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Designing measures to increase oil recovery based on the identification and grouping of deposits

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Abstract. The article provides a grouping of development objects using the method of the main components of the fields developed by the Langepasneftegaz TPP and identifies landfill sites. Based on the geological and field analysis, a set of measures has been substantiated to increase the efficiency of development of objects in four groups. The identified patterns allow us to make informed technological decisions aimed at increasing oil recovery, reducing water inflow and increasing the efficiency of the facilities development, taking into account the peculiarities of the geological structure of the deposits.

1. Introduction
Grouping (identification) of development objects is carried out to identify groups of objects with similar and relative bedding conditions, geological, physical and physico-chemical properties of productive formations and formation fluids. Such an analysis (grouping-identification) with the determination of the degree of similarity and difference is carried out using a modern mathematical apparatus and high-speed computing. The features of the geological structure of the selected groups of deposits established during grouping make it possible to take them into account in the development process when making technological decisions at various levels [1–4].

2. Materials and methods
High-quality, sufficient information about the reservoir and the processes occurring in it, creates the prerequisites for the effective solution of the problems of analysis, design, monitoring and regulation of oil field development processes, and application design of enhanced oil recovery methods. Obtaining such information is possible after performing a complex of geophysical, hydrodynamic and laboratory studies and studying the history of field development. Therefore, we can formulate the necessary requirements for the selection of objects for grouping:

- the object has been developed for a long period of time and there is enough geological and field information about it to solve the tasks;

- the object has been drilled with a sufficient number of wells for various purposes with a high grid density.

A sufficient number of hydrodynamic, geophysical and laboratory studies were carried out at the facility to solve the tasks.

Here, under the object we mean the object of development - one or more productive formations of the field, selected on the basis of geological, technological and economic considerations for drilling and operating a single grid of wells.

If the geological structure of the analyzed objects is studied quite thoroughly according to the information obtained from wells drilled at other horizons, we can take objects that are not developed for a short period of time and do not correspond to the requirement 2 for successful grouping (identification). When selecting objects this kind one should take into account the hydrodynamic relationship between the individual layers.

The increase in the efficiency of development of oil deposits is closely linked to an increase in the quality of design, reliability of control and the correct regulation of the oil and gas extracting processes and gas. Taking into account the above requirements, we selected more than 50 objects for the development of deposits in Western Siberia.

Under the conditions of the selected objects, characterized by significant intervals of changes in the bedding conditions, geological, physical and physicochemical properties of the formations and the fluids saturating them (table 1), the grouping operation takes the first place, i.e. selection in the array of objects of groups with relatively uniform characteristics.

Table 1. Values of parameters (characteristics) of grouping objects

Parameter	The numeric value of the parameter		
	minimum	maximum	average
Depth of bed, m	1750	2742	2308.9
oil recovery, unit	0.061	0.55	0.261
Effective oil saturated thickness, m	0.8	12.2	3.99
Porosity coefficient, unit fraction	0.14	0.23	0.190
Permeability Coefficient, μm^2	0.002	0.572	0.139
Oil saturation coefficient, unit	40	67	54.8
The density of reservoir oil, kg / m ’	0.8	0.88	0.847
The conversion factor, units	0.78	0.93	0.859
Viscosity of reservoir oil, mPa · s	0.37	2.6	1.39
Gas content of reservoir oil, m^3 / t	25.4	116	61.9
Initial reservoir pressure, MPa	17.5	28.3	23.1
The initial temperature of the reservoir, ° C	56	102	84.75
Sulfur content,%	0.75	1.8	1.1
The paraffin content,%	1.2	15.2	2.68
The content of resins and asphaltenes,%	4.1	12	7.9
Sandiness coefficient (K_s)	0.18	0.817	0.505

Grouping allows us to solve the most important tasks of oil and gas field geology and development: to assess the similarity and difference of productive formations when identifying development objects, to justify development systems and methods for increasing oil recovery, to set up control and regulation measures, etc. [5–11].

