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## Applied aspects of maintaining gas production in a gas condensate production field at a late stage of operation

The authors are offering to use an integrated methodology based on an innovative formula for developing mature fields. Essential factors are analysed, which affect the stabilisation of natural gas and gas condensate production in mature fields in Ukraine. Examples are given of forecasted and actual increase in production of hydrocarbons with reduced well production pressures by introducing new booster compressor stations.

Key words: well, field, production, stabilization, booster.

### Zastosowane aspekty utrzymania wydobywania gazu ze złoża kondensatu gazowego w późnym stadium eksploatacji

Autorzy proponują wykorzystanie kompleksowej innowacyjnej metodologii dotyczącej szczytowania złóż znajdujących się w późnym stadium eksploatacji. Analizuje się istotne czynniki dotyczące stabilizacji wydobywania gazu ziemnego i gazowego kondensatu ze złóż Ukrainy znajdujących się w późnym stadium eksploatacji. Podane są przykłady dotyczące prognozowania i faktycznego zwiększenia wydobywania węglowodorów przy zmniejszeniu roboczych ciśnień złożowych poprzez wprowadzenie nowych stacji sprężarkowych z doładowaniem.

Słowa kluczowe: odwiert, złożo, wydobywanie, stabilizacja, doładowanie.

Maintaining gas production levels and achieving a maximum hydrocarbon recovery factor in partially depleted fields calls for an integrated approach to the problem because of both remaining gas reserves, the energy capacity of the field, its geological and field conditions, and the engineering-and-technological and economic conditions of current production. It is for this reason that several studies of the institute UkrNDIgas, and the joint activity (JA) of SE Ukrgasvydobuvannia and LLC Karpatygas [1–3,

7–14] have considered the options of developing several promising mature fields in Ukraine. Gradually, we have been developing innovative technologies for integrated and compressor-based development in the Western and Eastern oil and gas production regions of Ukraine. In particular, research efforts [1–3, 14] have substantiated the necessity of installing booster compressor stations (BCS) and gas generation equipment directly in field facilities (the technology of reducing the producing pressure of wells, the cycling

process and other methods). Studies [5–8] offer a basis for apparatus and coiled tubing intensification of stripped wells, and give relevant recommendations. Projects have been initiated for geological and geophysical simulation and development of the Novotroitsky, Yablunivsky, Letniansky, and Zaluzhansky fields [10, 12]. They have proved the necessity of transferring many wells to other beds, side-tracking and developing fields prospected earlier. Applied research efforts [5, 6, 14] and research-and-engineering project [11] have demonstrated the viability of using both BCS and wellhead compressor equipment in the Shebelinka gas condensate field (GCF) and similar mature fields in terms of redevelopment of these fields. The study [13] has disclosed the features of estimating incremental gas and condensate production, as well as incremental recovery of liquefied propane and butane (LPB) by building BCS.

In-depth analysis of the results of research activities [1, 2, 4, 5, 14], which were conducted earlier and subject to in-field testing with the participation and support of the authors, has proved the theoretical necessity of iteratively refining the indicators of mature field development at each stage of field implementation of completed upgraded complexes, and of successful intensification or drilling of new high-production wells. These latter activities will be called in their totality real economically-viable elements of implementing development options (REZERV) when performance indicators are better than 3 to 5 payback period years and demonstrate a 30 to 50% return on capital investment for the field in general. Undoubtedly, innovation and investment mechanisms rely on achievements in applied research and production design, as well as on experience gained in implementing the best thematic developments. In turn, such mechanisms have a non-static structure and algorithms due to macroeconomic and local production reasons. Hence, they affect the transformation of tasks for research groups in institutes, sectoral enterprises and joint activity operators.

Because of the aforesaid and follow-up integrated applied research development of REZERV, the following top priority activities for the Eastern oil and gas production region of Ukraine requiring implementation have been identified:

- building BCS in fields with reduced formation energy capacity parameters (Zakhidno-Khrestyshchenske, Shebelinka, Yuliivske, Markivske, Stepove and other fields),
- upgrading gas treatment plants (GSP) with gas dehydration systems (GDS) in fields with increased moisture-laden fluid discharge (Markivske, and other fields),
- building a modern enhanced hydrocarbon recovery plant (EHRP) in the West-Khrestyshchenske GCF,
- revamping borehole and wellhead equipment, and installing low-capacity wellhead compressors (zero stage),

- drilling boreholes and side-tracks in the Kobzivske, Zakhidno-Khrestyshchenske, Krasnokutske and other fields,
- upgrading and developing an auxiliary field infrastructure, including field and interfield hydrocarbon transport lines, and automation systems in Zakhidno-Khrestyshchenske, Shebelinka, and Yuliivske fields.

In spite of gradual preparation and implementation of the top-priority and maximally transparent REZERV, an integrated solution to the problem of a low hydrocarbon recovery factor in a mature production field will demand that applied sectoral research accelerate the following activities:

- investigate the current life cycle and energy capacities of separate fields in their dynamics,
- refine the prospects of long-term development of fields with account of geological and field conditions,
- develop the methodology of intensification for promising field wells with abundant remaining gas reserves in place (with an individual approach to each field and well),
- conduct production design and deliver detailed projects for retrofitting fields, which have changed significantly in terms of their actual development indicators,
- conduct a feasibility study of efficient redevelopment options, allowing to continue effective well operation and manage field development as a whole.

