Efficiency analysis of hydrodynamic enhanced oil recovery methods on the example of Las-Eganskoye field

V Dyagilev, N Lazutin, T Dyagileva and V Baksheev
Tyumen Industrial University, 38, Volodarsky St., Tyumen, 625000, Russia

E-mail: glibazval.dyagilev@yandex.ru, kpw72@yandex.ru, LazutinaTV@yandex.ru, baksheev46@yandex.ru

Abstract. The majority of oil fields in Western Siberia are at the late stage of their development. Therefore, the minimization of economic and technological costs aimed at enhanced oil recovery is becoming a primary task. Hydrodynamic methods of enhanced oil recovery (HM EOR) fully satisfy these requirements, which makes them the most promising in further development of oil fields in Western Siberia. The methodology includes measurement and description, which use allows analyzing and assessing the study of HM EOR application. The purpose of this study is to demonstrate the efficiency of HM EOR on the example of Las-Eganskoye field. The study of hydrodynamic methods of enhanced oil recovery included the analysis of results, which allowed developing recommendations for the implementation of HM EOR in the oil fields of Western Siberia. It is shown that the technological opportunity of HM EOR requires clarification based on the current state of field development taking into account the peculiarities of reservoir pressure maintenance system, technical condition of pipelines and the stock of active injection wells proposed for cyclic injection.

1. Introduction
At present, the search for effective methods and technologies that provide for qualitative and quantitative increase of the volume of extracted natural reserves is becoming ever more critical in the field of oil production and refining technologies. Therefore, the core object of this study is Las-Eganskoye field located within the territory of Nizhnevartovsk district of Khanty-Mansi Autonomous District – Ugra of Tyumen Region, 120 km north-west of the district center Nizhnevartovsk and 30 km north of Langepas.

As of 01.01.2015 the efficiency analysis of hydrodynamic methods (HM) for enhanced oil recovery (EOR) in Las-Egan field was carried out from January 2010 to December 2014.

2. Literature review
The scientific community was centered around the problem of the rational use of hydrocarbon resources [10] that was theoretically solved in the works of domestic [1, 5] and foreign studies [6, 7], which are focused on the search for methods to forecast the technological efficiency of oil production and evaluation. The analysis of modern methodology of resource development within oil and gas complexes [3, 4] showed the timeliness of the study of existing techniques and principles of assessing the current state of oil reserves in northern territories of the Russian Federation. Modern researchers overestimate the existing methods to forecast oil production [1, 2, 8] thus suggesting the latest techniques aimed at predicting the technological efficiency of oil production and evaluation.
3. Methods
Hydrodynamic methods of enhanced oil recovery (HM EOR) included the analysis of shutdowns of injection wells, forced fluid production (FFP) and development of production wells for injection (DWI).

4. Results and discussion
The non-stationary (cyclic) water flooding (NWF) at the facilities of Las-Eganskoye field TPP Langepasneftegaz under special programs based on the study of geological features of the field and technological possibilities of their implementation was carried out in 2013 and 2014.

Since the number of planned measures at field facilities is not sufficient for statistical assessment of NWF efficiency and subsequent calculation of predicted oil production, the analysis of this measure regarding the shutdown of injection wells was carried out. Under certain conditions the shutdown of injection wells can be considered as NWF. Such conditions include the following: 1) shutdown of the injection well for more than 7 days (in this case the shutdown time of the injection well is considered as the half-cycle of NWF); 2) injectivity at the moment of shutdown more than 50 m$^3$/day. Such shutdowns are carried out to ensure various types of well interventions (WI), which are not intended to obtain additional oil production from NWF, hence no preliminary study of geological and technological features favorable to NWF were carried out. In this case, this action is mainly characterized by the side effect of the main purpose of the injection well shutdown.

A 50 % increase in the liquid rate in production wells was taken as FFP. Besides, the fluid flow rate after FFP shall on average remain at the same level within at least 6 months after WI. The fluid withdrawal is usually increased due to replacement of a pump with a pump that is more efficient, less often due to the change of the pump speed (ESP) or reciprocating speed (SRP). In documents such activities are usually referred to as Operation Mode Optimization (OMO), sometimes as Pump Revision and Change (PRC).

