Petro Myhailovych Smikh

LLC Research and production company «Centre of Oil and Gas Resources», Kyiv, Ukraine

Pseudo-optimization of well placement using a single simulation schema

Optimal well placement is an extremely challenging task of reservoir development, as it is focused on the implementation of a field development system, which provides the highest technical and economic indexes and takes into account all the available range of geological and technological factors often correlating in a nonlinear way. A possible solution of this problem is the application of reservoir models and hydrodynamic simulator, which allow consideration of a variety of well layouts and determination of the main figures of field performance that is further utilized for feasibility analysis and development planning. Finding the solution to this optimization problem requires a large number of simulations. In most cases a procedure for determining the whole range of the objective function values is very time-consuming and sometimes technically unattainable. Recently, a number of optimization algorithms such as genetic algorithm, simulated annealing, stochastic approximation and their modifications were presented to overcome this difficulty by reducing the number of simulations. This paper presents a novel approach which is based on a Single Simulation Schema (using the only single simulation) and analytical model that incorporates technological, economic and information criteria, and which is further referred to as 3S optimization. The rational variants (as optimal ones are impossible to estimate for real field conditions) of well placement are generated as a result of a single simulator run which dramatically reduces computation time and makes a reservoir engineer's daily job easier.

Pseudo-optymalizacja lokalizacji odwiertów z wykorzystaniem pojedynczych symulacji

Optymalne rozmieszczenie otworów wiertniczych jest zagadnieniem złożonym, ponieważ oznacza realizację takiego systemu rozwiercania złoża, który powinien zapewnić najlepsze efekty techniczne i ekonomiczne, biorąc pod uwagę cały kompleks czynników geologicznych i technologicznych, często nieliniowo zależnych. Jednym z możliwych rozwiązań tego zadania jest wykorzystanie geologicznych i technologicznych modeli złóż oraz symulatorów hydrodynamicznych, pozwalających przeanalizować różne schematy rozmieszczenia otworów wiertniczych i wyznaczać główne parametry rozwiercenia złoża, które później wykorzystuje się dla analizy technicznej i ekonomicznej oraz projektowania udostępnienia złoża. Rozwiązanie tego zadania optymalizacyjnego wymaga dużej liczby symulacji. W większości przypadków wyznaczenie całego zakresu wartości funkcji docelowej jest niezwykle pracochłonne, a czasami realizacja tego jest technicznie niemożliwa. Niedawno szereg optymalizacyjnych algorytmów, takich jak algorytm genetyczny, symulowane wyżarzanie, aproksymacja stochastyczna i różne jej modyfikacje, były zastosowane dla rozwiązania tego zadania tak, aby obejść istniejące trudności przy pomocy mniejszej liczby przebiegów symulatora. W tym artykule przedstawiono nowe podejście, które jest oparte na schemacie z jedną symulacją i analitycznym modelem, zawierającym kryteria technologiczne, ekonomiczne i informacyjne (nazwane optymalizacją 3S). W wyniku pojedynczego przebiegu symulatora możemy obliczyć racjonalne warianty (optymalne są praktycznie niemożliwie do oceny w przypadku realnego złoża) rozmieszczenia otworów wiertniczych, co znacznie skraca czas analizy i ułatwi codzienną pracę inżyniera złożowego.

Article

The solution of the well optimization problem should allow reservoir engineer to place wells in a way to ensure the most efficient field development during a specified period under certain economic conditions.

Analysis of well optimization techniques showed that currently two main research directions are supported. The first one includes methods that use detailed reservoir models and a hydrodynamic simulator and where the running of the simulator is considered as the most time-consuming phase. Larger part of the research aims to improve the efficiency of search algorithms which generate the well layout by reducing the number of simulator runs. Another approach, though inseparable with the above, is scaling and continuous growth of computing capabilities.

For most of these algorithms adequate initial well layout is required. If we consider, as an additional element, estimation of optimal well number, these techniques can only offer an iterative run for every well number.

