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THE PROCESS OF MONITORING THE CURRENT CONDITION OF OIL RECOVERY AT THE PRODUCTION FIELDS IN WESTERN KAZAKHSTAN

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Key words: *repair-insulation works, polymer flooding, enhanced oil recovery, technical-and-economic efficiency*

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THE PROCESS OF MONITORING THE CURRENT CONDITION OF OIL RECOVERY AT THE PRODUCTION FIELDS IN WESTERN KAZAKHSTAN

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The problems of improving the technology aimed at reducing the volume of associated water production and increasing oil recovery from partially flooded deposits is very urgent. This paper discusses topical problems of further effective development of depleted oil fields to increase their final oil recovery on the example of the oil field in Western Kazakhstan. The methods of bottomhole zone treatment implement a deflecting effect on filtration flows. Therefore, this method includes a wide range of geological and technical measures: down-spacing; water production restraining; conformance control of injectivity profiles; forced production; all types of mechanical, thermochemical and thermal technologies. Geological and statistical models are proposed for diagnosing wells for a premature increase of water production using factor analysis calculations for base production and Hall plots. The degree of temperature influence of the primary components of the compounds on the rheology, filtration characteristics, and stability of inverted emulsions was determined. The classification of oil loss factors was carried out based on the results of downhole analysis and oil production losses were determined. Geological and statistical models for well diagnostics for premature increase in water production were built using factor analysis calculations for base production and Hall plots.

Key words: repair-insulation works, polymer flooding, enhanced oil recovery, technical-and-economic efficiency

INTRODUCTION

Many researchers have studied and established the main reasons for water encroachment, the breakthrough of injected water through highly permeable and undersaturated layers [1]; pulling up the water cone from oil-water zones [2]; breakthrough of stratal waters from above and below-lying water beds along the borehole annulus [3]. Leakage of production strings in various water-saturated sections. Examples of operating costs optimisation and acceleration of the efficiency of making engineering decisions have been carried out. In this paper, geological and statistical calculations are proposed for diagnosing wells candidates for RIW (repair and insulation works) [4-7].

The present paper examines the increase in the efficiency of water shut-off works with the use of new technologies, taking into account the geological and technological characteristics of the Karamandybas production field operation. The field is located in the western part of the Mangyshlak Peninsula and is administratively subordinate to the Karakiyansky district of the Mangistau region of the Republic of Kazakhstan. At the field, drilled wells uncovered a stratum of Paleo-Meso-Cenozoic deposits with a maximum depth of 3202 m (well 27). In the section of the wells, rocks of the undifferentiated Carboniferous, Triassic, Jurassic, Cretaceous, Paleogene systems were identified [8-10]. The region under consideration is part of the Turan Plate, which is part of the Central Eurasian young epi-Hercynian platform. There are three structural levels in the section, separated from each other by regional stratigraphic and angular unconformities [11, 12].

The cumulative oil withdrawal amounted to 60.5% of the approved recoverable reserves of the field, the current oil recovery is 22.5%. The main developed objects of the Karamandybas deposit: U-2 and U-3 – at the initial stage; U-5ab, U-5v6, U-8, U-9, U-10, U-11 – on the second and third; U-12 and U-13 are at a late stage. Below is a brief description of production zone development. The largest withdrawal from recoverable reserves was noted for U-12 and U-13 (92% and 87.7%), the smallest – U-4 (17.7%), U-11 (31.6%). The changes in indicators since the beginning of development for the production in total is shown in the Figure 1.

Selective isolation of water production is used when part of the productive formation is flooded. The mechanism consists in selective isolation of highly permeable interlayers and cracks by the effect of transition of the silicate-polymer solution injected into the well into the gel at an elevated formation temperature. The hydrogel formed in the reservoir has low mobility and high viscoelastic properties [13-15]. Selective action technology is relatively easy to implement in the case when it is necessary to stimulate its perforated lower section. In this case, the tubing is run into the well with a packer, which is set above the lower formation interval [16-18]. It requires the presence of a caprock over the lower formation interval