Based on these conditions during the period from January 2010 to December 2014, as of 01.01.2015, 434 activities were performed in developed objects of the field, $AV_{1-2}$, $BV_6$, $BV_8$, AC and JV1, which resulted in the effect from HM EOR. Among them 29 well operations were performed according to a specially developed and justified program.

Since 2013, all NWF works at Las-Eganskoye field were planned, so the maximum number of activities fell within 2013 and 2014, which is 104 and 85 WI respectively. The minimum number of activities was carried out in 2010 (39). In 2011 and 2012, approximately equal number of activities were carried out (50 and 49 respectively).

Figure 1 shows the distribution of HM EOR by year of the analyzed period of development and objects of Las-Yeganskoue field.

We see that the maximum number of NWF was performed in 2013 (104) and in 2014 (85), the minimum – in 2010 (39). In 2011 and 2012, approximately the same number of activities were carried out (50 and 49 respectively), of which 226 WI in $AV_{1-2}$, 76 in JV1 and 23 in $BV_6$.

FFP was most often performed in 2011 and 2014 (15 and 13 activities respectively). In 2010, 2012 4 activities were carried out, in 2013 – 7. At the same time, the maximum number of FFP was carried out in JV1 (20) and $AV_{1-2}$ (16), the minimum – in $BV_6$.

Similar to FFP, the maximum number of DWI was carried out in 2013 – 23 WI. Since 2011, the number of DWI was reduced from 23 to 5 in 2014. The maximum number of DWI for the entire period under review was performed in JV1 (34) and $AV_{1-2}$ (26). 2 FFP actions were carried out in $BV_6$. In AC there were 2 NWF and 1 DWI.

The effect from each performed action was calculated. The effect of HM EOR refers to additional actions in a formation site, which is influenced by the change of the operation modes of injection wells (NWF, DWI) or production wells (FFP).
The number of observation wells on the site was selected from the nearest wells where the operations were carried out based on peculiarities of object development in different periods. If the observation wells were in the zone of influence of several wells, where HM EOR were performed simultaneously (or sequentially, in 1–5 months), then such sites were combined into one and additional oil production was calculated based on their joint impact.

223 sites were selected for efficiency calculations.

The effect was calculated for all observation wells of the site for the next six months after the operations were completed. If well operations were carried out with some periodicity (from 15 days to 4 months) or the site was influenced by two or more shutdown wells, the effect was usually calculated after six months from the last shutdown.

The overall effect was calculated according to Medvedsky’s characteristic of displacement in Delta software, which allows dividing the overall effect into two components: oil recovery and development stimulation. The positive effect of oil recovery is understood as additionally extracted oil due to WI, which under the basic development would not be extracted (WI resulted in the improvement of oil displacement characteristics). The positive effect of development stimulation is understood as additionally recovered oil in a given period of time (at calculations for a period of 6 months), which under the basic development would be extracted from the formation for a longer period of time.

Alongside with NWF, other WI were carried out on some selected areas, for example, perforation (isolation of separate intervals), start-up of a production well, transfer to another object with subsequent perforation, well fracturing, bottom hole treatment, etc. If their obvious effect on additional oil production from HM EOR was observed, then such wells were excluded from the calculation of additional oil produced in the site.

Calculations show that HM EOR for the last 5 years of development allowed producing additional 101.34 thousand tons of oil. Figure 2 shows the distribution of the total quantity of additional oil production and the quantity of HM EOR in Las-Eganskoye field by years (left) and by objects (right).
Figure 2. Distribution of the total number of additional oil production and number of hydrodynamic methods in Las-Eganskoye field for the analyzed period of development (left) and by objects (right) [5]

Figure 3 shows the distribution of specific additional oil production by types of HM EOR.

Figure 3. Distribution of specific additional oil production by types of hydrodynamic methods of enhanced oil recovery [5]

