The impact of integrated modelling on the technical and economic indicators of the oil production process

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Abstract. The article outlines the findings of the reviewed list of tasks to be solved at different stages of oil fields development and operation with the use of integrated modelling technology. Operational and technological models are the most popular nowadays. However, there is no unified field model that would include all the elements of integrated planning. Systematisation of the solved problems and directions for reducing operating and investment costs at different stages of oil field development and operation remains relevant with the use of new modelling technology. Considering the possibilities of a series of integrated modelling programs (Mbal, Prosper, Gap) for optimising oil production process allows us to group the main problems using integrated modelling technology at the following stages: design and strategic decision-making, evaluation and optimising individual activities in the process of operational management, monitoring the development and oil field operation. Based on the analysis of open sources, we have concluded that the introduction of new ‘smart’ technologies significantly impacts technical and economic performance of oil and gas companies, including the level of oil recovery, reduction of drilling time, reduction of operating costs and profit growth, increasing the stability of design solutions and project efficiency in general.

Keywords: integrated modelling, intelligent field, oil production modelling, technical and economic parameters of oil production, list of integrated modelling tasks.

1. Introduction
The growing cost of developing new oil and gas fields under conditions of fluctuating demand for hydrocarbons forces subsoil users to develop and implement new technologies that reduce production costs. Field design plays an important role in this process, enabling optimisation of technological modes and ensuring an appropriate level of technical and economic performance.

The major driver of ensuring the search for optimal solutions in the area of field development and exploitation is the acceleration of data processing and application of intellectual technologies, which are extensively used by global foreign companies (Shell, BP, Exxon Mobil, Schlumberger, etc.) in new previously unprofitable projects, as well as to increase oil recovery at existing fields. Among Russian companies, Oil Company Rosneft and Gazprom are the most successful in implementing digital technologies. Rosneft is developing 10 digital fields, while Gazprom is developing 7, including one unmanned marine field, and LUKOIL is developing 5 of them [1].

The analysis of global and domestic experience of intelligent field technology implementation allows researchers to conclude that it is of great interest to the oil and gas industry of Russia as a tool for managing high-tech projects for oil and gas field development, ensuring competitiveness and high
industry profit [2]. The significance of applying new information technologies grows as oil producers switch to developing fields in remote areas with a high level of reserve recovery complexity.

Modern integrated solution technologies in the oil and gas industry are united by the following categories: 'intellectual field', 'smart field', 'digital field'. These concepts are relatively new yet often used by experts when discussing the problems of improving the efficiency of hydrocarbon production and field development. The stages and directions of their development are intensively discussed by the scientific community [1; 3-8]. In the meantime, researchers focus on engineering and technical issues:

1) justification of the name and configuration of the components included in the 'intellectual field' system, based on the introduction of hardware and software package into production processes of oil and gas producing enterprises, a set of 'business processes for operational management of the field, technical development project based on the most advanced technologies and fully automated infrastructure [2];

2) analysis of relevant trends in the development of digital and intellectual technologies for the oil and gas industry, promising solutions for geology, drilling, development and operation of intellectual fields in Russia and abroad [1, 9];

3) development of systems for control of large volumes of oilfield information, its processing and display in comprehensible form based on the implementation of information technologies and high-tech equipment providing cybernetic control of individual field components (intellectual well, intellectual oilfield, integrated modelling of work planning)[9];

4) analysis of the innovative programs for the development of oilfield services in major oil and gas companies: Rosneft, Gazprom, Gazpromneft and Zarubezhneft [10], establishment of digital twins for production enterprises using modern simulation tools [11] etc.

Few works consider the following:

– opportunities to leverage integrated field modelling for effective business planning of field development [16],

– characteristics of technical and economic indicators of oil and gas field exploitation at various stages of development associated with the assessment of innovative oil production technologies progresses [13];

– methods of modelling indicators’ calculation for the field development investment project and its efficiency parameters as a part of integrated modelling technology, economic and management criteria for the selection of projects for the implementation of smart field technology, financial and economic model of oil and gas asset [2;14].

2. Problem Statement

Implementation of integrated field modelling technology by Russian companies is constrained by the high capital costs associated with the cost of equipment currently purchased from foreign service companies, which requires a detailed analysis of the limitations and opportunities of new technologies in order to improve the technical and economic parameters of oil and gas production.