To ensure the correct grouping in the presence of a significant number of objects of study and parameters characterizing them, it is necessary to use a method based on logical and mathematical analysis. For similar purposes, at present, various methods of the theory of pattern recognition are widely used - this is factor analysis, the method of principal components, cluster analysis, discriminant analysis, etc. The choice of a particular method is determined by the statement of the problem and the advantages (applicability) of the method. For tasks of this kind in geology and the development of oil and gas fields, the method of principal components and discriminant analysis are most used.

The reasons for choosing the principal component method (PCA) for solving the problem of grouping objects are as follows:

- grouping of many research objects is carried out according to generalized, independent indicators (main components), and is more objective than grouping according to individual initial parameters;
- grouping is carried out depending on the combination of parameters that most affect the efficiency of the development process (and not only depending on the general features of the geological structure of the deposits);
- to describe the objects of study requires a much smaller number of factors (main components) than the number of initial parameters, i.e. a multidimensional space is compressed, within which grouping is extremely difficult;
- the main components adequately reflect the initial information, and at the same time carry more information than individual parameters;
- the study of the structure of factors (main components) allows you to check existing and put forward new hypotheses about the causes of the relationship between the parameters, give a causal interpretation of the results, and also allows you to develop and adopt a scientifically based control effect that helps to increase the efficiency of the process of developing oil deposits ;
- the main components do not mutually correlate, which greatly facilitates the task of constructing various models of the development process based on the obtained main components.

Analysis of data by the method of principal components leads to the fact that the main share of the variance contains the first two to four components. Having identified the main components, you can calculate them for different objects and group these objects according to the values of the components, or based on these components, create a regression equation by which you can clearly identify significant and non-essential factors.

Unlike PCA, in which grouping is an internally closed procedure based on the original data set, discriminant analysis performs grouping based on a priori data, i.e. the number of groups must be predefined. Using the discriminant analysis method (MDA) allows you to:

- achieve the best separation of groups of objects in multidimensional space;
- check the correctness of the assignment of a particular object to a particular group after grouping using any method without a “teacher”.

The MDA's task is to find some discriminant function that takes different values on objects of different groups. The linear discriminant function converts the initial set of measurements of parameters included in the sample into discriminant numbers. These numbers, which are transformed variables, determine the position of an object in space, which is described by discriminant functions.

Grouping of deposits was carried out according to the standard number of features characterizing the conditions of occurrence of deposits, geological and physical parameters of reservoir systems and the properties of the fluids saturating them. These include: the depth of the formation (H_{form}, m); effective oil-saturated power (H_{ef}, m); porosity (m,%); permeability (K_{perm}, μm^2); sandiness coefficient (K_s, unit); oil saturation (K_{sat}, %); oil density ($г_o$, g / cm^3); volumetric coefficient of oil (b, unit); oil viscosity ($т_o$, mPa·s); initial reservoir pressure (P_{res}, MPa); reservoir temperature (t_{res}, °C); the content of sulfur, paraffin, resins and asphaltenes (c+a), %; final oil recovery, unit.

A graphical representation of the objects in the coordinate axes of the main components is shown in Figures 1–4.

