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High Oil Recovery using Traditional Water-flooding under Compliance of the Planned Development Mode

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Abstract

The dynamics and performance of major oil deposits in late (final) stage of development of large oil fields are given the current rates of oil recovery. The high oil recoveries are resulted as a consequence of the favorable geological and physical characteristics of the development objects, application of development systems and optimal density well spacing, adequate geological structure, maintain during the process of the development the optimal rates of technological development, the modes of operation of wells and a project of the fund of production wells, continuous improvement of the project systems taking into account the dynamics of the reserves development and the clarification of the geological structure.

Keywords: *Average project oil recovery, oil recovery, recovery factor, well spacing, EOR*

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INTRODUCTION

Some media published allegations that the development of domestic oil fields is characterized by a low oil recovery. In Russia, for 40 years, oil recovery allegedly declined by half from 60% to 29%, and now it is lower than in the US.

Herewith analyzing of the magnitude of the average project oil recovery (APR) is taking place. Meanwhile, the misconception is about that the status of the oil recovery can be judged from the magnitude of APR and comparing the data of 40 years ago.

For 40 years, the APR in the country has changed and is changing. This is due to the following circumstances.

1. In the middle of the last century several dozen of calculating facilities were introduced in the development of the major high oil produced fields, mainly in the Ural-Volga region, Tumazinsk, Seraphimovsk, Romashkinsk et al., which are characterized by a high value of APR. Over the past decade, in new regions of Western Siberia and other regions of discovered fields of other types and geological structure, are characterized by the unfavorable conditions of oil production (the traditional methods of development) and low project oil recovery factor. Now in the development are involved more than 1,300 hydrocarbon fields. And this could not but to affect the average APR.
2. The accumulated experience and knowledge of the development of oil displacement processes under water-flooding recovery and creation on their basis modern methods and programs allowed more accurately evaluate the project oil recovery, which also had an impact on the value of APR.
3. The process of achieving the development project of reservoirs is labor-intensive, long and in a market economy is not always stable. It is also varies depending on market conditions. This, of course, also affects the APR of different hydrocarbons fields.

To assess the state of the formations of oil recovery, it is not enough to study the dynamics of the average project oil recovery, calculated based on the amount of new discovered fields, most of which have not yet explored and therefore not ready to designing.

The true state indicators for the determination of development tendencies need to consider the dynamics of long-developed field's data and they can be known only by date of

hydrocarbons fields which are in the final stage.

For domestic oil production, the traditional practice in designing systems for oil fields development and its continuous improvement in order to increase the efficiency of production and enhanced oil recovery. Such a practice has been developed and tested on the major and large oil fields base for major oil and gas regions of the country, Bashkortostan, Tatarstan, Western Siberia (Tuimazy, Romashkinskoye, Arlan, Samotlor, etc.). These fields provide the main part of current production (up to 80% or more).

Thus, the first domestic development using water flooding was in Tuimazy field for 70 year history of its production, 15 project documents have been carried out in Samotlorsk, 17 project for 35 years, in Arlan field 18 project for 45 years (In these specified numbers of project documents does not include analyzes of the development, projects of experimental industrial work and field supervision and other research projects dedicated to the fundamental questions of the development of specific fields).

Continuous improvement of project development systems and their implementation in practice, allowed not only increasing the current oil production, improving the efficiency of oil production, reducing the current water cut, but also providing the conditions for enhanced oil recovery.

On Romashkinskoye field second by size and amount of oil reserves in Russia, more than 60 years of developing. At an early stage of development, improvement project systems were carried out by means of;

- Compacting well spacing;
- Optimizing the width of the development area and water injection pressure;
- Application of focal and selective flooding at selected areas;
- Transfer injection [1].

At a later stage of the development and to engage in active development of less productive formations became widely used:

- Further compaction of the well spacing;
- Dividing the water injection;
- Downscaling of the developed objects;
- Increasing the injection pressure to optimum values;
- Hydrodynamic methods, including transient water-flooding with the change in direction of liquid filtration flows in the formation;
- Injection into productive formations sulfuric acid, surfactants and other reagents [1].

Phased designing and implementation activities to improve the design of the systems has allowed, in Romashkinskoye field, gradually increase the annual oil production, improve the efficiency of oil production, optimize current water cut, designed to increase oil recovery by 2.6 times from 38 to 53% [1].

Technological parameters of the four major stages of designing and development of Romashkinskoye field are presented in Table 1.