Table 1 shows the distribution of additional production by objects, years and number of operations. The last column of the table shows specific additional oil production for each object and type of WI.
Table 1. Distribution of activities and additional oil production by types of hydrodynamic methods, objects and years for the analyzed period of development [5]

| Object | 2010 | 2011 | 2012 | 2013 | 2014 | Total |
|--------|------|------|------|------|------|-------|
|        | Additional oil production, th.t. | Additional oil production, Number of operations | Additional oil production, Number of operations | Additional oil production, Number of operations | Additional oil production, Number of operations | Additional oil production, Number of operations |
|        | JV | BV | JV | BV | JV | JV | BV | JV | BV | JV | BV | JV | BV |
| Total: | 4.18 | 3 | 3.29 | 7 | 2.63 | 3 | 0.15 | 6 | 1.31 | 10 | 11.56 | 29 | 0.4 |
| Well development for injection |  |  |  |  |  |  |  |  |  |  |  |  |  |
| AV_{1:2} |  | - | - | 1.14 | 4 | 0.02 | 1 | 0.53 | 3 | 0.29 | 4 | 1.98 | 12 | 0.17 |
| BV_{6} | - | - | 2.15 | 3 | - | - | -0.53 | 1 | -0.01 | 1 | 1.63 | 5 | 0.32 |
| BV_{8} | - | - | - | - | - | - | - | - | - | 0.41 | 2 | 0.41 | 2 | 0.21 |
| JV_{1} | 4.18 | 3 | - | - | 2.61 | 2 | 0.15 | 2 | 0.62 | 3 | 7.56 | 10 | 0.76 |
| Total: | 4.18 | 3 | 3.29 | 7 | 2.63 | 3 | 0.15 | 6 | 1.31 | 10 | 11.56 | 29 | 0.4 |
| Non-stationary water flooding |  |  |  |  |  |  |  |  |  |  |  |  |  |
| AV_{1:2} | - | - | - | 2.92 | 29 | 2.3 | 24 | 7.5 | 20 | 7.1 | 76 | 6.7 | 47 | 24.4 | 206 | 0.12 |
| BV_{6} | - | - | - | 0.32 | 3 | 1.2 | 3 | 0.16 | 5 | 0.1 | 7 | 0.15 | 3 | 2.03 | 22 | 0.09 |
| BV_{8} | - | - | 0.28 | 1 | - | - | - | - | 0.28 | 1 | - | - | 0.28 | 1 | 0.28 |
| JV_{1} | -0.56 | 2 | 0.1 | 5 | 1.5 | 6 | 6.0 | 17 | 3.99 | 28 | 11.1 | 58 | 0.19 |
| Total: | 2.68 | 39 | 4.6 | 33 | 9.18 | 50 | 13.1 | 101 | 10.8 | 78 | 40.8 | 288 | 0.13 |
| Non-stationary water flooding and well development for injection |  |  |  |  |  |  |  |  |  |  |  |  |  |
| AV_{1:2} | 0.25 | 2 | - | 18 | 0.94 | 7 | - | - | - | - | - | - | 0.64 | 27 | 0.02 |
| BV_{6} | - | - | 0.2 | 2 | - | - | - | - | - | - | - | - | 0.22 | 2 | 0.11 |
| JV_{1} | 0.73 | 2 | 1.5 | 3 | 0.55 | 2 | 0.7 | 4 | 1.13 | 3 | 4.64 | 14 | 0.33 |
| Total: | 0.98 | 4 | 1.1 | 23 | 1.49 | 9 | 0.7 | 4 | 1.13 | 3 | 5.5 | 43 | 0.13 |
| Non-stationary water flooding and forced fluid production |  |  |  |  |  |  |  |  |  |  |  |  |  |
| JV_{1} | 2.7 | 4 | 1.56 | 2 | 1.9 | 2 | 1.82 | 6 | 8.01 | 14 | 0.57 |
| Well development for injection and forced fluid production |  |  |  |  |  |  |  |  |  |  |  |  |  |
| AV_{1:2} | - | - | - | 2.2 | 2 | - | - | - | 1.65 | 2 | 3.85 | 4 | 0.97 |
| JV_{1} | - | - | 4.2 | 5 | - | - | - | - | 1.75 | 2 | 6.02 | 7 | 0.86 |
| Total: | - | - | 6.4 | 7 | - | - | - | - | 3.4 | 4 | 9.87 | 11 | 0.9 |
| Non-stationary water flooding, well development for injection and forced fluid production |  |  |  |  |  |  |  |  |  |  |  |  |  |
| AV_{1:2} | - | - | - | 0.3 | 7 | - | - | - | - | - | - | 0.3 | 7 | 0.04 |
| JV_{1} | 6.81 | 4 | - | - | - | - | - | - | - | - | 6.81 | 4 | 1.7 |
| Total: | 6.81 | 4 | 0.3 | 7 | - | - | - | - | - | - | 7.11 | 11 | 0.65 |