A key, top-priority issue is optimising well operation conditions, and monitoring and controlling their operation. The key areas of applied research, in particular, for increasing specific hydrocarbon recovery by separate wells and groups of wells are as follows:

- investigating the history of operation conditions and construction transformation of wells (including transfer to other beds),
- investigating the life cycle of production beds and wells, including the parameters of their bottom-hole zones,
- investigating the set of parameters for developing production facilities of fields with an operating network of wells,
- developing a 3D model of oil-and-gas deposits and production levels being developed,
- investigating the impact of civil engineering, maintenance and other innovation activities with incremental development of fields on specific hydrocarbon recovery indicators,
- investigating commercial and process gases and hydrocarbon fluids in field transport check points, preparation of commercial-grade hydrocarbons, SPBT production, and so forth,
- working out measures for intensifying well operation, cleaning bottom-hole zones, and improving field transport hydraulic and gas dynamic conditions,
- optimising operation of separation equipment and/or its

replacement due to the quality preparation of hydrocarbon products,

- working out integrated programs and techniques for increasing hydrocarbon recovery in separate sites according to their current condition, and the condition of production wells, flow line and separation systems, and process and compressor equipment and the general character of their joint operation, and
- innovative methodological and informational support of field services.

Authors' analysis of applied research design within the framework of joint activities identified the following pressing research and production problems in mature fields:

- comprehensive rapid appraisal of dynamic skin factors (concurrent logging and gas-dynamic measurements with sampling) are used insufficiently,
- routine acoustic-resonance profiling from the surface and between wells is done rarely,
- in-process measurement of well individual productivity is often absent,
- major overhauls of wells insufficiently involve the advanced techniques of coiled tubing intensification,
- visual (endoscopic) and parametric diagnostics are used irregularly,
- dewaxing, and salt and clay removal are not followed by comprehensive measurement of the final technical result,
- bed temperatures are measured using indirect methods,
- piezometric, observation and geophysical wells lack requisite instrumentation.

It is no secret that an insufficient database on the condition, operation and parameters of wells and field gathering lines and manifolds is the cause of a gradually increasing probability of non-optimal operation, emergencies and premature well abandonment. The above aspects of defect research and production interaction during hydrocarbon production fail to improve the quality of informational resources of responsible operation professionals. Therefore, the authors of this study have worked out a refined database scheme for operating groups of wells (Fig. 1). It is intended to extend the condition and geological bases of well production data due to the process, construction and geological-and-field features.

Developing a working model of a group of wells and adjusting the entire set of parameters (Fig. 1) will allow for making timely decisions on repairing and servicing each well, changing its process flow diagram and operating conditions, and on plans of increasing hydrocarbon recovery.

A reformatted database on performance of production facilities (about a doubled amount of data) will allow for the working out of activity schedules for increasing hydrocarbon recovery in groups of wells; establish the most optimal op-

erating conditions of development facilities as a whole; and schedule additional development and exploratory drilling in separate potentially productive zones. Besides, analysis of data from production facilities helps cutting costs of individual well investigation (lateral wells, identical in terms of design, equipment models, and drilling method and gas-field construction).

Besides improving the quality and user-friendliness of information resources in field facilities with regard to groups of wells and development facilities, and providing systemised and aligned interfield replicas of relational databases, the authors propose using an innovative formula for developing a field or a group of fields having gas and hydrodynamically-related facilities in subsurface and surface parts:

*Innovative program and methodical system for developing a group of fields = conventional development of separate fields\*, development of separate facilities\*\* + updating and correlating well development data (separate sections, wells\*\*\*) + accounting for the logistics of movement of raw stock, semi-raw stock, commercial products + balancing product transport (including BCS) and processing costs (including EHRP and GDS) + iterative adjustment\*, \*\*, \*\*\* for new obtained data.*

The mathematical-linguistics notation of the formula complements the conventional mathematical model system of equations [11, 14]. In this case, the authors place emphasis on the logical algorithmic structure of the iteration process of making adjustments to the complexes for development of separate facilities and groups of fields, as well as on functional accounting for field transport logistics and gas processing flow diagrams. Thus, when developing methodical materials for estimating incremental gas and condensate production from a group of wells connected to the Yuliivske oil and gas field (OGF) [14], interfield diagram data were used, and the hydrocarbon composition was appraised in general for groups of wells in separate sections of the Yuliivske, Skvortsivske, Naryzhnianske and Nedilne fields (Fig. 2). Diagram legend: GM – gas main, PGPT – preliminary gas processing terminal, TEA – turbo expanding assembly, and OMS – oil metering station.

The authors, in collaboration with the institute UkrNDIgas, have presently updated the operating parameters for a group of fields, which are included in the overall complexes of underground models of geological structures and interfield models for processing commercial products in the Yuliivske group of fields (Yuliivske, Skvortsivske, Bezliudivske, Naryzhnianske, Aksiutivske, and Nedilne). Note that the first four fields operate with one BCS, whereas the Bezliudivske, Aksiutivske, and partially, the Skvortsivske fields are operating without

a compressor and are connected directly to the gas mains and local consumer. Updating operation parameters, base and predicted development of conventional-type fields are also supplemented with data from advanced compressor development technologies with EHRP and dehydration systems.

Commissioning the new BCS in the Yuliivske GTP and launching compressor development of the Yuliivske and adjacent fields with enhanced hydrocarbon recovery with the existing liquefied gas recovery plant (LGRP) allowed for involving wells with low production pressures in optimal well development, as well as increasing the recovery of liquid hydrocarbons – gas condensate and LPB. The above innovative formula for developing groups of fields has also accounted for the above-mentioned fact.

Of importance is ample evidence of the need to extend the usage of GDS, the cycling process, BCS, EHRP and other technologies for the development of mature gas and gas condensate fields both in Ukraine (Chervonodonetska, Khrestyshchenska, and the Yuliivska BCS) and worldwide. The results of the effective usage of BCS at the mature development stage with reduced production pressure in the Shebelinka GCF are given in [3] (Table 1). Stabilised natural gas production in the Shebelinka GCF over 7 years (2002 through 2009) with the usage of the Chervonodonetsk BCS yielded 5.7 billion m<sup>3</sup> of gas.

