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CAPACITY ASSESSMENT OF THE SYSTEM OF GAS PIPELINES, RECEIVING AND TRANSPORTING GAS OF INLAND PRODUCTION

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Abstract

Today, the majority of gas fields in Ukraine are in the final stages of development, which is characterized by a significant decrease in wellhead pressure, as well as an increased gas-water factor. As is well known, when lowering wellhead pressure arises the problem of ensuring the design capacity of the gas production system as a whole.

The main function of the gas pipeline system of the gas producing company of Ukraine is collection of gas from deposits and transport natural gas to consumers.

Taking into account the tasks of ensuring the energy independence of Ukraine, as well as the program to build up gas of its own production, the question of assessing the capacity of the gas pipeline system remains relevant, performing the function of collection and transportation.

As part of the research, the current state of the gas collection and transportation system is analyzed. The workload of gas pipeline sections in the chain from the wellhead to the consumer is investigated. As a result, it is established that the initial sections of the gas production system are fully loaded. Areas that can be recharged are identified, as a result of which it will reduce the output pressure at the wellheads and stabilize hydrocarbon production.

On the basis of the conducted research, it is revealed that one of the alternative methods of increasing the capacity of the gas production system at the initial sections is to increase the equivalent diameter and length of the system by building new gas pipelines. It is also found that the periodic cleaning of pipelines in existing parts of the system prevents the decrease in capacity.

It has been established that reducing the backpressure of the system is possible only in conjunction with unloading the system by changing the flow directions, creating centralized gas collection points, as well as retrofitting existing booster compressor stations.

The availability of data on the load on the gas transmission system will allow the gas producing company to plan the distribution of gas to areas with available free capacity, while ensuring an increase in the production of its own gas. As a result, when the gas is distributed to areas with partial load, it will prevent excessive pressure losses in the system, as well as provide optimal system operation conditions.

Keywords: capacity, gas pipeline system, operation mode, production stabilization.

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1. Introduction

According to a report by IHS Cambridge Energy Research Associates [1], almost 60 % of the world's daily hydrocarbon production comes from mining fields that are in a downstream stage, or have reached the final stage of development. At this stage of development, gas and gas condensate fields are developed mainly in gas mode for depletion with a constant decrease in operating pressure at the wellhead. To reduce operating pressures, gas-collecting systems are equipped with a compressor station with its installation in accordance with the adopted collection scheme at group points or a centralized point at a sufficiently far distance from the wellhead. Subject to the use of a centralized gas collection scheme, gas is collected and transported to the central gas collection point by an extensive pipeline system, which makes it possible to use the existing infrastructure and reduce the need for investment in the development of a smaller booster compressor station in the fields. Despite the advantage of cost savings in the reconstruction of the system when organizing a centralized collection scheme, its implementation significantly affects the capacity of pipelines. This characteristic depends on three main factors:

– technical characteristics of pipes;
– working pressure of the system;
– presence of contamination of the internal cavity of gas pipelines;
– possibility of redirecting gas flows.

Accordingly, with a centralized collection scheme, there is a direct relationship between the operating pressure of the system and its capacity on the one hand, and the production of natural gas from the operating pressure in the system. Therefore, the issue of the possibility of influencing the minimum allowable pressures at the wellhead is becoming urgent, limited by the back pressure at the inlet to the booster well and hydraulic losses under low operating pressures.

2. Literature review and problem statement

In [2, 3], methods for determining the capacity of gas pipelines are proposed. The system approach to determining the capacity of gas transportation systems was first described in [4]. It is proposed by combining the characteristics of the BCS, CS and linear sections to determine the operating point of the gas transportation system, which consists of series-connected links – BCS, CS and linear sections. However, the proposed method can be successfully implemented only for an ideal gas transportation system, which consists of units of the same type.

