Journal of Engineering and Applied Sciences 13 (Special Issue 12): 9289-9294, 2018
ISSN: 1816-949X

Assessment of Performance of ASP-Flooding Technology Realization in the Oil Field Development in Russia

N.A. Balatsenko, L.A. Saychenko and D.S. Tananykhin
Department of Oil and Gas Fields Development and Operation, Saint-Petersburg Mining University, Saint-Petersburg, Russia

Abstract: The study is dedicated to the technology of ASP-flooding (Alkali-Surfactant-Polymer-Flooding) the process of injecting into the reservoir a complex solution which includes surfactant, polymer and soda. The essence of technology is revealed in the research, the prospects of its application in the fields of Western Siberia are analyzed. The estimation of technological and economic efficiency of the method was carried out on the example of the Kholmogorsk oil field and the main reasons which hinder development of ASP-flooding at Russian objectsare identified. The calculation of technological efficiency is based on estimating the amount of additional oil production in the pilot area due to an increase of the oil displacement factorwith a change in the capillary number. For the mathematical modeling of ASP-technology, the differential equation describing the process of oil displacement from a selected volume of the formationwas used. The adsorption of the reagents was accounted for by Henry's law. The estimation of profitability of the technology was made after its scaling to several similar areas of wells. Analysis of the structure of costs for the implementation of ASP-flooding showed that the main reasons for the loss of the project are high prices for imported reagents, specialized equipment and for its logistics. In order to find these problem solutions an analysis of foreign experience was made. The results of this research can be used to design ASP-flooding in Russian fields.

Key words: Oil field development, enhanced oil recovery, physical and chemical methods as P-flooding, technological efficiency, economic efficiency

INTRODUCTION

Today the main problems in the oil industry are the growing number of hard-to-recover reserves, farness of oil producing regions, growing number of mature fields within the profitability limits of development, etc. In Russia most of the mature oil fields are developed with the help of conventional waterflooding technology. When using conventional waterflooding about 60% of the recovered oil remains in the reservoir. In such conditions the selection of effective methods of Increasing Oil Recovery (EOR) becomes one of the most important tasks of the oil producing companies (Rogachevm and Kondrashev, 2016).

Technologies of physical and chemical impact on the reservoir deserve special attention. One of the most promising methods of chemical impact is the ASP-flooding of the reservoir. ASP-flooding-injection into the reservoir of a displacing agent of complex composition including surfactant, alkali and polymer.

Surfactant increases the mobility of the pinched oil by reducing the surface tension between oil and water. Alkali due to the interaction with petroleum acids enhances the action of surfactants and also, passivates the rock. Polymer reduces the mobility of the injected solution and promotes uniform displacement of oil in the direction of producing wells. The complex composition of the injected solution allows to achieve maximum results and also to increase the oil recovery factor by a third (Koh *et al*., 2016; Sheng, 2010).

According to the forecasts of the scientific and analytical center for rational use of mineral resources V.I. Shipilman it is possible to extract 3.8 billion tons of oil in 73 fields of the Khanty-Mansiysk Autonomous Districtdue to ASP-water flooding in Russia, providing a 12% increase the oil recovery factor (Volokitin *et al*., 2015).

But despite this fact, now there is only one oil field in Russia where ASP-flooding is tested-Zapadnosalimskoye. The analysis of the pilot project at this object showed thatthis method is technologically effective-according to forecasts the oil recovery factorwill exceed 7%. Nevertheless, the companydoes not start full-fledged implementation of the technology (Volokitin *et al*., 2015; Denney, 2013; Qi *et al*., 2010).

Corresponding Author: N.A. Balatsenko, Department of Oil and Gas Fields Development and Operation, Saint-Petersburg Mining University, Saint-Petersburg, Russia

Analysis of researches on the research technology showed that, basically, many researchers describe the ASP-technology, the methods for selecting of the reagent composition and the analysis of the method implementation experience but the reasons for the weak development of the ASP-technology in Russia are not disclosed in detail.

For example, Semikhina *et al.* (2015) describe only one of the problems of ASP in Russia in their research. Researchers give a method of agents selection for ASP-technology which combines the study of reagents aqueous solution phase states on the border with kerosene and oil with its kerosene solutions. The study conducted by the researchers of more than 50 surfactants produced in Russia showed the absence of reagents among them, allowing to achieve maximum efficiency of ASP-technology. This result indicates the need for a more detailed consideration of more types of surfactants produced in Russia.