The second direction combines methods that do not use hydrodynamic modeling and which are based on simplified approaches with approximation techniques. For the majority of them optimal well layout is estimated prior to the stage of hydrodynamic simulation. The decision is made by analyzing a set of reservoir parameters often with the introduction of additional qualitative parameters. One important feature of these methods is the approach in which authors seek for a "rational" and not an "optimal" solution to the problem.

3S optimization technique includes the advantages of each of the described directions. It uses hydrodynamic modeling to justify optimal zones for well targets and an approximation scheme to estimate cumulative well production. Altogether, it provides a useful and flexible tool for well placement optimization.

The objective of the optimization problem is to determine the field development system (and respective well layout) with criteria close to optimal. The main criteria considered are the technological, economic and information parameters.

3S optimization includes evaluation of the economic attractiveness of field development project which is based on the conventional model of net present value (NPV) [1].

An important element of designed well layout is the assessment of its contribution in future refinement of the reservoir model. Currently this problem is unformulated and assessment of well layout is mainly conducted at the level of expertise.

To solve this problem common approaches from information theory and geostatistics are considered. To evaluate the information component of well layout the author introduces an information confidence factor of reservoir model.

Let the information confidence C_i for each grid cell ranges from 0 to 1, and new well increases the confidence in some effective radius R_e around the well. A model is considered in which the amount of information received from the new well decreases by some relation with distance from the well. Expression of this relationship is elaborated on the basis of the Kriging interpolation and exponential variogram model.

Since the information that appears with each new well is an independent variable, then the information confidence factor C_i for each grid cell is an additive characteristic, which can be determined as follows:

$$C_i = \sum_{j=1}^{n} \left(1 - \sqrt{\begin{matrix} 1 - e\dfrac{3h_{ij}}{R_e}, & h_{ij} < R_e \\ 0, & h_{ij} \geq R_e \end{matrix}} \right), \qquad \max_i C_i = 1 \quad (1)$$

where h_{ij} – distance between the i cell and cell with j well; R_e – effective radius around the well.

An integral information confidence factor C_{avr} that characterizes the whole reservoir model is estimated as an average for all grid cells:

$$C_{avr} = \frac{1}{N_{cell}} \sum_{i=1}^{N_{cell}} C_i \qquad (2)$$

Maximization of this parameter leads to an increase of information which can be received from the realization of specific well layout thus improving the efficiency of the field development system.

Taking the well layout $L(x,n)$ as the main control, the problem of field development optimization is formulated as follows:

$$\begin{aligned} &\max_{x,n}\{NPV(x,n,T), C_{avr}(x,n)\} \rightarrow L(x,n), \{x,n\} \in D; \\ &D = \{x \in M, n = \overline{1, N_{cell}}\}; \\ &q(x,n,t) \geq q_0(t),\ \beta(x,n,T) \geq \beta_0,\ NPV(x,n,T) > 0 \end{aligned} \qquad (3)$$

where M – set of grid cells; N_{cell} – total number of grid cells; $q_0(t)$ – given oil (gas, condensate) production profile; β_0 – given hydrocarbon recovery (lower margin); T – development period; x – grid cell's coordinates; n – well number.

The formulated problem (3) aims to maximize two parameters – NPV and average information confidence C_{avr} – which cannot be reduced to one basis. Therefore, a final decision is made on the basis of expert analysis, though methods of multiobjective optimization may be utilized.

The sequence of calculations in 3S optimization technique is as follows.

The first stage includes building of geological and hydrodynamic models of a studied object according to well-known rules.

The second stage is the design of an input well layout. This initial well configuration is constructed using a rectangular grid pattern and takes into account the acceptable minimum (3-5 grid blocks) for inter-well spacing along the major axis (Fig. 1, left), which should meet adequate discretization conditions of reservoir grid. At the same time all wells of input layout are set up to work with equal technological constraints to ensure equal production opportunities.

