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EXPRESS PREDICTING MOVEMENT OF DISPLACEMENT FRONT TO HIGH VISCOSITY OIL RESERVOIRS

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ЭКСПРЕСС-ПРОГНОЗИРОВАНИЕ ПЕРЕМЕЩЕНИЯ ФРОНТА ВЫТЕСНЕНИЯ НА ЗАЛЕЖИ С ВЫСОКОВЯЗКОЙ НЕФТЬЮ

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Practically in all oil fields water injection is performed to maintain formation pressure. At bottom holes of injection wells pressures are created which significantly exceed formation pressure. In case of significant layer to layer heterogeneity water from injection wells will start flowing through low filtration resistance channels to productive wells. In the most intense way movement of injection water from injection well to productive well manifests itself in high viscosity oil reservoirs. In case of productive well water flooding works on water shutoff and equalizing input profiles are performed. To evaluate time of water breakthrough from productive well to injection well using software suite TempestMore a series of mathematic experiments was made to forecast displacement front movement in formation with different formation oil viscosities, reservoir permeability, bottom hole pressures in injection and productive well. Information on fluid properties and relative permeability at fields of Nozhovskaya group (Perm territory) was used. According to results of generalization of simulation data an equation for evaluation of time of displacement front movement in reservoir is obtained. Analyzing calculation results, it is possible to conclude that time of displacement front movement for certain distance is influenced by mobility coefficient according to exponential dependency. In reservoirs with mobility over 2 μm^2/Pa*sec water-oil front moves with velocity of around 1 m/day. Comparison of forecasted values of production wells water flooding time for high viscosity oil reservoir obtained by hydrodynamic simulation and equation developed demonstrates high enough results reproducibility. Usage of the equation will permit to plan in advance measures on well water shutoff and equalizing input profiles.

Ключевые слова:
залежь нефти, скважина, вязкость нефти, проницаемость, обводненность, водоизоляция, прогнозирование, многомерная модель.

Практически на всех нефтяных месторождениях для поддержания пластового давления производится закачка воды. На забоях нагнетательных скважин создаются давления, существенно превышающие пластовые. В случае значительной послойной неоднородности вода из нагнетательных скважин начнет поступать по каналам с низкими фильтрационными сопротивлениями в добывающие скважины. Наиболее интенсивно движение закачиваемой воды от нагнетательной к добывающей скважине проявляет себя на залежах с высоковязкой нефтью. При обводнении добывающих скважин проводятся работы по водоизоляции и выравниванию профилей приемистости. Для оценки времени подхода воды от добывающей скважины к нагнетательной в программном комплексе Tempest More выполнена серия математических экспериментов по прогнозированию движения фронта вытеснения в пласте с различными вязкостями пластовой нефти, проницаемостью коллектора, забойными давлениями в нагнетательной и добывающей скважинах. Информация о свойствах флюидов и относительной фазовой проницаемости использовались с месторождений Ножовской группы (Пермский край). По итогам обобщения результатов моделирования получено уравнение для оценки сроков продвижения фронта вытеснения по коллектору. Анализируя результаты расчетов, можно сделать выводы, что на время продвижения фронта вытеснения на определенное расстояние по экспоненциальной зависимости влияет коэффициент подвижности. В коллекторах с подвижностью более 2 мкм^2/Па·с водонефтяной фронт продвигается со скоростью около 1 м/сут. Сопоставление прогнозных значений времени обводнения добывающих скважин для залежи с высоковязкой нефтью, полученных с помощью гидродинамического моделирования и разработанного уравнения, показывает достаточно высокую сходимость результатов. Использование уравнения позволит заранее планировать мероприятия по водоизоляции скважин и выравниванию профилей приемистости.

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Introduction

Development of oil fields is accompanied with water injection to maintain formation pressure, leading to increase of reservoir oil recovery and increased water cut in productive wells. Injection water moves in reservoir from injection to productive wells. If there are sublayers with low filtration resistance in reservoir, speed of water movement increases. Along with increase of reservoir layer to layer heterogeneity and oil viscosity probability of premature water breakthrough to productive wells increases [1]. Together with geological parameters [2, 3, 4], well flooding is influenced by development systems and well operation process patterns [5–9]. Along with increase of well water flooding during oil field development current production decreases, oil recovery coefficient decreases, inorganic salts sedimentation intensifies and oil production cost increases [10]. main reasons for well water flooding are coning and advanced movement of water front along highly permeable sublayers [11–16]. In Perm territory water movement along most permeable sublayers is one of main sources of productive wells water flooding. To prevent premature well water flooding and to increase formation coverage they perform injection of polymers, cyclic water flooding, and other processes are used, meanwhile greatest process effectiveness is demonstrated by usage of gel-forming processes [17–42].