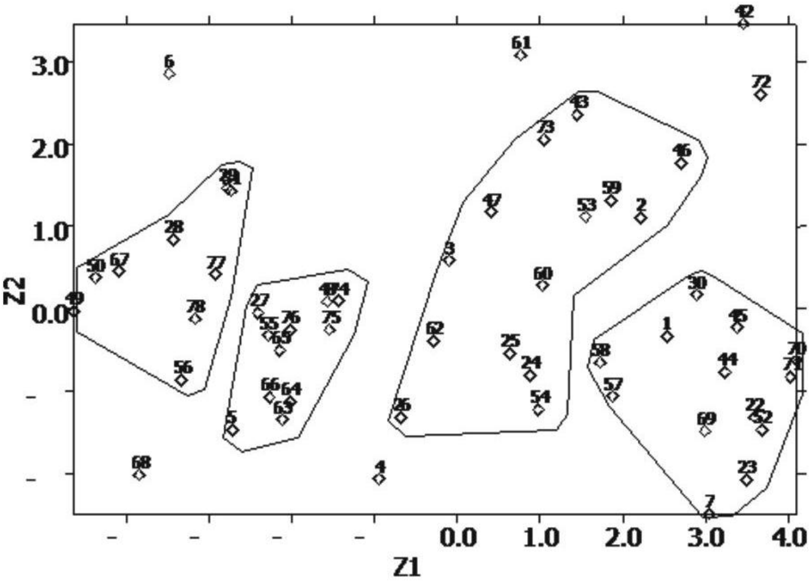

Figure 1. The distribution of objects in the axes of the components $Z_1 - Z_2$

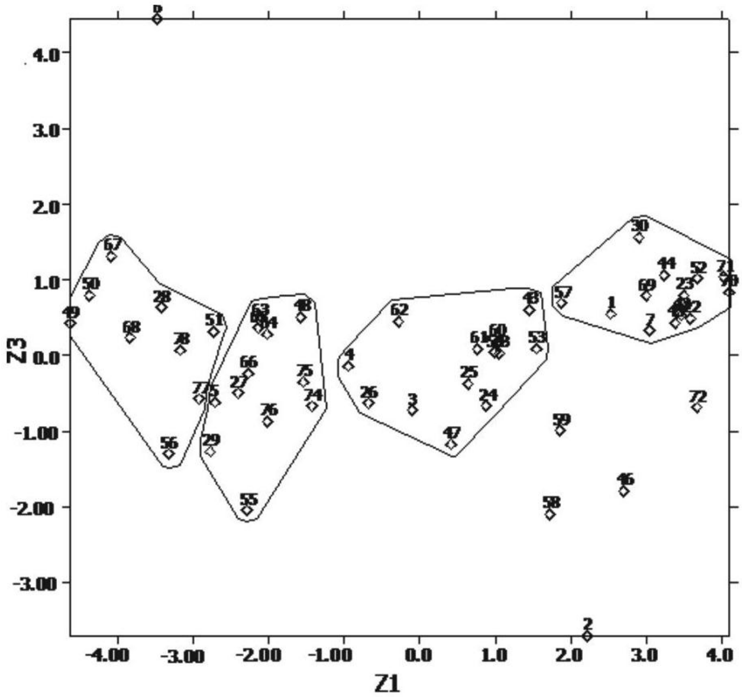

Figure 2. The distribution of objects in the axes of the components $Z_1 - Z_3$

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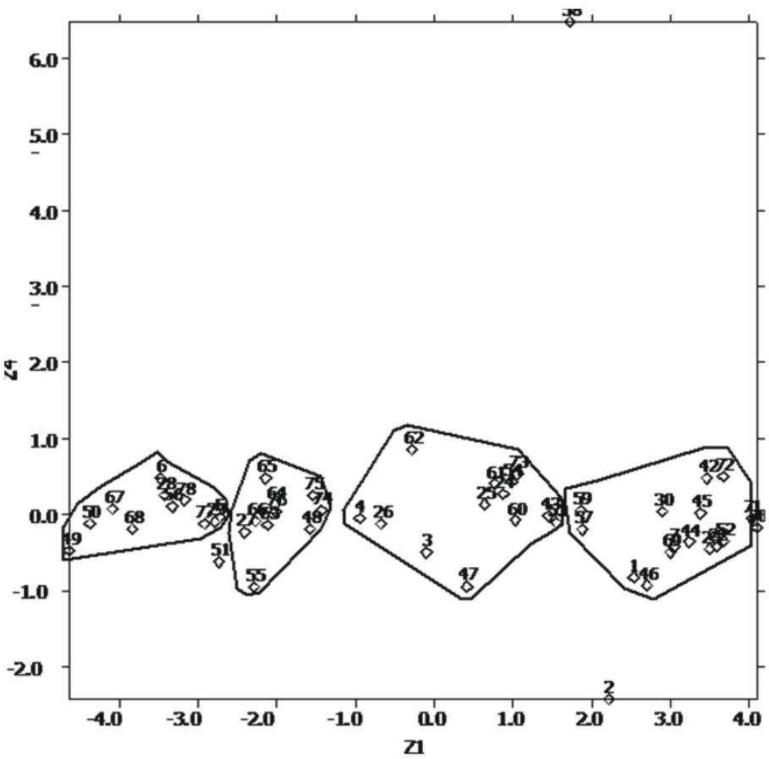