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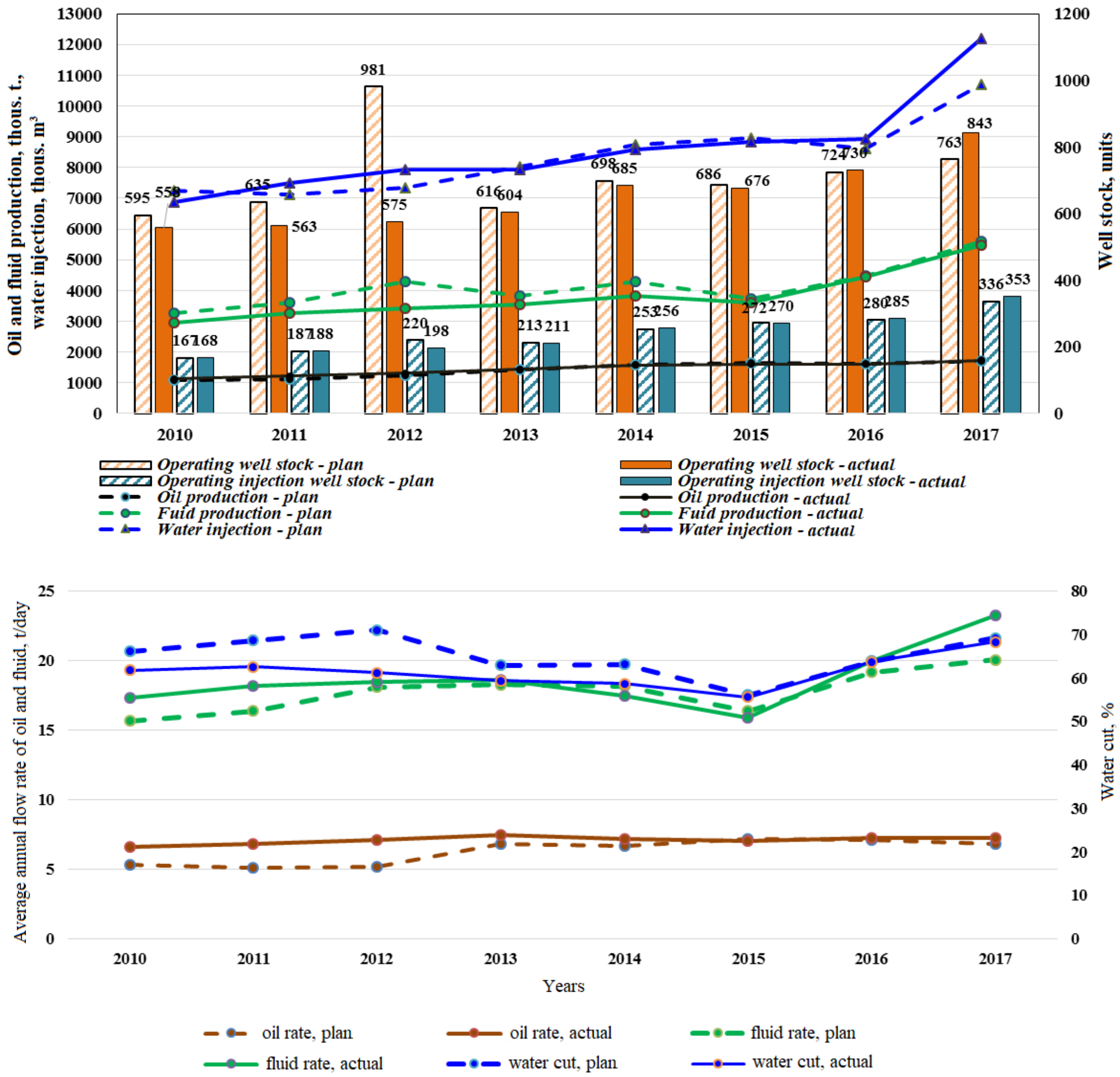

Figure 1: Dynamics of the main development parameters for the Karamandybas field

and the absence of perforation in this production string interval. Then, appropriate measures are taken to stimulate the lower perforated part of the productive formation. In this case, the upper interval is isolated by a packer [19, 20]. In the case when it is necessary to stimulate the middle (upper) part of the formation in the well, the lower (middle) perforated part is covered with a cement bridge.

MATERIALS AND METHODS

The operational analysis related to limiting the water inflow directly from a layer-by-layer heterogeneous reservoir has been conducted. At the same time, methods are used that make it possible to disconnect the watered interval or interlayer from the development or significantly reduce the permeability of water-encroached zones. Such an interval shutdown of flooded formations from the development, before water encroachment throughout the facility, makes it possible to increase the current oil recovery ratio by 4-5% with a decrease in the water-oil factor by 1.5-1.7 times compared to joint production without stimulation. The number of RIW carried out at production wells is shown in the Table 1.

