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Pilot Tests of New EOR Technologies for Heavy Oil Reservoirs

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Abstract

Thermal-steam stimulation (TSS) is considered as the most effective among all up-to-date methods for heavy oil production. However problem consists in lower coverage by steam injection and decreased TSS efficiency at later stage of the development. Paper presents the results of solving this problem by combining thermal-steam and physicochemical stimulations and using ″cold″ technologies involving thermotropic gel-forming and oil-displacing systems: gels increase reservoir coverage, whereas oil-displacing systems increase oil displacement.

In 2008-2013 172 wells were treated on the Permian-Carboniferous reservoir of high-viscosity oil in Usinsk oilfield using IPC SB RAS technologies. As a result the increase in oil production rate ranged of 3-24 ton/d per one well and incremental oil production amounted to 980 tons per one well treatment. It is promising to use integrated technologies alternating injection of steam, gel-forming and oil-displacing systems. They are commercially produced in Russia and China.

In 2014 to improve TSS efficiency pilot tests of new technologies were successfully carried out: using gelled system based on surfactants with controlled viscosity to increase simultaneously reservoir coverage and oil-displacement factor; using polymer gel-forming system – for selective water shutoff in production wells.

TSS is effective, but expensive method. It is promising to use ″cold″ technologies. To enhance oil recovery from high-viscosity reservoirs at 20-40 °C we propose to use gels and sols based on low temperature inorganic gel-forming system and oil-displacing alkaline and acid systems based on surfactants, inorganic buffer solution and polyol with controlled viscosity, from tens to hundreds mPa·s, and low freezing point, -20÷-60 °C. In 2014 pilot tests of new ″cold″ technologies were carried out in Usinsk oilfield. Alkaline system was injected into 5 and acid system into 10 low productivity production wells. After injections oil production rate increased by 5-15 ton/d, fluid flow rate increased by 15-25 m^3/d. The technologies were recommended for commercial application.

Introduction

In the global structure of raw hydrocarbon resources the portion of difficult-to-recover reserves which includes heavy and high-viscosity oils is constantly growing. In Russia the portion of difficult-to-recover oil reserves is also constantly increasing. The active reserves account for a third of all prospected reserves, the difficult-to-recover oil reserves account for 67 %, where high-viscosity oils – 13 % and low-permeability collectors – 36 %. The reserves of heavy and high-viscosity oils are several times greater than those of light and low-viscosity oils. They constitute an essential part of the raw material base in the oil industry both in Russia and in a number of other oil-producing countries in the world (Yakutseni, V.P. and etc., 2007; Maksutov, R. and etc., 2005; Tarasyuk, V.M. 2014). Therefore, the development of the deposits of heavy high-viscosity oils is paid more attention. To date, the total average annual production of such oils in the world is approaching 500 million tons and the cumulative production exceeds 14 billion tons. In explored reserves of heavy oils Russia ranks third in the world after Canada and Venezuela. Significant reserves are also in Mexico, the United States, Kuwait, China and Kazakhstan. In Russia oils with a viscosity of more than 30 mPa×s accounts for 7.3 billion tons, most of which are concentrated in the Komi Republic, Tatarstan and Tyumen region (Maksutov, R. and etc., 2005; Tarasyuk, V.M., 2014). For effective development of heavy high-viscosity oil reservoirs and further increase in oil production it is necessary to create and widespread new integrated EOR technologies, combining a basic reservoir stimulation by water or steam injections and physicochemical methods increasing reservoir coverage with basic stimulation and oil-displacement factor at simultaneous improvement of the development (Tarasyuk, V.M. 2014; Muslimov, P.Kh., 2012; Burzhe, J. and etc., 1989; Surguchev, M.L. and etc., 1991; Altunina, L.K. and etc., 2007[a]).

In recent years, the thermal methods – oil displacement with steam, cyclic-steam injection into the reservoir and gravity drainage at steam injection are the most widespread EOR methods used in oilfields of heavy oils (Muslimov, P.Kh., 2012; Burzhe, J. and etc., 1989; Surguchev, M.L. and etc., 1991). Such reservoir stimulation is mainly used in Canada, the United States, Brazil, Venezuela, Russia and China. One can improve the efficiency of steam stimulation by combining it with physicochemical methods, in particular, using thermotropic gel-forming and oil-displacing systems increasing the reservoir coverage by steam injection and providing additional oil displacement (Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2011[d]; Altunina, L.K. and etc., 2014).

Integrated physicochemical and thermal-steam stimulations

This approach implements the created at the Institute of Petroleum Chemistry SB RAS (IPC SB RAS) concept of using reservoir energy or that of injected heat carrier to generate in situ ″intelligent″ chemical systems: gels, sols, solutions of surface-active agents (surfactants), and buffer systems with controlled alkalinity. They preserve for a long time and self-support in the reservoir a complex of properties, being optimal for oil displacement (Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2011[d]). We have created physicochemical fundamentals of the EOR method using intelligent chemical systems – gel-forming systems and surfactant compositions. On their basis the IPC SB RAS has created 11 new commercial technologies to enhance oil recovery and decrease water shutoff in deposits with difficult-to-recover reserves, including high-viscosity oil reservoirs (Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2011[d]; Altunina, L.K. and etc., 2014).

To increase oil recovery from heavy high-viscosity oil reservoirs at a later stage of their development and to improve the efficiency of thermal-steam and cyclic-steam stimulations we have created EOR-technology alternating thermal-steam and physicochemical stimulations by the surfactant-based systems, which generate CO2 and alkaline buffer solution in situ (Altunina, L.K. and etc., 2007[a], Altunina, L.K. and etc., 2011[d], Altunina, L. and etc., 2010). In 2002-2009 field tests of the technology were carried out in the Usinsk oilfield, Russia, and in the Liaohe oilfield, China, being at later stages of their development. Since 2009 the technology is applied commercially. The application of the technology at stationary steam injection in the Usinsk oilfield in Russia decreased water cutting of well production by 10-20 % and increased oil flow rate by 40 %. At cyclic-steam stimulation in Liaohe oilfield, China, oil production increased 1.8-2.3 times, the period of oil production was prolonged for 3-5 months and oil viscosity decreased 3 times. The solid marketable form of the oil-displacing system based on surfactants is commercially manufactured by Liaoyang Oxiranchem Co., LTD in China.