Object of study

Large group of reservoirs with highly viscous oil in Perm territory is associated with fields of Nozhovskaya group. Viscosity of formation oil in carbonate objects of Nozhovskaya fields group changes from 7,9 to 87,08 mPa·sec, permeability of productive objects according to core data – 0,060–0,646 μm^2, compartmentalization – 1,0–9,6. In the greater part of carbonate objects in the group significant advantage of water flooding over production of recoverable reserves. On a number of objects well production water flooding exceeds production of recoverable reserves by 1,5 times and more. Main reason for production water flooding of wells associated with carbonate reservoir objects in Nozhovskaya fields group is water flooding through more permeable part (separate layers) of laminary non-uniform reservoir (56,3 %). Also to most common water flooding reasons pertain edge water breakthrough (18.8 %) and coning (12.5 %). For more effective implementation of processes on equalizing injection wells input profiles and water shutoff in productive wells it is necessary to evaluate time of their appropriate application. A task of practical importance is determination of production wells water flooding time and time of displacement front movement in reservoir parts having different permeability. It is possible to evaluate time of displacement front passing over distance from injection to productive well using geological hydrodynamic displacement method. Availability of multidimensional statistical models will permit to substantially simplify and improve promptness of front movement time evaluation.

Simulation of water front movement

In work [43, 44] dependencies of well water flooding on production of recoverable resources for oil having different viscosity are given. These dependencies permit to forecast amount of water flooding at different stages of reservoir development. Oil recovery coefficients and rates of reserves recovery depend on reservoir permeability, formation oil dynamic viscosity, levels of production and compensation of recovery by fluid injection [45]. Dependencies described in the literature permit to obtain integral values of water flooding for reservoirs in whole.

A model is created in software suite TempestMore of uniform reservoir compartment with productive and injection wells. Calculations of displacement front movement from productive to injection well depending on formation oil properties, reservoir permeability and bottom hole pressures of productive and injection wells are performed. Displacement front movement border was considered to be increase of water saturation of model grid blocks. Average reservoir permeability, relative permeability and fluid parameters values were set similar to actual fields of Nozhovskaya group.

Analyzing calculation results we may conclude that time of displacement front movement over certain distance is influenced by mobility coefficient according to exponential dependency (ratio of permeability coefficient and formation oil dynamic viscosity) (fig. 1). In sublayers with mobility coefficient less than 2 μm^2/Pa·sec time of displacement front movement from injection well to productive well corresponds to times of oil recoverable resources production, and premature water flooding of productive wells is unlikely. In reservoirs with mobility over 2 μm^2/Pa·sec water-oil front moves with velocity around 1 m/day. Especially intensely water-oil front moves in formations with mobility coefficients over 5 μm^2/Pa·sec, and time of displacement front movement between wells may not exceed one year. It is necessary to monitor in productive objects water-oil front movement in sublayers with high mobility coefficient and plan measures on equalizing injection wells input profiles and water shutoff in productive wells [46].

In Statistica program regressive analysis of main model parameters influence on times of water-oil front movement in formations was performed. The priority for analysis is area in reservoirs with mobility over 2 μm^2/Pa·sec.

An equation for evaluation of time of displacement front movement (years) for distance X from injection well is obtained:

– for objects with mobility coefficients 2–5 μm^2/Pa·sec:

$$T = 0{,}14\,X - 0{,}96k/\mu + 1{,}82(P_\mathrm{i} - P_\mathrm{p})/P_\mathrm{f} - 1{,}02; \quad (1)$$

– для объектов с коэффициентами подвижности более 5 μm^2/Pa·sec:

$$T = 0{,}018\,X - 0{,}18\,k/\mu + 1{,}14\,(P_\mathrm{i} - P_\mathrm{p})/P_\mathrm{f} + 2{,}8, \quad (2)$$

where X – distance from injection well, m; k – reservoir permeability, 10^{-3}·μm^2; μ – formation pressure dynamic viscosity, mPa·sec; P_i, P_p – bottom hole pressures in injection and productive wells correspondingly, MPa; P_f – formation pressure, MPa.

For dependency (1) it is necessary to use following limits on source parameters:

X – 50–500 m;

k/μ – 2–30 μm^2/Pa·sec;

$(P_\mathrm{i} - P_\mathrm{p})/P_\mathrm{f}$ – 0,625–1,06 unit fraction.

