of 49 %. The gas flow velocity is inherent in the stratified structures of the gas-liquid flow (below 3.5 m/s) or the floor (up to 8.2 m/s) for this case, but is not able to create an annular flow structure in one of the differently oriented areas in space. In the course of this work, the places of the most probable localization and accumulation of liquid that correspond to natural fluid traps are formed in the cavity of the pipeline as the trail passes through valleys, tracts, ravines, floodplains of rivers and the like. Plans-profiles of the traces of the constituent gas pipelines for tracking the localization of the liquid are shown in Fig. 2–6 [2].

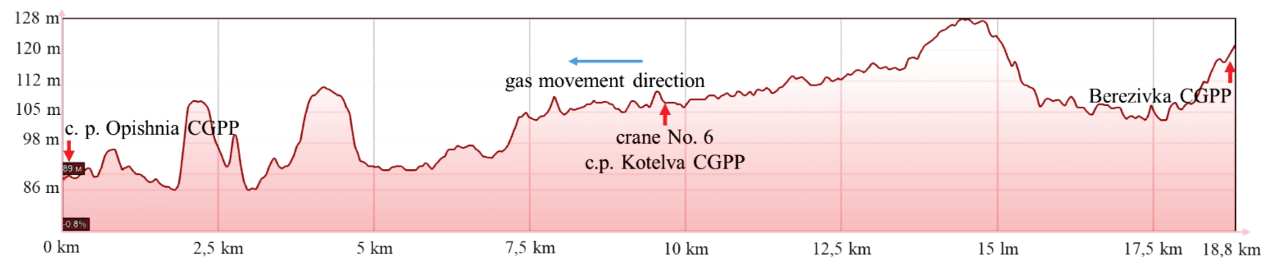

Fig. 2. Plan-profile of the route of the high-pressure gas pipeline Berezivka CGPP – c. p. of Opishnia CGPP (section No. 1, 2)

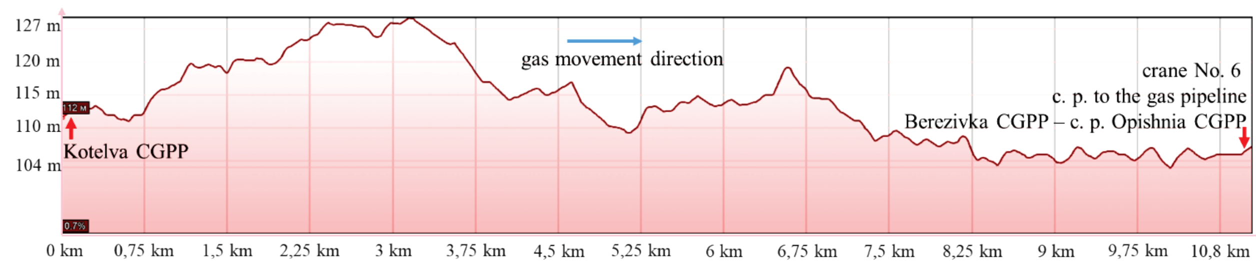

Fig. 3. Plan-profile of the route of the high-pressure gas pipeline Kotelva CGPP – crane No. 6 of c. p. to the gas pipeline Berezivka CGPP – c. p. of Opishnia CGPP (section No. 3)

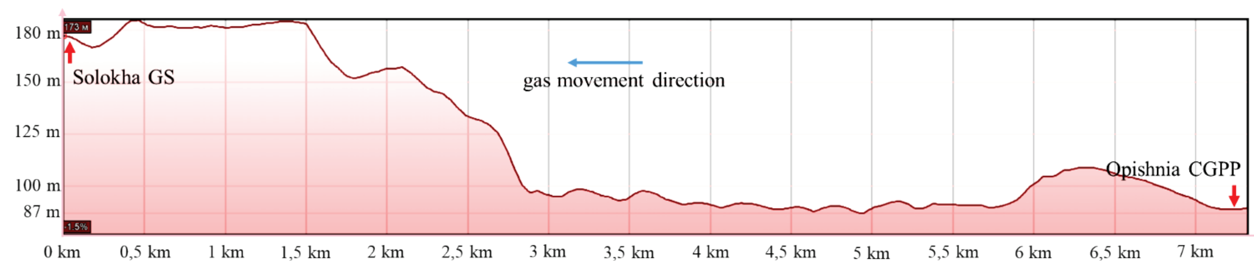

Fig. 4. Plan-profile of the route of the high-pressure gas pipeline Opishnia CGPP – Solokha GS (section No. 4)