The most part is occupied by repair-insulation works associated with the transfer to the higher (lower) horizon (73%). When selecting the well conversion to a higher (lower) horizon, wells with the production of recoverable

Table 1: The number of RIWs carried out at production wells in 2016-2018

Repair type	Number of wells	Percentage of the total, %
Production casing leakage and behind-the-casing flow	59	19%
Aquifer isolation	24	8%
Transfer to a higher (lower) lying horizon	223	73%
Total	306	100%

reserves of more than 90% are considered. Water shut-off works account for only 8% of all repair works. The reason for such a low indicator can be the small number of cases of injection water breakthrough or the coning of the bottom waters in the production wells. Also, the option with a non-operational response to the above case in production departments is not excluded.

As can be seen from Figure 2, based on the results of the factor analysis of oil losses in production wells, it was revealed that 58% of the accumulated losses are due to high water cut at the beginning of the year. Since 2016, 24 water shut-off works have been carried out on production wells at the production field. The effectiveness of water shut-off works was assessed by two criteria: geological according to the results of well log survey; the increase in oil production and water cut before and after the water shut-off. The total increase in all wells amounted to 80.8 tonnes/day, additional production is 62.2 thousand tonnes of oil. It should be borne in mind that, in two wells, additional geological and technical measures were carried out (Figure 11). No incremental growth was observed in 9 out of 20 wells. In more than 50% of wells, logging operations were not performed after water shut-off [21, 22].

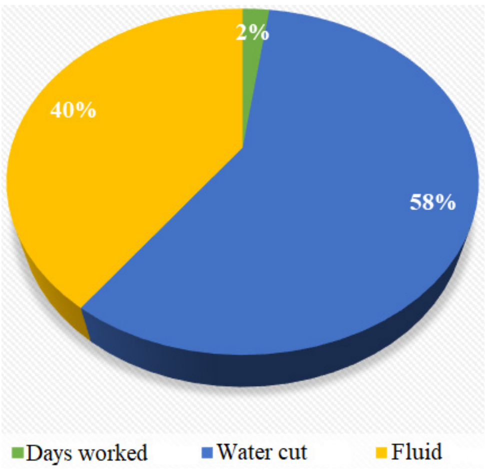

Figure 2: Distribution of accumulated losses by factors

According to the results of testing and implementation of selective water shut-off works using a gelling agent as exemplified by the literature sources, the success rate averages at 79%. Thus, the proposed technologies have a real technological effect (better than water shut-off): due to the blocking ability of the presented gelling agent, reliable isolation of water inflows is provided for a long period of time and, therefore, the water cut is reduced. In addition, it should be noted that the presented waterproofing compounds have low corrosivity and are practically non-toxic.

Consider the factor analysis, the influence of individual factors (reasons) on the effective indicator using deterministic or stochastic approaches. Moreover, factor analysis can be both direct, i.e. consists in splitting the effective indicator into its component parts, and in reverse (synthesis), when individual elements are combined into a common effective indicator. The distribution of deviations in oil production by factors is shown on the example of a simplified (Eq. 1) of oil production from a well for a month. Oil production is equal to the product of the average oil production rate per month by the number of work days [23]. The planned and actual volumes of oil production from a well per month are determined by the formulas:

$$Q_p = N_p \cdot q_p \tag{1}$$

where Q_p – planned monthly production from the well, *t*.; N_p – planned number of days worked, day; q_p – planned oil production rate, *t*/day.

$$Q_a = N_a \cdot q_a \tag{2}$$

where Q_a – actual monthly production from the well, *t*.; N_a – actual number of days worked, days; q_a – actual oil production rate, *t*.

Analytically, the deviation (difference) of the actual oil production from the planned ΔQ is equal to the difference of (Eqs. 1-2):

$$\Delta Q = Q_p - Q_a = N_p \cdot q_p - N_a \cdot q_a \tag{3}$$

When considering deviations in oil production by two factors separately (Figures 3 and 4) and adding the dark

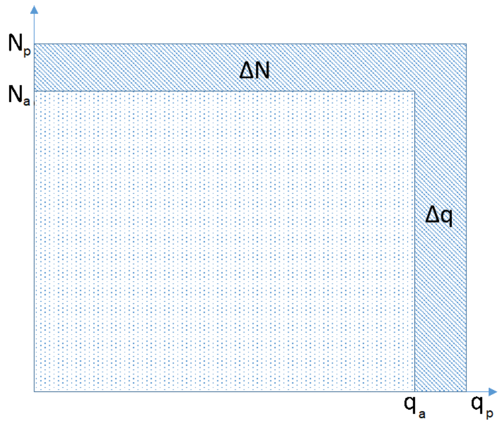

Figure 3: Graphical presentation of planned and actual oil production from the well