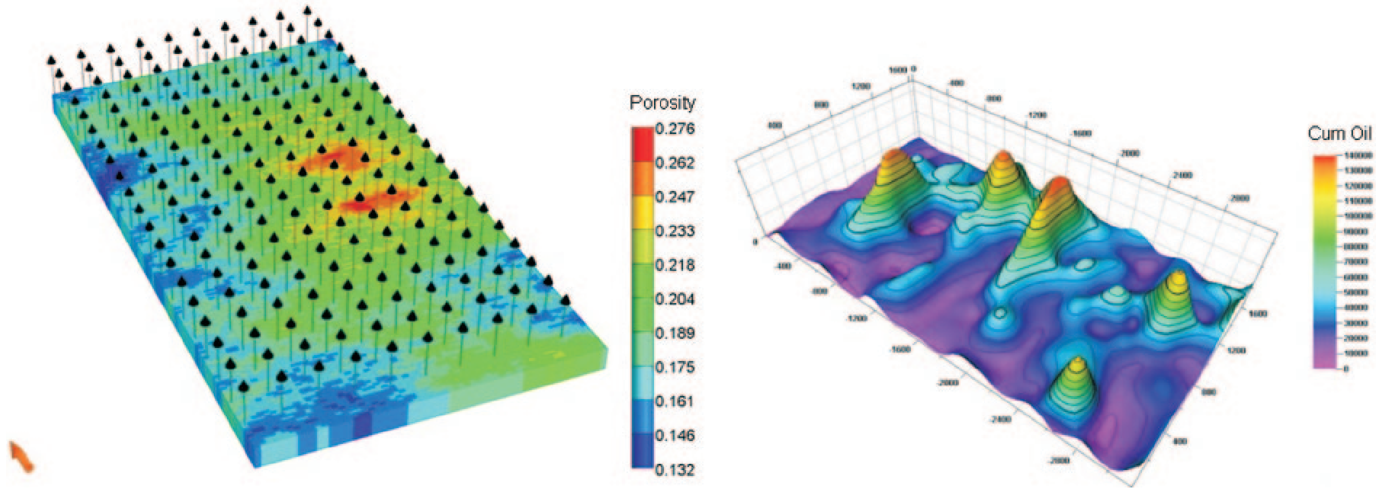

Fig. 1. Input well layout (left) and cumulative oil surface (right)

Thus, after one run of the hydrodynamic simulator, main production profiles are generated for each well from input layout and the surface of cumulative oil (gas) production is constructed on their basis (Fig. 1, right).

Analysis of available techniques showed that for schemes that do not use hydrodynamic modeling the choice of well layout is based on reservoir parameters such as permeability, porosity, effective thickness, HC saturation, reservoir pressure and other quality indexes, which are a combination of the above ones. Weaknesses of such approaches are the impossibility to assess the interaction of static reservoir characteristics in dynamic of field development.

Consequences arising from the superposition principle show that cumulative productions for wells placed according to the input layout will be a critical parameters of reservoir performance, as they will be affected by neighboring reservoir zones, faults, fluid contacts etc. Therefore, we propose to use cumulative production surface generated from input well layout (Fig. 1, right) as a first-priority key for targeting the design wells.

The third stage is the sequential placement of the design wells in the reservoir model. To justify the selection of well target zones and evaluation of their cumulative production, an appropriate mathematical model was developed, which assumes that to recover initial volumes (Z_0) with the minimum well number it is necessary to sort all possible well locations (from input layout) in descending order of cumulative production and select first n wells that meet the criteria of optimization problem (3). Thus, the design wells are sequentially placed in max points (sorted in descending order) of the cumulative production surface and cumulative production is estimated for each well using decline analysis (other analytical techniques also can be used) as follows:

$$
\begin{aligned}
&Z_0 \geq Z = \sum_{i=1}^{n} Q_i\left(X_i, \lambda_i, T_i\right) \\
&Z_0 \geq Z = \frac{1-\exp\left(-\lambda_m T_{\max}\right)}{\lambda_m} \sum_{i=1}^{n} q_{0i}\left(X_i, 0\right), \quad T_i = 0
\end{aligned}
\tag{4}
$$

where Q_i – cumulative well production; q_{0i} – initial well production rate; X_i – well coordinates; T_i – start of well operation; $T_{\max}$ – period of field development; λ_i – coefficient of monthly (annual) production rate change.

