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COLLECTOR PROPERTIES – TECHNOLOGICAL AND ECONOMICAL ASPECTS OF INTRODUCTION OF NEW TECHNOLOGIES

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Practical aspects of applying modern technologies of oil mining have been considered taking into consideration collector properties. Methods of designing radically new facies-sedimentation models in effective reservoirs from the viewpoint of collector facies heterogeneity and use of individual development systems within the isolated heterogeneity zones were laid as a basis of increasing efficiency of carbohydrates pool development.

Actuality

Modern methods of designing and management of oil deposits development are based on computer modeling with construction of three-dimensional seismic, geological and hydrodynamical models of reservoirs. Modeling methods of hydrocarbon deposits development demands increased requirements to construction of productive reservoir geological models. In particular, in a model all diversity of collector filtration-capacitor heterogeneity should be considered. The latter actualizes perfection of approaches to researches of reservoir heterogeneity properties, caused by lithologic features of the layer. The structure of the collector predetermines motion dynamics in it of a liquid phase. Construction of geological models of oil pools, in a view of reservoir structure, can essentially raise efficiency and adequacy of reservoir computer modeling to resolve practical problems.

Creation of modeling techniques of filtration processes in reservoirs, in view of heterogeneous collector properties demands procedures of formalized description of reservoir heterogeneity. Research of collector properties has been carried out by many authors through constructions of dependences between various parameters of collectors. In particular, reflection of porosity and permeability parameters at description of filtration-capacitor properties (FCP) of granular collector is considered in view of the stream hydraulic units concept (collector). Methodical approaches to distribution of terrigeneous collectors in view of their heterogeneity by types of stream hydraulic units are considered with participation of authors in works [1, 2].

Technological and economical aspects of reservoir developments with heterogenous collectors

The technique of deposit geological model construction on the basis of division of collectors on types of stream hydraulic units offered in the work allows performing updating of the deposit hydrodynamical model in view of permeability change in the process of magnitude specification of modeling cell collector type at constant magnitude of porosity. At the same time, it is possible to calculate more effective variant of deposit development without changing the magnitude of balance stocks in hydrocarbon deposits, at new magnitudes of permeability and hydrodynamical parameters.

Methodical approaches formulated in mentioned works allow switching from discussions on qualitative distinctions of collector properties to quantitative estimations of properties of the latter, and through them to come to construction of dependences of collector filtration-capacitor properties. The account of property diversity in collectors and their heterogeneity, allows applying the address technologies optimizing extraction at construction of deposit geological models. The quantitative description of collectors allows forming criteria of more effective technologies application.

An oil company in the initial stage of time t=0, on initial geological stocks $Q^{d=1}_{\text{geol}}$, (d=1,...,D, index of stock recalculation variants), at specified vector of parameters Ω, characterizing a layer: ϕ is the porosity, k is the permeability, p is the pressure, ρ is the density, μ is the viscosity, etc., makes extraction levels in a deposit $q_t \geq 0$ for a period $1 \leq t \leq T$, formally this period continues up to approval of new stocks in a deposit.

Let's establish two assumptions. *First*, we believe that heterogeneity of collectors is the fact. Many works are devoted to a question of heterogeneous collectors development. *Secondly*, we shall distinguish conditions of an oil deposit model essentially and insignificantly differing in stocks. A group of conditions of deposit geological model with insignificant distinctions in stocks (limit of deviations is no more than established by normative documents) we shall define as multiple model conditions with identical stocks. The second assumption allows generating the algorithm of optimization of deposit stock development due to optimization of reservoir management in process of collector properties specification and application of corresponding address technologies.

The total volume of extraction is limited by magnitude of approved extracted stocks $Q^d_{\text{extr.}}=k_{\text{kin}}(Q^d_{\text{geol}})$; ($d$=1,...,$D$), k_{kin} is the coefficient of oil extraction.

Statement: there is an ordered set (sequence) of conditions in a deposit geological model $Z^d=\{Z^d_1...Z^d_s...Z^d_S\}$ with identical stocks on the d^{th} variant of stock recalculation, for which levels of extraction in wells and as a whole in a deposit will differ. It follows from Darcy's formula [3]:

$$q^w(s) = \frac{k(s_w)h(p_{res} - p_{bh})}{18{,}41 B_0 \mu \left(\ln \frac{r_e}{r_w} - 3/4 + \Theta \right)} \qquad (2)$$