The dominant role belongs to gel-technologies increasing reservoir coverage by water flooding. Under surface conditions thermotropic gel-forming systems are low-viscosity aqueous solutions, while under reservoir conditions they are converted into nanostructured gels. Gelation occurs under the action of the thermal energy of the injected heat carrier, without any cross-linking agents (Altunina, L.K. and etc., 2007[a]; Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2011[d]; Altunina, L.K. and etc., 2014; Altunina, L. and etc., 2010; Altunina, L.K. and etc., 2008[e]; Altunina, L.K. and etc., 2011[f]). Kinetics of gelation, rheological and filtration characteristics of the gels of different types have been investigated for heterogeneous reservoirs the permeability of which ranged from 0.01 to 10 μm2. We have proposed the following thermotropic gel-forming systems: polymer systems based on cellulose ethers and inorganic systems ″aluminum salt – carbamide – water″ with a different time of gelation – from some minutes to several days – in the temperature range of 30-320 °C. Using these systems, five gel-technologies have been created to improve oil recovery from highly heterogeneous reservoirs. They are commercially used in oilfields of West Siberia and in Komi Republic (Altunina, L.K. and etc., 2007[a]; Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2011[d]; Altunina, L.K. and etc., 2014; 1 Altunina, L.K. and etc., 2008[e]; Altunina, L.K. and etc., 2011[f]; Altunina, L.K. and etc., 2011[g]; Kuvshinov, I.V., 2010). Due to environmental safety of the reagents and their harmless to humans the gel-technologies can be widely used in oilfields of Russia and other countries.

Field tests of the integrated technologies, combining thermal-steam and physicochemical stimulations, were carried out in high-viscosity oilfields in Russia and China. Thus, during 2008-2013 172 wells were stimulated on the Permian-Carboniferous reservoir of the Usinsk oilfield using EOR technologies created at IPC SB RAS. The increase in oil flow rate ranged from 3 to 24 tons a day per well, incremental oil production amounted to 980 tons per one well treatment. Geophysical studies carried out before and after the injection of the gel-forming system showed redistribution of filtration flows and increased reservoir coverage by TSS. The integrated technologies alternating injections of steam, thermotropic gel-forming and oil-displacing systems were proved to be promising. In 2008-2011 after the injection of the systems into 41 steam-injection wells in the Usinsk oilfield the oil flow rate in the production wells increased by 4-30 tons a day and water cut decreased by 5-20 % (Altunina, L.K. and etc., 2011[g]; Altunina, L. and etc., 2012). The systems are commercially manufactured in Russia and China. The results of the works showed synergism of thermal-steam and physicochemical stimulation methods, as well as the prospect of their combined applications for enhanced oil recovery from high-viscosity oil reservoirs.

Thermoreversible polymer gels for water shutoff at thermal-steam stimulation

In 2014 pilot tests of the new technology of selective water shutoff in the production wells, which were hydrodynamically connected with the steam-injection wells, were successfully carried out on the Permian-Carboniferous reservoir of the Usinsk oilfield to improve the TSS efficiency using the thermoreversible polymer gel-forming system.

The IPC SB RAS has developed a method to enhance oil recovery of highly heterogeneous reservoirs by regulating filtration flows, increasing reservoir coverage by water flooding or TSS with the thermoreversible polymer gels (Altunina, L.K. and etc., 2007[a]; Altunina, L.K. and etc., 2011[f]), which are formed from the solutions of polymers with a lower critical dissolution temperature. Reservoir energy or that of the injected heat carrier is a factor causing gelation. With increasing temperature the conversion of a low-viscosity solution into gel is a reversible phase transition. Cellulose ethers (CE) are the most promising polymers. The dependence of CE solution viscosity in the temperature range of 20-120 °C has an extreme character – first at heating the viscosity decreases and then at further heating the viscosity increases and the solution is converted into the gel. One can regulate temperature and the time of gelation in the range of 40 to 120 °C with inorganic and organic additives, adjusting them to the specific reservoir conditions – temperature and water salinity. The action of electrolyte and non-electrolyte additives is additive. The gels are stable at temperatures up to 220 °C and can be used as effective means for water shutoff, to prevent gas breakthrough and eliminate gas cones.

Based on the studies we have created gel-forming systems and technologies to increase reservoir coverage and for water shutoff (Altunina, L.K. and etc., 2007[a]; Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2011[f]). In 1996-1997 large-scale pilot tests of the technologies were successfully carried out in Western Siberia, since 1998 Oil Company ″LUKOIL″ commercially applies these technologies in oilfields. Industrial mobile installation was designed to prepare and inject the systems. After the systems injection one observed decrease in water cutting of well production and increase in oil production rate. During 1998-2003 the systems were injected into 382 wells, incremental oil production amounted to 480 thousand tons. The period of payback was 5-9 months. The efficiency of the technology was on average 1300 tons per one well treatment. The studies of physicochemical, rheological and filtration characteristics, oil-displacing ability of the thermoreversible gel-forming systems showed their efficiency for increasing reservoir coverage with thermal-steam and cyclic-steam stimulations of high-viscosity oil reservoirs, as well as for the water shutoff. In 2005-2006 the thermoreversible gel-forming system was injected into cyclic-steam wells on high-viscosity oil reservoir in Gaoshen oilfield (a part of Liaohe oilfield). After the injection the water cut decreased and the oil production rate increased. The gel-technology involving thermoreversible polymer system is environmentally safe and economically effective. It can be recommended to improve the efficiency of cyclic-steam stimulation and for water shutoff in high-viscosity oil reservoirs.

At the TSS by areal steam injection in certain time in the production wells, which are hydrodynamically connected with the steam-injection wells, one observes a breakthrough of steam or hot water, thus increasing water cuttings of well production and decreasing the oil production rate. The injection of the gel-forming systems into the responding production wells with bottomhole temperatures from 30 to 220 °C causes gelation in situ. It promotes selective water shutoff from the heated and washed reservoirs, changes the direction of filtration flows, decreases water cut and restricts breakthroughs of the injected working agent.

In 2014 on the Permian-Carboniferous reservoir of the Usinsk oilfield pilot tests were carried out to improve the efficiency of the TSS by selective water shutoff using the thermoreversible polymer gel-forming system. From July 1, 2014 till August 5, 2014 the ″OSK″ Ltd. injected the gel-forming system into the following 5 production wells: 7185, 6170, 3083, 4243, and 2678. The volume of the injected gel-forming system ranged from 19 to 95 m^3. After the injection of the system one observed increased oil production rates and decreased water cutting of well production, Figs. 1, 2.