The review of publications has shown that only separate instruments of field economic modelling for calculation of basic engineering package parameters for field development are currently applied. The main disadvantage is the absence of a single field model, which would include all elements of integrated planning. Unfortunately, the scientific publications have paid insufficient attention to these issues, which makes it urgent to systematise the list of tasks to be solved and directions to reduce operating and investment costs through the optimisation of technical and economic parameters and indicators of oil production at different stages of development, as well as operation of oil fields using integrated modelling technology.

3. The Integrated Model of Oil Production: Opportunities and Limitations

Oil production is a complex production process, which includes geological exploration, drilling and construction of wells, well repairs, as well as purification of produced oil from water, sulphur, paraffin and other impurities. As a rule, the life cycle of oil fields is several decades long.
Optimisation of technological modes of production well exploitation includes the creation of favourable conditions for oil inflow from the formation, the selection of downhole equipment, and the establishment of its mode of operation in line with the productive characteristics of wells and other factors, which creates the necessary conditions for improving technical and economic performance of oil production. For example, reducing the suspension depth of pumps in wells to optimal values leads to a reduction in the frequency of underground repairs and a decrease in the repair price [15].

Integrated modelling allows to automate data collection, filtering, storage, and processing, describe physical processes, predict hydrocarbon production, and visualize key parameters for management decisions. Availability of an integrated model provides an opportunity to make a reasonable choice of development field of project options, reduce operating and investment costs, energy consumption by infrastructure facilities located in the fields, and increase the speed of management decision-making.

System analysis and optimisation of well and downhole equipment operation modes requires a large amount of calculations, which is impossible without development and use of appropriate information models adapted to the conditions of specific fields. Therefore, over the past years, there has been a trend towards more active use of methods of mathematical modelling of processes related to oil and gas production in the oil industry. This is facilitated by the active introduction of modern well research technologies, information systems enabling the registration of diverse data on the state of field development facilities, formations and wells [9].

Commercial and technological models are the most common. They are based on displacement characteristics, fluid filtration equations, and low-parametric regression models of oil, liquid, and water production. At the same time, the actual conditions of oil and gas production are characterised by insufficient adequacy of models, errors in registration of geological and technological parameters, deficiency, heterogeneity, incompleteness of initial data that characterise the energy state of oil reservoirs. In such circumstances, the use of traditional methods to identify technological parameters of development often does not ensure the required solution accuracy. To overcome the complexity of the oil and gas production process, limited information, and ensure the stability and accuracy of solutions, it is recommended to use integrated identification systems that record information related to previously accumulated experience, provide the ability to use expert assessments, models of technological parameters of development within a set of models that reflect the properties inherent in real systems [11].

The integrated model presents related models of reservoirs, wells, and engineering infrastructure of oil field, which allows optimising the process of oil production as a whole. The increase in prediction accuracy is ensured by taking into account the limitations associated with the reservoir and the collection network when calculating the well operation and production mode. The inherent advantages of the integrated model are as follows: taking into account the impact on the indicators characterising well exploitation, collection networks, identification of bottlenecks within collection networks, etc.

At the same time, the integrated model is characterised by the slowdown of calculations in comparison with local models; its implementation requires more significant computing power and labour costs, the requirements to the initial data increase. Table 1 shows the limitations of the hydrodynamic and integrated models, which demonstrate the advantages of the integrated model in terms of managing factors for optimising technical and economic indicators of field development.

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1 Materials used: Nizhelsky D V Presentation of the project ‘Conducting Comprehensive Research to Configure the Well Model and Optimize the Operation of Wells Without Technological Losses’, Perm, 2018
Table 1. Comparison of Limitations of Integrated and Hydrodynamic Models

| Limitation Nature                                                        | Models          |
|------------------------------------------------------------------------|-----------------|
| Optimization of well equipment operation                               | Integrated      |
| Taking into account the performance limitations inherent in a compressor station that provides complex gas treatment | +               |
| Optimisation of the ground collection system                           | +               |
| Taking into account the specifics of well operation methods            | +               |
| Taking into account maximum pressure limits in the collection system   | +               |
| Taking into account limitations inherent in well equipment            | +               |

Integrated modelling provides a way to see the possibilities, simplify and speed up work, reduce errors and shorten the time to correct them. One of the most popular integrated modelling programs in the world comprise Mbal, Prosper, Gap [16] which, when operated as a complex, allow for the analysis of the field during the entire period of exploitation. If we consider this software as modelling tools, we can describe the main features of each program for solving problems that arise in the oil production process.