and conclusions formulated in the work [2], about an opportunity to conduct updating of deposit hydrodynamical model in view of permeability change in process of collector type specification of modeling cell at constant magnitude of porosity. In the formula (2): $q^w(s)$ are the debit wells w; $k(s_w)$ is the collector permeability along the stem of the well (parameter of geological model described as condition Z^d_{s1}); p_{res} is the rock pressure; p_{bh} is the bottom-hole pressure; B_0 is the oil volumetric coefficient; mis liquid viscosity; r_e is the radius of recharge external contour; r_w is the well radius; Q is the skin-factor; $w=1,...,N_w$ is the indexation of wells. For two conditions Z^d_{s1} and Z^d_{s2} at least one cell is available where at a constant magnitude of porosity (ϕ=const), the type of collector and parameter of collector hydraulic unit indicator are corrected (parameter *FZI*) and then $FZI(\phi,k_{s1})$ $FZI(\phi,k_{s2})$. Where *FZI* is parameter of collector hydraulic unit indicator characterizing the structure of pore space and calculated by values of porosity and permeability [2].

The expression (2) reflects extraction in separate well. Investors are interested in the deposit. In that case, levels of extraction by itself are solution to the problem described by expression [4]:

$$\vec{q}_{место} = \sum_{w=1}^{Nw}\sum_{i=1}^{Ncompl\,j} T_{compl\,j}(p_i - p_{bh,w} - H_{w,i})\sum_{\alpha=1}^{3} M^r_{\alpha,i}, \quad (3)$$

where $T_{compl,i}$ is conductivity parameter of the i^{th} net cell opened by the w^{th} well allowing to pass from pressure in a cell to bottom-hole pressure in a well. $P_{bh,w}$ is the bottom-hole of the w^{th} well, $M^r_{\alpha,i}$ is the mobility of r component in phase α of cell i. $H_{w,i}$ is the coefficient which takes into account structure of filtering fluid in a well and allows recalculating bottom-hole pressure to different altitude marks.

As criterion of constructed geological model efficiency estimation (search for condition Z^d_s, giving the optimum solution) for a current variant of the approved stocks we use the so-called discounted accumulated oil production [4] which corresponds to discounted cash stream, at the assumption of stable oil price z_t=const). Maximization of discounted production V^d_{prod} for approved geological stocks Q^d_{geol}, we shall express as follows

$$V^d_{доб} = \max_s\{\sum_{t=1}^{T}\frac{q^1_t}{(1+\Delta)^t},....,\sum_{t=1}^{T}\frac{q^s_t}{(1+\Delta)^t},....,\sum_{t=1}^{T}\frac{q^S_t}{(1+\Delta)^t}\}, \quad (4)$$

where Δ is discount rate, q_t are levels of extraction in deposit, during t, under conditions:

$$\sum_{t=1}^{T} q^s_t \le Q^d_{извл}, s = 1,..., S; \quad (5)$$

$$q_t \le K, t = 1,..., T, \quad (6)$$

where K is the limited level of extraction on the deposit in a single period by which levels of extraction (day, month, year) are considered. Magnitude K is limited by many parameters of the deposit such as: quantity of wells on 1 hectare, productivity of pumps, pipelines, oil intake by the pipeline system, market, etc.

As much as possible, it is the magnitude of deposit potential opportunities, or the summarized potential of each well,

$$K \le \max_t \sum_{w=1}^{Nw} q^w_{\text{pot},t}, \;\; t=1,...,T,$$

where $q^w_{\text{pot},t}$ are the potential levels of extraction. We shall additionally designate: $q^w_{\text{fact},t}$ is actual (design) levels of extraction in a well w; then

$$H = \sum_{t=1}^{T} h(t) = \sum_{w=1}^{Nw}(q^w_{\text{pot},t} - q^w_{\text{fact},t})$$

is theoretically postponed extraction.

Computer analysis of extraction potential levels by physical properties of the layer and actual (design) debits in separate wells and in the deposit as a whole, defines a subject for in-depth studies of liquid movement in the layer, formation of completeness and a correctness of the data considering heterogeneity of the collector. Use of numerical methods to solve the equations of liquid and gas motion in porous environment, mostly on this basis the applied bandages of hydrodynamical modeling Eclipse and others are created, sets the problem of creation even more authentic geological models of deposits in view of heterogeneities of the collector.

All over the world significant resources on well minimization η are directed by oil and service companies, efforts on new technology introduction are aimed at it. The iterative solution of the problem (4) will minimize the postponed extraction. In reality this magnitude defines a limit of technology use.

The formulated approach describes oil recovery (stock development) in such a manner that for each condition of deposit geological model – Z_1^d ...Z_s^d... Z_S^d – solution of the problem (3) is defined. In intervals $t=1,...,T$ extraction in view of restrictions (4, 5) is reached. Solution of the problem for each condition is carried out with application of standard bandages (for example, Eclipse). Optimization of searches is carried out by optimization of geological model in view of formation methodology of hydraulic stream units. The approach allows limiting solution (3) on limited conditions of geological model from the set of model conditions with identical stocks.

