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IMPLEMENTATION OF THE INTEGRATED HYDROCARBON RESERVOIR MANAGEMENT SYSTEM BY THE EXAMPLE OF EXPLOITING POLISH LOWLAND'S NATURAL GAS RESERVOIRS

Abstract: Nowadays, because of the smaller and smaller chances of discovering new hydrocarbon deposits with abundant resources as well as significant technological advance, the proper strategy of reservoir management connected with simultaneous optimization of its production parameters is the key element in the process of development the most economically advantageous variant of reservoir management and field development. In Polish Oil and Gas Company, the project called as "Digital reservoir" based on the interactive IAM platform was initiated, thanks to which the work of all upstream segments was integrated, starting from geophysics, geology through reservoir engineering, production engineering, process engineering ending with the economic model that allows for verification of the economic efficiency of the investment. This paper presents the methodology of integration all of the above elements and the results of the IAM system implementation with further production forecasts, on the example of selected natural gas reservoirs in the Polish Lowlands being PGNiG S.A. assets.

Keywords: data integration, optimization, field management, production forecasts, economic efficiency

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1. INTRODUCTION

Nowadays, due to the smaller and smaller chances of discovering new hydrocarbon deposits with abundant resources as well as significant technological advance, the proper strategy of reservoir management connected with simultaneous optimization of its production parameters is the key element in the process of development the most economically advantageous variant of reservoir management.

Because of the fact that petroleum industry is a very complex system, thus hydrocarbon field management requires integrated asset approach to couple different domains and departments within all-encompassing study for making critical decisions about an asset's development and field operations. Adopting an integrated asset approach enables cooperation in multi-discipline team in order to achieve the common goal and enhance asset value. Deploying such approach significantly mitigates any potential uncertainties and risks on each stage hydrocarbon field lifecycle, considering various development plans with their further optimization process. Since integrated asset approach consider all segments and respective pressures drops over the total system, production profiles and forecasts are more reliable and consistent, comparing to the traditional standalone approach which consist of modeling each part of the system separately from the others, excluding upstream-downstream interactions [1].

As a standard approach to integrated asset study, the reservoir simulation model is coupled to the wells and surface network model, then to process facility model and finally to the economic study. Thanks to the domains integration it is possible to identify possible constraints, potential deviations and flow assurance at any parts of entire production system. Integration ensures that all set boundary conditions are honored at all times [2]. This solution can be applied for daily production optimization as well as short- and long-term field development planning.

Currently, because of technology development and improvement in computing capability, modeling and simulations becomes the inherent part of oil and gas field management. Simulations plays a vital role in supporting strategy and operational decisions at every stage of field development and exploitation [3]. In petroleum industry there are available numerous of advanced computer applications which allow to describe, optimize and manage each segment in upstream and downstream system. To these tools we can include reservoir simulators, wells, pipelines and network simulators, surface process facility simulators and economic applications [1].

Integrated asset modeling (IAM) software enable to couple together different applications within one environment to perform a single production simulation involving all steps in field management from reservoir to the point of sales and economic analysis. Simply saying it provides a complete picture of production system and collaborative platform for the asset team. Due to flexibility of couple any combinations of models it helps to solve a range of complex technical challenges taking into account sensitivity analysis on different elements of the system and possible impact of analyzed elements e.g. choke or tubing size, manifold pressure, compressor parameters, etc.

This paper presents the methodology of integration all upstream/downstream elements and the results of the IAM system implementation with further production forecasts, on the example of selected natural gas reservoirs in the Polish Lowlands, being assets of PGNiG. The main goal of the study was to evaluate the existing development plan and propose possible alternative variants of development, including various compressors location assumptions, the optimization of compressors operating parameters and chokes sizes. This operations leads to enhance ultimate gas recovery factor and revenues from the field with simultaneously limitation of investment expenditures.

2. INTEGRATED MANAGEMENT OF FIELD DEVELOPMENT

The process of development an integrated simulation of hydrocarbon field consists of preparing reliable models of main parts of entire exploitation system utilizing proper software. The key element of any modeling process is data gathering combined with further verification and detailed analysis of collected data. The consecutive steps consist of building reservoir model, modeling inflow fluid from reservoir to the wells and flow of fluid through pipes up to surface process facilities (Fig. 1). Before coupling all models together within IAM platform it is essential to accurately match of all individual models to measured data.