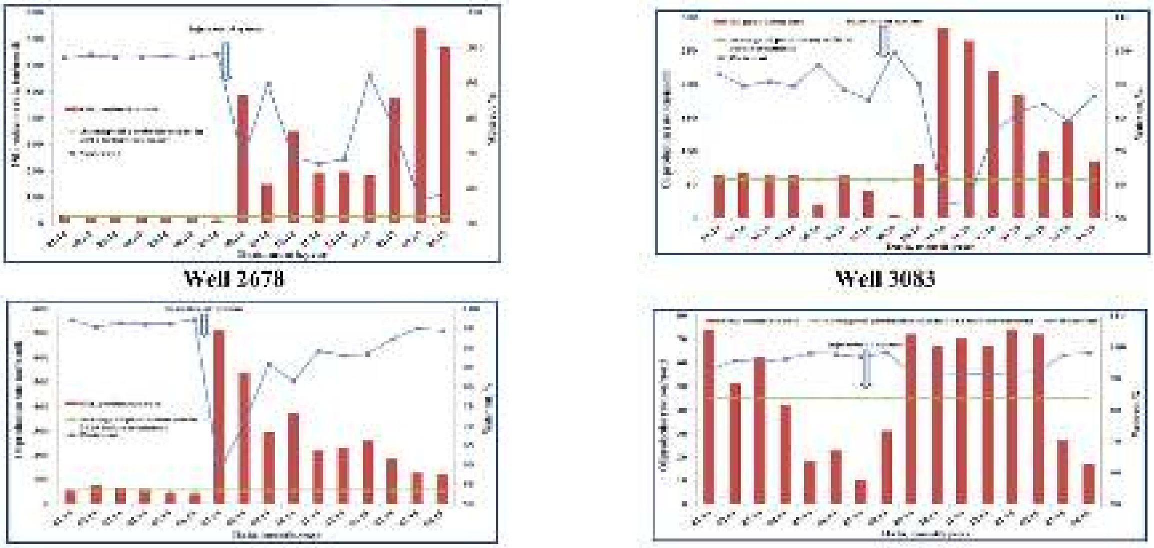

Figure 1—The results of pilot tests on selective water shutoff using the thermotropic gel-forming system on the Permian-Carboniferous reservoir of the Usinsk oilfield at TSS in June – September 2014: increase in oil production rate and decrease in water cuttings of well production

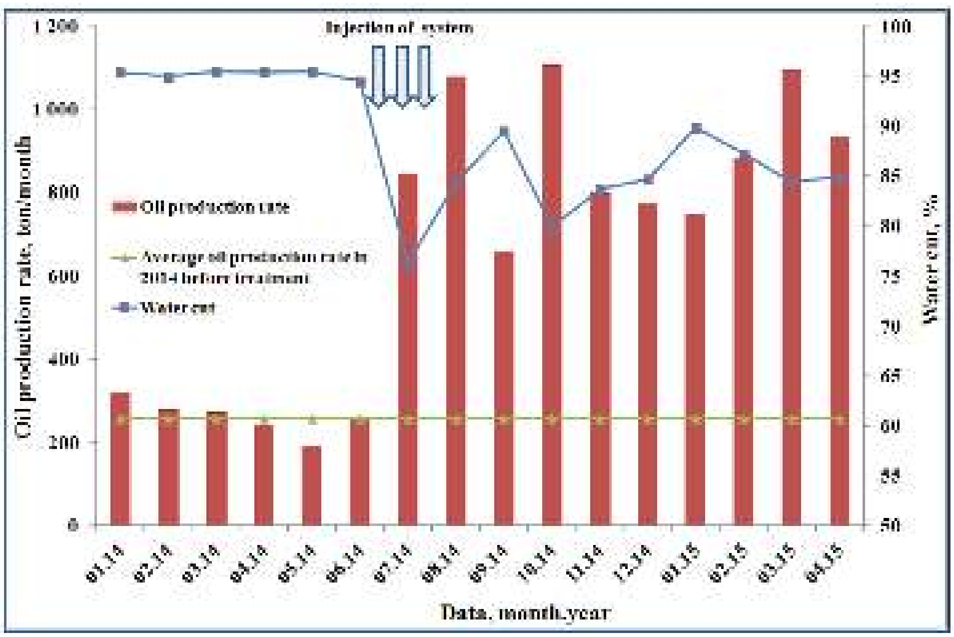

Figure 2—Increase in oil production rate and decrease in water cuttings of well production resulted from selective water shutoff due to application of the thermotropic polymer gel-forming system on the Permian-Carboniferous reservoir of the Usinsk oilfield at TSS in June – September 2014, in total for 5 wells

The success of the treatments was 80 %. In April 2015 incremental oil production amounted to 6328 tons, an average 1266 tons per well treatment. The maximal fixed absolute decrease in water cut was 39 %, i.e. from 97 % before to 58 % after the stimulation. The average decrease in water cut for 5 wells was 24 %.

The effect is still in progress, the current fixed duration of the treatment effect was 10 months. The average efficiency of the system amounted to 19 tons of the additionally produced oil per a ton of the injected system. According to the results of the pilot tests the technology of selective water shutoff in the production wells at the areal steam injection using the thermoreversible polymer gel-forming system was recommended for commercial application.

Gelled oil-displacing system based on surfactants with controlled viscosity

To improve the technology of the areal injection of the heat carrier (steam or hot water) and cyclic-steam stimulations (CSS) of production wells, a gelled oil-displacing system based on surfactants with controlled viscosity has been created. These studies are an extension of the concept involving the reservoir energy of that of the injected heat carrier to generate in situ ″intelligent″ chemical systems – compositions based on surfactants and alkaline buffer solutions preserving for a long time and self-supporting in the reservoir a complex of properties being optimal for oil displacement (Altunina, L.K. and etc., 2007[a]; Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2011[d]; Altunina, L. and etc., 2010).

Earlier IPC SB RAS created oil-displacing surfactant-based systems generating CO_2 and alkaline buffer solution in situ due to the reservoir energy or that of the injected heat carrier (Altunina, L.K. and etc., 2007[a]; Altunina, L.K. and etc., 2011[d]; Altunina, L. and etc., 2010; Altunina, L. and etc., 2012). The systems are micellar solutions based on surfactants with micelles size of tens nanometers. The systems include ammonium salt and carbamide, which generate CO_2 and ammonium buffer solution in situ, providing a complex of colloidal-chemical properties of the surfactants, optimal for oil displacement and preserved in a wide range of concentrations, reservoir water salinity and temperature. This results in the reduced oil viscosity, interfacial tension and swelling of clays, as well as in increased mobility of the reservoir fluids, thereby increasing an oil displacement factor (Altunina, L.K. and etc., 2007[a]; Altunina, L. and etc., 2010).

Due to introduction of the gelling agents into the system, which provide controlled increase in viscosity, the surfactant-based system becomes both flow-deflecting and oil-displacing and it can be used to improve the efficiency of the TSS owing to increased sweep efficiency and oil displacement factor. The injection of the gelled system into the injection wells with bottomhole temperatures from 70 to 350°C promotes controlled increase in the system viscosity in situ. This equalizes mobilities of the displaced and displacing agents, increases the reservoir coverage with stimulation, decreases viscosity instability of the displacement front, restricts breakthroughs of the injected working agent into the responding production wells and involves low permeable seams. Furthermore, in addition one observes decrease in oil viscosity due to CO_2 dissolution in the oil and oil after-washing from the already washed zones. As a result reservoir coverage by thermal stimulation and the oil recovery factor increase and oil production intensifies.