Certain improvements to the proposed method are made in [5, 6], where the carrying capacity of the linear sections and the capacity of the booster compressor station, compressor station are determined taking into account the hydraulic efficiency of gas pipelines and the operating parameters of gas pumping units. However, the proposed technique can be used in conditions of a limited number of linear sections and compressor stations. In addition, the graphoanalytical approach to the problem introduces a certain error in the calculation results. The proposed approach to determining the capacity of complex gas transmission systems is aimed at improving the systems approach taking into account the real characteristics of linear sections and compressor stations and the possibility of controlling their operating modes.

According to it would also be desirable to note the influence of the hydraulic state of the linear part on the capacity of the gas collection and transportation system. In [7, 8], an estimate of capacity is given when the hydraulic state of a section changes. However, all the proposed studies are local in nature, without a realistic assessment of the impact on capacity on the distribution of the minimum allowable pressures at the wellhead and, accordingly, natural gas production.

Taking into account the tendency to increase gas of its own production, as well as the fact that the vast majority of fields are at the final stage of development, the question of studying the capacity of the gas collection and transportation system in today's realities remains topical. This issue is especially acute for systems differing in the centralization of gas pumping equipment.

3. Materials and methods of research

The overwhelming majority of Ukrainian oil and gas condensate fields are located in the Dnipro-Donets Basin in three regions of Eastern Ukraine: Kharkiv, Sumy and Poltava. The fields are among the extensive network of gas pipelines. The main gas pipelines laid in eastern Ukraine can be divided into:

– transit, intended for transportation of export gas through the territory of Ukraine to European countries;

– focused on the supply of export gas and gas of own production to consumers and injection into UGS;

– focused on transporting domestic production from the production regions (Eastern Gas Production Region) to the gas consumption regions (Central, South and Western Ukraine).

The last two types of pipelines are interconnected by metering nodes, industrial gas distribution stations, booster stations, therefore, in the summer period in conditions of reducing gas consumption by large industrial hubs, gas is directed to the west or south through the trunk gas pipeline system (PS) Shebelynka-Dykanka-Kyiv (ShDK), Shebelynka – Poltava – Kyiv (ShPK), Efremovka – Dykanka – Kyiv (EDK) and Shebelynka – Dnipro – Kryvyi Rih – Izmail (ShDKRI), respectively.

If visualize the data of the operating modes of the main gas collecting networks in **Fig. 1**, then it is possible to conclude that the Shebelynka and Dykanka nodes are the central points of gas collection, measurement and distribution. If take their start or end points of the main gas pipelines, then in the process of collecting and transporting gas from their own production in a westerly direction, the system of GP ShDK, ShPK, EDK and KK; southward – PS ShDKRI, DKKR, EKKR; north – PS Shebelynka –Kharkiv (ShH) and ShBKB; in the east – Shebelynka – Slaviansk – Lysychansk (Luhansk). Operational operating pressures in gas pipelines oriented to the transportation of gas from own production are lower than in transit ones, since they receive gas from individual fields, mainly with low operating pressures:

– within 10 atm – in the area between Chervony Donets and Khrestyshche BCS;

– within 25 atm – in the area between Khrestyshche BCS and Dykanka CS;

– within 30 atm – in the area between Dykanka and Lubny CS.

The transit system of gas pipelines, by which the gas flow from the territory of the Russian Federation is transported to European countries, not connected with the intake of gas from Ukrainian fields, is operated at a high working pressure within 45–54 atm.

The analysis of the technological modes of operation of the PS ShDK, ShPK, EDK and EKK system, which is the most powerful in Eastern Ukraine, where more than 90 % of all gas produced in Ukraine is extracted (as of 2017 – 199 billion m^3) shows that and transports 80 % of the produced gas to the west during the summer period of operation (**Fig. 1**). It is this artery that is a vivid example of the centralization of equipment at Khrestyshche BCS (for collecting gas from fields) and the Dykanka CS (for collecting gas from GPP).