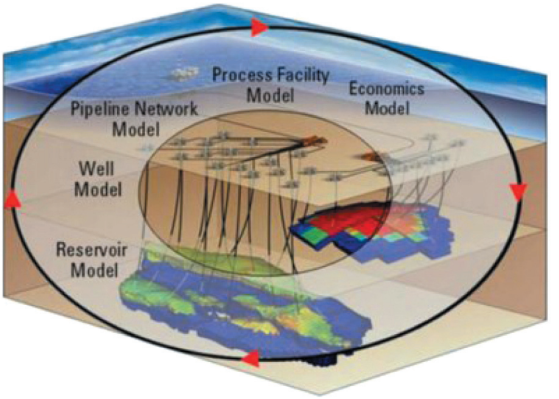

Fig. 1. The full production system coupled in IAM [4]

So far, in the PGNiG S.A. there have been performed three full scale integrated model of natural gas fields. First two projects were related to reservoirs in the Rotliegend formations which are in their final stage of exploitation period, “Field A” and “Field B”. The last one was performed in order to create the optimal field development plan for the carbonate reservoir being in the middle stage of its lifecycle – “Field C”.

Geology and reservoir engineering

The first part of integrated asset modeling is to determine fluid flow from the reservoir to the bottom of the well. At the beginning geologists are preparing three dimensional, spatial, static reservoir model, that consist of stratigraphic and seismic interpretation, lithological facies, and geocellular property distribution of rock porosity, permeability and initial fluid saturation. Subsequently, reservoir engineers are transforming model from the static into dynamic one. There are defined the proper initial conditions as for instance fluid contacts, PVT properties, rock compressibility, capillary pressures and relative permeabilities. Finally, in order to perform valid production forecast, the created dynamic model is calibrated to match real field data, as for example well production rate or reservoir pressure.

The static models for all studied examples were built in PETREL software (Fig. 2) while the numerical simulation (history match and production forecast) was performed using ECLIPSE simulator. Because of homogeneous gas composition as well as computation time, black oil model was considered to be sufficient and used in all simulation models.

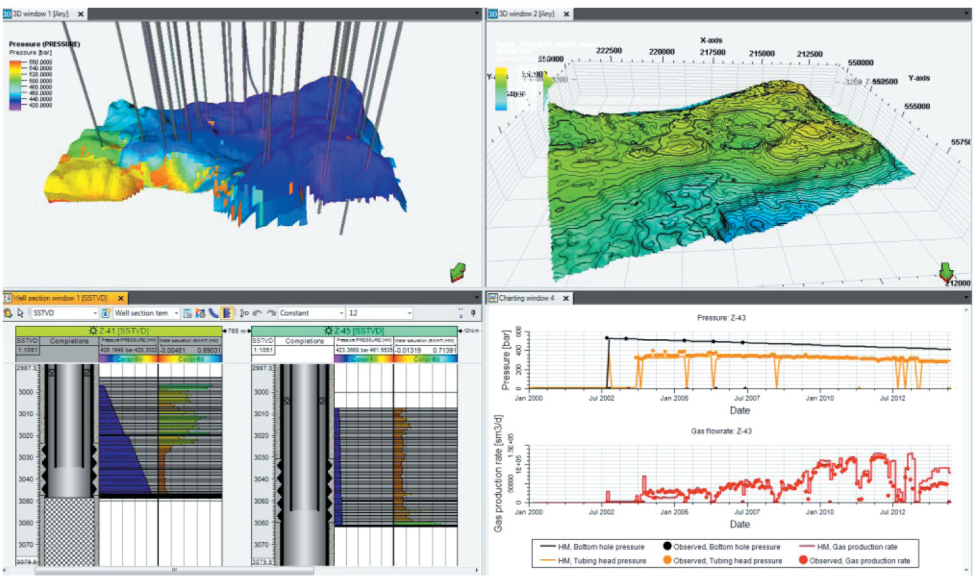

Fig. 2. PETREL software – reservoir model

If there is no sufficient petrophysical and geological data to build reliable static model, it is possible to perform simplified material balance calculation or decline curve analysis and connect it to the further well and pipeline model via IAM platform.

In PGNiG MBAL software is used to perform simple volumetric field cases. In most cases of multiple reservoirs connected to one process facility, the model of the main field is built as a full-scale reservoir simulation using ECLIPSE simulator, whereas the rest smaller reservoirs are connected by MBAL calculation (Fig. 3). It enables to save time, because building simulation model is time consuming as well as later whole system IAM calculations using reservoir simulator involve much more time comparing to analytical approach.