In general, it can be said that additional oil production for each year of the analyzed period is approximately the same and varies from the minimum of 18.4 thousand tons (in 2011) to 24 thousand tons (2013). At the same time, the maximum additional oil production accounts for JV_{1} (57.5 thousand tons) and AV_{1:2} (36.8 thousand tons). The maximum additional oil production was received from NWF.
(40.8 thousand tons in 141 sites). However, the specific additional production from FFP and DWI made 0.14 thousand tons/pr.well, which is 11.6 and 16.9 thousand tons of oil respectively, with higher specific additional oil production (0.40 and 0.44 thousand tons/pr.well respectively).

In sites where the operations were carried out jointly, the maximum amount of additional oil production was obtained where FFP and DWI were performed simultaneously (9.9 thousand tons in 5 sites).

The lowest production was obtained from the joint influence of NWF and DWI (5.5 thousand tons in 14 sites). In areas where specific additional production was carried out simultaneously with NWF and DWI the specific additional production was high (up to 0.9 thousand tons/pr.well). However, it is not possible to draw conclusions and make recommendations on the joint application of FFP with other HM EOR due to insufficient statistical data.

The impact of hydrodynamic methods of enhanced oil recovery on development indicators of Las-Eganskoye field is shown below.

In order to answer the question, how HM EOR affected field development indicators, the frequency of distribution of positive and negative effects of oil recovery and stimulation was carried out. The oil recovery effect is understood as additional oil produced due to WI, which under basic development would not be covered by development. The stimulation effect means additionally produced oil in a given period of time (calculated for a period of 6 months), which under basic development would be extracted from the formation for a longer period of time [2, 5].

For this assessment, the number of positive, negative and unclear HM effects at Las-Eganskoye field were calculated.

Diagrams of distribution of oil recovery and stimulation effects were designed. In calculating the number of positive and negative effects, sites with additional oil production ranging from –200 to +200 tons were removed to improve the quality of sampling. These effects are classified as unclear. The figures apply the following symbols: “+” – positive, “−” – negative and “UC” – unclear effect [4].

In the majority of cases NWF has a positive effect in terms of oil recovery – 72 sites (or 51% of sites) (Figure 4). The number of sites with positive stimulation effect is small – 14 (10% of sites), at the same time in 98 sites this effect at NWF is unclear.

FFP can both increase oil recovery and stimulate oil production, but the number of sites with a positive stimulation effect is greater than the number of sites with a positive recovery effect – 15 (55%) and 11 (40%) sites respectively. In most cases, FFP results in stimulation of oil production.

Similar to NWF, DWI in most cases has a positive effect in terms of oil recovery – 18 sites (62%). The number of sites with positive stimulation effect is 7 (24%), with negative – 6 (20%), at the same time in 16 sites out of 29 the effect is unclear.

In sites where NWF and DWI were performed simultaneously, the number of sites with the positive effect of oil recovery is also greater than the number of sites with the positive effect of stimulation, 9 and 4 sites respectively. The number of sites where NWF and FFP were performed simultaneously (5 sites), DWI and FFP (5 sites) or NWF, OSN and FFP (3 sites) is not sufficient to draw a statistically reliable conclusion.

Based on statistically reliable data, it can be concluded that NWF and DWI operations in Las-Eganskoye field in most cases allow obtaining additional oil production due to enhanced oil recovery. In most cases FFP (OMO, PRC) operations intensify oil production.

Figure 5 shows the trend of the main development indicators during NWF operations in Las-Eganskoye field.
5. Conclusion

Additional oil production as a result of HM EOR for each year of the analyzed period is approximately the same and varies from a minimum of 18.4 thousand tons (2011) to 24 thousand tons (2013). At the same time, the maximum additional oil production accounts for objects: JV₁ (57.5 thousand tons) and AV₁₂ (36.8 thousand tons). The maximum additional oil production was received from NWF (40.8 thousand tons in 141 sites). However, the specific additional production from FFP and DWI made 0.14...
thousand tons/pr.well, which is 11.6 and 16.9 thousand tons of oil respectively, with higher specific additional oil production (0.40 and 0.44 thousand tons/pr.well respectively).

In sites where the operations were carried out jointly, the maximum amount of additional oil production was obtained where FFP and DWI were performed simultaneously (9.9 thousand tons in 5 sites).