The gelled system based on surfactants is a low-viscosity and fire-safe liquid with a low freezing point. Therefore it is technologically effective to apply this system in northern regions, in particular in the Komi Republic. Based on the experimental laboratory studies we have found that the injection of the gelled system with controlled alkalinity and viscosity at the TSS and CSS on the Permian-Carboniferous reservoir of high-viscosity oil in the Usinsk oilfield causes redistribution of filtration flows, decreases the rate of filtration in highly permeable seams and increases the rate of filtration in low permeable seams, equalizes fluid mobilities in a heterogeneous reservoir model, that is accompanied by oil after-washing from both low- and high-permeability zones of the reservoir model. As a result, the coefficient of oil displacement with water or steam increases in the model as a whole. The increase in the oil displacement factor ranges from 5 to 39 %, achieving high absolute values of the oil displacement factor and low residual oil saturation.

In 2014 in the period from June 15 to July 31 the gelled surfactant-based system was injected into the following 5 steam-injection wells 1584, 1598, 1596, 1587 and 1593 in PTV-3 area at TSS on the Permian-Carboniferous reservoir of the Usinsk oilfield. The volume of the injected system ranged from 80 to 110 m^3. It was calculated by computer programs, taking into account the history of the development and geological-physical conditions of that area on the Permian-Carboniferous reservoir of the Usinsk oilfield. Standard oilfield equipment was used to prepare and inject the gelled system under the field conditions.

The efficiency of the gelled system with controlled viscosity for thermal-steam injection wells in ″PTV – South-West″ area in Usinsk oilfield was analyzed by displacement characteristics. We used the data, provided by PechorNIPIneft on the following thermal-steam injection wells: 1584, 1598, 1596, 1587 and 1593, into which the gelled system was injected in the period from June to July 2014, and the data of monthly operational reports for 75 surrounding production wells. The effect was monitored in total for all production wells in the area (75 wells, Fig. 3). The positive effect was clearly defined in 3 months after the injection, Fig. 4, it is still in progress.

Figure 3—A map of ″PTV-South-West″ area in the Usinsk oilfield where the gelled surfactant-based system with controlled viscosity was injected

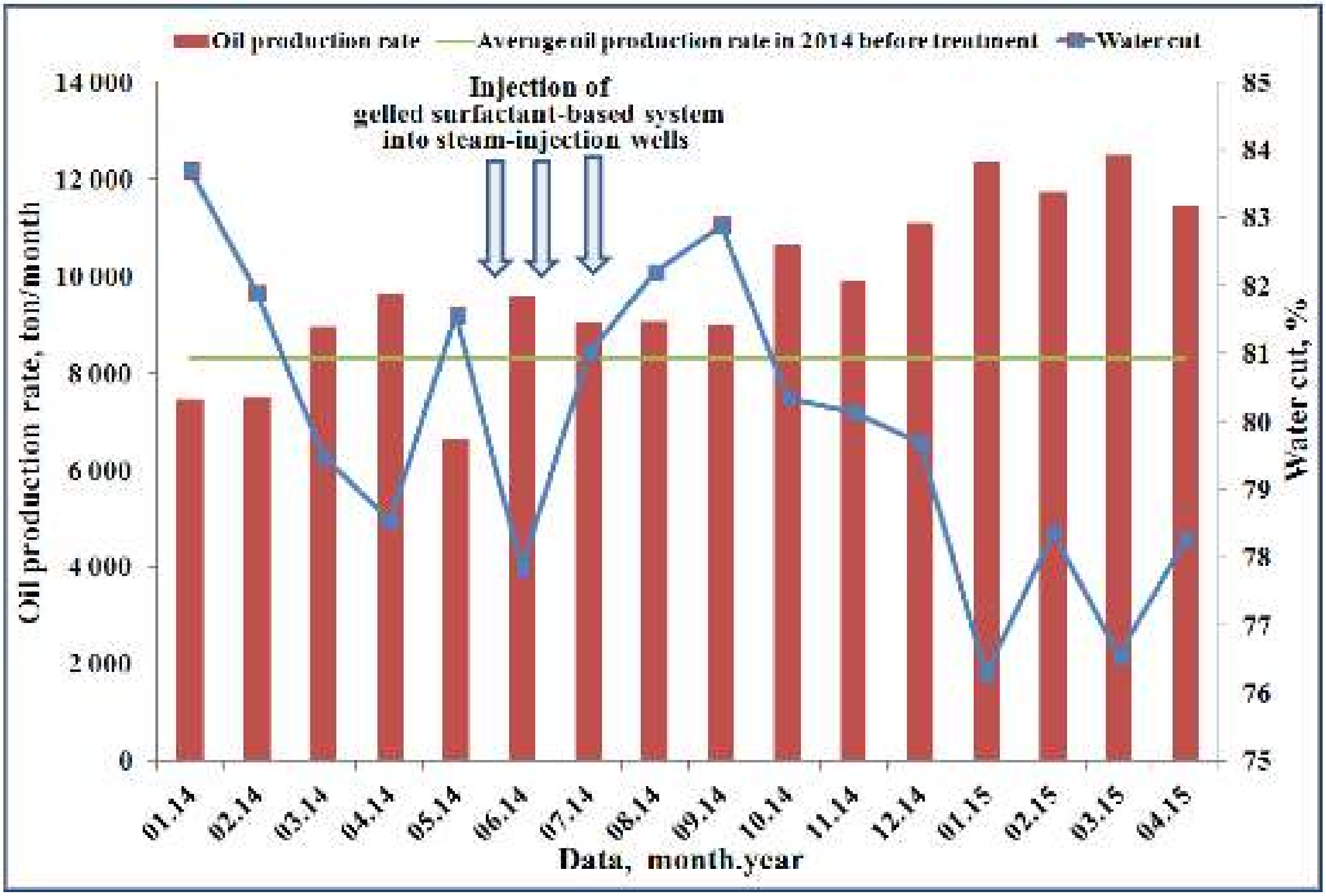

Figure 4—Oil production and fluid flow rates before and after the injection of the gelled surfactant-based system with controlled viscosity at the TSS in ″PTV – South-West″ test area in the Usinsk oilfield

The additional oil production was analyzed using the following procedure: by the data on the oil and fluid productions before the stimulation we plotted the dependence of the cumulative oil production from the cumulative fluid production, which was interpolated with a function of the form:

$$f(k,x) = \frac{k_1 \cdot x^{k_3}}{1 + k_2 \cdot x^{k_3}}$$

where f(k,x) – cummulative oil production, x – cummulative fluid production, k1,2,3 – a set of coefficients for the interpolation. This function clearly describes the process of oil production by flooding, when at the initial stage the oil production dominates and at the final stage of the development the cumulative oil production reaches certain maximum at the linearly continuing fluid production, i.e. at reaching maximal water cut. Then the obtained dependence of the cumulative oil production from the cumulative fluid production is extrapolated as a predictive baseline for the period after the well stimulation and the effect is defined as the difference between the actual and forecast values. Since we use the cumulative values, then this difference between the values in the last defined point after the stimulation will reflect the current effect of this treatment. The results of the analyses are graphically presented in Fig. 5. The total incremental oil production for April 2015 was 10,207 tons and the effect is still in progress.