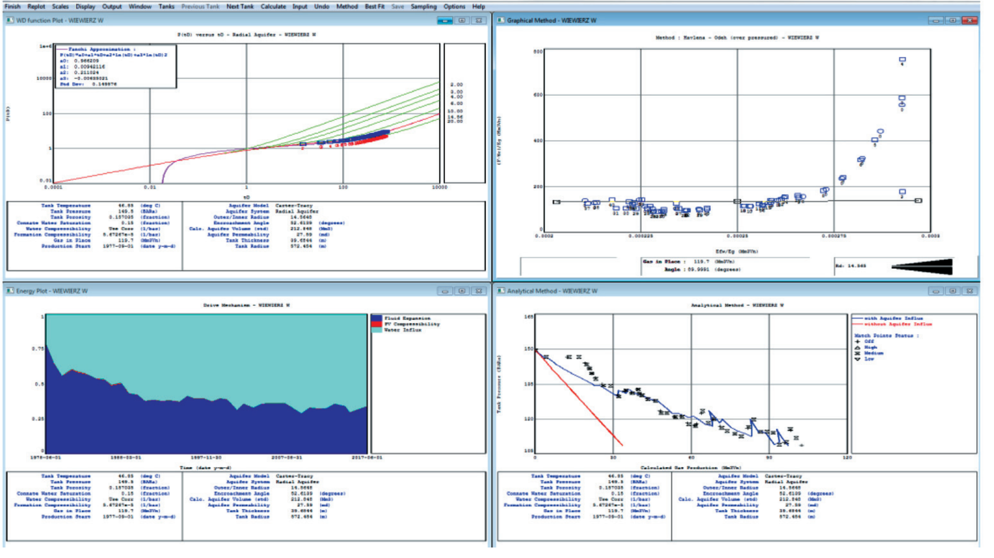

Fig. 3. MBAL software – material balance model calibration

Production engineering

The simulations of flow reservoir fluid are conducted in steady-state multiphase flow simulator called PIPESIM which covers three core areas of flow modeling – multiphase flow, heat transfer, and fluid behavior to well and pipeline integrity [5]. As the steady-state simulator PIPESIM makes possible to create static network model with determined boundary conditions in particular point of time what does not exclude the forecast of future system performance.

First stage of model preparation incorporates the uploading of GIS map (Fig. 4) into project, which allow for localization of all elements of the system with proper geographical coordinates.

The mapping of actual distances and elevations between wells and the rest of equipment has a significant impact of any phenomena occurring during production period as for instance pressure and temperatures changes.

Fig. 4. GIS mapping of the part of gas field

Second stage of model preparation includes the creating of existing well models with relevant tubing, completion data and preliminary choosing of flow correlations. The next stage is connected with the calibration process of well production that consist of adjusting of well parameters such as roughness, thermal conductivity coefficient or well IPR model in order to match well test data (Fig. 5).

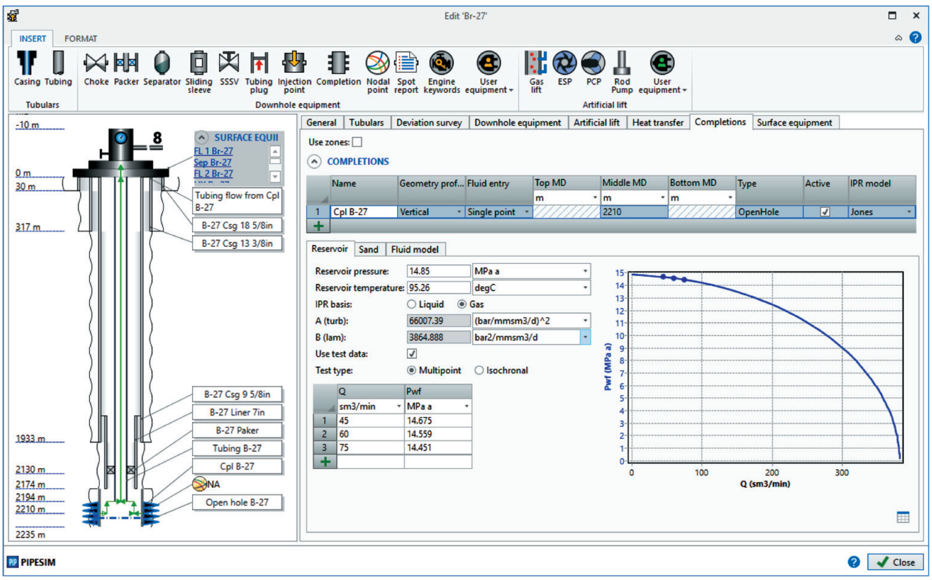

Fig. 5. The construction of the wellbore with base inflow performance parameters

The final step of the creating of PIPESIM model is matching network (Fig. 6) results to the measured parameters such as:

- well production rate, well production ratio (WGR, LGR, water cut, etc.);
- well tubing head pressures, well head temperatures;
- pressures, temperatures and ratios after reduction.