After that a circle shape drainage area is calculated for each well on the basis of forecasted cumulative production (Q_i) and initial oil (gas) in place, and grid cells intersected by well's drainage area are associated with each well [3]. Design wells are placed in such a manner that their drainage zones intersect minimally. In case of their intersection an overlap value (δ) is estimated as a percentage of the radius of

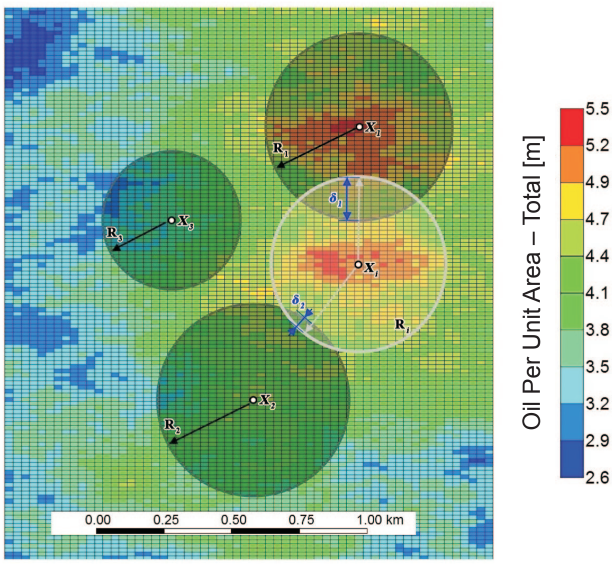

Fig. 2. Estimation of drainage area and overlap value

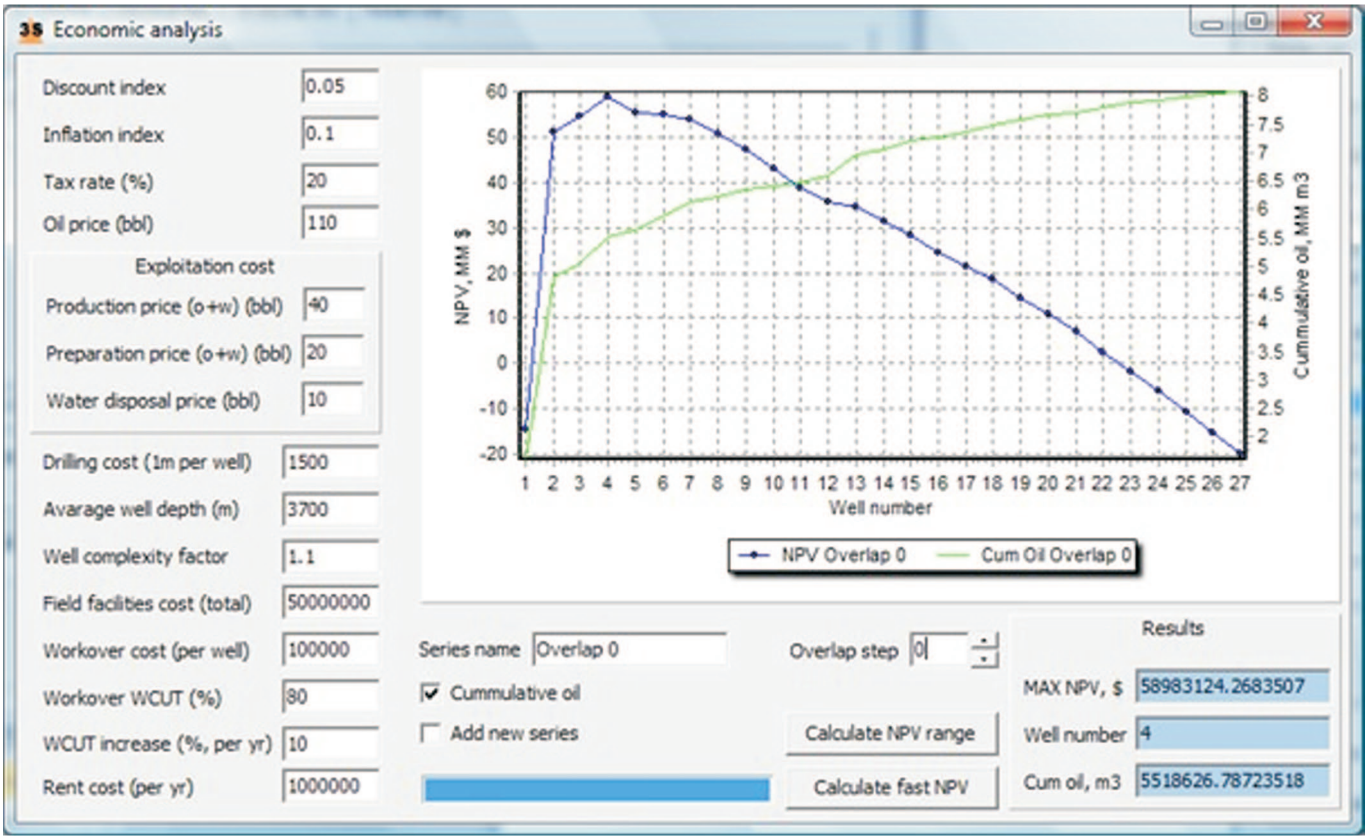

Fig. 3. NPV vs. well number for model A at $\delta_{max} = 0$ generated by 3S optimization technique

the well's drainage area (Fig. 2). Accordingly, setting up the maximum overlap value (δ_{max}) allows generating a rational set of well layouts with all other constraints being equal.

The rational well number for each layout is determined using a simple NPV model [1]. For each set of pre-placed design wells NPV value is calculated and placed on a graph (NPV vs. well number), where the region of max NPV (Fig. 3) becomes a basis for selecting a rational well number for field development.

Testing of 3S optimization technique was performed on a SPE model presented in a project «The 2001 SPE Comparative Solution Project» [2]. Two data sets which differ in petrophysical properties were used for testing. 35 layers of Tarbert formation were used for model A and 50 layers of Ness formation were used for model B.

According to the formulated procedure, the initial well layout is designed for model A and one simulation performed to build cumulative production surface and to estimate well production decline. Then, design wells are consequently placed, their cumulative oil production are forecasted using (4), drainage areas are then estimated. Finally, applying respective economic model (see Fig. 3) and by changing maximum overlap δ_{max} constraint in range 0÷100% with 10% increment a set of well layouts is generated for model A, which includes 3 different layouts (Fig. 4).