Figure 3. The distribution of objects in the axes of the components $Z_i – Z_2$

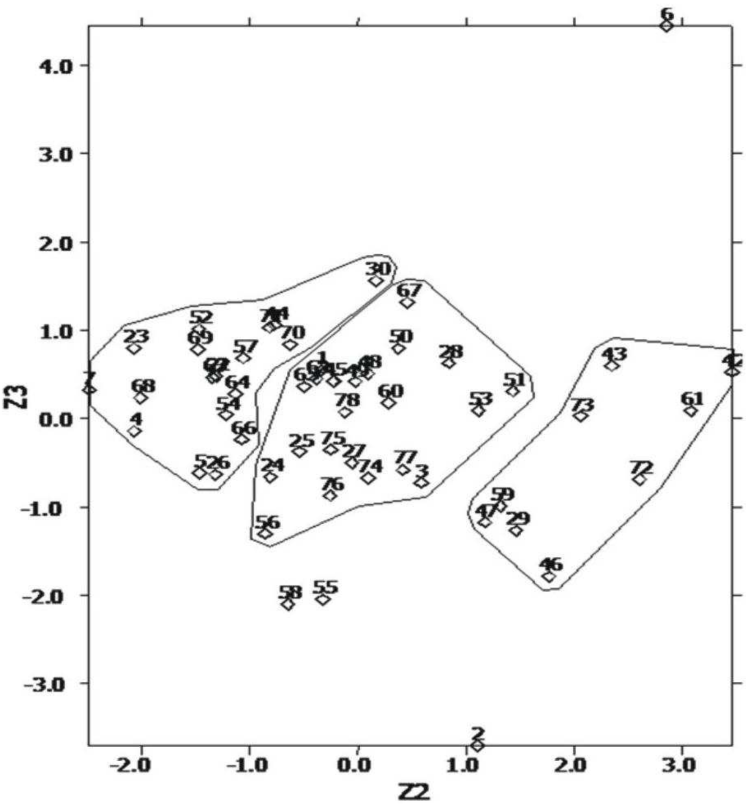

Figure 4. The distribution of objects in the axes of the components $Z_2 – Z_3$

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3. Results and Discussion

The objects are characterized by a significant difference in a number of geological and physical characteristics, which will further highlight the groups. The largest range of changes is noted for such indicators as permeability coefficient, effective oil-saturated power, sandiness coefficient, oil viscosity, content of paraffins, resins and asphaltenes, oil recovery coefficient.

Statistical data processing was carried out by a standard package of statistical programs. As a result, we obtained: coefficients of equations, characteristics of the significance of the main components, the percentage of variance introduced by each of the components, and the coordinates of the objects in the axes of the main components.

As a result of the PCA solution, 16 main components out of 16 grouping parameters were obtained. The first five components are most significant; the total contribution to the total variance for them is 78.3%. As the sequence number of significant components increases, the proportion of the dispersion introduced by them decreases.

Each of the selected components to a greater extent reflects only certain properties of the layers, which allows you to select when grouping the initial geological and physical characteristics by which grouping is performed.