Similarly, to the previous steps the most common calibrations parameters are roughness, thermal conductivity, choke sizes or inside pipe diameter. As the rule of thumb in the PGNiG S.A. the deviation from measured data should not exceed 1%.

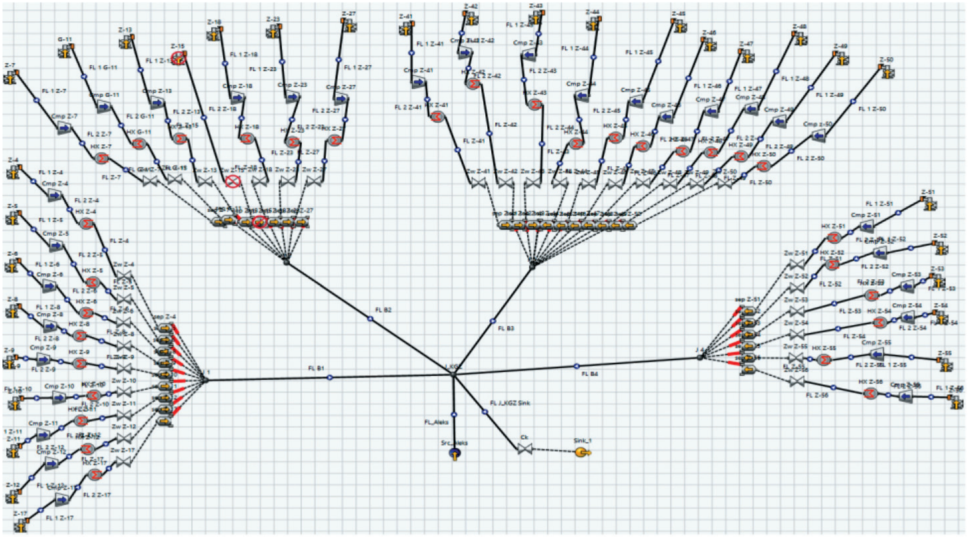

Fig. 6. The schematic PIPESIM network model of gas field with proposed wellsite compressors

Process engineering

The simulation of processing facilities are performed in Aspen HYSYS that is a chemical process simulator integrating unit operations, gathering networks to full chemical plants and refineries. HYSYS is able to perform many of the core calculations of chemical engineering, including those concerned with mass balance, energy balance, vapor-liquid equilibrium, heat transfer, mass transfer, chemical kinetics, fractionation, and pressure drop [6].

Firstly, depending on the complexity of facility and processed fluid all of the particular units with designed parameters have to be mapped into model (Fig. 7).

Subsequently, the inlet conditions and maintained parameters set points for each unit are input (Fig. 8) and the simulation runs in order to check correctness of generated results such as flowrates and compositions of particular streams.