On the basis of comparative analysis of the main criteria a rational well layout, which uses 7 production wells (overlap 90÷100%), is proposed. It results in the highest net present value of 61.2 million USD and cumulative oil production of 6.592 million m^3 (simulation result – 6.093 million m^3). This scheme also allows to maximize the average information confidence factor at 31%.

Model A was used to compare the 3S technique with an iterative scheme, which required 725 runs of the simulator to estimate "optimal" well layout for 7 production wells. As it is very difficult to implement exhaustive iterative procedure (≈ 2,2 trillion simulations are required) an incremental scheme was organized as follows: 1) optimal placement (based on maximization of cumulative oil production) for the first well was determined and this well was fixed for the next runs; 2) optimal placement for the second well was determined while the first one was fixed and producing; 3) step 2 was iterated until 7 production wells were "optimally" placed. As a result, cumulative oil production for such well layout is 6.065 million m^3 (NPV expected to be the same as for the 3S procedure), average information confidence factor – 31.2%. Comparison shows that 3S optimization does not yield an iterative scheme at major figures, moreover, from the field development perspective, 3S technique results in more uniform HC recovery due to the lack of closely spaced wells, as was observed in the case of the iterative procedure.

A sensitivity test of 3S techniques on model A was conducted for porosity and permeability distributions. A series of