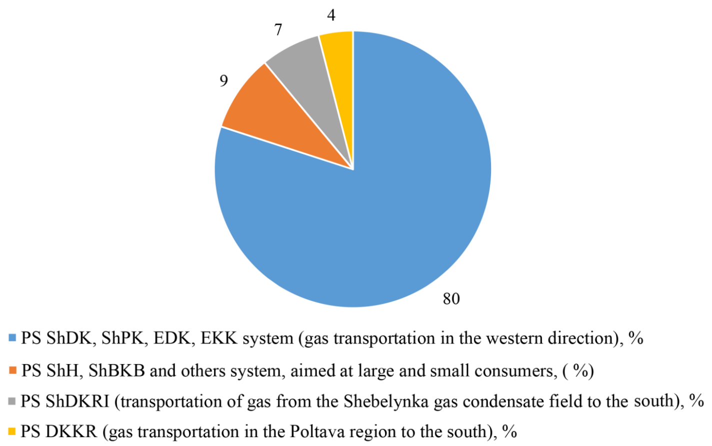

Fig. 1. Distribution of own gas production by main gas transportation arteries

In addition to analyzing the technological modes of operation, this work used mathematical modeling of the distribution of working pressure values at the control points of gas gathering and gas transmission systems in order to assess the future impact on gas production volumes.

The calculation is carried out by the method of equivalent lengths, the essence of which is replacing a complex system of gas pipelines with a single-line simple gas pipeline, also of diameter, but of equivalent length [9]. The main condition is that the pressure loss on the gas transportation process in the simulated simple gas pipeline and the complex gas pipeline system are the same. In fact, if the complex system of PS ShDK, ShPK, EDK and Kursk – Kyiv is a system of parallel and serially connected pipes, equivalent diameters and lengths are calculated using well-known formulas [10].

The complexity of the considered system of gas pipelines is not only in the technical performance of pipes of different lengths and diameters, but also the presence of large and small selections (in this case – boosting). Relatively small gas withdrawals and pumping are considered small, the volume of which does not exceed 0.5–0.7 % of the total volume of gas that is transported. Their influence in the calculation can be neglected, since in the design calculations their value is taken into account when selecting a gas pipeline with a constant diameter, and hence the value of the transmission capacity will become conditionally isobaric [11]. The purpose of this work is calculation of the capacity of the system of gas pipelines involved in the transportation of own gas in the west direction, at different operating pressures on linear sections. Also, the impact of changes in the pressure mode of operation on gas production volumes and its technological costs for compressing is evaluated.

In this work, large discharges and gas inflows, characteristic of the presence of large industrial hubs and the location of natural gas deposits, which are taken into account. Since in this case we are already dealing with an existing system of gas pipelines, the main task of the calculation is determination of the capacity at certain sections of the gas pipeline with a certain technical characteristic.

For the first time, the work presents the results of an integrated and systematic approach to assessing the impact of the operation mode of the gas transmission network on the operation of the gas production system.

4. Experimental research

The gradual reduction of the working pressure at the wellhead by introducing a booster compressor station in the gas collection system and reducing the energy consumption for gas compression is associated with the average working pressure in the gas pipeline system, which receives and transports its own production gas. It is the working pressure on the section between the linear compressor stations or in the final GP area that determines the capacity of the pipeline, that is, the maximum volume of gas that can be pumped over a certain amount of gas. The lower the value of the working pressure in the PS system, the lower the pipeline capacity, and, consequently, the amount of gas entering the system is limited. On the other hand: minimization of the working pressure in the PS system will reduce the working pressure at the wellhead of fields without BCS in the collection system, reduce energy consumption for compression and have a positive effect on gas treatment at the GPP.

The problem of low capacity is acute in the summer period of operation due to the reduction of gas consumption by large industrial hubs. Gas that has not been fulfilled to consumers from the Shebelynka and Efremovka group of fields is directed to the west through the PS ShDK, ShPK, EDK system and south along the ShDKRI PS. The Dykanka knot also distributes gas of its own production in the western direction through the PS system of the ShDK, ShPK, EDK, and in the south along the DKKR PS.