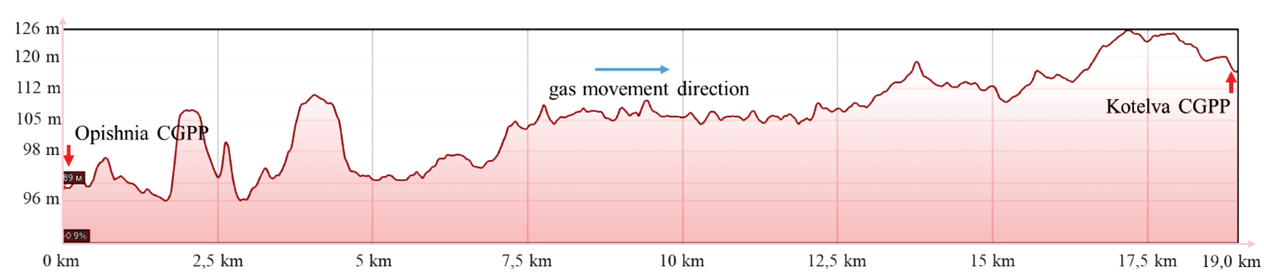

Fig. 5. Plan-profile of the route of the high-pressure gas pipeline Opishnia CGPP – Solokha GS (section No. 5)

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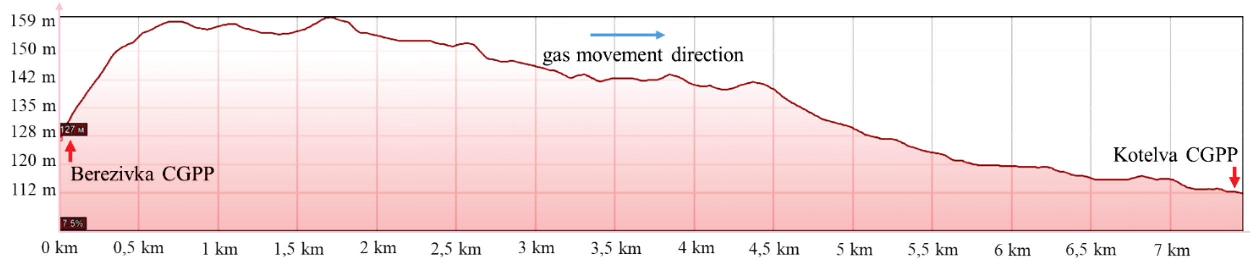

Fig. 6. Plan-profile of the route of the low-pressure gas pipeline Berezivka CGPP- Kotelva CGPP (section No. 6)

Such approach to assessing the impact of the high-speed mode of operation on the formation of structural forms of motion in the sections of the system makes it possible to develop a set of measures to increase the loading of the system and increase the linear velocities of the gas.

The package of measures for re-planning the flow included the reconstruction of the collection system and inter-field transportation of gas with an increase in its loading:

1) additionally produced gas with a decrease in working pressure from 26 to 12 atm;

2) the construction of a new gas pipeline for gas supply to consumers, and also as a fuel gas from the Solokha GS to Solokha BCS, cr No. 2 of the Kotelva CGPP, the Opishnia CGPP, which envisages an increase in the volumes of gas transportation that was previously used for industrial and technological needs;

3) construction of a new gas pipeline Opishnia CGPP – Solokha CS, which provides for separation of high-pressure and low-pressure gas flows and increase of gas loading from the Kotelva gas condensate field;

4) construction of a new gas pipeline Zakhidna-Berezivka CGPP – Zakhidna-Berezivka CGPP with the aim of dosing out BCS and gas system in the amount of up to 20 % of current productivity.

Simulation of the process of fluid movement and its redistribution between the sections of the system indicates the possibility of reducing the volume of contaminants when the load and working pressure change by a factor of 3.5. This almost doubles the pressure drop across the sections, leading to an increase in gas production volumes by an additional 5–20 %, depending on the current working pressure of the wells (Tables 5, 6).