Zhu (2015) describes an example of the successful implementation of ASP-technology in Chinese fields where the gain to the oil recovery ratio was 20%. The researcher considers the optimization of ASP composition and ways of scaling the technology. The research does not describe other possible problems in the implementation of the technology but the experience described can be used for ASP design in Russia.

A. Weatherill (Zheltov, 1998) describes the mechanism of ASP-technology, the main problems that arise in its implementation and the strategy for their prevention. But this problems are not described in details. For this reason this study does not provide concrete solutions for Russian deposits.

In the researches of Volokitin *et al.* (2015) and Denny (2013) the steps of selecting the composition of the injected solution for a specific russian field, the results of tracer investigations are described. In these researches the reasons stopping commercial development of a method on the considered object are specified. But this point is not described in detail. For this reason, the researchers set a goal in this study on the basis of design of technology on one of the Russian fields to determine the reasons that impede the development of the ASP-technology in Russia.

The purpose of the researchison the basis of design of technology on one of the Russian fields to determine the reasons that impede the development of the ASP-technology in Russia.

Objectives of the study:

- To prove the possibility of using ASP-technology at the Kholmogorsk oil field
- Toevaluate the technological effectiveness of the method
- To evaluate the profitability of the project and identify the main factors that reduce it
- To analyze foreign experience of technology implementation
- To offer ways to increase the prospects for the development of ASP-flooding at Russian fields

The results of research can be used in the design of technology ASP-flooding on the Russian oil fields. The recommendations obtained in the course of the research will form a vector of ASP-flooding development in Russia and avoid critical errors.

MATERIALS AND METHODS

Kholmogorskoye oil field is at the final stage of development, the average value of watercut of the extracted production exceeds 95%. The analysis of geological and technical measures used at its objects showed that the methods aimed at the reservoir pressure maintenance system provide the highest efficiency which confirms the relevance of ASP-flooding implementation.

The parameters of the object considered for testing of the technology meet the criteria for the applicability of ASP-waterflooding (Table 1).

The choice of a pilot area for ASP-flooding was based on the analysis of current development indices, the waterflood scheme, the residual oil saturation and the general energy state of the formation. Analysis of the dependence of the degree of generation on watercut showed that, first of all, it is necessary to consider zones with water cut and cumulative oil-waterl ratio are above the average for the field. Such zones are most developed. On this basis it is possible to assume that the residual reserves are small and have the nature of film and capillary oil. The complex action of alkali, surfactant and polymer will increase the mobility of such oil (Ibatullin, 2011).

The implementation of ASP-flooding consists of several stages. The first is testing the technology in the pilot area (2-5 wells), testing the work of the solution and determining the effect. The second is the scaling of technology and implementation on the large block.

In the process of selection of wells for the implementation of the technology, several sections of wells located in the most attractive zones were considered. First of all, hydrodynamically isolated areas consisting of one or several injection wells and surrounding producing wells were considered. Wells had to open only one object. At the moment, they should not be implemented another interventions. The absence of behind casing leak and cross-flow was verified as was the

Table 1: Criteria for the applicability of technology (Nazarova, 2011)

Parameter	Criterion
Formationtemperature (°C)	<90
Oildensity (kg/m^3)	>850
Oilviscosity (mPa•s)	<150
Shaliness	Low
Waterhardness (ppm.)	<20
Salinity of formation water (g/L)	<35

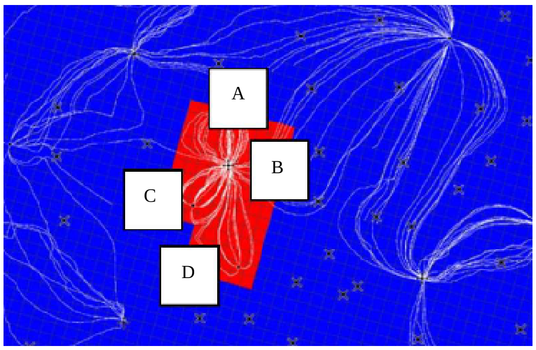

Fig. 1: Current lines from the selected injection well (from the hydrodynamic model)

effect of bottom water on the growth of water cut. The injection well should have a water injection capacity that meets the criteria of the technology (more than 200 m 3/day). For the selected injection and production wells an analysis of their interaction was carried out. As a result, the best candidate for pilot implementation of the technology was a section from one injection well and three producing wells surrounding it (Fig. 1).