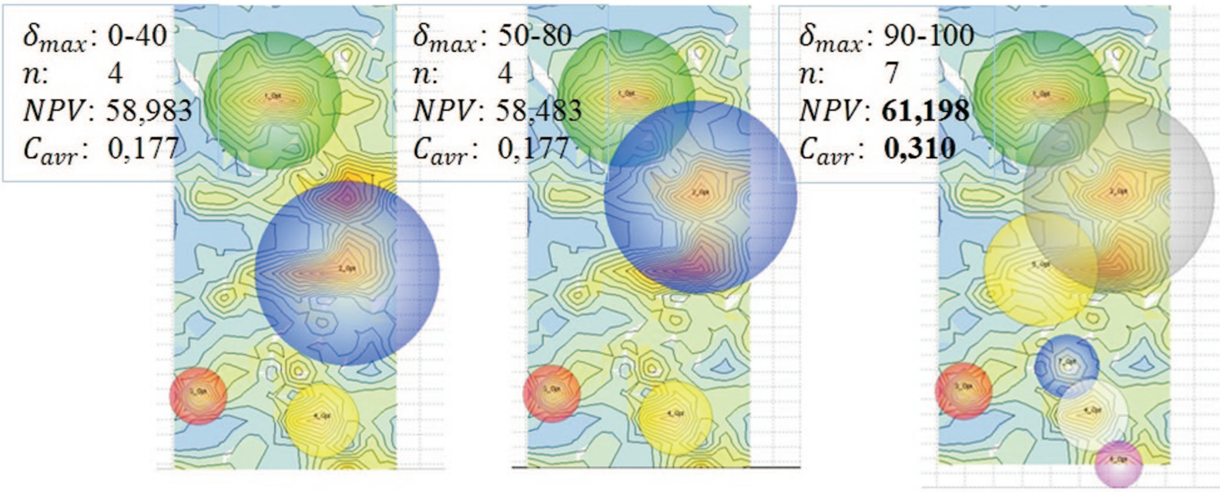

Fig. 4. Variants of well layout and values of the main criteria for model A generated by 3S optimization technique

δ_{max} – maximum overlap value [%]; n – well number; NPV – net present value [million USD]; C_{avr} – average information confidence factor

experiments were performed to model possible systematic and random errors in values of porosity and permeability, which resulted in the introduction of specified amount (10÷50%) of randomness. The simulation results showed that random errors in the distribution of porosity and permeability at 10% level virtually does not affect the results, and even at a 30% error level provides a satisfactory coincidence of well layouts. Nevertheless application of the 3S technique requires special attention at high-permeability zones of reservoir model.

3S optimization technique was practically used for HG field (situated Western Desert, Egypt) development planning. In order to design a rational well layout for one of the most prospective development object, all necessary stages of reservoir modeling were performed, an economic model was proposed and 3S optimization was run in the same sequence as it was shown for model A. As a result, 9 options of well layout were generated for overlap range δ_{max} = 0÷100% and the main criteria were evaluated (Fig. 5).