From the results of the presented studies (Tables 5, 6), it is noted that when the input pressure on the Solokha BCS is reduced to 2 atm, the gas velocity of the low-pressure sections of the pipelines will reach extremely low values. This will negatively affect the operation mode of low pressure wells. As a result, the energy of the formation will not be sufficient to remove the gas-liquid mixture from the bottom of the well. This will lead to a complete shutdown of the well and loss of gas production.

Table 5

The results of simulating the distribution of working pressure on production volumes with a decrease in working pressure from 25 to 12.5, 5, 2 atm the entrance to the Solokha BCS, respectively (current systems are contaminated)

Name of deposit	Production (under the established operating conditions of the Solokha BCS), mln. m^3	Production (with a decrease in the input pressure on the Solokha BCS to 12 atm), million m^3/day	Production (with a decrease in the input pressure on the Solokha BCS to 5 atm), million m^3/day	Production (with a decrease in the input pressure on the Solokha BCS to 2 atm), million m^3/day
Kotelva GCF	0.92554646	1.0808466	1.1053702	1.0813344
Zakhidna-Berezivka GCF	0.55133620	0.64357610	0.64781770	0.64744850
Opishnia GCF	0.62547870	0.72330250	0.73208310	0.71348870
Total	2.10236136	2.44772520	2.48527100	2.44227160
Additional production, %/day	–	16.43	18.21	16.17

Table 6

The results of simulating the distribution of working pressure on production volumes with a decrease in working pressure from 25 to 12.5, 5, 2 atm the entrance to the Solokha BCS, respectively (current systems are purified)

Name of deposit	Production (under the established operating conditions of the Solokha BCS), mln. m^3	Production (with a decrease in the input pressure on the Solokha BCS to 12 atm), million m^3/day	Production (with a decrease in the input pressure on the Solokha BCS to 5 atm), million m^3/day	Production (with a decrease in the input pressure on the Solokha BCS to 2 atm), million m^3/day
Kotelva GCF	0.92554646	1.1284586	1.1551746	1.1556903
Zakhidna-Berezivka GCF	0.55133620	0.64939290	0.65432150	0.65545250
Opishnia GCF	0.62547870	0.73227000	0.74185810	0.72030760
Total	2.10236136	2.51012150	2.55135420	2.53145040
Additional production, %/day	–	19.40	21.36	20.41

The most optimal mode of operation is reducing the input pressures up to 5 atm, at which the increase in gas production is clearly noted. As well as ensuring the optimal gas velocity for delivering a gas-liquid mixture from low-pressure wells and in areas of low-pressure pipelines.

7. SWOT analysis of research results

Strengths. Carrying out cyclical studies of the effectiveness of the gas production system primarily leads to the prevention of abnormal situations, which in turn results in sustainable gas production and avoidance/prevention of additional costs of the company.

As a research result, the dependence of the influence of the ambient temperature on the quality of gas preparation, as well as the influence of the gas flow rate on the formation of liquid contaminants in the cavity gas pipeline, is experimentally confirmed.

The main manifestation of economic efficiency for the gas pipelines of the system for collecting and inter-field transportation of gas from the fields that are at the final stage of operation is the reduction of the excess (or excessive) pressure losses that arise in this process. Leveling or virtually complete elimination of their influence is achieved through the implementation of the above activities.

Weaknesses. The results of the research differ somewhat from the actual data, and require detailed study in the future.

Opportunities. Considering the fact that the majority of the world's explored deposits are currently at the final stage of operation, research into the effectiveness of the gas production system is promising not only for gas producers in Ukraine, but for the whole world.

Threats. When implementing this research, additional human resources are needed.

8. Conclusions

1. At the first stage of the research, field measurements of the operating modes of the system in summer and winter have been carried out. It has been experimentally established that during the winter operation the process of gas separation on separating equipment is performed more qualitatively than in summer operation, which is associated with the effect of low temperatures on the process of liquid phase precipitation from natural gas.