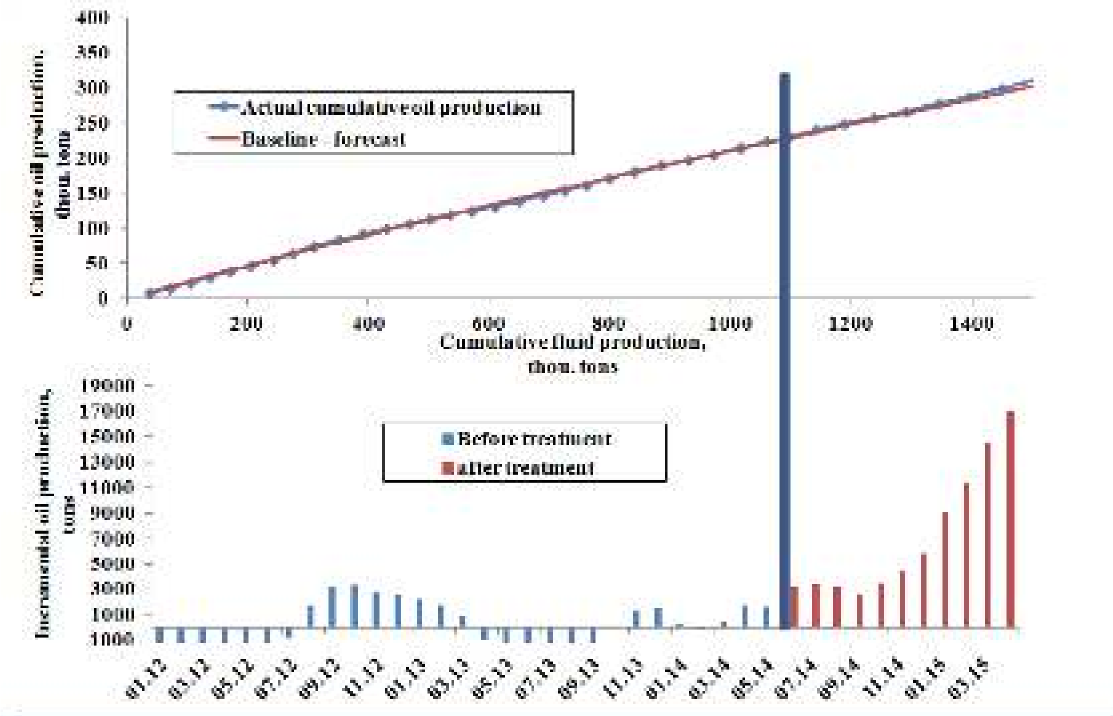

Figure 5—The results of the analyses of the injection of the gelled surfactant-based system with controlled viscosity at the TSS in the test area ″PTV – South-West″ in the Usinsk oilfield (thermal-steam injection wells: 1584, 1598, 1596, 1587 and 1593; 75 surrounding production wells)

The results of the executed works show that it is promising to use the integrated thermal-steam and physicochemical stimulations to enhance oil recovery from high-viscosity oil reservoirs.

Technologies for enhanced oil recovery from heavy oil reservoirs without thermal stimulation

Though the TSS is effective but it is technologically complex and highly expensive system of the development. Therefore, it is promising to apply physicochemical methods without the TSS, i.e. ″cold″ technologies. To enhance oil recovery from high-viscosity oil reservoirs without TSS, at 20-40 °C, we propose to use gels and sols based on a low-temperature gel-forming GALKA®-NT system, as well as alkaline and acid oil-displacing systems based on surfactants, an inorganic buffer solution and polyol with the controlled viscosity. They are compatible with the formation waters of high salinity and have a low freezing point (minus 20 °C ÷ minus 60 °C).

To enhance oil recovery from high-viscosity oil reservoirs without the TSS we propose ″cold″ technology in the variant of cyclic-reagent stimulation, which is similar to cyclic-steam stimulation. A slug of the system is injected into the production well followed by water injection and the well is closed for 7-14 days, then the well is put into operation. The oil is produced as a low-viscosity emulsion. After the completion of oil production in the first cycle, the next cycle is performed – alternated injections of system slug and water followed by the well shutdown and then oil production from the well.

The laboratory research and field testing of the ″cold″ technologies using such systems were carried out in the test areas on the Permian-Carboniferous reservoir of the Usinsk oilfield developed in a natural mode without the thermal stimulation.

Low-temperature inorganic gel-forming and sol-forming GALKA®-NT systems

To enhance oil recovery from high-viscosity oil reservoirs with low reservoir temperature without the TSS ″cold″ technology were proposed, using a gel-forming and sol-forming GALKA®-NT system: creation in situ of a movable screen with controlled viscosity, stimulation of low productivity production wells by cyclic-reagent stimulation, gradient and component-wise injection of GALKA®-NT system.

The ability of ″aluminum salt – carbamide – water″ system (GALKA® system) to generate in situ inorganic gel (sol) and CO_2 served as a basis for the technology intended to increase reservoir coverage by water or steam injections in the temperature range of 20-320 °C (Altunina, L.K. and etc., 2007[a]; Altunina, L.K. and etc., 2008[b]; Altunina, L.K. and etc., 2007[c]; Altunina, L.K. and etc., 2008[e]). The gel-forming liquids are low-viscosity solutions at pH 2.5-3.5. They are capable of dissolving carbonate minerals of reservoir rock and decrease clay swelling. The solutions may be prepared using water of any salinity. They are injected into the reservoir using standard equipment. In the reservoir due to its thermal energy or that of the injected heat carrier carbamide is hydrolyzed to form ammonia and carbon dioxide. This causes gradual increase in solution pH. When the pH reaches 3.8-4.2 aluminum ions are hydrolyzed and as a result in a certain time a gel of aluminum hydroxide is almost immediately formed in the entire volume of the solution. The time of gelation depends on the reservoir temperature and components ratio in the gel-forming system. Due to gelation the permeability of the reservoir rocks to water decreases 4-35 times. A degree of permeability is higher the higher is the initial water saturation and permeability of the reservoir rock. Static shear stress of the gel is in the range of 3-40 Pa. Solid and liquid marketable forms of GALKA® system are commercially produced in a number of Russian industrial enterprises: GALKA®-C for 70-320 °C, GALKA®-U – for 40-70 °C and GALKA®-NT – for 20-40 °C in the reservoir. The main features of GALKA® system: solubility in water of any salinity, regulated temperature of gelation, homogeneity and low viscosity of aqueous solutions as well as low freezing points of the solutions. This makes it possible to apply the systems in a wide range of temperatures (20-320 °C), including the TSS; it makes them suitable for low-permeability reservoirs