Mbal is an analytical tool used for dynamic modelling of fluid distribution in a reservoir (material balance). This program provides the ability to determine the main parameters required for modelling the volume of oil and gas reserves, and the mechanism of production. It also allows you to adapt the models taking into account the geological and field data at the stage of field development. Mbal is actively used to form a preliminary model of dynamic processes occurring in the reservoir prior to hydrodynamic modelling, which allows for the following [17]:

- adaptation of the reservoir model based on available field data to determine hydrocarbon reserves and the displacement mechanism;
- forecast of production dynamics;
- analysis of field development scenarios;
- determination of the daily contract amount of gas;
- modelling the dynamics of gas condensate field operation in the depletion and recycling modes;
- analysis of the production drop curve;
- construction of a multi-collector field model, Monte Carlo modelling, linear flooding modelling, modelling of gas production in dense rocks and methane production from coal seams.

Prosper is a program for modelling most types of oil and gas well configurations, including design and optimisation of operation modes and production forecasting. The program provides the ability to [15]:

- distribute production between wells;
- design and optimise well completion for horizontal, multi-layer, and multi-hole wells;
- to design piping and tubing, to carry out the optimisation;
- monitor the operation of wells, identify the need for repairs;
- design wells with centrifugal, hydraulic, jet, cavitation pumps, gas lift wells, and optimise them;
- determine the temperature of the fluid in relation to pipelines and wells;
- calculate pressure drop in relation to fittings, conduits, and wells;
- investigate the continuity of the fluid flow in the well.

The GAP program is an optimiser software that simulates surface product collection system. GAP integrates the reservoir model (MBal) and well model (PROSPER) in dynamic mode, focused on optimising gas and oil collection networks. This program makes it possible to create a production model for oil, gas and gas condensate fields, as well as gas and water injection systems, field modelling taking

\[2\] Based on the work [12]
into account elements in the form of productive reservoirs, wells, ground-based pipelines, and liquid injection systems. The GAP program features fast and powerful optimisation algorithm that provides the following features [16]:

- designing surface pipelines network,
- integration of models of gusher and with mechanised extraction wells, including gas lift, centrifugal, cavitation, hydraulic, jet and rod pumps;
- optimisation of fields with mixed well types;
- optimisation of closed oil collection systems,
- calculation of parameters of wellhead fittings to provide a plan for monitoring the development of the field,
- production forecast.

GAP program allows to integrate MBAL and PROSPER, which makes it possible to model and optimise the production process as a whole [2]. Monitoring the oil production process using integrated modelling capabilities allows solving a wide range of practical tasks at different stages of oil field development and exploitation, and management levels.

3.1. Field design, strategic decision-making level.

At this stage, the presence of an integrated model allows to reasonably choose certain options for the development of the project, the concept of field development, and solve problems related to the justification of the effectiveness of implementing certain components of smart field technology. Typical issues addressed by integrated modelling at this stage [19]:

- choice of the appropriate concept of field development;
- justification of the effectiveness of implementing certain components of smart field technology;
- optimisation of measures to intensify development, optimise well operation (selection of pumps, optimisation of gaslift, selection of string diameter, etc.);
- optimisation of surface network operation (changes in pipeline diameter, pipeline re-routing).

3.2. Evaluation and optimization of individual activities, operational management level.

At this stage, the integrated model can solve a wide range of tasks related to optimizing measures to intensify development (hydraulic fracturing, transferring wells to another category, etc.), optimizing the operation of wells (selection of pumps, optimization of gas lift, selection of column diameter, etc.), as well as optimizing the operation of the surface network (changes in the diameter of the pipeline, re-routing of pipelines, modernization of the booster compressor station, etc.).

3.3. Monitoring of field development.

At this stage, the integrated model can solve a wide range of tasks related to optimizing measures to intensify development (hydraulic fracturing, transferring wells to another category, etc.), optimizing the operation of wells (selection of pumps, optimization of gas lift, selection of column diameter, etc.), as well as optimizing the operation of the surface network (changes in the diameter of the pipeline, re-routing of pipelines, modernization.

The integrated model displays the field operation based on the available views of the formation, wells and equipment. Therefore, periodic updating of the model and its comparison with the available actual data allows to quickly identify changes in the state of the model components, which are reflected in the form of discrepancies between actual and calculated data. Thus, for example, violation of tubing tightness will lead to discrepancies between the calculated and actual pressure losses in the well. Thus, the integrated model can serve as an important indicator of problem occurrence.