Due to the fact that the dispersion fraction of the fifth component is the smallest and the objects in the axis of this component will mainly be grouped into a single field, when grouping it is sufficient to take into account the first four components. The first main component mainly reflects the geological and technological parameters, since the main contribution to it is made by the final oil recovery, effective oil-saturated power and sandiness coefficient.

The main contribution to the second main component is permeability, gas factor, and reservoir pressure. The third main component reflects the properties of reservoir oil, the main contribution to it is made by the density of oil, oil shrinkage coefficient and sulfur content in oil. The fourth main component reflects the chemical composition of oil - the content of paraffin and asphaltene-resinous compounds in oil.

Table 2 presents the groups of objects identified by the results of the PCA. The first group includes 9 objects, it is allocated mainly by geological and physical characteristics.

The first group of objects is characterized by the minimum values of effective oil-saturated power, oil viscosity, coefficients of sandiness, porosity and permeability, tar and asphaltene content, maximum values of the depth of the reservoir, reservoir pressure, temperature and gas factor.

The second group is distinguished mainly by the properties of oil. It included 11 objects. The group notes: the minimum values of the effective oil-saturated thickness, paraffin content, oil saturation coefficient.

The third group of objects was identified by the geological characteristics and properties of oils, it included 13 objects, characterized by the highest values of final oil recovery, porosity, permeability, reservoir thickness, initial oil saturation, oil viscosity, sandiness, high tar and asphaltene content, and lowest reservoir pressure.

The fourth group included 12 objects. The group is distinguished by oil properties and is characterized by a high paraffin content and low sulfur content.

The selection of characteristic objects within the selected groups of objects was carried out using the formula:

$$\mathrm{X}_{st} = (\mathrm{x}_{av} - \mathrm{x}_i)/\sigma_\mathrm{x}, \quad (1)$$

Where x_{av} – the average value of the parameter for all objects; x_i – parameter value for a specific object; σ_x – standard deviation of the parameter; X_{st} – the belonging of a given object to any group in the axes of the main components is determined.

Table 2. Distribution of research objects into groups

№	Field	Plast
1	2	3
	Group I	
28	Nivagal	Achim.
29	Nivagal	ЮВ1/0
49	Uryevskoe	БВ10
50	Uryevskoe	ЮВ1/1
51	Uryevskoe	ЮВ1/2
56	Chumpasskoe	Achim.
67	Potochnoe	Achim.
77	Las-Egan	БВ23
78	Las-Egan	ЮВ1/1
	Group II	
5	Uzhno Pokachevskoe	БВ10
27	Nivagal	БВ8
48	Uryevskoe	БВ8
55	Chumpasskoe	БВ6/2
63	Potochnoe	БВ9
64	Potochnoe	БВ10/1
65	Potochnoe	БВ10/2
66	Potochnoe	БВ11
74	Las-Egan	БВ8
75	Las-Egan	БВ20
76	Las-Egan	БВ21
	Group III	
3	Uzhno Pokachevskoe	БВ6
24	Nivagal	АВ2
25	Nivagal	БВ5
26	Nivagal	БВ6
43	Lokosovskoe	БВ5
46	Uryevskoe	АВ2
47	Uryevskoe	БВ6
53	Chumpasskoe	АВ1/3
54	Chumpasskoe	БВ6/1
59	Potochnoe	БВ5
60	Potochnoe	БВ6
62	Potochnoe	БВ8
73	Las-Egan	БВ6
	Group IV	
1	Uzhno Pokachevskoe	АВ1/3
7	Uzhno Pokachevskoe	ЮВ1
22	Nivagal	АВ1/2
23	Nivagal	АВ1/3
30	Nivagal	ЮВ1/1
44	Lokosovskoe	БВ6
45	Uryevskoe	АВ1/3
52	Pokamasovskoe	ЮВ1/1
57	Chumpasskoe	ЮВ1
69	Potochnoe	ЮВ1/2
70	Las-Egan	АВ1/3 + АВ2/1
71	Las-Egan	АВ2/1 + АВ2/2 + АВ2/3

Calculations were carried out for all objects. From the minimum value of the Euclidean distance from the center of grouping of each group, we determined a characteristic object.