In addition, no less important factor is the hydraulic condition of the pipelines. The flow of gas from different fields with different working pressure, moisture content and the specific weight of heavy hydrocarbons is the root cause of the formation of pollution and deterioration of the hydraulic state. Changes in the load areas, directions of flow change the hydraulic state, because they can have a linear movement of the accumulated fluid. Only in areas with constant loading, which operate in a quadratic mode, can the hydraulic state be considered conditionally constant.

Considering the above factors, the daily capacity of the pipeline is estimated by the formula (1) [10] for various sections of a complex system of gas pipelines, which is replaced by an equivalent gas pipeline of a certain diameter d_{eq} and length l_{eq}.

$$q = 0{,}326 \cdot 10^{-6} d_{eq}^{2,5} \sqrt{\frac{P_1^2 - P_2^2}{\lambda \Delta T z l_{eq}}}. \quad (1)$$

The calculation is carried out for different final pressures at the inlet to the last linear BCS – P_2 and modeled initial pressures – P_1, the value of which forms the hydraulic state of the gas pipelines, determined by the coefficient of the actual hydro-pores λ. The physicochemical properties of the medium and the coefficient above the compressibility of the gas are calculated by the method in [12] and are presented as the relative density of the gas in air Δ and the coefficient above compressibility – z. Thermal operating mode of the gas pipeline is accepted according to the standard operating conditions.

The system is reviewed at the section from the Shebelynka gas condensate field (GCF) (Chervonyi Donets BCS (ChBCS), PBCS "Shebelynka-1" Kyiv – the starting points of PS ShDK, ShPK) to the gas distribution station (GDS), Kyiv. The choice of this particular area of the complex system is due to the third factor – the presence of the largest gas piping from fields to the ShDK, ShPK, EDK PS system. Below **Fig. 2** presents the results of the calculation of the capacity of a complex system of gas pipelines used to transport gas from its own production in the western direction.