Table 1: *Development of the Systems of Romashkinskoye Field Develop.*

Designing year of the development											
1- 1953 year			**2- 1965 year**			**3- 1977 year**			**4- 2002 year**		
NO.s of wells	WS	RF	NO.s of wells	WS	RF	NO.s of wells	WS	RF	Numbers of wells	WS	RF
9400	45	38	12000	35,4	42	21000	22,2	49	24200	17,6	53

Where; WS: Well spacing – hectare/well, RF %: Oil recovery factor

After years of consistent work on continuous development and improvement of working systems on 167 unique and largest oil fields in Russia, that contained 78% of the initial reserves of oil and providing more than 80% of its current production, made increase in recoverable reserves against the initial assessment in total about 8 billion tons. The accumulated experience in the development of oil fields has allowed establishing quantitative dependencies of oil recovery on various geological and physical conditions of the oil occurrence and the working regimes. under the drainage of oil wells, the fullness of

development of oil reserves is influenced by: natural geological and physical parameters of the deposits (type of the pay-zones and its properties, morphological features of the structure of deposits, properties of formation fluids, etc.) and technological factors (well spacing WS, drainage mode, displacement characteristics of the agent, the rate of extraction of oil and liquids from reservoir, the duration of the development and the volume of the reservoir flushing, etc.) [2].

The dominant influences on the process and the final results of the developments, including RF, have natural structural features of the operating object (such as structure of deposits, conditions of oil occurrence, litho-physical properties of the reservoir, oil viscosity, etc.). From technological factors, the most significant is the effect of the density the well spacing [3].

In practice, it is proven the dependency on this factor (well spacing compaction) to enhance oil recovery, the most effective and most widely used method of enhanced oil recovery. The achieved high oil recovery in the majority of long-developed objectives, for the most part, is considered the optimization results of the well spacing (Arlanskoe, Tuymazinskoe, Romashkinskoye, Samotlor and others oil and gas fields) (Table 2).

Table 2: *RF for Large, Long-developed Oil Fields.*

The field, the reservoir	Year of putting into exploration	Project	Current
Tuymazinskoe (D1 + D2)	1944	0,59	0,56
Romashkinskoye (Devon)	1948	0,53	0,47
Arlanskoe (Coal-bearing strata)	1955	0,435 0,55	0,55
Samotlor, including AV2-3 AV4-5 B8	1969	0,49 0,440 0,559 0,656	0,354 0,37 0,475 0,586
Mamontovskoye	1970	0,416	0,333
Fyodorovskoye B-10 (Moss pl.)	1973	0,440 0,494	>0,418

Particularly high oil recovery rates are achieved if optimum well spacing is applied from the beginning of the field development. In this case, the high oil recovery can be achieved in a relatively short period of development, with a minimum production of associated water (low water-oil ratio) and the best technical and economic indicators.

Raewski field, from the very beginning, has been drilled and has been extensively developed with the optimal conditions for the development of the Devonian strata in well spacing of 8–12 hectare / well. For 30 years, oil recovery has reached 0.66, and water-oil ratio did not exceed 1,5.

Designing systems of oil field development represent an important and responsible stage in the field life. The quality of the project planning and the projected technology of the development (and its implementation) largely depend on the completeness of the use of the natural potential of the oil fields (oil recovery project and level project of oil production) and techno-economic indicators of oil production. In domestic practice, the design development for over 50 years is based on the scientific foundations. Over the years a wealth of experience has accumulated in designing and implementing of development planning for more than 1200 fields with different geo-physical characteristics and technologies of development.

In Russia, established practice, since the late 40-ies of the last century, involves the use from the beginning of the development the maintenance of reservoir pressure by water injection. Currently, most of the major oil fields, developed with the water flooding, are in a mature stage of development, which is characterized by high water cut, natural decline in oil recovery and economic efficiency. Therefore, relevant and forehanded for most fields is to find, study and implement

enhanced oil recovery methods. In recent years, the development of oil fields increased the attention to the EOR methods and the requirements for their justification. Generally, the development projects of oil fields that are in late stage are not allowed to consider options without providing for EOR. Table 3 shows the systematic ways (methods) of exploration and drainage of oil-containing rocks, and Table 4, Classification of enhanced oil recovery methods. The methods of enhanced oil recovery include methods to increase the amount of recoverable oil that can be achieved by the additional drain for that part of the deposit, which is not covered by the development under the natural mode and water-flooding. The term deposit is geologically understood as limited oil capacity, representing the hydrodynamic closed single development object.

Table 3: *The Ways (methods) of Oil Field Development.*

The ways(methods) group	Method	Extraction method
Discovering	Depuration(Mining)	Create mine workings in the open air. Extraction of oil-bearing rock, followed by separation and washing off the oil from the open rock.
	Pit(mine)	Create underground mine workings and drainage of oil-saturated formations by underground wells.
Drainage by means of wells drilled with the ground surface	Using natural formation energy	Active water pressure
		Elastic energy
		Energy of dissolved gas
		Gas cap
		Energy of gravitational forces
	Supplement natural formation energy artificially	Injection of water in various methods

Table 4: *Classification of Enhanced Oil Recovery Methods.*

Group of methods	Methods
Physico-chemical	Water flooding with surfactants
	Polymer flooding
	Micellar flooding
Gas	Injection of hydrocarbon gases
	Injection of liquid solvents
	Injection of CO2
	Injection of Nitrogen
	Injection of flue gases
Thermal	Displacement oil by heat transfer fluids
	The impact by means of exothermic intrastratal oxidation reactions
Microbiological	Injection of bacterial products (BP)
	Forming of BP in the oil formation
Combined (improved EOR)	The combination of elements of groups 1–4 with modern technical means and methods (horizontal wells, etc.)
	compacting of well spacing

Enhanced oil recovery methods include:

- Physicochemical methods (water flooding with surfactants, polymer flooding, micellar flooding, etc.);
- Gas methods (injection of hydrocarbon gases, liquid solvents, carbon dioxide, nitrogen, flue gas);
- Thermal methods (oil displacement by heat transfer fluids, the impact of using *in-situ* exothermic oxidation reactions);

- Microbiological methods (an injection of bacterial products in the oil reservoir or forming them directly in the oil reservoir).