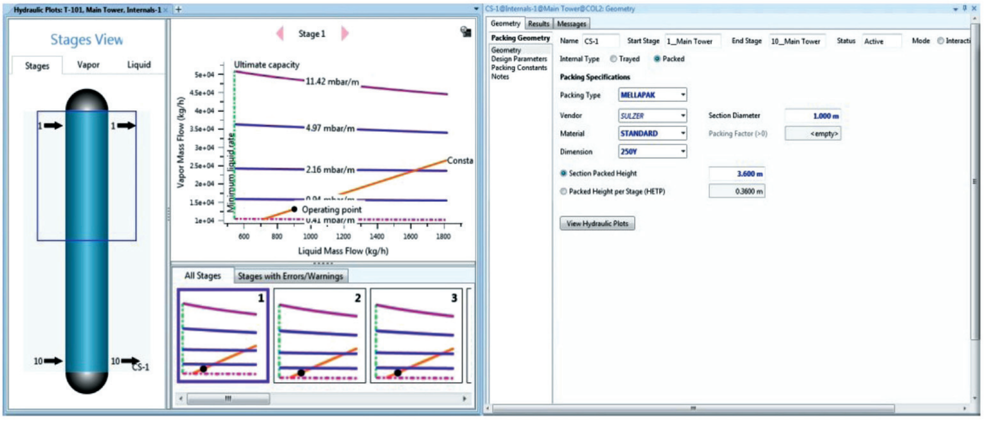

Fig. 7. Separator unit with mapped parameters, HYSYS

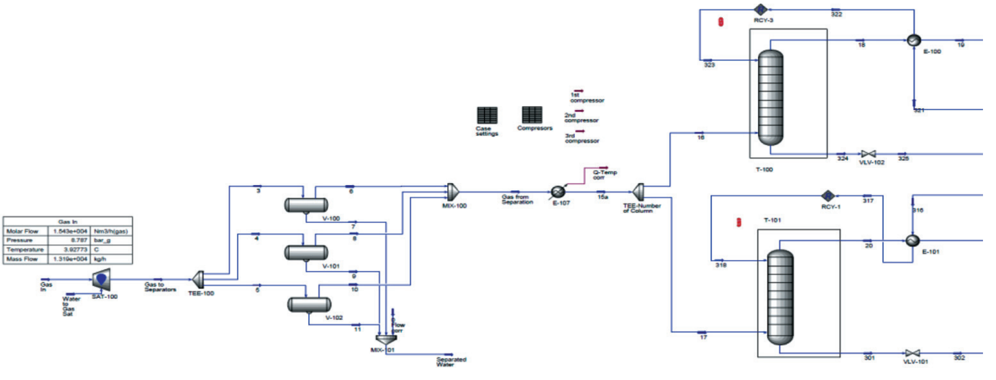

Fig. 8. The scheme of the part of gas process facility, HYSYS

According to Figure 8 the simulator calculates all of equations in cascade way from the inlet, during computation users are able to control any convergence problems. If the planned level of data matching is satisfying, the created process facility system is deployed into integrated model. Currently, the main reasons of utilizing HYSYS in integrated system is to assess the amount and quality of produced sales gas, energy requirement and to properly design gas compressors that allows for increase gas production taking into consideration lower reservoir pressures.

Economic model

The advantage of IAM is integration the whole hydrocarbon production system with the economics evaluation, since all companies' decisions are an integrated process that involves economics, planning, finances and risks management. Uncertainty and risk play a huge role in any decision-making process, therefore uncertainties as for instance floating oil or gas prices, must be taken into account because they have a significant impact on the economics of any project. As a result, it is crucial to understand how technical decisions can impact business goals [7].

Economic models include all capital and operating expenditures (CAPEX, OPEX) for investment, tax system, current and forecasted oil and gas prices, as well as interest rates. Economic model is a key thing for proper assessment and further comparison of different development plans in order to choose the most profitable solution.

During performed study economic model was built in EXCEL (Fig. 9) spreadsheets and coupled with the full production system in IAM platform. Nevertheless, it is also possible to attach to IAM economic model performed in MERAK PEEP – Schlumberger's software.

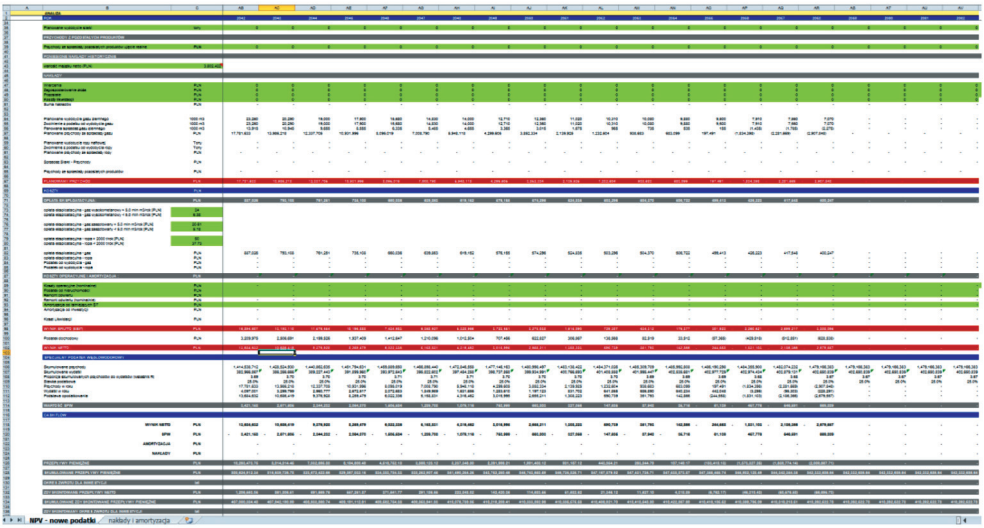

Fig. 9. Economic model, EXCEL

Integrated asset modeling system

IAM is a framework which allows to link together different types of software. The complete IAM model consists of at least one or more reservoir, network, facility and economic models. At the very beginning the process involves data gathering, reviewing historical data, evaluating of existing stand-alone models and checking the consistency of thermodynamics and equations of state. This stage is followed by studying field development operational issues and future planning. Before beginning of creation an integrated asset model, it is crucial to possess a complete understanding of the comprehensive picture of an asset, as well as its constraints, and objectives [7].