Within the first group, the ЮВ1/1 layer of the Las Egan field is located closest to the center of grouping; within the second - layer БВ8 Uryevskoe` field; within the third – laye БВ6 of the Potochnoe` field, within the fourth – layer AB1/3 of the Uzhno-Pokachevskoe` field. The average values of the parameters in groups are presented in table 3.

Table 3. The values of the parameters of the most characteristic objects of the selected groups

Parameter	Group, field, layer			
	1, Las-Egan, ЮВ1/1	2, Uryevskoe, БВ8	3, Potochnoe, БВ6	4, Uzhno Pokachevskoe, AB1/3
Depth, H_{form}, m	2717	2245	2220	1843
oil recovery, unit	0.25	0.41	0.288	0.135
Effective Thickness, H_{ef}, m	4.5	9.56	8.2	2.89
Porosity, m, unit	0.14	0.205	0,2	0.195
Permeability, K_{perm}, μm^2	0.011	0.306	0.21	0.043
Oil saturation, K_{sat}, unit	53.5	58	55	47
Density of oil, ρ_o, t/m^3	0.836	0.843	0.857	0.857
Shrink coefficient, b, unit	0.82	0.845	0.89	0.883
Oil viscosity, m_o, mPa·s	0.14	0.205	0.2	0.195
Gas content, Γ_f, m^3/m^3	80	57.5	42	45.2
Reservoir pressure, P_{res}, MPa	27.3	22,3	22,2	18,1
Formation temperature, T_{res}, °C	101	78	84	72
Content in%:				
sulfur	1.2	0.83	1.41	0.79
paraffin	1.2	2.7	2.65	2.31
resins + asphaltenes	5.92	5.3	8.92	9,8
Sandiness, K_s	0.323	0.69	0.759	0.408

Thus, the following was accomplished:

- the objects of the Langepasneftegaz TPP are grouped and four relatively homogeneous groups of objects are identified that are similar in their geological and physical characteristics;
- geological features of various groups of objects have been identified that allow to outline measures to improve development systems in order to increase oil recovery based on existing criteria for the applicability of oil recovery enhancement methods;
- an algorithm has been developed to search for analogous objects for new deposits in order to use their experience in developing deposits that have been in operation for a long time;
- grouping centers were identified and the closest facilities for them were selected for further geological, technological and feasibility studies: group 1 — the Las Egan field, layer ЮВ1/1; Group 2 - Urevskoye field БВ8; layer; Group 3 – Potochnoe field, БВ6; layer; Group 4 - Uzhno Pokachevskoe field, layer AB1/3;
- based on the results of the grouping, a brief analysis was made of the geological and field characteristics of the landfill facilities and a choice of methods for increasing their oil recovery.

The first group: a landfill facility, a seam ЮВ 1/1 of the Las Egan field. The analyzed formation is thin (average productive thickness 4.5 m), low permeability (average permeability 0.011 μm^2), clayey (sandiness coefficient 0.323). Low viscosity gas oil with low viscosity. The reservoir temperature is 101 ° C. Reserves of the reservoir are poorly developed at a design value of 0.25.

Improving the flooding of the reservoir is to increase the coverage of the reservoir by displacement. The use of surfactants and inorganic polymers for this purpose is not recommended due to the high losses of adsorption reagents in clay layers and their temperature destruction, which is observed at temperatures above 80–90 °C. The low reservoir properties of the formation impede the use of polymer and fiber disperse systems (PDS and FDS) and liquid glass reagents. To equalize the injection profiles of high-yield wells, the RV-3P-1 thermotropic gelling reagent is recommended (a type of GALKA reagent whose commercial form the oil recovery AN RB - INTNM RB has been developed), but cyclic flooding with alternate closure of production and injection wells. To increase the injectivity (productivity) of wells, it is recommended to use clay-acid treatments and reagents for stabilization of clays KOH, KS1. Massive use of hydraulic fracturing is impractical due to the low power of productive thicknesses.