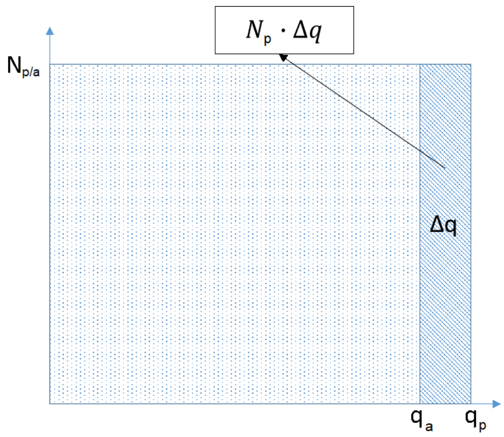

Figure 4: The area of deviation of oil production from the deviation of the actual production rate from the planned

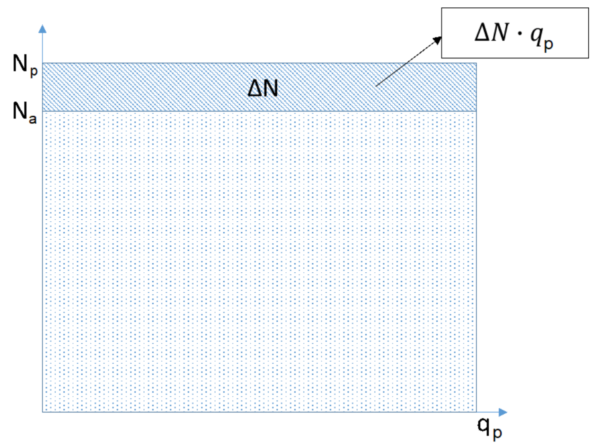

Figure 5: The area of deviation of oil production from the deviation of the actual time interval from the planned

blue areas, the two areas indicated by the red frame will overlap. Accordingly, the sum of the deviation areas from the influence of each factor exceeds the dark blue area in Figure 5, which is equal to the deviation of the actual oil production from the plan.

Analytically, the area of these figures is represented as (Eqs. 4-5):

$$S_{c.f}=\Delta N \cdot q_p-\frac{\Delta N \cdot \Delta q}{2} \quad (4)$$

where $S_{c.f}$ – area of completed factor analysis (deviation from the flow rate).

$$S_{c.f.a}=N_p \cdot \Delta q-\frac{\Delta N \cdot \Delta q}{2} \quad (5)$$

where $S_{c.f.a}$ – area of compound factor analysis (deviation from days worked).

Then the sum of the areas is:

$$S_{c.f}+S_{c.f.a}=\Delta N \cdot q_p-\frac{\Delta N \cdot \Delta q}{2}+N_p \cdot \Delta q-\frac{\Delta N \cdot \Delta q}{2}=\Delta N \cdot q_p+N_p \cdot \Delta q-\Delta N \cdot \Delta q \quad (6)$$

$$S_{c.f}+S_{c.f.a}=\Delta Q \quad (7)$$

To summarise, in the example described above, it is necessary to emphasise two main admissions/assumptions used in the methodology.

1. Presentation of actual indicators in the form of the difference between the predicted indicator and the delta indicator, for example (Eq. 8):

$$N_a=N_p-\Delta N \quad (8)$$

2. Distribution of deviations from the simultaneous influence of several factors in equal shares on the number of influencing factors, for example: $\Delta N \cdot \Delta q$-2 influencing factors => (half $(\Delta N \cdot \Delta q)/2$ on the influence factor, half $(\Delta N \cdot \Delta q)/2$ on the oil production influence factor).

Based on the above method of allocation of oil production deviations, two types of factor analysis have been developed:

- Factor analysis of monthly production "Plan/Actual".
- Factor analysis of actual monthly production from wells "Actual/Actual".

RESULTS AND DISCUSSION

Presenting each actual indicator as the difference between the planned indicator and the delta (the absolute difference, for example: $Rpl_{act}=Rpl_{pl}-\Delta Rpl$ and using the distribution method presented at the beginning of this paper, the distribution of the deviation values in tonnes of oil is calculated by factors *Kprod*, *Rpl*, *Rzab*, water cut, the average producing well stock, and *Kexpl* (days worked). An example of the results of the "Plan/Actual" factor analysis is presented in Figure 6.

Factor analysis is also applied under field conditions to identify wells with the highest oil losses, as well as for further operational actions to restore oil production. The following is an algorithm for applying the results of well after well factor analysis (Figure 7).

Mapping of oil losses to identify zones with highest losses for further regulation and field development monitoring (Figure 8).