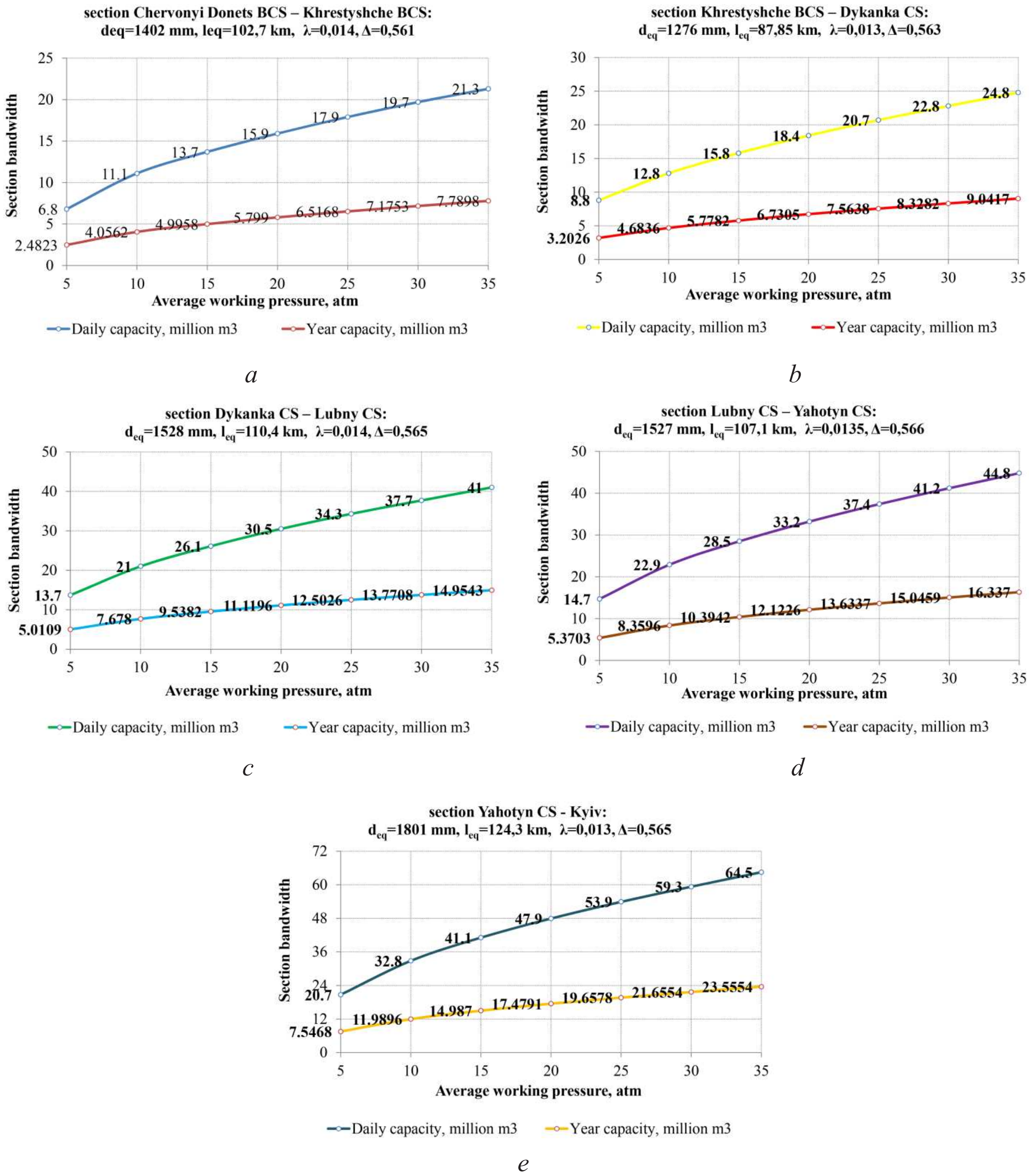

Fig. 2. The capacity of the section of the complex system of gas pipelines ShDK, ShPK, EDK at different average pressures: *a* – section Chervonyi Donets BCS – Khrestyshche BCS; *b* – section Khrestyshche BCS – Dykanka CS; *c* – section Dykanka CS – Lubny CS; *d* – section Lubny CS – Yahotyn CS; *e* – section Yahotyn CS – Kyiv

5. Analysis of operating modes of gas gathering and gas transportation systems

To estimate the actual load of the gas pipeline system, the volumes of gas pumped into the PS system and its actual capacity at the current average working pressure (**Table 1**) are estimated.

Table 1

Actual load of the ShDK, ShPK, EDK and EKK PS system

Section	Average operating pressure as of the summer period of 2018, atm	The corresponding capacity of the section (Fig. 3), million m^3/day	Actual loading of a section of the PS system in the summer period, million m^3/day	Load percentage
Chervonyi Donets BCS – Khrestyshche BCS	10,0	11,1	11,1	100
Khrestyshche BCS – Dykanka CS	26,0	21,7	21,7	100
Dykanka CS – Lubny CS	34,0	40,0	37,0	92,5
Lubny CS – Yahotyn CS	38,5	46,0	39,2	85,2
Yahotyn CS – Kyiv	39,0	72,0	39,2	54,4

The data in Table 1 indicate that the initial sections of the ShDK, ShPK, EDK PS system are fully loaded and operate in the quadratic mode. An increase in gas supply volumes will lead to an increase in pressure losses due to friction with a corresponding increase in the operating pressure in the system to the Dykanka CS. Thus, it is possible to increase the capacity of the system of these gas pipelines in the section between Chervonyi Donets BCS and Dykanka CS only by building additional gas pipelines. In addition, the model ShDK, ShPK, EDK PS system in the section Khrestyshche BCS – Dykanka CS is simple gas pipeline with the smallest equivalent diameter. Therefore, it is the main factor determining the impossibility of reducing the working pressure in this area below 26 atm.