In one of divisions of Berezovskoe oil field water flooding of productive well 727 by water injected into injection well 779 is observed. In injection well 779 with input profile of 30 m^3/day about 80 % of injected water goes into upper perforation interval and moves to well 727 (fig. 2).

Study of time of water flooding in well 727 depending on time after activation of injection well 779 was performed (fig. 3). Water flooding of well 727 began to rise step by step and reached 85 % in 6 years. According to results of processsing well testing average mobility coefficient in well drainage areas was 16,9 μm^2/Pa·sec. Bottom hole pressure in productive and injection wells was 11 and 23 MPa respectively. Formation pressure – 16 MPa. Time of water-oil front movement from injection to productive well during forecasting using dependency (2) will be 7 years, which corresponds to well water flooding in fig. 3.

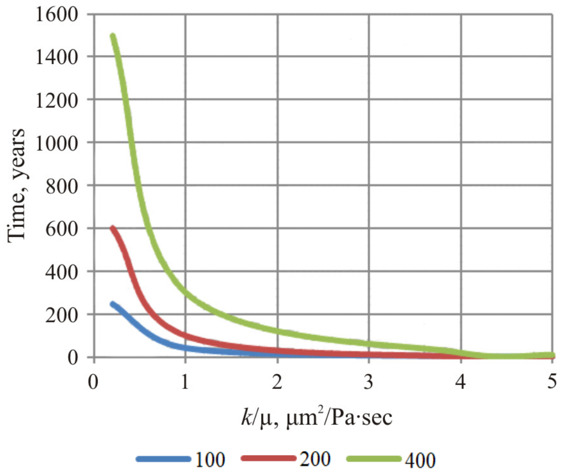

Fig. 1. Dependency of time of water front movement over distance 100/200/400 m from injection well in relation to mobility coefficient

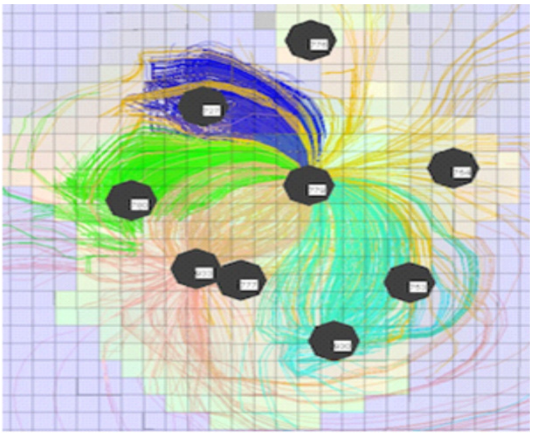

Fig. 2. Directions of filtration flows in oil reservoir compartment

Before expected well water flooding through highly permeable sublayer it is necessary to plan measures on equalizing input profile of injection well. Timely usage of flow diverting technologies will permit to increase effectiveness of reservoir management and will lead to increase oil recovery coefficient.

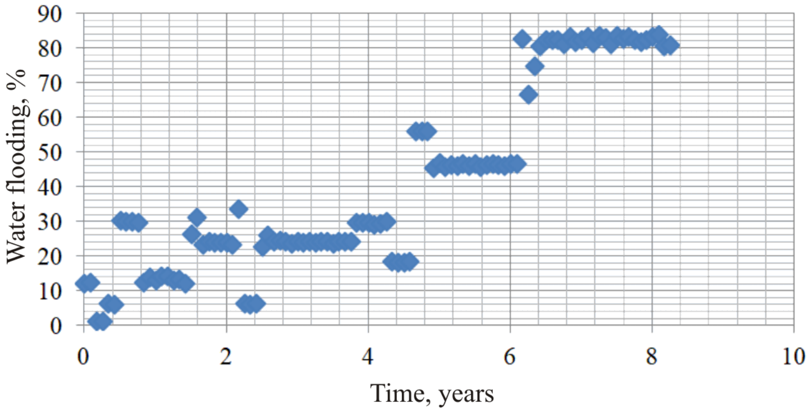

Fig. 3. Dynamics of water flooding well 727 after beginning water injecting to well 779

Conclusions

At present substantial part of productive objects contains hard to recover oil reserves. Such objects are characterized by significant layer to layer and zonal heterogeneity, high viscosity of oil and other complicating factors. For effective implementation of input profile adjustment and well water shutoff processes it is necessary to forecast time of arrival of water being injected into formation to productive wells. The work proposes dependencies for evaluation of time of water front movement in formation. Special attention should be given to sublayers with mobility coefficient value exceeding 2 μm^2/Pa·sec, as in these substantial speeds of water-oil front are obtained.

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