The Hall plot is another useful method for assessing injection well performance. Most of the well testing meth-

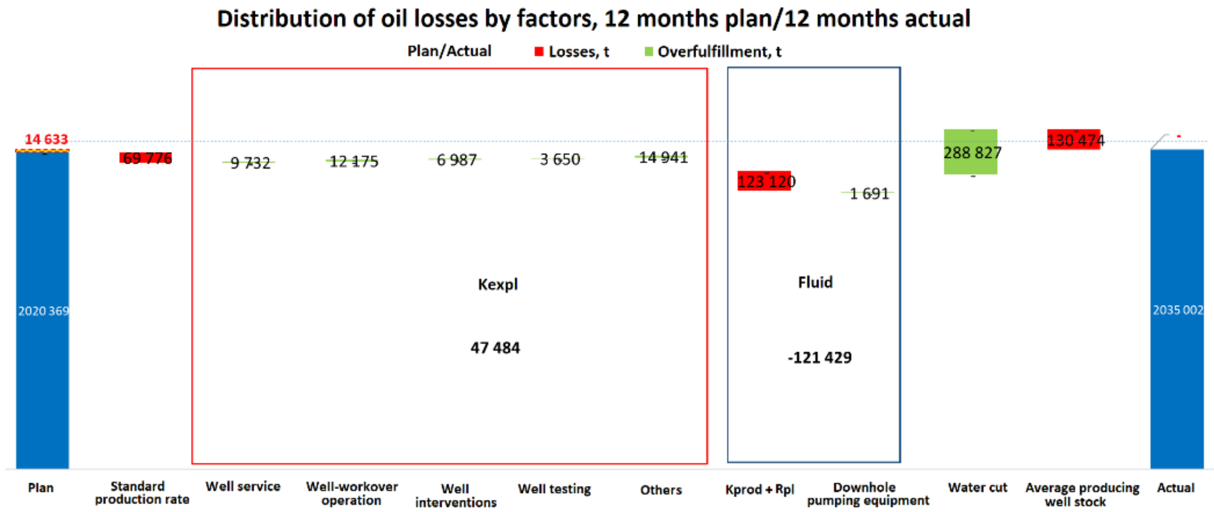

Figure 6: Distribution of oil losses by factors Plan/Actual

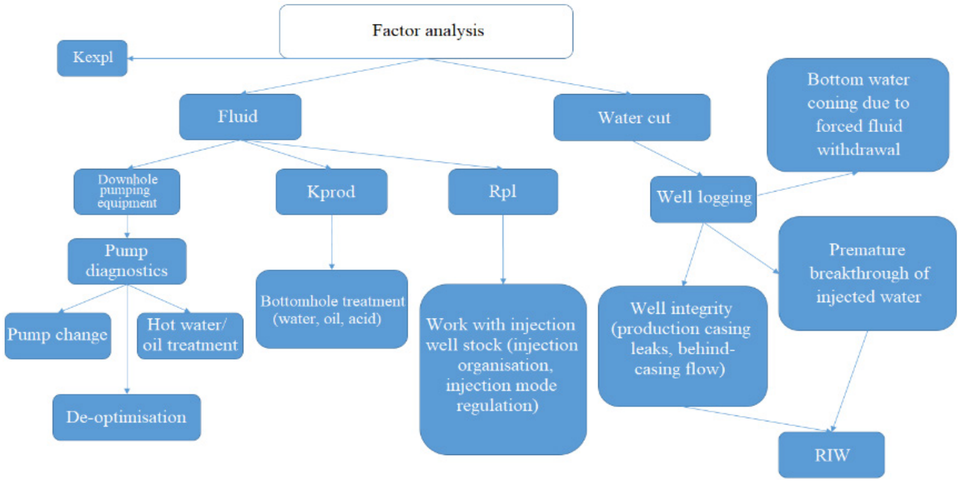

Figure 7: Algorithm for applying the results of factor analysis

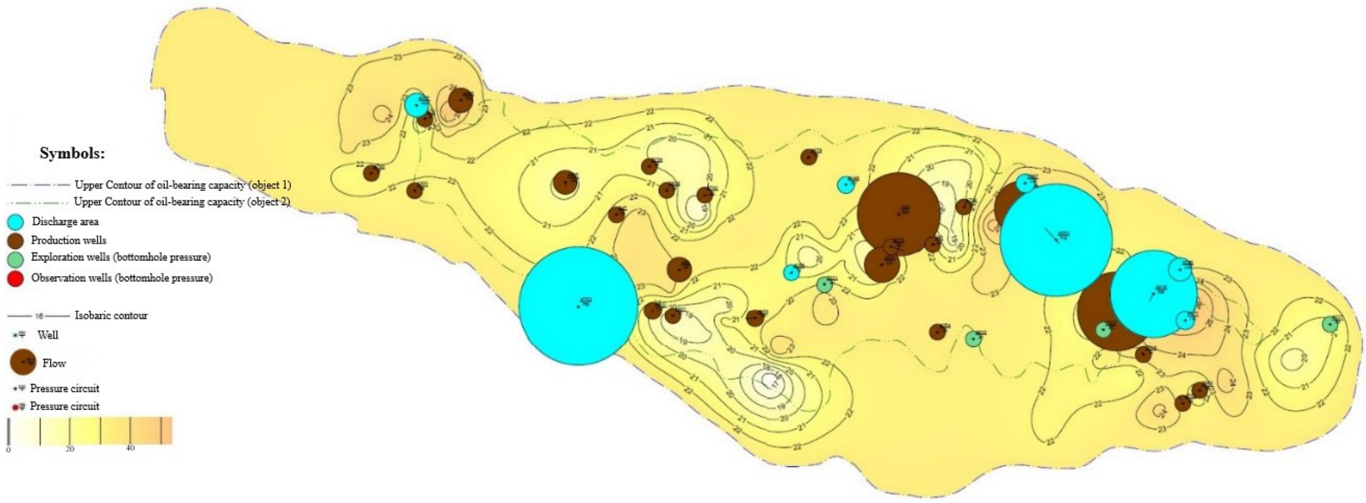

Figure 8: Oil loss map

ods are complicated by changes in flow rate, pressure, fluid inflow into the well after it was shut down, i.e., by unsteady operation mode. The Hall plotting method is based on the use of injection data sometime after the operation is established, which allows to reduce the influence of the listed effects [24]. Figure 9 is a schematic example of a Hall plot used to illustrate the determination of some parameters using this technique. Part of curve A – concave, ascending – demonstrates the beginning of injection into the well. During this period, the reservoir is filled with fluid, and *re* and *pe* increase. At point B, the filling of the reservoir with injected water ends and re and pe become constant. All conditions for linearity are satisfied. The path to point C demonstrates the deviation from linearity associated with disruption in reservoir performance. The path to point D describes the well with constant skin layer, *rw* and *kh*. The path to points E and F shows a Hall plot view for a well that uses hydraulic fracturing, acidising, etc.