Further, after the gas movement, the system is maximally loaded by 92.5 %, which is a reserve in reducing the working pressure at the Dykanka CS – Lubny CS, Lubny CS – Yahotyn CS and Yahotyn CS – Kyiv sections. The corresponding calculated values of the average working pressure sufficient for pumping gas from inland production in the above-mentioned areas are summarized in **Table 2**.

Table 2

Optimal values of working pressure in the sections of the ShDK, ShPK, EDK PS system

Section	Average operating pressure for the summer period of 2018, atm	The estimated value of the working pressure for the summer, atm
Chervonyi Donets BCS – Khrestyshche BCS	10,0	10,0
Khrestyshche BCS – Dykanka CS	26,0	26,0
Dykanka CS – Lubny CS	34,0	30
Lubny CS – Yahotyn CS	38,5	28
Yahotyn CS – Kyiv	39	15*

*Note: * – the system is designed to Kyiv*

In fact, the data in Table 2 indicate the possibility of reducing the working pressure at the Dykanka CS – Lubny CS, Lubny CS – Yahotyn CS, Yahotyn CS – Kyiv sections by at least 4 atm, which will reduce the working pressure at the outlet of the integrated GPP and BCS and lead optimal loading of sections of the ShDK, ShPK, EDK PS system.

6. Evaluation of the effect of capacity on gas production from fields

The next step is assessing the impact of the capacity of the gas-collecting and gas-transport systems in the centralized collection of products on the volumes of natural gas production from the fields. The initial two sections of gas pipelines are considered as such where the dependence on the working pressure and the volume of the piping is clearly visible. In fact, since at such working pressures and loads, the speed limit will be within 12–15 m/s depending on the location of the section relative to the central gas collection point. On the basis of this, the effect of excessive hydraulic resistance is eliminated due to the fact that their value exceeds the average value of linear velocities, sufficient to remove liquid and other contaminants from the cavity of gas pipelines.

In order to assess the impact of the system unloading, it is achieved by (a) redirecting the gas flow in the total amount of 1.6 million m^3/day to the input of another central gas collection point in parallel with (b) reducing the operating pressure at the entrance to the existing centralized booster system to 4 atm.

The results of modeling the distribution of operating pressures in the system before and after the implementation of measures are summarized in **Table 3**, respectively.

Table 3
The distribution of the values of operating pressures at the outlet of the GPP according to the system unloading option

Gas supply to the new shop	Operating pressure at GPP, atm			Trend	Gas supply to the old shop	Operating pressure at GPP, atm			Trend
	2018	2019	2020			2018	2019	2020	
Khrestyshche BCS (entrance to the new CS)	4,10	4,10	4,10	–1,00	Khrestyshche BCS (entrance to the old CS	4,00	4,00	4,00	without changes
Khrestyshche BCS – cranes of new shop	4,15	4,15	4,15	–1,00	Khrestyshche BCS – cranes of old shop	4,30	4,30	4,30	without changes
GPP-1 Khrestyshche GCF	4,34	4,35	4,36	–0,98	Lanna GPP	8,25	8,34	8,43	–3,00
GPP-2	5,05	5,06	5,07	–0,98	Sosnivka GPP	7,18	6,97	6,82	–5,27
GPP-3	4,69	4,70	4,71	–0,98	Kobzivka GPP-1	10,66	10,17	9,82	–5,91
GPP-4	4,72	4,73	4,74	–0,93	Kobzivka GPP-2	12,98	12,32	11,85	–6,47
GPP-5	5,77	5,86	5,93	–0,43	Kobzivka GPP-3	13,20	12,53	12,05	–6,53
Rozpashne GPP	6,38	6,37	6,37	–0,95					
Vesnianka GPP	5,25	5,24	5,24	–0,95	Gas supply to 0-st. of Kehychivka UGS	–	–	–	–
Zakhidna Staroverivka GPP	8,10	8,09	8,09	–1,12					
Melykhivka GPP-1	11,36	11,78	12,11	1,08					
					0-st. of Kehychivka UGS	2,00	2,00	2,00	without changes
Melykhivka GPP-2	7,16	7,33	7,47	–0,72	Medvedivka GPP	5,89	6,01	6,11	–6,63
					Kehychivka GPP	2,89	2,90	2,90	–8,83
Bezpalivka GPP	8,36	8,38	8,41	–4,02	Yefremivka GPP-3/4	4,40	4,51	4,60	–5,92
PBCS Shebelynka-1 Kyiv	12,25	12,43	12,57	–2,30	Yefremivka GPP-1/2	6,35	6,46	6,55	–5,92