Improved Oil Recovery involves a combination of elements of listed above four groups of EOR, and the use of modern means and methods of enhanced oil recovery.

Stimulation technologies of oil flow from wells (formation stimulation techniques); listed in the Table 5, have a goal to intensify the flow of oil from the well, affecting the limited space of formation zone near the bottom-hole or at some distance from it. In this group of technologies the author felt justified in the inclusion of hydraulic fracturing. In the last two decades – during the period of intensification of oil production caused by the rapid increase in world oil prices, Russian oil companies have significantly increased the scale of the use of hydraulic fracturing. Now Russia is the world leader in the intensive use of hydraulic fracturing. In 2005, in the oil industry held about five thousands of operations, that in terms of one functioning oil well, three times greater than in the US.

Oil companies suggest increase the scale of application of hydraulic fracturing in future. They are attracted by the fact that the current increase in production of oil/fluids in most wells selected for operations is comparable to the average flow rates of functioning wells or even exceed them, through the implementation of intensive generous technology.

Table 5: *Stimulation Technologies of Oil Flow from Wells (Stimulation treatments of bottom-hole zones).*

Groups	Technology
Physical / hydrodynamic	Hydraulic Fracturing
	Horizontal and directional drilling
	Sidetracking
	Implosion
	Wave
	Forced fluids recovery
Chemical	Acid treatment and their modifications (thermoacid et al.)
	Processing solvents
	Sediments-gel forming technology
Thermal	Processing bottom-hole zones by transfer fluids
Microbiological	Microbiological method of processing bottom-hole zone

Among experts there is no unity of views of the impact of hydraulic fracturing on oil recovery. Although the work is regulated on the surface, it is hardly controlled in the formation with physical destruction of the heterogeneous nature of the reservoir. Opinions differ in a wide range. At reservoirs characterized by low permeabilities, oil recovery, through the use of hydraulic fracturing, may grow from 0,109 to 0,337, i.e., in three times [4]. At the same time a lot of facts show that in heterogeneous high permeability reservoirs with low-viscosity oils, hydraulic fracturing does not increase oil recovery, but only intensifies the extraction of oil. Obviously, the most convincing undeniable data allowing judging the real oil recovery are the indicators of the accumulated oil production at Tuimazinskaya field (70 years is already in development).

Tuymazinskoe field is the first large in size, and oil and gas reserves, discovered in Russia and "the firstborn of the domestic advanced technologies of oil extraction and the standard by which to look up other fields at the late stage of their development" [5].

The accuracy of oil recovery is due to the high accuracy of calculation of geological reserves, based on the results of drilling more than three thousand wells, the operation of which in for 60 years was accompanied by all the necessary researches, relevant to time.

The accuracy of estimates of geological reserves only confirmed on a final and complete calculation, which was based on all accumulated in the field reliable geologic information.

Real oil recovery of Devonian formation, achieved in the field, is quite satisfactory for the deposits that are characterized by:

- Natural combination of geological parameters, on the basis of which deposits usually referred to as complex (the heterogeneity and discontinuity of the reservoirs, wide oil-water zones, etc.);
- No optimality in the number of elements of the system design and the mode of operation of wells (rare well spacing, massive restriction of fluid withdrawal from wells with high water cut).

Of course, it should be emphasized that high oil recovery is primarily the result of applying system development with application of maintaining reservoir pressure support by water injection. Conducted field experiments to test methods of increasing oil recovery significantly did not affect the final results.

The achievement of high oil recovery also contributed to:

- Optimal well spacing in most of the areas of oil fields (18 – 21 hectare/well);
- Continuous improvement of the development systems and modes optimization of operation of wells in the process of developing of formations;
- Support, based on the technological reasonable level, the operational mode of the wells exploration fund (high operating ratio, minimum inactive fund).

CONLUSIONS

Thus, according to the analysis results of the development of oil reserves of major long-developed objects, in late and final stages of development, we can make the following conclusions:

1. Long-developed with the application of water-flooding on the basis of and in accordance well-founded projects of development objects. Projects are characterized by a growing current and satisfactorily high final oil recovery.
2. The main components of satisfied high oil recovery, reached on long-developed fields with water-flooding, are:
   - Favorable geological and physical characteristics of the development objects.
   - Application of systems design and optimum density of the well spacing, adequate geological structure.
   - Support in the developing process of the optimal geotechnical development rates, well exploration modes and project funds of exploration wells.
   - Continuous improvement of the project systems taking into account the dynamics of the development of reserves and clarify the geological structures.

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