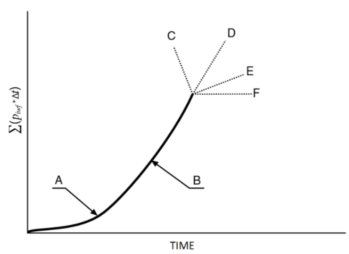

Figure 9: Example of the Hall plot

A Hall plot was plotted to describe the operation of water injection well No. 3013. The Hall plot is based on monthly injection and wellhead pressure data since 2011. In November 2009, hydraulic fracturing treatment of the well was conducted. According to the analysis of the pressure drop curve (efficiency) in October 2012, a negative skin factor (-4.46) was diagnosed, and the flow in the reservoir proceeds along a system of fractures, the interpretation results revealed a fracture with a length of about 111 m (Figure 10).

1st section: the well is operating with hydraulic fracture.

2nd section: for a short period of time, a decrease in injectivity occurs at the same injection pressure, perhaps this is due to the deterioration of the bottomhole zone condition, closing of the fracture.

3rd section: with increasing injection pressure, injectivity increases accordingly. During this period, the pressure draw-down curve has occurred, the presence of a crack

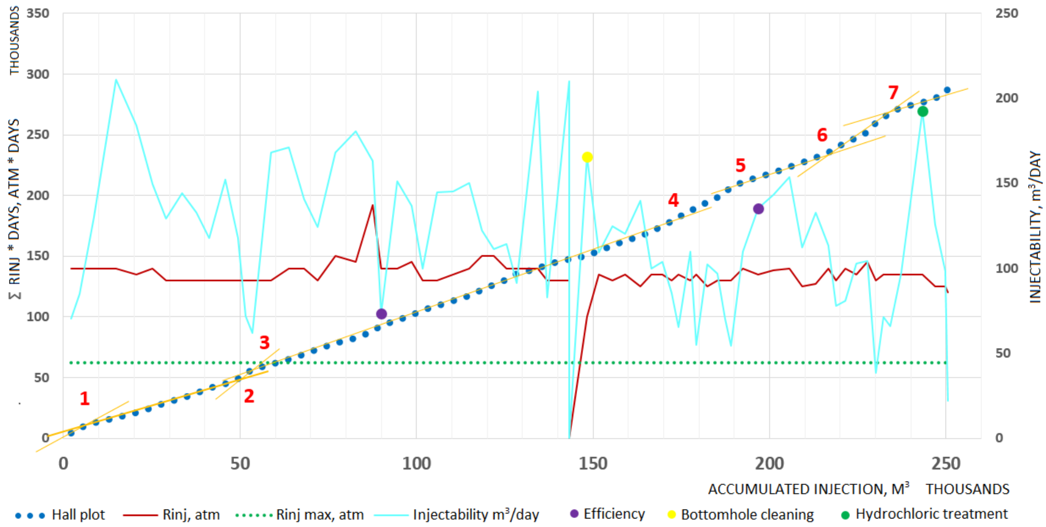

Figure 10: Hall Plot for water injection well No. 3013

and a negative skin factor were diagnosed.