An example of the combined usage of BCS and LGRP in the Yuliivsky OGP according to data [14] has shown actual and predicted indicators of incremental production (stabilisation) of natural gas (Fig. 3), gas condensate and LPB recovery. Only during the first five years, the forecasted incremental production of natural gas will be 767 mln nm<sup>3</sup>; gas condensate, 33 300 tons; and incremental recovery of LPB will be 54 400 tons. Actual incremental gas production during August through October 2012 due to BCS operation in the Yuliivsky OGP was 16 mln nm<sup>3</sup>.

In the cycling process, as a modern development method using a system for generating and processing commercial gas (SG-PCG), partially substituting recycle natural gas with less expensive

synthetic gas [3, 9] is profitable. The compressor equipment helps in increasing injection volumes and the effectiveness of recovering condensates and higher hydrocarbons. Note that we are again considering a group of two dynamically-related gas fields (the Tymofiivske and the Kulychykhynske ones), both sharing joint development facilities and equipment.

We have done the first theoretical forecasts on upgrading compressor, separation/turbo expanding and other process equipment in the course of the integrated development of a group of fields producing for the Khrestyshchenska BCS for the option of multistage compriming with a minimal input pressure of 0.6 MPa (Fig. 4). For a more accurate forecast, we intend accounting for the actual degradation of the hydraulic condition of field and interfield gas pipelines. This becomes evident based on the logistics diagram for the given group of fields (Fig. 5). The diagram shows gas mains, fields and the field gas distribution station (FGDS). The key factors to be taken into account during final consideration of the REZERV feasibility study should be the distance from the field to the BCS with EHRP, the product storage facility and proven reserves of gas, gas condensate and LPB.

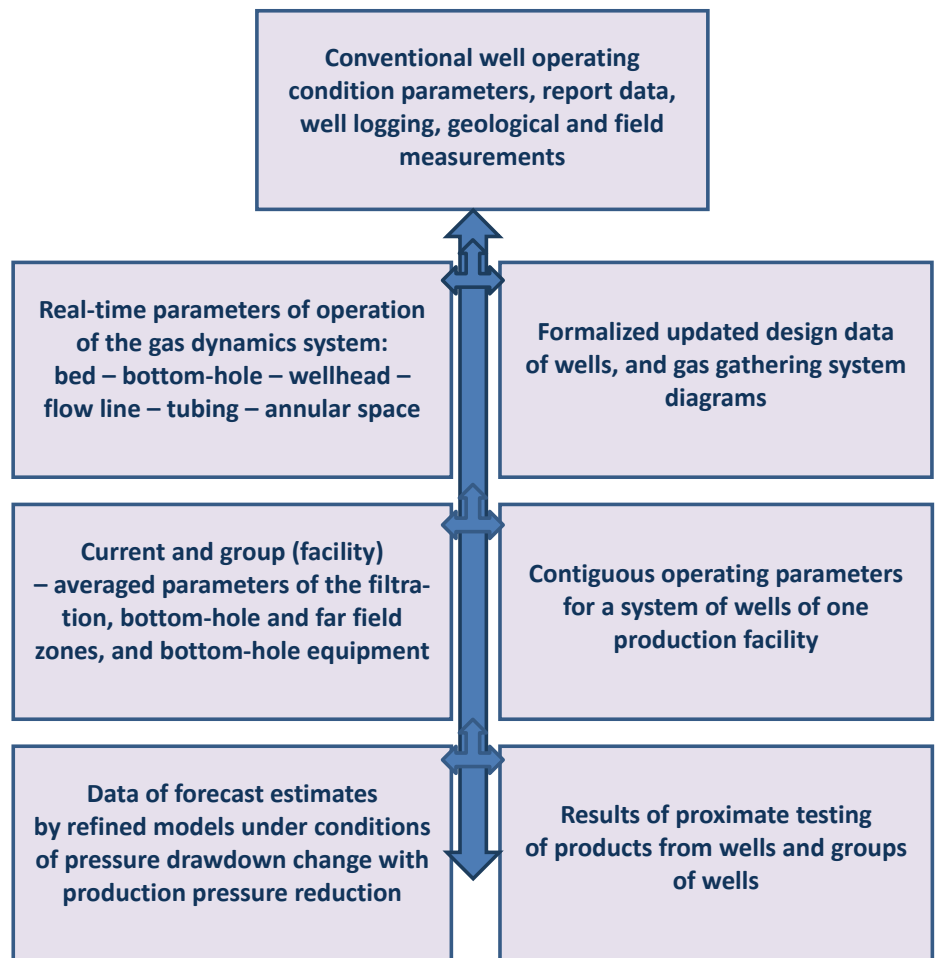


Fig. 1. Updating and extending the set of parameters of current operation and forecasted operating conditions for groups of wells in one development facility