When external constraints (e. g. oil or gas production target) are encountered, the integrated model automatically determines the optimum operating points for the equipment, taking these constraints into account so as to minimise network pressure losses and energy consumption for the operation of pumps and compressors. When using the active components of a smart field system (e. g., controllable
connectors or flow control systems), the integrated model can be used to develop the optimal algorithms for controlling them depending on sensor readings.

Due to technologies related to integrated modelling, it provides increased efficiency and savings in the design and implementation of investment projects, current operating costs, including:

- reduced costs and shorter R&D and industrial testing periods due to more accurate field modelling and reserve forecasting;
- reduction of investment costs, profit growth and decrease of the payback period for capital investments when commissioning new industrial facilities due to development project optimisation;
- reduction of energy consumption costs for infrastructure facilities located in the fields based on optimisation of equipment usage modes;
- minimisation of costs for repair, maintenance and operation of fixed assets by optimising their operation and maintenance modes, increasing the productivity of production wells, reducing the number of oil production wells downtime and all types of emergency incidents (including leaks and emissions); reducing oil, gas and water losses by optimising separation, dewatering, desalination and early detection of gusts of oil and gas collection networks;
- reduced staff costs due to automation and increased efficiency of management decision-making, increased productivity and labour safety;
- increase in production volumes due to an increase in the oil recovery coefficient as technologies develop [20; 21].

The publications of various authors provide estimates of expert organisations that confirm the significant impact of new ‘intelligent’ technologies on the technical and economic results of oil and gas companies.

Linnik Yu N, Balashova A D and Bolshakova O I with references to foreign sources [22] argue that the widespread introduction of integrated modelling technologies and intelligent fields will increase global oil recovery from 30 to 50% [1 , 39; 20]. Based on the analysis of data from six foreign projects (oil and gas companies: Brunei Shell Petroleum, Saudi Aramco, Statoil, ONGC, PEMEX, Saudi Aramco), the introduction of smart field technologies will result in increase in average annual profit from 15 to 20% [13; 23–26].

The significant impact of integrated modelling technology on technical and economic indicators of oil field development is also demonstrated by the statistics of Russian companies. Thus, as a result of the introduction of digital technologies, Rosneft has developed Digital Centre for analysis and visualization of geologic formations, Digital shelf, Integrated Field Model, Production Robotisation, and Digital Worker. The company plans to reduce the drilling time by 5%, increase the efficiency of well capital repairs by 20%, achieve a reduction in operating costs by 2–3% per year [21], and increase profits by more than 20% [9] by 2022.

NOVATEK benefited in 40% reduction of metal consumption in terms collection system due to the new technology compared to the traditional approach to design; according to preliminary estimates Gazpromneft-Khantos LLC (Gazpromneft subsidiary) may reduce operating costs for the development of the field by 15% due to the launch of the digital double system at the Yuzhno-Priobskoye field [1].

Application of integrated modelling allows to transfer the revealed uncertainty of parameters at early stages in the category of project risks, to carry out their estimation and to receive possibility to make decisions on prevention of risks or essential reduction of their negative influence. It improves stability of design decisions and efficiency of the project as a whole.

4. Conclusion

This article provides an overview of publications and practices of integrated modelling in oil and gas industry in terms of opportunities to improve the technical and economic performance of the oil production process. It is urgent to develop a classification of the main technical and economic parameters and factors to reduce operating and investment costs of the oil producer when using technology intelligent field to assess the effectiveness of its implementation.
References

[1] Linnik Yu N and Kiryukhin MA 2019 Digital technologies in the oil and gas complex (University Bulletin) 7 pp 37-40. DOI: 10.26425 / 1816-4277-2019-7-37-40

[2] Berezina AA 2015 Economic and managerial criteria for selecting projects for the implementation of intellectual field technology (Internet journal "SCIENCE") 7 (1). DOI: 10.15862 / 20EVN115

[3] Rosendahl T and Hepso V 2013 Integrated Operations in the Oil and Gas Industry: Sustainability and Capability Development (Business Science Reference) (an imprint of IGI Global).

[4] Al-Balushi M et al., Real-Time 2014 Surveillance: How System Integration Allows One Company to Minimize Deferment, Optimize Production, Maximize Test Unit Capacity, and Track the Operating Envelopes of its Wells, SPE-167857-MS.

[5] Talabi O A et al. 2016 Integrated Asset Modelling: Modernizing the Perspective for Short-Term Forecasting and Production Enhancements, SPE-182496-MS.

[6] Vliet van JP M and Male P T 2017 Well, Reservoir and Facility Management - Process, Practice and Impact, SPE-185880-MS.