2. It is established that the hydraulic efficiency of gas pipelines in winter and summer periods of operation fluctuates within 49 %, that is, the speed of the gas flow contributes to the accumulation of liquid contaminants. I would like to note that in all sections of the gas pipelines there are no conditions ensuring the transfer of liquid with the gas flow in the form of films on the walls of pipelines in a dispersed state. It has been experimentally confirmed that during the winter operation, the ambient temperature creates favorable thermodynamic conditions for the «dropping out» of the liquid phase from the gas on separation equipment, that is, the separation equipment works more efficiently. It follows that the gas that enters the pipeline during the winter operation has a lower moisture content of the liquid phase compared to the summer period of operation. Accordingly, it is also clearly noted that the improvement in the coefficient of hydraulic efficiency in the sections of this gas gathering unit is confirmed by a much smaller volume of contamination in the cavity pipelines.

3. In the course of the research, the estimated and critical levels of contamination were experimentally calculated. Also, the places of the most probable localization and accumulation of liquid corresponding to natural traps that are formed in the cavity of the pipeline are lowered, as the trail is lowered through valleys, tracts, ravines, floodplains of rivers. It is established that the actual amount of contamination is slightly different from the calculated one.

4. It is confirmed that the probability of a «volley» discharge of liquid in the winter period of operation is somewhat lower than in summer. It is established that the inclination of hydrate formation is present only in the winter period of operation.

5. Taking into account the hydraulic state of the gas production system, which is considered in the work, the self-cleaning process of the sections of the gas pipelines is modeled. The operating modes of these sections significantly influence the distribution of pressure on the CGPP and the operation of low-pressure and medium-pressure wells due to re-planning of gas flows in the system with justification of their feasibility in technical and economic calculations. In fact, a change in the loading of the system and a decrease in the operating pressure in it will lead to an increase in the linear velocities sufficient for the transition of the structural form of the flow from the stratified (wave) to the cork and ring flow. Consequently, the provision of traffic contamination and self-cleaning of the system.

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RESEARCH INTO ENERGY EFFICIENCY OF THE UNDERFLOOR HEATING SYSTEM, ASSEMBLED DRY

Об'єктом дослідження є теплотехнічні параметри роботи фрагмента системи підлогового опалення сухого монтажу в умовах реальної експлуатації, який встановлено в лабораторному приміщенні.

Одним з найбільш проблемних місць при проведенні експериментальних досліджень виявилась мала площа досліджуваної системи опалення, відносно об'єму приміщення. При значних добових коливаннях температури зовнішнього повітря виявлялись складнощі з виходом роботи системи опалення на квазістаціонарний режим.

В ході дослідження встановлено вплив товщини теплоізоляційного шару під опалювальним контуром на зміну густини теплового потоку від поверхні підлоги до повітря в опалювальному приміщенні. Зазначається, що система підлогового опалення сухого монтажу має малу теплову інерційність завдяки відсутності відносно товстого шару монолітної бетонної плити (із високою питомою теплоємністю), в якій зазвичай облаштовується контур системи опалення.

Зокрема встановлено, що використання керамічної плитки, як фінішного покриття, в порівнянні із ламінатом, суттєво зменшує загальний термічний опір теплопередачі від теплоносія до повітря в приміщенні, що опалюється. При цьому наявність алюмінієвої теплорозподільної пластини, з якою безпосередньо контактує зовнішня поверхня труби опалювального контуру, позитивно впливає на рівномірність розподілу теплового поля в площині підлоги. Це в свою чергу призводить до зменшення термічних напружень у фінішному покритті.

Розрахунки показують, що кількісне регулювання теплового навантаження такої системи, завдяки зміні витрати теплоносія, виявляється менш ефективним аніж якісне, за допомогою зміни його температури.

Експериментальні дослідження демонструють, що густина теплового потоку на поверхні підлоги збільшується майже вдвічі при використанні керамічної плитки у порівнянні із ламінатом при всіх, майже ідентичних, інших теплотехнічних параметрах системи.

Проведені дослідження дають змогу розробити математичну модель роботи системи підлогового опалення сухого монтажу, за допомогою якої, стане можливим провести оптимізаційні розрахунки та вдосконалити конструкцію даного опалювального приладу.

Ключові слова: *водяне підлогове опалення, опалювальний контур, теплове навантаження, термічний опір теплопередачі, тепловий режим приміщення.*

1. Introduction

Global trends in increasing the energy efficiency of heating supply systems in general are aimed at the utilization of natural renewable energy sources, damped secondary energy resources, decentralization of heat supply, as well as a transition to low-temperature heating systems. When applying heat pump installations as part of heat supply

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