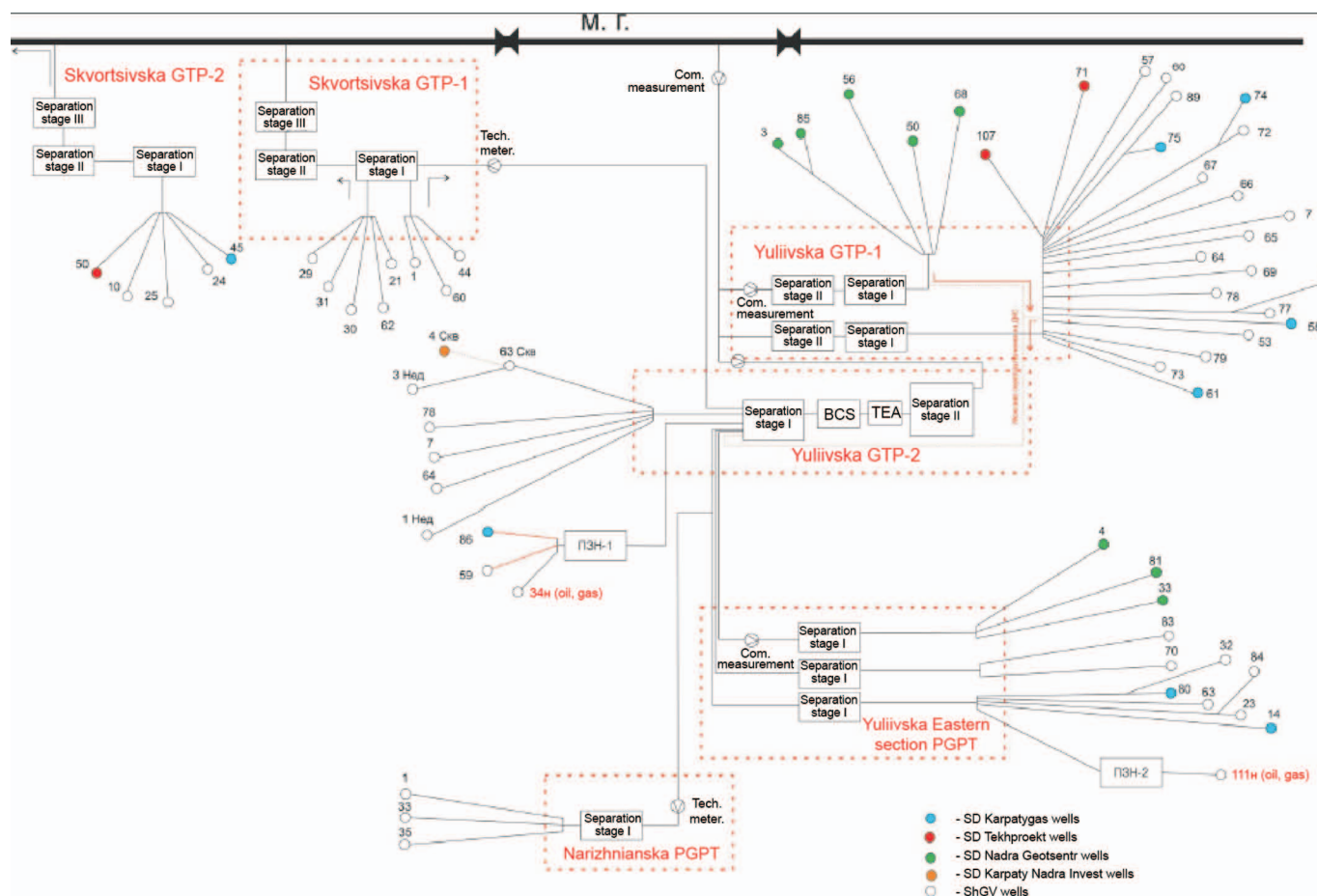


Fig. 2. Diagram for gathering natural gas from wells and groups of fields to the BCS of the Yuliivsky OGP

Table 1. Example of incremental (above-base) natural gas production by reducing well production pressures from 1.76 to 1.3 MPa after the reconstruction of the first stage of the Chervonodonetsk BCS with  $P_{in} = 0.6$  MPa

Years	Gas production as per variant [mln m <sup>3</sup> ]					
	Base	Forecasted (reduced pressure)	Actual production	Forecasted above-base	Actual above-base	Actual above-base accumulated
2002	1 868.0	1 998.1	1 983.0	130.1	114.0	114.0
2003	1 778.9	2 207.0	2 091.8	428.1	312.9	426.9
2004	1 697.5	2 415.5	2 451.2	718.0	753.7	1 180.6
2005	1 611.5	2 687.9	2 427.1	1 076.4	815.6	1 996.2
2006	1 534.9	2 575.7	2 408.3	1 040.8	873.4	2 870.6
2007	1 461.1	2 451.3	2 398.3	990.3	937.8	3 808.4
2008	1 394.5	2 339.7	2 383.9	945.2	989.4	4 797.8
2009	1 323.4	2 222.8	2 370.0	899.4	946.6	5 744.4
2010	1 259.6	2 118.3	2 350.0	858.7	1 090.4	6 833.8
Total	13 929.4	21 016.3	20 863.6	7 087.0	6 833.8	

The investigations of applied research scientists working at UkrNDIgas, NTU KhPI and JA PJSC Ukrgasvydobuvannia, jointly with GPD Shebelinkagasvydobuvannia and LLC Karpatygas [11] have also demonstrated the need to extend the inventory of zero-stage compressor equipment for a group of wells in mature gas condensate fields (GCF).

Reduced bed energy capacity near the bottom-hole, involving energy feedstock or electric power near the wellhead and the GTP, as well as operating compressor equipment changes the gas hydrodynamic parameters in the uplift, pressure and production lines, and in commercial hydrocarbons gathering and processing lines.