4th section: in this period, the rate of injection increment is less than the rate of pressure increment, which is associated with the deterioration of the bottomhole formation zone, at the same injection pressure, injectivity decreases.

5th section: the nature of the curve change shows that in the absence of any measures in this period, the injectivity increases with a small increase in the injection pressure. Perhaps this is due to an increase in withdrawal in this area.

6th section: presumably the bottomhole formation zone is deteriorating or fractures are closing.

7th section: during this period the hydrochloric treatment was carried out. The growth rate of accumulated injection is higher than the growth rate of injection pressure, the effect of geological and engineering measures can be characterised as positive.

At the Karamandybas deposit, selective water shut-off works using a hydrophobic emulsion were not carried out. On this basis, in order to recommend a further increase in the efficiency of water shut-off works using emulsions at the Karamandybas field, experimental research and analyses were taken as a basis to justify and implement the technology of flow-correcting compositions in order to limit water inflow in wells. The selection and investigation of properties of polymers in laboratory conditions were carried out according to the following diagram (Figure 11).

The laboratory studies serve as the basis for the selec-

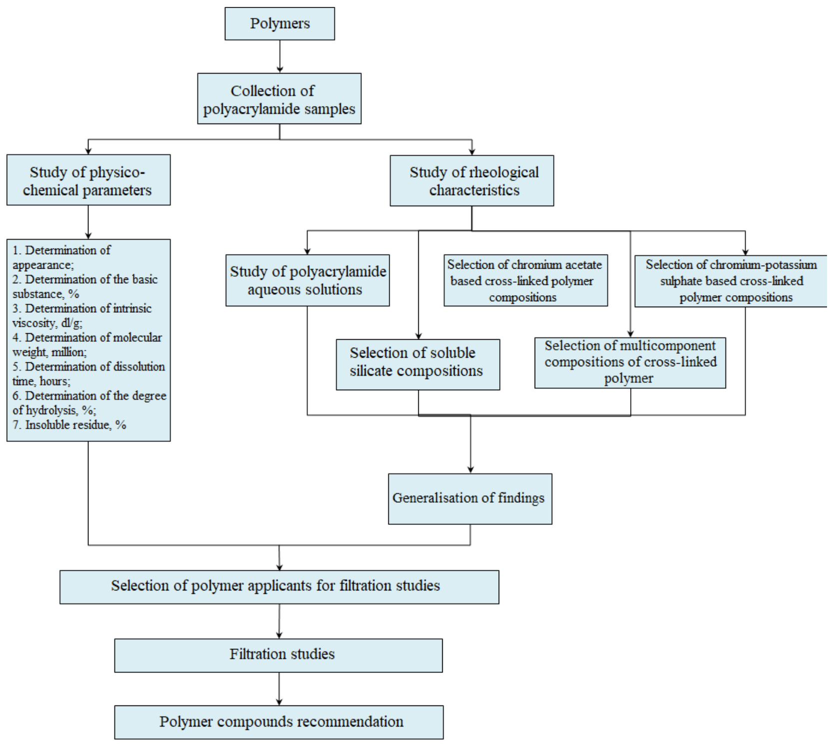

Figure 11: Diagram for selection and investigation of polymer properties

Table 2: List of selected polymers

Sr. No.	Product name	Country of origin	Manufacturing plant
1.	FP-107	France	SNF S.A.S.
2.	FP-307		SNF S.A.S.
3.	Superpusher K-129		SNF S.A.S.
4.	SD-6800	China	–
5.	GL-50		“Kechuan-Biochemistry” LLC
6.	GL-50-analogue		“Kechuan-Biochemistry” LLC
7.	ENM-P-20	Russia	“ELKAM-service” LLC
8.	Seurvey R1		Chemical Group “OSNOVA” LLC
9.	Temposcreen-Lux		“Atombiotech” LLC
10.	Soluble silicate		“Partner-M” CJSC
11.	Polycar-MEGPT	Oman	«Gulf power technologies» LLP

tion of the optimal parameters for the use of the polymer composition for flow correcting technologies in the conditions of the X field. As a result of the laboratory analysis, recommendations are issued on the use of the polymer composition, which ensures the achievement of the projected properties of the injected agent, the possibility of using the composition in the implementation of flow-correcting technologies is assessed.