The process of creation starts by adding each model into a flow diagram. Then there are created links between different applications by connectors which links variables from one model to those in another one. It is specified which parameters are passed from the source model to the connected model (Fig. 10). As an example, in performed studies below results from ECLIPSE simulator are passed to PIPESIM as an initial parameter of PIPESIM calculations:

WBP9 – average reservoir pressure from 9 grid cells around the well,
WBHP – well bottom hole pressure,
WBHT – well bottom hole temperature,
WPI – well productivity index.

Productivity index determines reservoir potential but PIPESIM simulator calculate if the well and surface network is able to work within specified condition and pressure constraints. Otherwise PIPESIME sends back information to ECLIPSE with acceptable well rate target and simulation is repeated as an iterative process. The same loops are performed for every simulation time step. After reaching convergence between ECLIPSE and PIPESIM the results from PIPESIM are transferred to HYSYS which is responsible for process engineering. HYSYS calculates such parameters as gas dew point, pressures and temperatures at each point of process facility, power of compressors and use of energy, process of gas dewatering, glycol regeneration, gas parameters and composition in sales point, and many others. All above process is coupled with economic model so each interaction within any point of upstream or downstream system has influence and is visible on profitability ratios of the project.

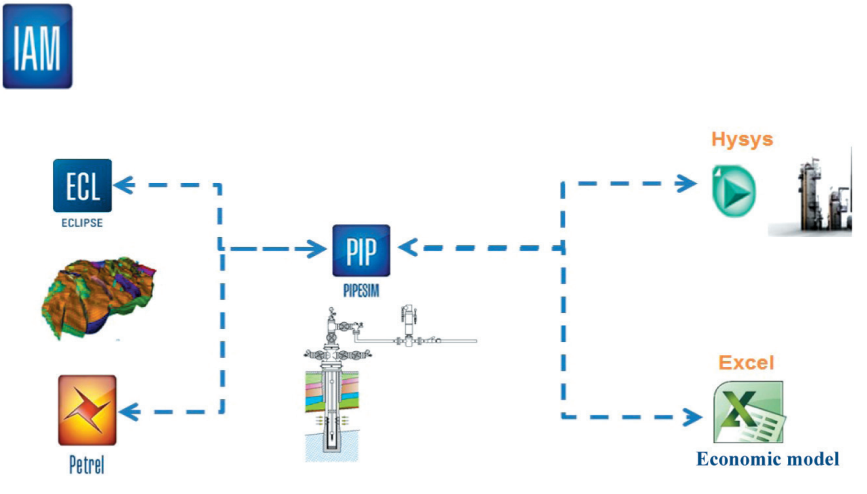

Fig. 10. Schematic software connection on the IAM platform

In analyzed cases in view of very low pressures and gas rates, condensation water plays essential role in well production system. A lot of wells produces below critical water unloading rate which is necessary for continuous lifting of water. This causes incomplete water loading, accumulation of water in the well and suppress tubing head pressure. As a consequence, this phenomenon leads to permanent well stop. To prevent it, foaming agents or plunger lift are supplied so as to ease water loading. Another option is to decrease tubing head pressure and increase gas rate. However, in order to achieve required sales pressures, it is obligatory to ensure appropriate compressors working conditions.

ECLIPSE simulator does not consider condensate water at all. The biggest challenge was to take account of condensate water and link estimated values of water to the whole flowing system. This concept was performed by calculation in EXCEL spreadsheet the amount of condensate water which is changing and increase while depletion of reservoir pressure. Then this volume of water was linked to PIPESIM simulator in the bottom of the well and mixed with gas and water rates passed from ECLIPSE at every time step of simulation. This approach allowed to the detailed investigation of each well and predict time of well inundation for more reliable production forecast.

3. RESULTS

The analysis of investment in expansion of front-end gas compressors – "Field A"

In the case of the "Field A" project, the authors had to analyze the plan of investment into new gas compressors and provide the support towards the optimization of its operating parameters. Performed study yielded the significant improvement in forecasted ultimate field recovery due to lowering the network pressure and extending the exploitation time. According to the (Fig. 11) the production will be increased of over 62% within 17 years.