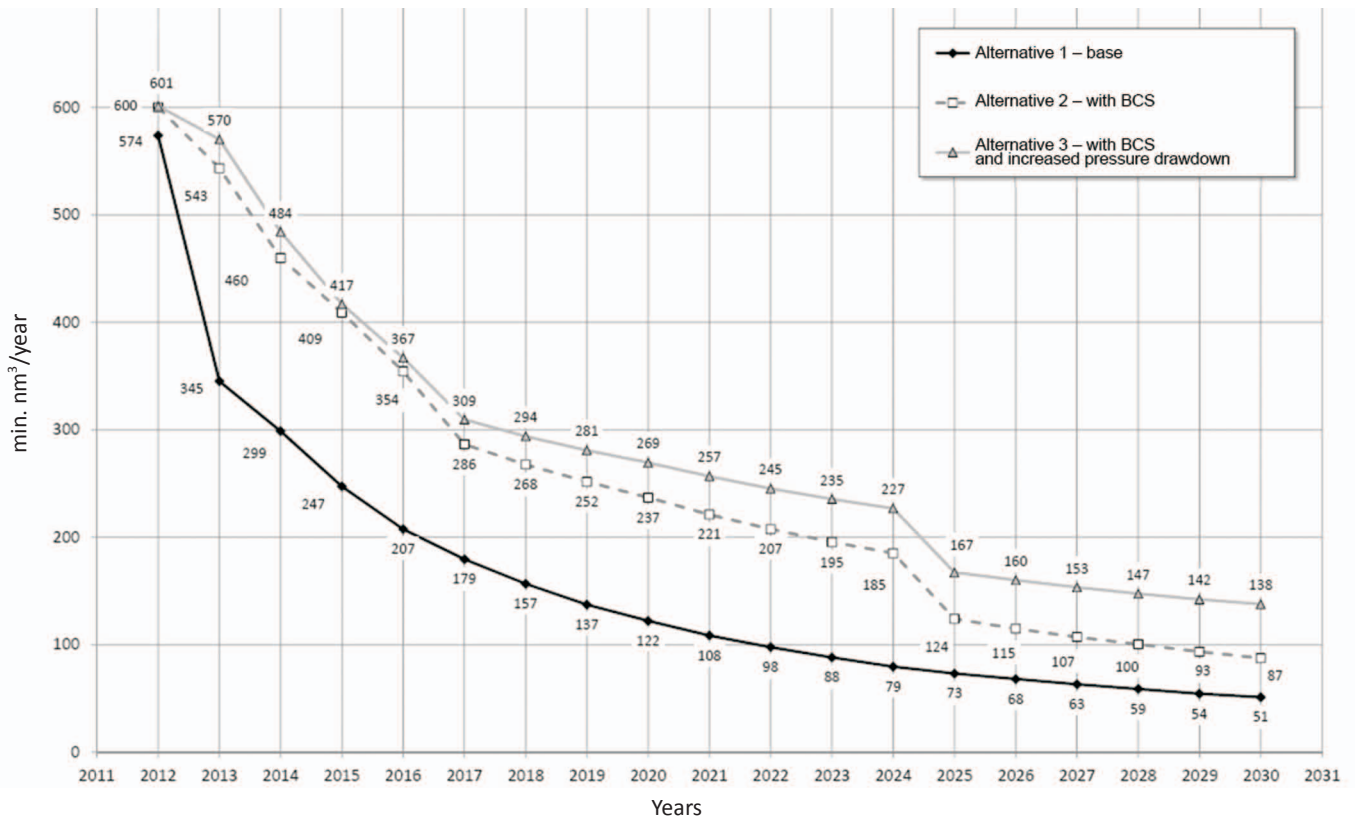


Fig. 3. Forecasted gas production from groups of fields as per development alternatives

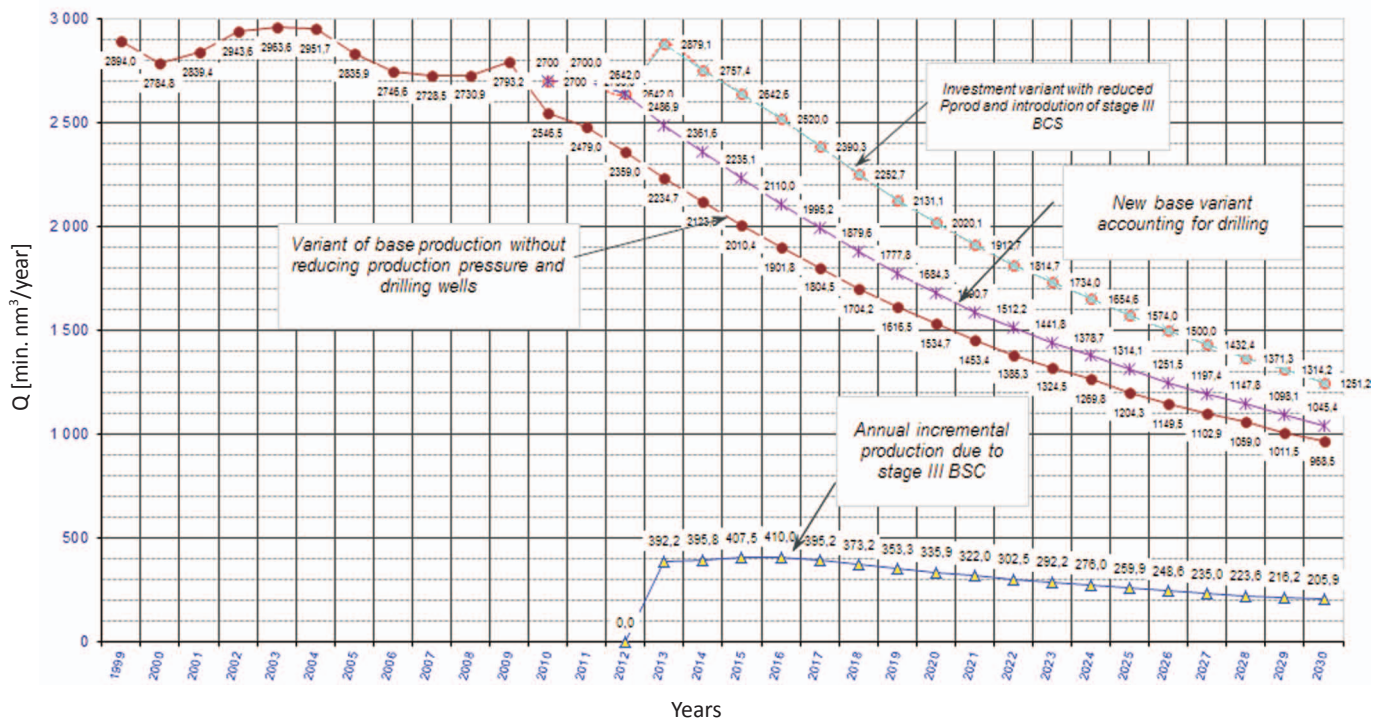


Fig. 4. Forecast of base, investment and incremental gas production in the Khrestyshchenska group of fields in 2013 through 2030 after upgrading the Khrestyshchenska BCS

Fig. 6 is a diagram showing production gathering in the Shebelinka GCF from wells and the GTP, and further transport to manifolds where simple flow gathering from branch lines is combined with parallel-series network nodes. With

such system configuration, installing small-size compressor equipment is necessary both in extreme points (near the wellhead of separate wells) and in GTP for operation of a group of wells.