The choice of polymers for laboratory research consisted in the fact that 11 samples of chemical reagents (polyacrylamides) were selected for research in order to develop a viscoelastic composition for closing high-permeability interlayers and preventing water breakthrough, behind-the-casing flows, etc. All samples are industrial products [25]. The main criteria for choosing a reagent for research were the potentially acceptable physicochemical characteristics of the reagents in accordance with the technical requirements. A list of selected polymers is presented in the Table 2.

As the analysis shows, FP-107 is a high molecular weight polymer for high volume pumping and leveling of the injectivity profile. FP-307 is a polymer for large-volume pumping and leveling of the injectivity profile with a long crosslinking time. Superpusher K129 polymer solution has good filterability. Polyacrylamides GL-50, GL-50-analogue, SD-6800 are used for the purification of natural and industrial wastewater, intensification of the clarification, thickening, and filtering of technological brines, suspensions, flotation concentrates, and flotation waste, for the processes of increasing oil production and drilling. ENM-P-20, Seurvey R1 are used when carrying out works on limiting water inflow, leveling the injectivity profile, inflow diverting technologies during polymer flooding. Temposcreen-Lux, Soluble silicate allows controlling the flow of underground fluids; Polycar-MEGPT is aimed at solving the problem of high water cut in wells.

The considered polyacrylamide-based polymers are used:

– when carrying out water shut-off works;
– to create a blocking rim in the reservoir for conformance control;
– in flow deviation technologies and polymer flooding;
– to eliminate water breakthroughs into production wells;
– blocking flushed zones and cracks, redistributing filtration paths of the injected fluid.

The investigated chemical reagents have the form of highly molecular partially hydrolysed polyacrylamide (copolymer of polyacrylamide and sodium acrylate) and belong to the group of synthetic, water-soluble polymers specially designed for hostile environments with different temperatures and mineralisation. The structural formula of hydrolysed polyacrylamide is shown in Figure 12.

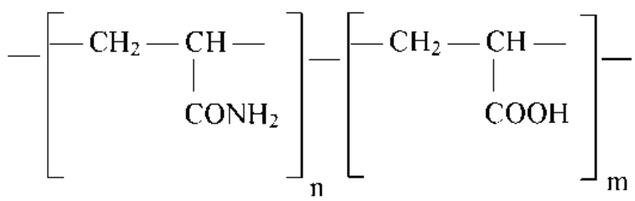

Figure 12: The structural formula of hydrolysed polyacrylamide

All analysed reagents comply with the accepted regulatory requirements for the content of the main substance, intrinsic viscosity, molecular weights and carboxyl groups. The results of studies of the solubility of polymers showed that 9 out of 11 samples of acrylamide polymers dissolve well in the mineralised water of the X production field. Poor solubility in this water is characteristic of the “Temposcrin-Lux” samples and soluble silicate. The sample of “GL-50” does not meet technical specifications for the content of insoluble sediment.

CONCLUSIONS

According to the results of the receipt inspection of the tested reagents for conformity with the specifications for the content of insoluble sediment, reagents of the brands “Temposcrin-Lux”, “GL-50” and soluble silicate are excluded from further studies. As a result of calculations on the effectiveness of water shut-off at the Karamandybas field for 2016-2019, additional production amounted to 62.2 thousand tonnes of oil. Most of the RIW is occupied by geological and engineering measures (well re-completion to overlying formation). Isolation of the aquifer is only 8% of the total repairs. The field uses traditional methods of water shut-off by installing cement stone, packers and running an additional production string.

In order to assess the geological efficiency based on the results of PLT for all wells where water shut-off works were carried out, the survey coverage is 50%. As the results of testing and implementation of selective waterproofing works using gelling agents according to literature sources show, the success rate averages at 79%. Thus, the proposed technologies have a real technological effect (better than that of the applied water shut-off): due to the blocking ability of the presented gelling agent, reliable isolation of water inflows is provided for a long period of time and, therefore, the water cut of the well production is reduced. In addition, it should be noted that the presented waterproofing compound have low corrosivity and are practically non-toxic. Hall plots were proposed to optimise unproductive injection in order to identify string failure in injection wells. Based on the analysis of 171 wells, the estimated production casing leaks were identified in 23% of the calculated well coverage. Based on the results of core studies, the economic feasibility of the recommended polymers will be calculated for further pilot testing at the Karamandybas field.

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