To create ″cold″ technologies IPC SB RAS proposed in situ generation of nanostructured gels and sols with autoregulated viscosity. In a certain time, depending on the concentration of the components (dilution) of GALKA®-NT system either a free-dispersed movable system (sol) or bonded-dispersed immovable system (gel) can be generated in situ. A globule is a primary nano-sized element in the inorganic gels (sols). The globule is a spatial oligomer resulting from hydroxypolycondensation of aluminum ions caused by carbamide hydrolysis. At sol formation the system viscosity increases tens and hundreds times, but the system remains movable. One can pump sols at any distance from the well, displace the residual oil and create screens for the redistribution of filtration flows anywhere in the reservoir. In September-October 2014 the technology, intended to enhance oil recovery, intensify oil production and for water shutoff, was tested on the Permian-Carboniferous reservoir of high-viscosity oil in the Usinsk oilfield developed in a natural mode, without thermal stimulation, using the thermotropic inorganic sol-forming GALKA®-NT system. ″OSK″ Ltd. injected the sol-forming system into 3 low productivity production wells using cyclic-reagent stimulation. The volume of the injected system ranged from 40 to 120 m^3. The application of GALKA®-NT system generating sol in situ for cold treatment of low productivity production wells increases oil production 2.1-4.8 times. Figure 6 shows the respond of two test wells. In 4 months after the stimulation oil production amounted to 70-400 tons per well, the effect is still in progress.

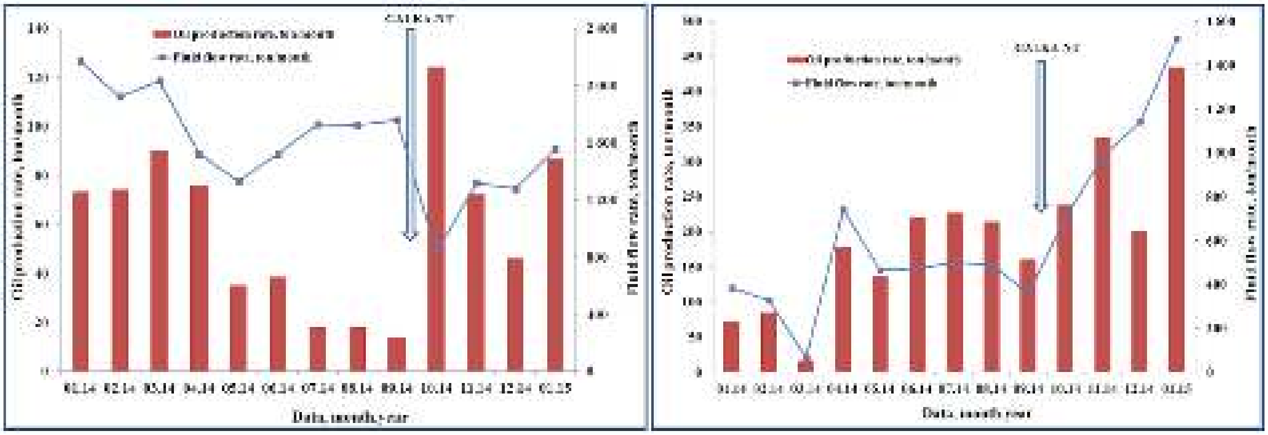

Figure 6—Increase in oil production rate after the injection of GALKA®-NT in 2014 into low productivity production wells on the Permian-Carboniferous reservoir of the Usinsk oilfield developed in a natural mode

Alkaline oil-displacing systems based on surfactants, inorganic buffer solution and polyol

To enhance oil recovery from oil deposits with different geological and physical conditions, including high-viscosity oil reservoirs, the Institute of Petroleum Chemistry SB RAS has created oil-displacing systems with controlled viscosity and alkalinity based on surfactants, inorganic alkaline buffer solution and polyol. The systems have low freezing points (minus 20 ÷ minus 60 °C).

The systems have low interfacial tension with oil, their density can be regulated in the range of 1100-1300 kg/m^3 and viscosity – from tens to hundreds mPa·s. The systems are applicable in the natural mode of the development of high-viscosity oil reservoirs. The high oil-displacing ability, compatibility with saline formation waters and decrease in clays swelling promote after-washing of the residual oil from both high-permeable and low-permeable zones of the reservoirs. In addition, the injection of mobile slugs of the system with controlled viscosity into the injection wells can equalize mobility of the oil-displacing agent and of oil, decrease viscosity instability of the displacement front, equalize the displacement front, restrict breakthroughs of the displacing agent into production wells and increase reservoir coverage by stimulation.

Beside the injection of the surfactant-based systems into injection wells to enhance oil recovery from high-viscosity oil reservoirs without thermal treatment we proposed cyclic-reagent stimulation, similar to cyclic-steam stimulation. A slug of the surfactant system was injected into the production well followed by water injection and well shutdown for 7-14 days (similar to impregnation at cyclic-steam stimulation), than the well was again activated. The oil was produced as a low-viscosity emulsion. After the completion of oil production in the first cycle, the next cycle is performed – alternated injections of system and water slugs followed by well shutdown and then oil production from the well. As a result oil production increased from both high permeability and low permeability reservoir parts.

The created systems based on surfactants, inorganic buffer solution and polyol can be used to enhance oil recovery from high-viscosity oil reservoirs not involved into thermal stimulation. One can either inject them into production wells at any stage of the development including combined injection with the gel-forming systems or inject the systems into the production wells using cyclic-reagent stimulation.

In 2014 to increase oil production and fluid flow rates pilot tests were carried out on the Permian-Carboniferous reservoir of the Usinsk oilfield without TSS using the system based surfactants, inorganic buffer solution and polyol. From August 30, 2014 to September 27, 2014 ″OSK″ Ltd. injected the system into 5 production wells. The volume of the injected system ranged from 24 to 45.5 m^3. After the injection of the system one observed the increase in oil production and fluid flow rates, Figs. 7, 8. Incremental oil production for the semiannual period amounted to ~ 4000 tons for 5 wells, ~ 800 tons per well, the effect is still in progress. By the results of the conducted works the technology, based on surfactant, inorganic buffer solution and polyol, intended to increase oil production rates from low productivity production wells, has been recommended for commercial application.

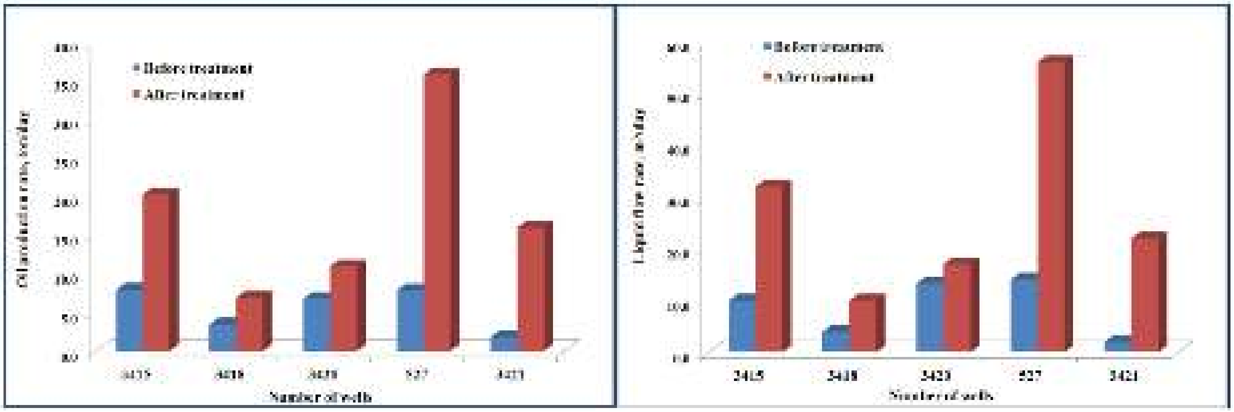

Figure 7—The results of bottomhole zones stimulations in low productivity production wells on the Permian-Carboniferous reservoir of the Usinsk oilfield using the system based on surfactants, inorganic buffer solution and polyol: increase in oil production rates and liquid flow rates