The next step is the selection of reagents for injecting the formation. The choice of the composition of the solution must take into account the reservoir temperature, reservoir clay, mineralization of formation water, oil density, viscosity and acidity. For accurate selection of all reagents it is necessary to conduct long-term laboratory studies with cores, oil and formation water (Semikhina *et al*., 2015; Nazarova, 2011). In this case, experiments were not possible. For this reason a composition that has shown good results when implementing ASP-technology at the West Salym field (the characteristics of this field are similar to those of Kholmogorsky) is considered to assess the technological efficiency of ASP-flooding in the pilot area. Internal olefin sulfonates were used as surfactants, hydrolyzed polyacrylamide was used as the polymer, soda and isobutyl alcohol assolvent were also, added.

Before the direct determination of the technological efficiency of the injected solution, the main injection parameters such as the volume of the slug, the time of its formation, the number of reagents for the preparation of the solution, the injection capacity of well were calculated

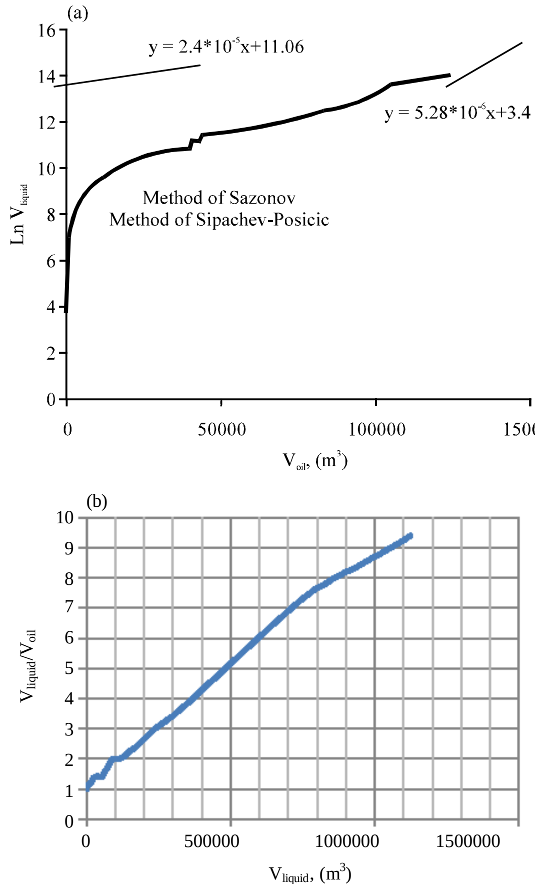

Fig. 2: Integral characteristics of displacement for the considered section of wells by the method of Sazonov and sipachev-posicic

(Zheltov, 1998). The adsorption of reagents was accounted by Henry's law, the results of the calculation are shown in Table 2.

To evaluate the technological efficiency of ASP-flooding integral displacement characteristics were constructed. They made it possible to estimate the value of potentially recoverable reserves during the implementation of a conventional waterflood before the end of the development (Table 3). Figure 2 shows one of the displacement characteristics with the largest correlation coefficient.

Judging from the obtained characteristics of data displacement as well as the known value of initial recoverable reserves, it was concluded that it is possible to produce another order of 18651.3 tons of oil.

The technological calculation of the effectiveness of ASP-flooding was based on the analysis of the change of the capillary number and the estimation of the decrease in the residual oil saturation. The decrease in residual oil saturation has led to an increase in the oil displacement ratio. To determine the effect of injection of the active

Table 2: Calculation of the basic parameters of injection ASP-slug

Injection capacity of well (m^3/day)	Volume of injectable slug (m^3)	Formati on time of slug (day)	Total consumption of surfactants (t)	Total consumption of polyment (L)	Total consumption of soda (T)	Total consumption of solvent (t)
200	63921.0	320	627.2	224	1792	179242

Table 3: Data obtained in the analysis of displacement characteristics

Calculation method	Cumulative oil production at the time of analysis (m^3)	Potentially recoverable oil reserves (m^3)	Remaining oil in place (m^3)	Correlation coefficient
Sazonov	119454	145077.80	25623.80	0.95
Sipachev-Posicic	119454	147654.65	28200.65	0.98
Govorova-Ryabinina	119454	141201.70	21747.70	0.90
Average values	119454	144644.70	25190.70	

solution, differential equations were derived that characterize the process of displacement of oil from the extracted volume of the formation.