The lowest production was obtained from the joint influence of NWF and DWI (5.5 thousand tons in 14 sites). In areas where specific additional production was carried out simultaneously with NWF and DWI the specific additional production was high (up to 0.9 thousand tons/pr.well). However, it is not possible to draw conclusions and make recommendations on the joint application of FFP with other HM EOR due to insufficient statistical data.

Based on statistically reliable data, it can be concluded that NWF and DWI operations in Las-Eganskoje field in most cases allow obtaining additional oil production due to enhanced oil recovery. In most cases FFP (OMO, PRC) operations intensify oil production.

It shall be noted that the highest efficiency of HM EOR is achieved in case the average injection in the site prior to NWF is equal to the average injection in the site during NWF operations. For this purpose, it is necessary that the capacity of operating injection wells during the half-cycle of their operation is approximately twice more than their capacity prior to the start of cyclic injection. Therefore, it is necessary to study the possibility of increasing the capacity of injection wells in the semi-cycle of their operation.

If this is not done, there may be a problem with the injection of formation water. In general, the amount of formation water at NWF is usually reduced. One of the efficiency criteria of cyclic injection of water into the formation is the reduction of water content of observation production wells of the site and the reduction of the quantity of formation water. Besides, the quantity of formation water may decrease in production wells located in the homogeneous part of the formation and having direct hydrodynamic connection with shut-off injection wells, which did not react to non-stationary flooding. As a result, such wells may be characterized by the decrease in fluid and oil flow rates. As the experience of cyclic injection shows, in Las-Yeganskoye field and in other fields, this problem is usually solved by the redistribution of water through other injection wells not involved in cyclic injection. If it is not possible to do so for any reason, then inactive or temporary abandoned injection wells (especially those located in the border zone) may be used for the injection of formation water. If water from the wells of PC formation (the Cenomanian) is used for injection, it is recommended to shutdown such wells for the period of non-stationary flooding.

References

[1] Vakhrushev V V, Melnikov V N and Moskvitin S A 2016 Generalization of experience of development of the target area YUV1 of fields of LLC “LUKOIL – Western Siberia” to increase the validity of the forecast of technological parameters *Oil industry* 8 44–7

[2] Dyagilev V F, Abramov N V and Belyaev O V 2018 Technology of development of water-oil zones in the North Orekhov field *Opyt, aktual’nye problemy i perspektivy razvitiya neftegazovogo kompleksa* (Materialy Mezdunarodnoj nauchno-prakticheskoj konferencii obuchayushchihsya, aspirantov i uchenyh no 1) pp 96–100

[3] Seigman Yu V, Gumerov O A, Karimov R M and Shamaev G A 2010 Hydrodynamic methods of regulation of oil field development *Aktual’nye voprosy razrabotki neftegazovyh mestorozhdenij na pozdnih stadiyah. Tekhnologii. Oborudovanie. Bezopasnost’. Ekologiya* (Materialy nauchno-prakticheskoj konferencii) 258 p

[4] Report on the main technical and economic indicators of exploitation of deposits of CCI "Langepasneftegaz" for the period 1999–2014 2015 245 p

[5] Surguchev M L and Sharbatova I N 1988 *Cyclical effects on heterogeneous oil reservoirs* (Moscow: Subsoil) 121 p

[6] Wang L et al 2017 Advances in improved/enhanced oil recovery technologies for tight and shale reservoirs *Fuel* 210 425–45
[7] Xian’e L, Zhi X, Hongyao Y, Yujun F and Hongping Q 2017 Comparative Studies on Enhanced Oil Recovery: Thermoviscosifying Polymer Versus Polyacrylamide Energy fuels 31(3) 2107–3328

[8] Xian’e L, Zhi X, Hongyao Y, Yujun F and Hongping Q 2017 Comparative Studies on Enhanced Oil Recovery: Thermoviscosifying Polymer Versus Polyacrylamide Energy fuels 31(3) 2479–87

[9] Wang X and Sheng J J 2017 Effect of low-velocity non-Darcy flow on well production performance in shale and tight oil reservoirs Fuel 190 41–6

[10] Etminan S R, Maini B B and Chen Z 2017 Determination of mass transfer parameters in solvent-based oil recovery techniques using a non-equilibrium boundary condition at the interface Fuel 120 218–32