[7] Hujiang Shen et al, 2017 Design of an Integrated Production Planning System Framework Based on Simulation Using a Production Information Model, Proceedings of the Twenty-seventh (International Ocean and Polar Engineering Conference), San Francisco, CA, USA, June 25-30.

[8] Volkov S et al., 2016 Optimization of Oil and Gas Production Based on Integrated Planning, SPE-181955-MS.

[9] Vlasov A I and Mozchil A F 2018 Technology overview: from digital to intelligent field (In Russ.) (PRONEFT. Professionalno o nefti) no. 3(9), pp. 68-74. DOI: 10.24887/2587-7399-2018-3-68-74

[10] Beloshitsky A I 2019 Technological trends in the development of the oilfield services industry (Oil and gas business) 17 (2) pp 50-55. DOI: 10.17122/ngdeло-2019-2-50-55

[11] Makarov VL et al. 2019 Development of digital doubles for evaluating enterprises (Business Informatics) 13 (4) pp 7-16.DOI: 10.17323/1998-0663.2019.4.7.16

[12] Apasov RT 2018 Integrated modelling - a tool for improving the quality of design solutions for the development of oil rims of multi-layer oil condensate fields (Oil Industry) 12 pp 46-49. DOI: 10.24887/0028-2448-2018-12-46-49

[13] Cherepovitsyn A E and Kraslavsky A 2016 Study of the innovative potential of an oil and gas company at different stages of field exploitation (Notes of the Mining Institute) 222 pp 892-902. DOI: 10.18454/PMI.2016.6.892

[14] Bogatkina Yu G and Eremin NA 2019 Intelligent modeling technologies for calculating economic indicators for the evaluation of oil and gas fields (Bulletin of Tula State University. Earth Sciences) 3 pp 344-355. eLIBRARY ID: 40870199

[15] Ushmaev OS et al all 2016 Integrated modeling as a tool for assessing the impact of well operating modes and a surface collection network on the development of an oil rim , SPE182007

[16] Petroleum Engineering And Structural Geology Software [Electronic resource ] – URL https://www.petex.com

[17] Ismagilov R P et al. 2014 Integrated model for integrated management of field development and development (Oil industry) 12 pp 71-73. https://elibrary.ru/item.asp?id=22704011

[18] Grishagin AV 2009 On the problems of integration of the reservoir - well - development - economics system using the example of the development project of the West Kommunarshoye oil field (Scientific and Technical Bulletin of NK ROSNEFT) 1 pp 30–35. eLIBRARY ID: 15200634

[19] Acosta L M et al. 2005 Integrated modeling of the Furrial Field Asset applying risk and uncertainty analysis for the decision taking, SPE 94093

[20] Balashova A D and Bolshakova O H 2019 Influence of business digitalization on oil recovery coefficient and increase in the efficiency of oil and gas companies (University Bulletin) 5 pp 73-79. DOI: 10.26425/1816-4277-2019-5-73-79
[21] Katysheva E G 2019 Economic and institutional problems of digital transformation of the oil and gas complex of Russia (Digital Economy and Industry 4.0: Trends 2025 Proceedings of the scientific and practical conference with international participation. Edited by A.V. Babkina) pp. 175-184.DOI: 10.18720/IEP/2019.1/25
[22] New Realities in Oil and Gas: Data Management and Analytics 2017 (White paper Cisco public) https://www.cisco.com/c/dam/en_us/solutions/industries/energy/docs/OilGasDigitalTransformationWhitePaper.pdf (19.03.2019).
[23] Al-Dhubaib T A 2011 Intelligent fields: industry's frontier and opportunities (Proceedings of conference:SPE Middle East Oil and Gas Show Conference, Manama, Bahrain, September 25-28) pp 9-11.
[24] Al-Mulhim W A 2010 Mega I-Field Application in the World (Proceedings of conference: SPE intelligent energy conference and exhibition, Utrecht, The Netherlands. March 23-25) pp 6-9.
[25] Sankaran S 2009 The Promise and Challenges of Digital Oilfield Solutions: Lessons Learned from Global Implementations and Future Directions (Proceedings of conference: SPE digital energy conference and exhibition held. Houston, Texas, 7-8 April)13 pp 10-12.
[26] Soma R 2006 Service oriented data composition architecture for integrated asset management (Proceedings of conference: SPE Intelligent Energy Conference and Exhibition, Amsterdam, The Netherlands. April 11–13) pp. 1–2.