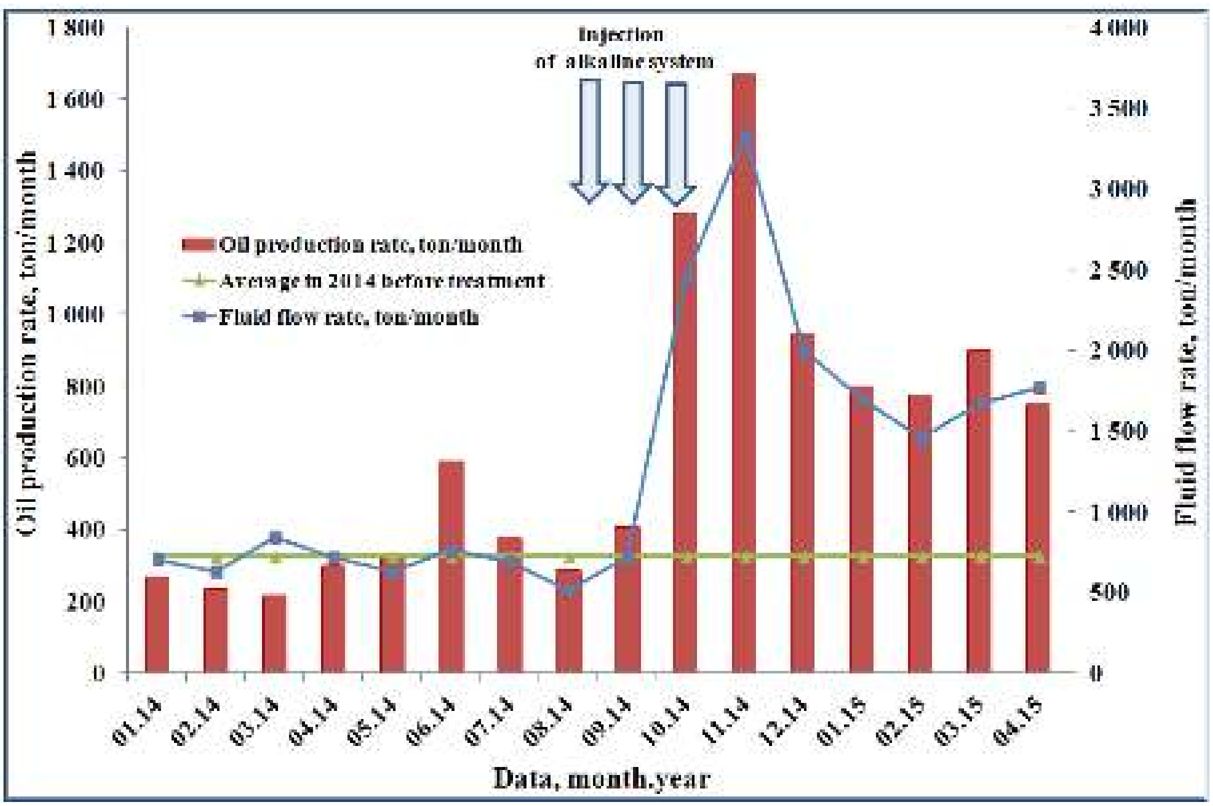

Figure 8—The results of bottomhole zones stimulations in low productivity production wells on the Permian-Carboniferous reservoir of the Usinsk oilfield using oil-displacing system based on surfactants, inorganic buffer solution and polyol, summary schedule for 5 wells

Oil-displacing acid system of the prolonged action based on surfactants, adduct of inorganic acid and polyol

To improve oil production by increasing the permeability of the reservoir rocks and to increase productivity of production wells the Institute of Petroleum Chemistry SB RAS has created an oil-displacing acid system of the prolonged action, based on surfactants, adduct of inorganic acid and polyol. The system is compatible with saline formation waters, has a low freezing point (-20 ÷ -60 °C) and low interfacial tension with oil. The system can be used in a wide range of temperatures, from 10 to 130 °C, it is the most effective in carbonate reservoirs, in particular, on the Permian-Carboniferous reservoir of the Usinsk oilfield. The system has a slower reaction with carbonate rocks, prevents the formation of insoluble products of the acid reaction in a porous medium, has a dehydrating effect and restores the initial permeability of the reservoir.

From May 29, 2014 to July 26, 2014 pilot tests of the acid system of the prolonged action, based on surfactants, adduct of inorganic acid and polyol, were carried out on the Permian-Carboniferous reservoir of the Usinsk oilfield. ″OSK″ Ltd. injected the acid system into 10 low productivity production wells. The volume of the injected system ranged from 30 to 50 m^3, the volume of the system concentrate – 9-15 m^3. Figure 9 shows a typical respond of the wells immediately after the injection, and Figure 10 – a generalized schedule for all 10 wells for the entire period available for observation after the treatment – 7-9 months.

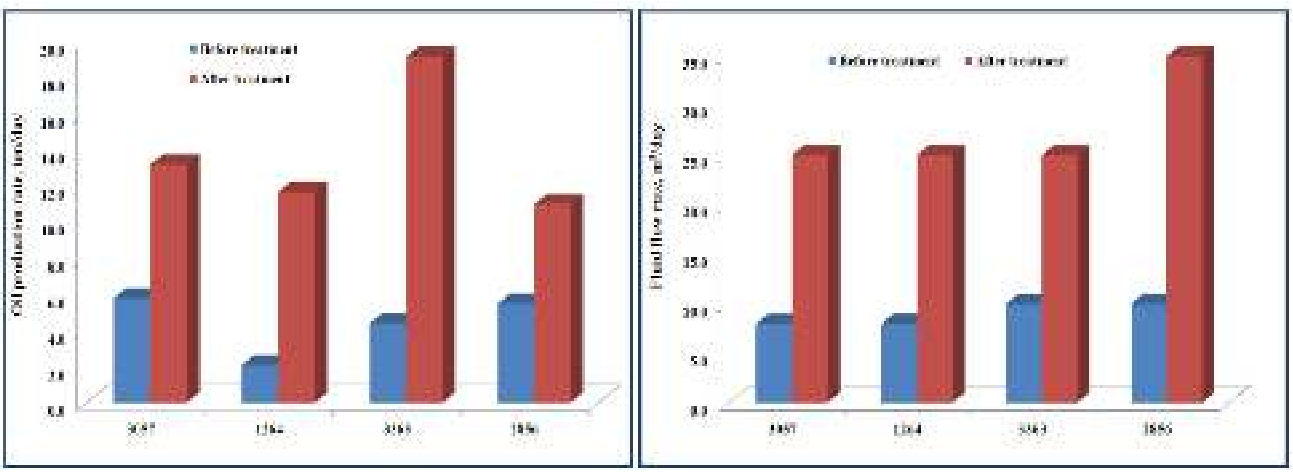

Figure 9—The results of pilot tests using acid system of the prolonged action in low productivity production wells 3057, 1264, 3363 and 2856 on the Permian-Carboniferous reservoir of the Usinsk oilfield: increase in oil production and fluid flow rates