Provided the process diagram of the connecting compressor equipment in the GTP shall be set up as shown in Fig. 7, each well can be serviced individually to a preset algorithm with optimal process parameters and actuation periods (by programming the APCS controller). An advanced approach to compressor development of mature fields with a developed structure of gathering hydrocarbon products is setting up jump-over lines and gas flow line-manifold transformation with the help of automated multipurpose valves and top-level APCS. Fig. 8 shows this by example of flow lines and manifolds in the Shebelinka GCF. Changing the load on the flow lines and gathering manifolds, and the lengths of overall paths from a well to the required transfer endpoint in this case offers additional options for optimisation of field transport logistics. At the same time, this brings up the issue of feasible operating conditions of the GTP separation equipment.

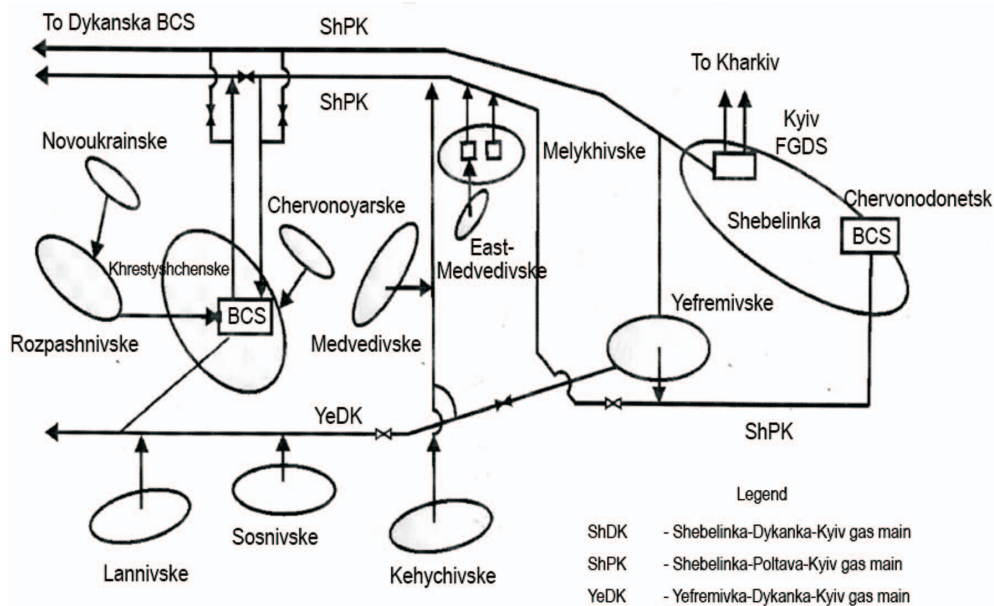


Fig. 5. Diagram for gas gathering and transport to the Khrestyshchenska BCS from the GPD Shebelinkagasvydobuvannia group of wells

That is, optimisation of the drawdown pressure, the production pressures of wells and field transport schemes, and processing and recovery of commercial hydrocarbons becomes functionally dependent on the operating conditions of energy-active components with different installation points, starting from one or several bottom-holes and ending with the