Efficiency of stock extraction is connected with costs. Introduction of costs into the model has practical value for introduction of new technologies. Costs in dynamics are not constant. It is better to describe them by function from vector of parameters [5]. Costs:

- usually increase during growth of accumulated extraction. We shall designate the level of accumulated extraction as parameter Q_t^d ($Q_t^d \le Q^d_{\text{extr.}}$);
- are connected to levels of oil production in the deposit. Levels of extraction are reflected by the parameter q_t.

Costs in dynamics are theoretically described in the form of the empirical dependence totality of extraction costs from volume. Then $C_t=C(q_t, Q^s_{\text{prod.}})$, at the same time $c_{t+1}>c_t$, which means costs grow in process of extraction (flooding growth, stock deterioration, etc.). One day there will come a situation when further extraction, at existing technologies, leads to work at a loss. That means a part of stocks will not be taken. Theoretically all these stocks fall into the category of postponed extraction. Practically only a part of them will be extracted in subsequent stages at introduction of new and more perfect technologies.

It is necessary to address to the concept of oil market price – z_t for further argumentation. The difference $\lambda(t)=z_t-c_t$ is of interest to us. Let's call this difference a valuable extraction for estimation of different types of funds formation, including investment for introduction of new technologies. The essence of the argumentation is that in a period of time $t_2>t_1$ introduction of new generation technologies becomes relevant, with a purpose to retain oil production in parameters of the effective price of extraction formula. It is promoted by either growth of the world oil or introduction of new technologies essentially reducing production costs. As an example, the companies conducting oil production in Northern Sea in the 90s of the last century, applied chemical methods of petrofeedback increase at oil price in the market higher than 165 USD/t. In that case, investment in introduction of new technologies should create conditions of extraction effective price growth not less than the rate of percent:

$$(z_{t+1}-c_{t+1})\geq(z_t-c_t)(1+\Delta)^{t_2-t_1}.$$

Let's enter $\lambda_0=\lambda_{t_1}$ as a minimal limit of the effective price of new technologies introduction in deposit development. Then the limit of the minimal effective price during any period can be estimated by the formula

$$\lambda_{t_2}\geq\lambda_0(1+\Delta)^{t_2-t_1}.$$

The problem for the oil company in that case can be formulated as follows: on each step of stock confirmation Q^d_{geol} it is necessary to maximize incomes:

$$\max\sum_{t=1}^{T}\frac{q(t)z(t)-C(q(t),K)}{(1+\Delta)^t}-\Phi(K)$$

at restrictions (5) and (6), $\Phi(K)$ are costs on installation of magnitudes in oil production. If we represent that there are no technical restrictions, then at calculations of limiting magnitude the layer parameters and specific quantity of wells on one unit of the area, for example on 1 hectare, are starting to play a role.

As it is known, the whole deposit in set borders is broken into multitude of cells at modeling. There were $w=1,...,N_w$ wells drilled on the deposit. Vector of parameters has been ascertained to each *i-th* net cell opened by the *w-th* chink. These parameters are a function from the parameter *FZI* of collector class in a cell $\Psi=\xi(FZI_i^w)$. Ψ trough *FZI,* depends on collector parameters of porosity and permeability. Porosity and type of stream hydraulic unit are predicted for each net cell of the interwell space, with use of acoustic liquids calculation (inversion procedure) [2]. As a result, for geological model $\Psi=\xi(FZI)$ is fair. Besides, vector of parameters W is defined for each cell and characterizes reservoir parameters. In that case, in a multitude Z^d of geological model conditions the concrete condition Z_s^d is defined in view of parameters

$$Z=F(\Omega,\Psi).$$

The parameters defining values of functions Ω and Ψ in the process of information accumulation at each subsequent stock calculation (giving as a result the new subset Z^{d+1}) will be more correct than at previous (subset Z^d). It defines that in the subset Z^{d+1} there will be more correct calculation of stocks, than in the subset Z^d. Let's express it by the parity

$$Q_{\text{геол}}(Z^{d+1})\equiv\triangleright Q_{\text{геол}}(Z^d).$$

The resulted argumentations allow speaking about optimization of hydrocarbon stock development. It is obvious that stocks $Q_{\text{geol}}(d+1)$ on the step $d+1$ do not necessarily increase in comparison with $Q_{\text{geol}}(d)$. Finally, optimization can be formulated as oil minimization in remaining reservoirs

$$\min\left|Q_{\text{геол}}(Z^d)-Q_{\text{извл}}(Z^d)\right|.$$

Limitations here are the same (4, 5). Introduction of new technologies at each new stage will allow extracting oil that was impossible to extract at previous stages based on economic reasons. Solution of problems in introduction of new technologies, with application of approaches on studying collector properties is relevant throughout all stages of deposit development.