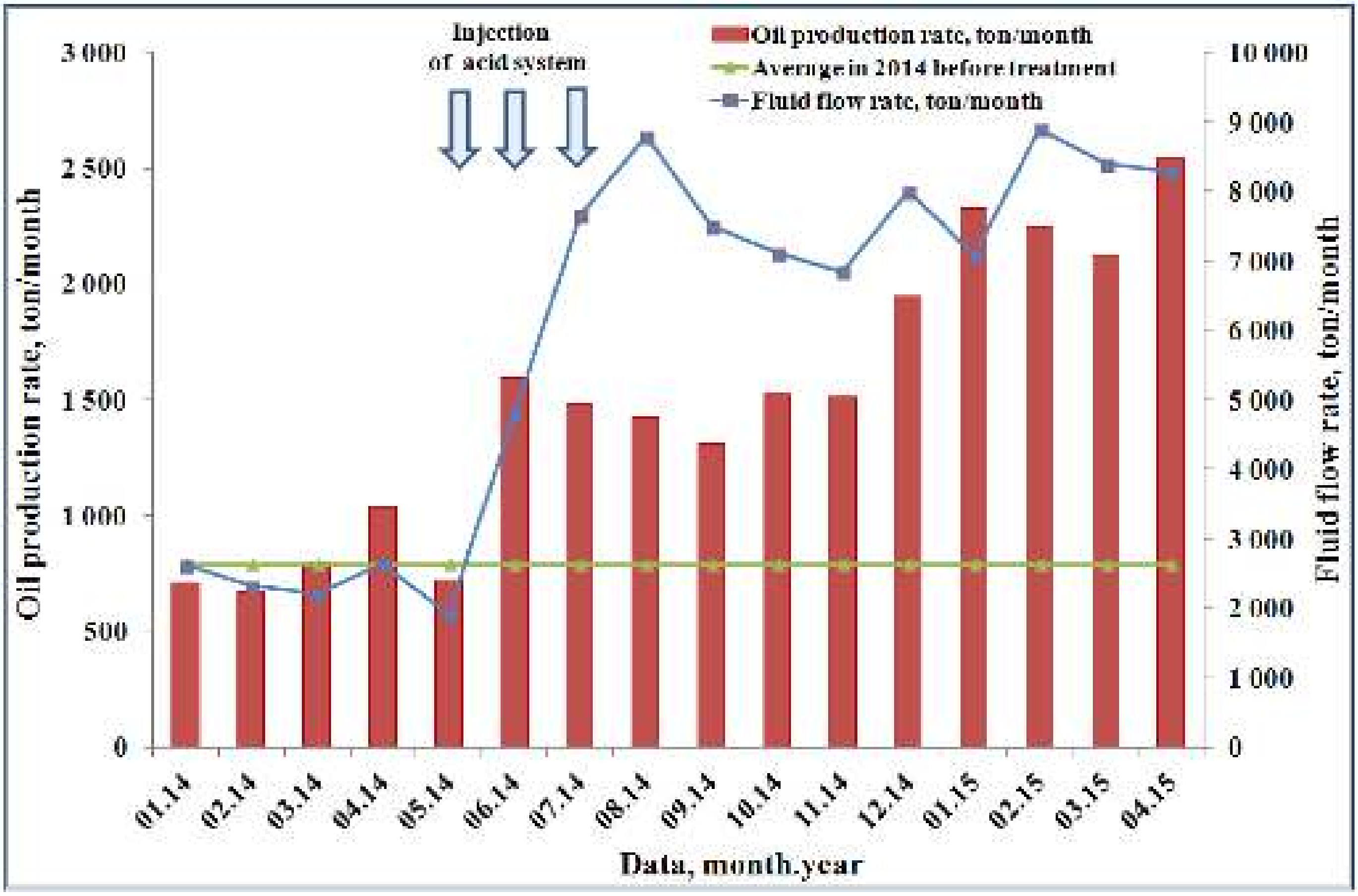

Figure 10—The results of pilot tests using acid system based on surfactants, adduct of inorganic acid and polyol total for 10 low productivity production wells on the Permian-Carboniferous reservoir of the Usinsk oilfield: increase in oil production and fluid flow rates

After the injection of the acid system of the prolonged action, based on surfactants, adduct of inorganic acid and polyol, oil production rate increased by 5.5-14.8 tons a day and fluid flow rate – by 15-25 m^3/d. Incremental oil production for the semiannual period amounted to ~ 6000 tons for 10 wells, about 600 tons per well, the effect is still in progress. By the results of the conducted works the technology involving acid system of the prolonged action intended to improve oil production by increasing the permeability of the reservoir rocks and increasing the productivity of low productivity production wells has been recommended for commercial application.

Conclusion

All the technologies presented in this paper proved their efficiency under field conditions and are recommended for further pilot projects and commercial application. One should note the high processability of these systems, since they can be prepared and injected by standard oilfield equipment.

Flow-deflecting technologies based on the use of the gel-forming and sol-forming systems for the injection wells are recommended for oilfields or large enough areas to have significant effect.

″Cold″ technologies intended to enhance oil recovery and intensify oil production from low productivity wells are considered as the most promising technologies due to good results of the pilot tests, as well as the potential flexibility and selectivity of their application in the most appropriate wells. Moreover, these technologies are suitable for cyclic application (cyclic-reagent stimulation) by analogy with cyclic-steam stimulation, but without heating the injected fluid.

Large-scale commercial application of the new integrated technologies to enhance oil recovery, combining a basic effect on the reservoir by water or steam injection with physicochemical methods that increase the reservoir coverage by the basic stimulation and oil-displacement factor at simultaneous intensification of the development, will extend the profitable exploitation of oilfields in later stages of their development, and involve oilfield with difficult-to-recover hydrocarbon reserves into the development, including heavy high-viscosity oil reservoirs and deposits in the Arctic region, will contribute to the development of the oil-producing industry and extend its fuel and energy basis.

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