Equation of balance of the concentration of injected reagents in a saturated solution (Zheltov, 1998):

$$\frac{dc}{dt}+\frac{q}{m.2.\pi.h.(1+\alpha).r}.\frac{dc}{dr}=0 \quad (1)$$

Where:

c = Concentration of reagents in the injected solution, unit fraction
m = Porosity, unit fraction
h = Effective oil-saturated thickness (m)
t = Time of injection into the reagent bed (sec)
r = Position of the rim in the reservoir at the considered moment of time (m)

On the basis of Eq. 1, a formula was obtained for calculating the velocity of the rim in the formation under conditions of plane-radial filtration (Zheltov, 1998):

$$v_c=\frac{dr_\phi(t)}{dt}=\frac{q}{2.m.(1+\alpha).\pi.h.r_\phi(t)'} \quad (2)$$

Where:

α = Coefficient of sorption of reagents on the rock (unit) fraction
q = Injectivity of the injection well in the solution (m 3/day)

In addition, a formula was derived for calculating the approach time of the reagent front to the selection line (Zheltov, 1998):

$$t=\frac{m.(1+\alpha).\pi.h}{q}.r_k^2 \quad (3)$$

where, r_k reservoir radius (m)

Equation 2 was used to calculate the capillary number N_c which influences the residual oil saturation as follows (Zhu, 2015):

$$S^*_{H.OCT}=0.280189+0.187062.InN_c+0.036483.(InN_c)^2+0.0017562(InN_c)^3 \quad (4)$$

In the course of the calculations, it was found that a change of the capillary number willled to the decrease in the residual oil saturation from 0.31 for normal waterflooding to 0.17 for ASP-flooding. The approach time of the slug to the selection line will be 4 years. During this period, about 35.750 m^3 of oil will be produced in the pilot area where 17.138.1 m^3 will be produced due to the implementation of the technology, the oil recovery rate will increase by 3.6%. The increase in production was estimated using the construction of integral forms of the curves of falling production rates. Accumulated oil production in 4 years, provided the continuation of the normal waterfloodingwas predicted based on the obtained dependencies (Fig. 3).

More accurate results in predicting the technological effect can be achieved by using specialized packages for hydrodynamic modeling, such as Eclipse, Mores, etc.

ASP-flooding method proves its technological efficiency on the object under consideration. But the assessment of the profitability of the project implementation at the Kholmogorskoe field showed a negative result, the pilot project was unprofitable.

The sensitivity analysis of the ASP-flooding project showed that the greatest impact on the amount of net discounted income is provided by revenue and cost which indicates the decisive role of the value in costs in the project's profitability (Fig. 4).

An analysis of the cost structure has shown that the main share of costs is the purchase and delivery of imported reagents in particular surfactants and specialized equipment (Fig. 5).

The main reasons restraining the development of commercial ASP-flooding projects on domestic deposits are: the high cost of imported reagents, the inaccessibility of specific equipment. In order to find solutions of the described problems, the successful experience of using ASP-technology in Canada and China was analyzed their main deposits are