The analysis of the possibilities of increasing gas production – "Field B"

First stage of the projects was connected with re-analysis of existing seismic interpretation. As a result, there was created new reservoir model which after calibration proved earlier presumptions about natural gas resources. Subsequently, in order to reconsider actual field development plan the comprehensive examination of existing production system was conducted. The obtained results (Fig. 12) depict that the non--investment enhancement in the capacity of existing compressors or investment in additional well compressors will allow to accelerate and boost gas production compared to previous forecasts with simultaneously decline in cumulative water production.

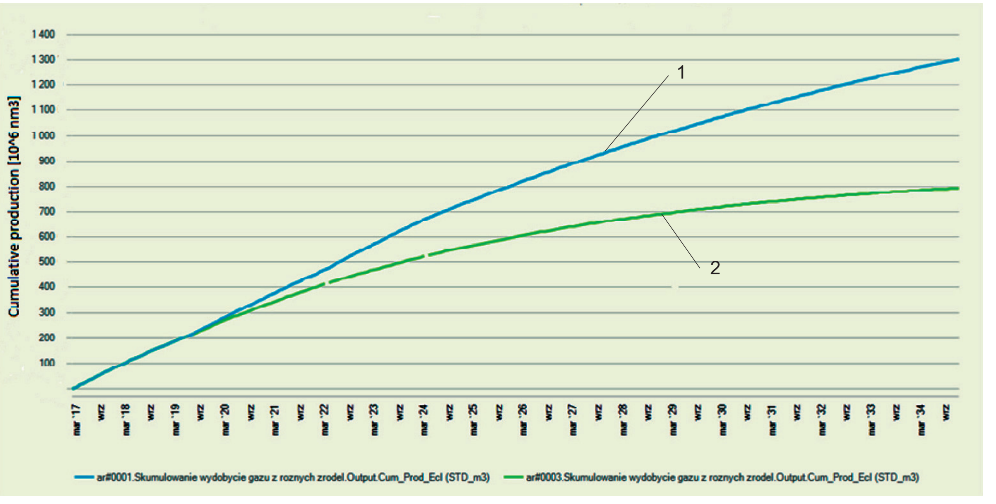

Fig. 11. Cumulative production – the comparison of two production forecast after (1) and before (2) optimization

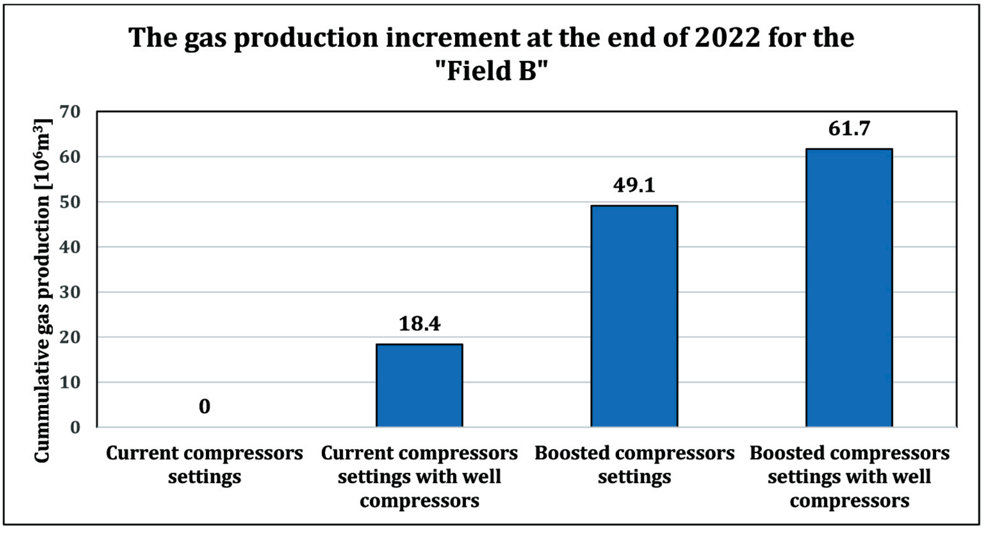

Fig. 12. The results of performed optimization study for "Field B"

The optimization of exploitation process – "Field C"

Taking into consideration the exploitation of "Field C" which consist of two separate reservoirs, the PGNiG company has struggle with the key problem concerning about reservoir pressure decrease. Because of both fields have mutual gas gathering system they work with the same network pressure, thus the pressure declines in the first gas field with simultaneous higher pressure in the second one which will suppress gas production from the first reservoir. Therefore, the main challenge was to properly design the field development plan aiming in lifecycle elongation of suppressed reservoir.