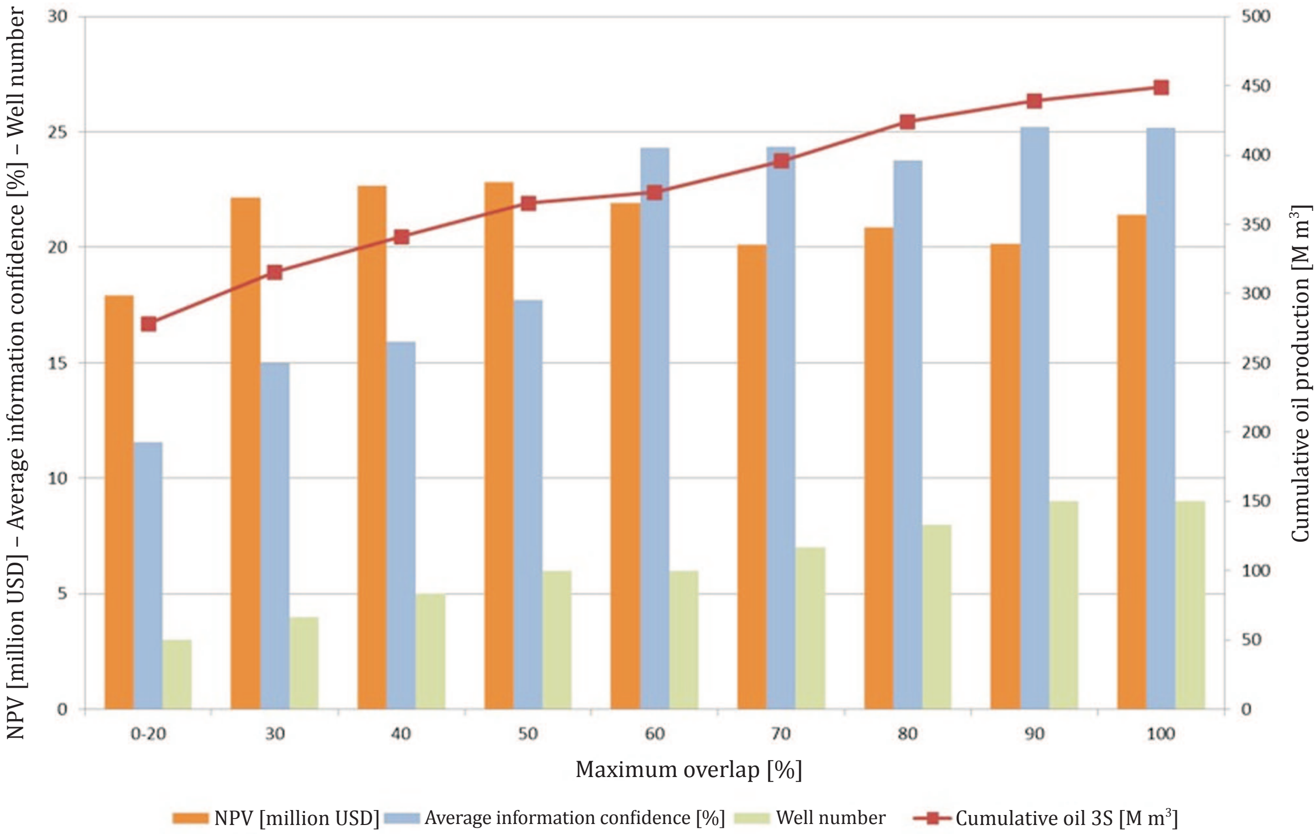

Fig. 5. Comparison of 3S optimization criteria for main development object of HG field

Two principle conclusions may be reached from the analysis of the above criteria (Fig. 5). From an economic point of view, the most efficient well layout is obtained with 50% overlap which uses 6 production wells. During a development period of 25 years it can achieve maximum NPV at 22.8 million USD and cumulative oil production of 365.2 thousand m^3. The average information confidence is 17,7%.

From a developmental point of view, and considering the fact that wells, which are designed for this development object can be further used to develop overlying objects, an option with 9 production wells which is obtained for 100% overlap is proposed as the rational one. NPV reaches 21.4 million USD (1.4 million USD less than for the above variant) and cumulative oil production is 448.8 thousand m^3. The average information confidence is maximum – 25.2% (7.5% higher than for the above variant).

Conclusions. 3S optimization technique combines modern approaches to reservoir modeling, incorporates technological, economic and information criteria and fast non-iterative optimization algorithm which allows reservoir engeneer to determine rational well number and well layout using a single run of the simulator.

Testing of the 3S optimization technique on SPE models showed its stability for different ranges of input data. Its application for HG field development planning allowed to justify basic variants of well layout and to estimate the main field's performance data. The results were used as a basis for expert analysis and subsequent design phases.

References

[1] Smikh P. M.: *Assessment of well number for rational field development on a basis of 3S optimization and economic analysis*. „Oil and gas industry", Kiev 2012, no. 6, p. 26–29.

[2] SPE official website. The 2001 SPE Comparative Solution Project. http://www.spe.org/web/csp/

[3] Zarubin Y. O., Smikh P. M.: *A new method of well placement optimization using 3D modeling – 3S optimization*. Potential of fossil fuel extraction in Belarus and forecast of its realization in the first half of XXI century. International scientific-practical conference. Gomel: RUE PA "Belorusneft", 2012, p. 757–765.

Petro Myhailovych SMIKH – Master's degree in petroleum engineering from Ivano-Frankivsk National Technical University of Oil and Gas (2005). Head of department development and production at LLC RPC "CORG". Author and co-author of 20 articles, 2 patents and 3 PC programs. Interests: reservoir modeling, optimization of field development and programming.