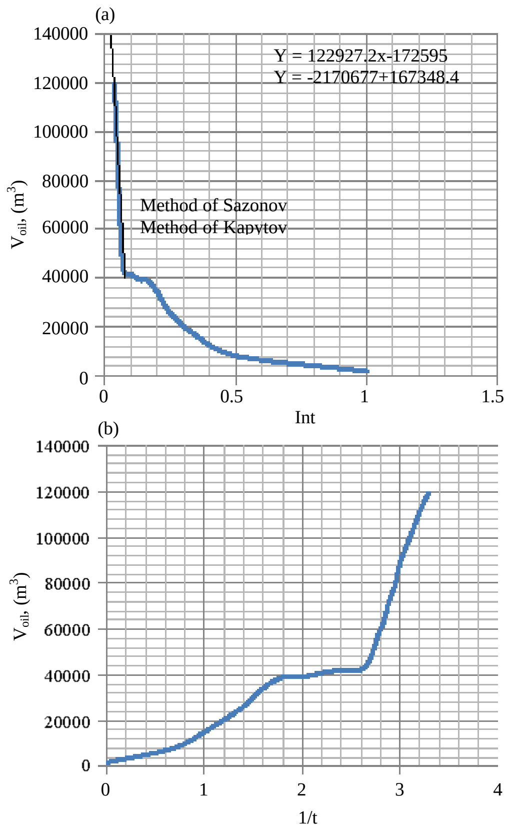

Fig. 3: Integral forms of the curves of falling production rates

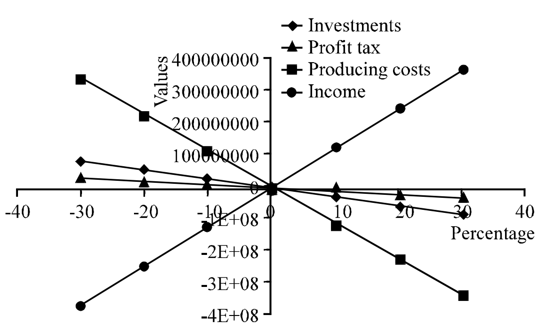

Fig. 4: Analysis of the sensitivity of the magnitude of the net present value of the project

similar in their parameters to the fields of Western Siberia. In China, 8 pilot ASP-flooding projects showedthe oil recovery rate increase of more than 20% which allowed to realize full-scale technology projects with a production gain of more than 2 million tons of oil (Zhu, 2015). In Canada as a result of the application of ASP-flooding technology, 20% of residual oil was recovered in the course of 20 years and at the Taber facility for 3 years to reduce water content by 10% and increase daily oil production by 6 times. The technology was applied to the

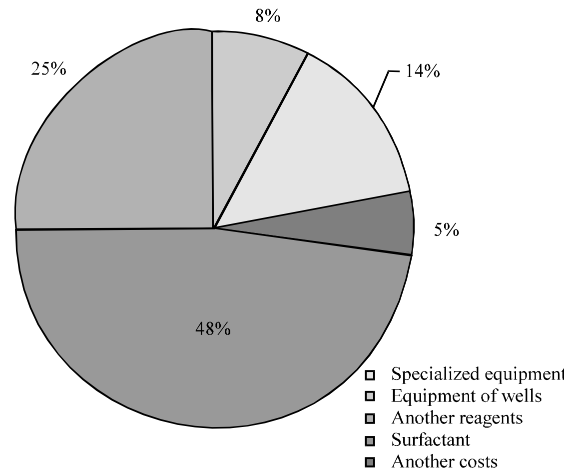

Fig. 5: Cost structure of the analyzed pilot project

offshore field in Malaysia where it worked even with a low content of active components (up to 0.5%) (Denny, 2013; Polishchuk and Mikhailove, 2013).

The reduction in the cost of oil production in China was achieved thanks to the availability of its own production of chemicals and equipment. In Canada in addition, modular mixing plants for reagents have been used which can be moved and used in other areas. In Canada, 20% of the residual oil was extracted at the David site for 20 years and at Taber site in 3 years, the water cut was reduced by 10% and the daily oil production was increased by 6 times. The technology was applied to the offshore field in Malaysia and worked even with a low content of active components (up to 0.5%) (Zheltov, 1998).

Due to the presence of its own production of chemicals and equipment, the reducing of the cost of oil production in China was achieved. In Canada, modular mixing systems for reagents were used which can be moved and used in another areas (Sheng, 2010, 2014).

RESULTS AND DISCUSSION

Assessment of performance of ASP-flooding technology realization in the oil field development in Russia Kholmogorsky oil field and the analysis of the experiences of Canada and China and also,the results of the technology at the West Salym deposit and the results of the conducted researches we may come to the conclusion that for the effective implementation of ASP-flooding on Russian fields, comprehensive measures are required, the priority of which should be.