In total for fields depleting, such a sharp decrease in the operating pressure will lead to a corresponding decrease in the minimum allowable value of the working pressures of the wells, was limited by the capacity of the gas collecting system. Accordingly, this will affect the additional gas production volumes calculated by the standard gas-dynamic calculations method for gas depletion fields (**Table 4**).

Table 4
Volumes of additional production of natural gas from fields, supply gas to the initial sections of the ShDK, ShPK, EDK PS

Indicator	2018	2019	2020	Total
Additional production from gas-condensate field to the old shop of Khrestyshche BCS, million m^3/year	694,4	982,975	1228,325	**2905,7**
Additional production from gas-condensate field to the new shop of Khrestyshche BCS, million m^3/year	341	487,75	610,95	**1439,7**
Total additional gas production, million m^3/year	1035,4	1470,725	1839,275	**4345,4**

Additional volumes of natural gas production and pressure drop at the compressor inlet will lead to a corresponding increase in the volume of fuel gas at the central gas collection points (**Table 5**).

Table 5
The results of the calculation of the additional consumption of fuel gas for the system unloading option

Gas consumption by options, million m^3/year	2018	2019	2020	Total
Base option	161,0088	165,6855	168,9464	**4956,407**
System unloading option	212,5051	216,1996	218,8061	**6475,108**
Additional consumption	51,50	50,51	49,86	**151,87**

So, as can be seen from the results of an assessment of the effect of capacity on gas production from fields, then in conditions of equipment centralization in field gathering and gas transportation systems that operate at low operating pressure, it is this factor that has a decisive influence on the minimum permissible operating pressures at the wellhead . On the other hand, in the presence of an extensive system of redevelopment of flows and a decrease in working pressure at the entrance to the central gas collection point, a radical drop in the working pressure in the system and the possibility of increasing production are affected. Other ways to reduce working pressures will be:

– reconstruction of gas pipelines through the construction of parallel threads;

– change of the collection and inter-field transportation scheme from centralized to decentralized, with the gradual approach of the BCS to the wellhead;

– cleaning of contaminated systems with modern methods, taking into account the possibility of their implementation on systems with a long service life.

7. Conclusions

1. It is established that this system of pipelines in the western direction transports 80 % of the produced gas from Ukrainian fields. At the same time, the loading of the initial sections of the system is 100 %, which indicates the operating mode of the initial sections of gas pipelines in the capacity mode (maximum load) at the current working pressure. The possibility of a significant increase in the volume of gas supply to the PS initial sections is missing.

2. It is established that the ShDK, ShPK, EDK PS system in the area between Chervony Donets BCS and Khrestyshche BCS plays the role of a centralized system of inter-field gathering and transportation of natural gas extracted from the fields. The percentage of gas produced in this system is 100 %. Selections along the pipeline do not exceed 0.7 % per year and are characterized as small.

3. It is predicted that the actual pressure drop at the inlet in the Khrestyshche BCS is able to ensure the reception of the predicted gas production volumes from all fields, supplying gas to

the initial sections of the gas pipelines. Reducing the backpressure of the system is possible only in conjunction with unloading the system by changing the flow directions, creating additional centralized gas collection points, retrofitting existing compressor shops, and the like.

Based on the estimated operating costs of fuel gas and additional gas production, the actual effect of capacity on gas production volumes from fields developed in the gas mode for depletion is determined and the ways to increase it are presented.

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