Practical application of reservoir properties to find solution to problems of introduction new technologies optimization

The experience of technologies creation on deposit development, considering collector properties, is available both in the world and in Russian petroleum industry.

The unique modern modeling technology of alternate (WAG) and simultaneous (SWAG) pumping of gas and water into delivery wells has been created by the research center of one of the western oil companies [6]. Application of such technologies allows increasing factor of oil extraction by 5...10 %. The uniqueness of this method is based on computer modeling and use of fundamental data of pore-scale physics. The technique of calculations has been created, as it was possible to formalize approaches and conduct exact and low-cost calculations for each type of rock. The created modeling technology allows realizing the step-by-step formalized transition from the first step, when rock properties are attributed to the model of pore-scale section, up to the final stage of deposit model construction. Modeling allows defining areas for application of the petrofeedback increase methods (technology WAG and SWAG).

The Russian example of «address» work with reservoir features at geological model of deposits construction having a collector of the «hazel grouse» type. Proceeding from sedimentational model of the «hazel grouse» sandstones, the considered strata, in a section, consists of row of bands the formation of which is connected with stages of consecutive stabilization of the coastal line. Filtration-capacitor characteristics of each band within the limits of certain territory are caused by two factors: the first is remoteness of the considered territory to the paleosoastal line and the second is intensity of storm influence prevailing at the moment of sedimentation of each band. Migration of the coastal line during formation of «hazel grouse» sandstones promoted vertical band escalating of «storm» deposits. At the same time, each band, depending on features of this or that factor display, is characterized by individuality of filtration-capacitor characteristics.

Bands of «hazel grouse» sandstones have significant lateral tracing of faltering stratification in volume of the band and high dissociation of separate bands both along the section, and along the area.

Similar structure of productive collectors demands a certain system of hydrocarbonic raw material, concentrated in collectors, development. The most comprehensible are: *first of all*, row system drilling of horizontal wells of various range stem forming within the limits of separate bands of «hazel grouse» sandstones, more spread out – in low-permeable collectors and less spread out – in well impermeable bands; *secondly*, the so-called «spare» hydrobreaks; *thirdly*, opening of the whole strata of band layered heterogeneity by the horizontal stem of the well; *fourthly*, the spatial scheme of development by separate bands, in view of lateral identity of collector properties.

The stated approaches promote creation of effective design documents on estimation (recalculation) of stocks and technological schemes of development and choice of the optimal actions of deposit development. By separate actions it should look as follows:

1. Decrease in dynamic level of operational wells is rational to conduct in collectors with chaotic stratification where break probability of layer waters into the well along high-permeable prolayers of the collector is minimal.
2. Alumina-acid and acid processing, as a factor of influence on the collector cementing matrix, is more expedient to conduct in reservoir with chaotic stratification where decomposition of layered structure considerably improves filtration characteristics of near-face zones.
3. Pumping gel-forming components into productive layer is effective in sandstones with ordered stratification as it leads to alignment of reservoir filtration characteristics along section, promoting uniform movement of water-oil section along the lateral during the process of deposit development.
4. Hydrobreak of the layer with crack fixing is expedient to conduct in collectors with chaotic stratification where matrix destruction of pore spaces promotes increase in oil extraction coefficient. In case of layer hydrobreak conduction in reservoirs with ordered stratification, the direction of cracks will be focused along obliquely laminated texture course, as lines of the minimal break resistance, which does not give such needed effect – increase in oil extraction coefficient and can lead premature flooding of wells. Application of layer hydrobreak in sandstones with ordered stratification lamination is justified in limited volumes at significant collector macroheterogeneity with the purpose of oil inflow activization from the low-permeable part of the productive layer.
5. Organization of individual systems of layer pressure maintenance is a basis for effective development of collectors with ordered stratification. At the same time, if technical opportunities allow, the maximal value of oil extraction coefficient will be reached at orientation of delivery and extracting rows along the stratified texture course of the collector. Organization of cyclic pumping is effective in case of spatial systems of flooding.
6. Horizontal drilling is effective in collectors with chaotic and ordered stratification. In the latter, orientation of stems construction in wells and further system organization of layer pressure maintenance should consider spatial orientation of collector layered structure.

Depending on kind of works and volumes of the initial information the technical means for project development are defined. Schedule including stages of the actual material supply, coordination of the initial and final information on various parts of the project, control points of project execution.

Conclusion and summary

As the main fundamental for efficiency increase of hydrocarbon deposit development in view of the above stated argumentations it is necessary to consider:

- construction of essentially new facies-sedimentational models of productive reservoirs;
- detailed analysis of oil deposit development from the position of collector facies heterogeneity and division development objects on subobjects;
- use of individual development systems within the limits of allocated zones, or their rearrangement within the limits of deposit operation.

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