Maximum localization of production of reagents and equipment on the territory of the Russian Federation. For example, domestically made alkyl phosphates can become a good alternative. Alkyl phosphates are anionic surfactants, exhibit high thermal stability and resistance to mineralization have anticorrosive properties and good detergency. By their properties, they are not inferior to the currently used internal olefin sulfonates but they have an important advantage the possibility of production in Russia (Norkem company). The localization of the production of reagents and equipment will significantly reduce project costs (by about 25-30%).

Development of research centers and constant scientific support. Introduction of special state programs and tax incentives: transition to a new tax regime for hard-to-recover reserves, compensation of costs due to a tax on the extraction of minerals.

CONCLUSION

With the help of the mathematical simulation of the ASP-flooding technology at the Kholmogorskoye oil field, the technological efficiency of the method at Russian fields has been proved. But despite the prospects, there are limitations of applicability which reduce profitability. Basically, these restrictions are associated with the production of reagents and process equipment.

Assessment of performance of ASP-flooding technology realization in the oil field development in Russia Kholmogorsky oil field, analysis of foreign experience in its implementation allowed to determine the factors hindering development technology and propose ways to eliminate them.

The complex solution of the described problems and the development of related industries makes it possible to introduce ASP-flooding in Russian fields. Successful implementation of only one full-scale project will bring profit to the state about 74 bill.rub..

The introduction of ASP flooding and other innovative methods contributes to the development of the oil industry in the face of a large number of uncertainties and will provide the multiplier effect through the development of related industries.

REFERENCES

Denney, D., 2013. Progress and effects of ASP flooding. J. Pet. Technol., 65: 77-81.

Ibatullin, R.R., 20111. Technological Processes of Oilfield Development. VNIIEENG, Moscow, Russia, Pages: 303.

Koh, H., V.B. Lee and G.A. Pope, 2016. Experimental investigation of the effect of polymers on residual oil saturation. Proceedings of the SPE Conference on Improved Oil Recovery Conference, April 11-13, 2016, Society of Petroleum Engineering, Tulsa, Oklahoma, USA, ISBN:978-1-61399-439-9, pp: 1-23.

Nazarova, L.N., 2011. Development of Oil and Gas Deposits with Hard-to-Recover Reserves. Publishing House of the Gubkin Russian State University of Oil and Gas, Moscow, Russia, Pages: 156.

Polishchuk, V.I. and N.N. Mikhailov, 2013. Numerical modeling of the residual oil saturation. J. Eng. Applied Sci., 12: 4809-4813.

Qi, L.Q., H.Q. Zhu and Y.P. Sun, 2010. Recommended low concentration surfactant system for ASP flooding. Pet. Geol. Oilfield Dev. Daqing, 29: 143-149.

Rogachevm, M.K. and A.O. Kondrashev, 2016. [Justification of intra-plastic technology water isolation in low-permeable collectors (In Russian)]. Proc. Mining Inst., 217: 55-60.

Semikhina, L.P., S.V. Shtykov and E.A. Karelin, 2015. Selection of reagents for ASP-technology improvement plastic oil recovery. Electron. Scientific J. Oil Gas Bus., 4: 53-71.

Sheng, J., 2010. Modern Chemical Enhanced Oil Recovery: Theory and Practice. Gulf Professional Publishing, Houston, Texas, ISBN-13: 9780080961637, Pages: 648.

Sheng, J.J., 2014. A comprehensive review of Alkaline-Surfactant-Polymer (ASP) flooding. Asia Pac. J. Chem. Eng., 9: 471-489.

Volokitin, Y.E., M.Y. Shuster and V.M. Karpan, 2015. [Enhanced Oil Recovery Methods and ASP Technology (In Russian)]. ROGTEC Russ. Oil Gas Technol., 42: 24-35.

Zheltov, Y.P., 1998. Development of Oil Deposits. Nedra, Moscow, Russia, Pages: 332.

Zhu, Y., 2015. Current developments and remaining challenges of chemical flooding EOR techniques in China. Proceedings of the SPE Conference on Asia Pacific Enhanced Oil Recovery (EORC'15), August, 21-38, 2015, Society of Petroleum Engineers, Kuala Lumpur, Malaysia, ISBN:978-1-61399-389-7, pp: 1-18.