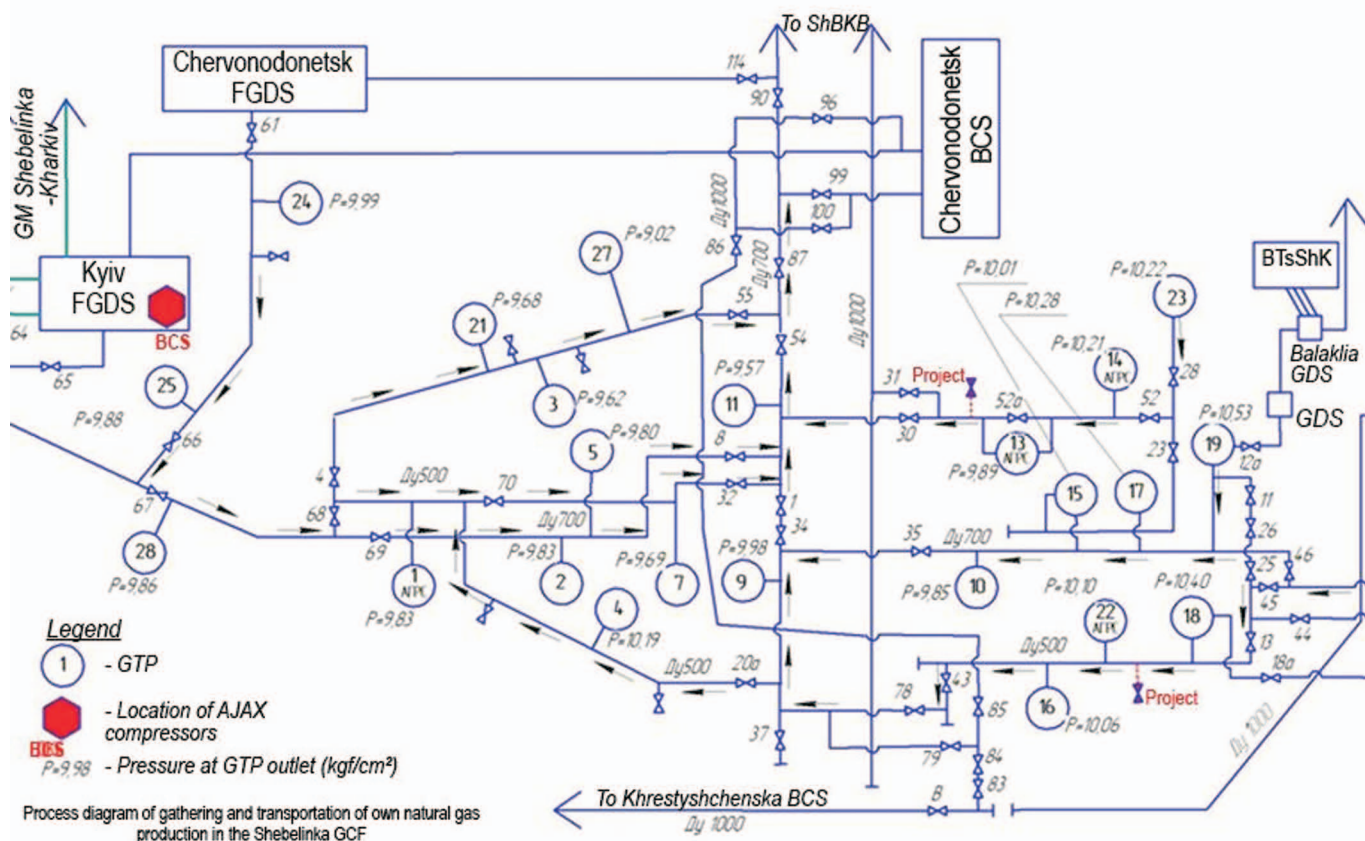


Fig. 6. Diagram for gathering and transportation of gas in the Shebelinka GCF



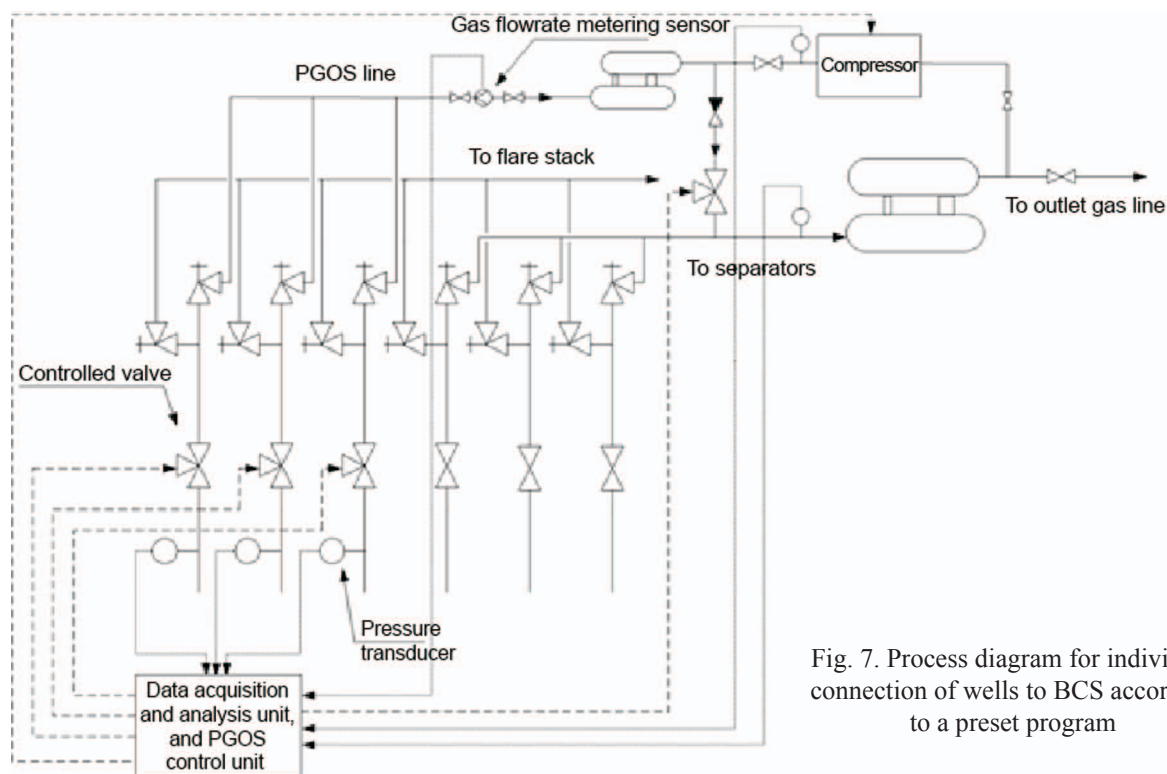


Fig. 7. Process diagram for individual connection of wells to BCS according to a preset program