The second group: the test site, reservoir БВ8 of the Urevskoye field. The object is represented by a reservoir with high capacitance-filtration properties; average thicknesses, permeability, and sandiness are 9.56 m, 0.306 μm^2, and 0.69, respectively. The formation is monolithic with a smooth transition from permeability above 0.4 μm^2 at the roof and 0.05 μm^2 at the bottom. Low-viscosity reservoir oil with low gas content. The average temperature of the reservoir is 78 ° C. The development of reserves is about two-thirds.

An analysis of the geological and field characteristics of the reservoir allows us to talk about the advisability of using the following enhanced oil recovery methods in the fields of the second group. The relative uniformity of the strata, their high sandiness, and the depletion of mobile reserves create favorable conditions for the additional washing out of capillary-trapped oil in a porous medium. Under these conditions, the process of displacing residual oil with large-volume rims of surfactant + alkali + water compositions, promoted along the reservoir by the rim of an aqueous polymer solution, has proven to work properly. In this case, the drop in injectivity of wells due to polymer injection is compensated by its increase during injection of surfactant + alkali. In laboratory conditions, the method allows to increase the oil displacement coefficient by 13 points, in the field to 7-8 points.

To combat watering, the reagent RV-3P-1 is recommended; to stimulate inflows in production wells it is recommended to use of surfactants and hydrocarbon solvents. To improve the waterflooding process, geological and physical conditions are suitable for the use of a cross-linked polymer-dispersed system, an emulsion-suspension composition, aluminosilicates and RV-3P-1.

The third group: the test site, reservoir БВ6 of the Potochnoe deposit. The object is represented by powerful productive deposits, a sandy reservoir with a low clay content and medium reservoir properties. The formation is a relatively homogeneous monolith with an average permeability of 0.210 μm^2. Low viscosity oil with low gas content. The reservoir temperature is 84 ° C. The depletion of reserves is about two-thirds of the design ultimate oil recovery (0.288).

The geological and production conditions of the objects of this group are similar to the characteristics of the formations of the second group. Therefore, recommendations for using enhanced oil recovery methods are similar. Surfactants and solvents are recommended for stimulation of production wells; surfactant-acid exposure and RV-3P-1 are used to combat flooding. To improve the waterflooding system, it is recommended that the injection wells be treated with the compositions of aluminosilicates, CPS + PAE (crosslinked polymer system + polymer-acid exposure), and systemic treatments are recommended - simultaneous treatments of the producers (intensification of oil production) and injection (gel barriers). It is proposed to implement projects for the injection of large-volume surfactant rims + alkalis rims advanced along the reservoir with water for oil washing from sections of the reservoir with good reservoir properties. The use of hydraulic fracturing is recommended on poorly developed with poor filtration characteristics.

The fourth group: the test site, layer AB1/3 of the Uzhno Pokachaevskoye field. The object of this group is represented by clay heterogeneous formations with low permeability (average value 0.043 μm^2). Low viscosity oil with low gas factor. At the facilities of this group, it is recommended to expand the experience of using PAE to stimulate inflow, as well as the use of clay-acid treatments and stabilization of clays with KOH and KC1 solutions. It is recommended to limit the bottom-hole zones to methods for increasing oil recovery when exposed to injection wells because of the high loss of reagents in clay formations. Geological and physical conditions in the reservoir are favorable for using such reagents as CPS, CPS + PAE and RV-3P-1.

4. Conclusion

During the research, we carried out grouping of development objects using PCA fields developed by TPP Langepasneftegaz and identified objects - landfills.

Based on the geological and field analysis, a set of measures has been substantiated to increase the efficiency of development of objects of four groups.

Identified patterns allow us to make justified technological decisions, taking into account the peculiarities of the geological structure of the layers.

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