After performing integrated analyze of entire system, it occurred that the best solution is deploying of front-end gas compressor in the field with lower pressure at the beginning of 2023 and in the reservoir with higher pressure in 2024. Moreover, the scenario with using by well compressors was considered as completely inefficient. As can be clearly seen on the (Fig. 13) the proposed proceeding will considerable improve the field performance.

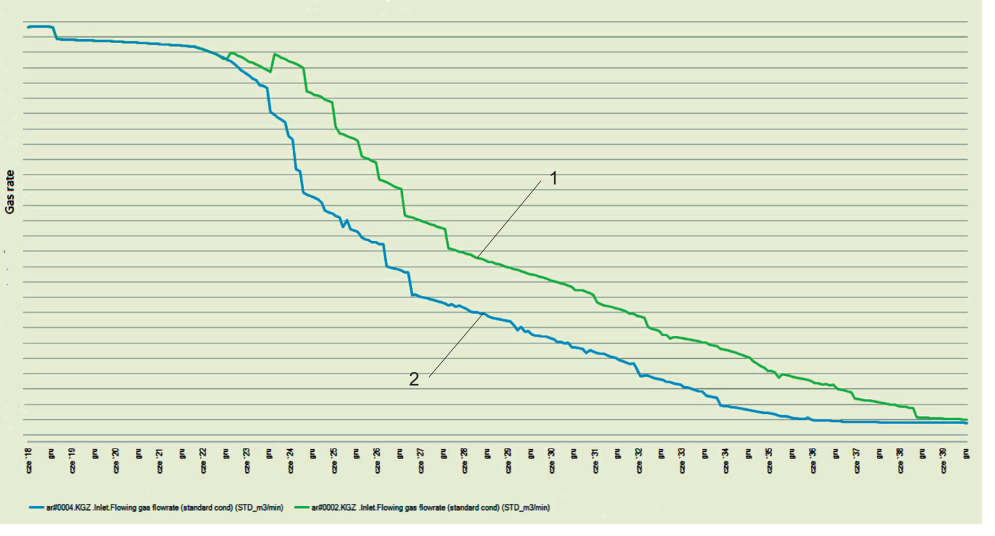

Fig. 13. Gas rate – the comparison of two production forecast after (1) and before (2) optimization

4. CONCLUSIONS

Regarding all of the obtained results it is obvious that implementation of the integrated hydrocarbon reservoir management system into PGNiG S.A. has opened a broaden area of the future optimization of hydrocarbon exploitation. In each project there are involved plenty of engineers who thanks to creating a multidisciplinary team are able to perform very detailed examination of any type field problem and to find the best possible solution. Moreover, continuous self-development of team member as well as gaining experience in using most up-to-date technical software will undoubtedly allow for facing more and more complex problems as for instance LMG or BMB reservoirs.

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IMPLEMENTACJA ZINTEGROWANEGO SYSTEMU ZARZĄDZANIA ZŁOŻEM WĘGLOWODORÓW NA PRZYKŁADZIE EKSPLOATOWANYCH ZŁÓŻ GAZU ZIEMNEGO NA NIŻU POLSKIM

Streszczenie: Obecnie, ze względu na to, że zarówno szanse na odkrycie nowych złóż węglowodorów o znaczących zasobach są coraz mniejsze, jak i postęp technologiczny jest znaczący, kluczowym elementem staje się właściwa strategia zarządzania pracą złoża wraz z jednoczesną optymalizacją parametrów jego produkcji, w celu opracowania najkorzystniejszego ekonomicznie wariantu zagospodarowania złoża i pracy kopalni. W Polskim Górnictwie Naftowym i Gazownictwie S.A. zainicjowano projekt „Cyfrowe złoża" oparty na interaktywnej platformie IAM, dzięki której zintegrowana została praca wszystkich segmentów wydobywczych, począwszy od geofizyki, geologii, inżynierii złożowej, produkcji oraz inżynierii procesowej, a kończąc na modelu ekonomicznym, pozwalającym na weryfikację efektywności ekonomicznej inwestycji. W artykule zaprezentowana została metodyka integracji powyższych elementów oraz wyniki implementacji systemu IAM wraz z prognozami produkcji, na przykładzie wybranych złóż gazu ziemnego na Niżu Polskim, których operatorem jest firma PGNiG S.A.

Słowa kluczowe: integracja danych, optymalizacja, zarządzanie złożem, prognozy produkcji, efektywność ekonomiczna