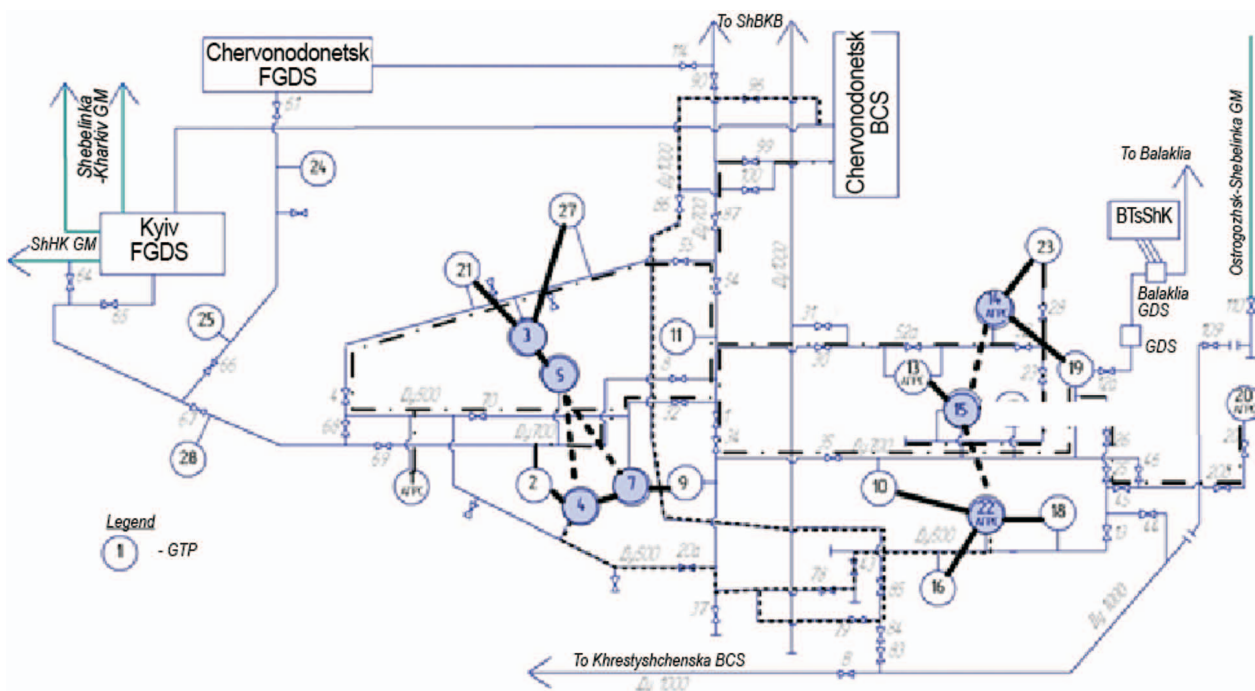


Fig. 8. Example of transformation of field gas transport paths over existing flow lines and gas gathering lines

point of connection to FGDS, GM, gas distribution stations (GDS), as well as to product export terminals. This once again stresses the necessity of using an innovative development methodology involving the formula suggested by the authors even for locally-separated reserves of individual fields.

Bottom-hole zone and well equipment operation intensification has several coordination techniques, which can be used effectively in the main part of the old inventory of

wells with significantly degraded filtration properties of the bottom-hole zone and pipeline transmission capacity. Such techniques rely for the most part on making additional coiling tubing perforations to the pay-out bed in conjunction with using suitable chemical catalysts and reagents. Of course, powerful integrated techniques are used in wells, which have failed to ensure hydrocarbon production increase with the help of other more „delicate” techniques. Proven integrated



techniques of individual production intensification in separate wells also need pump-and-compressor equipment in mature fields both in production lines and bed injection lines.

In the authors' opinion, the basic options of changing the methodology of redeveloping fields with reduced bed energy capacity, increased well drowning and viscosity of bed fluids, worn-out flow strings and plugged filtration-bottomhole channels are linked specifically to changing the pressure and temperature conditions, and the physico-chemical composition of hydrocarbons when using new field energy-active and energy transformation equipment as well as relevant hardware and software.

Provided all other factors are constant and under conditions of gradual implementation of accessible technological innovations, still the most significant and biggest operational impact on development indicators is achieved by installing compressor and pumping equipment as well as auxiliary systems for their normal and accident-free operation.

Hence, forecasting the parameters of developing separate fields comprising several sections and groups of adjacent fields (both hydraulically and gas-dynamically related, and isolated ones, with subsurface pumps, BCS, EHRP, GTS, SGPCG, APCS, and other means to be integrated in the development during 2013 through 2016) according to the innovative formula based on expanded user-friendly DBMS for field and interfield data, will offer new short-time and long-term prospects of developing mature production fields.

The most valuable auxiliary systems are EHRP, GTS, SGPCG, and APCS. On the other hand, significant results in maintaining the production of natural gas and liquid hydrocarbons by using modern compressor and pumping equipment relies directly on the quality and parameters of preparing vertical, inclined and horizontal lines for filtration/uplifting/

flow/and gathering of bed fluids; the performance parameters of field separation equipment, and the hydrocarbons transport and processing network.

Gas production stabilisation in mature gas condensate fields with the installation of compressor equipment in individual wells, groups of wells and fields has actually been proven and parametrically defined by several implemented projects. With reference to the Eastern oil-and-gas production region of Ukraine, it is necessary to mention the implementation of BCS construction and reconstruction projects in the Shebelinka, Khrestyshchenske and Yuliivske fields. Concurrently with installing or replacing compressor equipment and gas treatment systems, it is at the mature field development stage that most significant results are achieved by intensifying treatment of bottom-hole zones, employing physico-chemical water isolation methods, choosing effective production conditions, using inhibitors, choosing an optimal velocity of lifting the multiphase fluid in the production tubing, and individually metering operating condition parameters and the composition of production fluids from separate wells and their groups.

Introducing bottom-hole, wellhead and group compressor equipment according to design to the system of complexes of developing groups of fields, optimising gas comprising conditions in field gas gathering and processing networks with account of the above aspects can acquire a real-time character. This will demand algorithmic innovations for refined blitz prediction of field development indicators, and automation of receiving and adjusting source data, and calculating the indicators of gas hydrodynamic models. Therefore, the reported advances in applied sectoral research in Ukraine concerning improvements in forecasting the parameters of modern compressor multistage mature field development is indisputably topical at present.

## Conclusions

Introducing the technology of reducing well production pressure by installing compressor equipment in the flow lines of field production facilities, processing, recovering and transporting gas from mature gas condensate fields is an effective tool for boosting gas production.

Installing energy-active components in flow lines has a dramatic impact on the mature field development algorithm, opens new options for boosting the recovery of hydrocarbons, and improves the overall outcome of activities focused on intensifying the inflow of hydrocarbons.

Expanding the base of production data from wells, setting up coordinated DBMS and their actual provisioning with automatic and semi-automatic methods is a declaration for the speeding up of the integrated development of fields by employing advanced pumping and compression methods.

Predictive estimates and analysis of actual data from fields investigated in Ukraine have demonstrated a 10 to 15% increase in production of hydrocarbons by installing compressor equipment.

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