Abstract. Based on the geological and commercial material collected and systematized by the offshore fields of Azerbaijan, the article discusses the reasons for the varying degrees of use of their reserves. For this purpose, the identification of deposits was carried out according to the natural regime, as a complex factor affecting oil recovery. Oil recovery models have been obtained for offshore reservoirs, draining mainly in two types of mechanisms: mixed and solution gas drives. Based on these regression equations and geological-economical analysis, a comparative analysis of the factors influencing oil recovery was carried out. Study of the different nature of the implementation of reserves of deposits characterized by different natural mechanisms so as to determine the degree to which the geological and technological parameters at various stages of development influence oil recovery.

Objects: Offshore deposits of the Republic, characterized mainly by the solution gas and mixed drives. Application of the methods of mathematical statistics (Student’s and Fisher’s criteria) for the comparative analysis of the parameters of the mined deposits, confined to different natural conditions, allowing the revelation of the degree to which they are different and various patterns of the use of the reserves. In order to determine the influence of various factors on oil recovery, we used the method of correlation-regression analysis. It was found that a wide range of changes in oil recovery factors is associated with the internal structure of the deposits, with varying degrees of activity of the energy of the reservoirs and the fluids saturating them. It is known that each of the geological and technological parameters to one degree or another affects oil recovery, this influence is complex and subject to certain changes in the process of reservoir mining. In order to study the influence of parameters on oil recovery, we developed matrices of averaged values of a number of parameters of offshore deposits draining by mixed and solution gas drives. Using multivariate correlation-regression analysis and appropriate software, we obtained models for each of the above types of the mechanisms. A comparative analysis of those models, as well as geological and field studies of the parameters included in the obtained regression equations, make it possible to correct the oil production process in a timely manner, and can also be used in designing projects for the additional mining of those objects.

Key words: correlation-regression analysis, mode of gas dissolved in oil, mixed mode, oil recovery, balance and current reserves.
Introduction.

Almost any rationally designed project of mining oil and gas deposits requires elaboration, certain corrections and regulation of oil extraction at later stages. This is due to many factors influencing the extraction of hydrocarbons, dynamics of the process itself, clarification in the data on the internal structure of deposits, etc. Those factors are determined by natural conditions and mining systems, and their significance constantly changes regarding the processing time (Bagirov et al., 2007; Efimova et al., 2010; Muslimov, 2014).

Study of the parameters influencing the mining process and ultimately the oil extraction ratio of the strata is practical not for all oil deposits, but rather for objects characterized by identical natural properties. Such an approach is coherent with the conditions for detailed and adequate solution to the issue of factors affecting the degree of extraction of oil from productive strata. For this purpose, from our point of view, it is necessary to first identify the deposits specifically according to a natural drive mechanism (as complex factors which have a direct effect on oil recovery), and then conduct detailed study of causative nature of the differing extents of recovery of deposits from those objects.

The objects of our research were offshore deposits of Azerbaijan which are mainly characterized by two types of drainage: solution gas drive and mixed drive mechanisms (Bagirov 1986; Bagirov et al., 2012).

In the conditions of the solution gas drive, the filtration of oil in the strata is provided exclusively by the energy of gas bubbles released from oil when stratum pressure drops below the saturation pressure. Naturally, such a mechanism cannot lead to a successful recovery of the reserves and is characterized by low coefficients of oil recovery [the ratio of extracted oil to initial reserves – TN] (Chan et al., 2006; Thu et al., 2009).

In the deposits characterized by mixed drive, manifestation of stratum energy takes places as a result of expenditures of energy of beyond-contour regions and energy of gas resources, dissolved and accumulated in pores of productive part of the reservoir. It should be noted that manifestation of mixed drive has both spatial and temporal patterns. The first type of object – during the mining of elevated regions of the structures – is mined under pressure, mainly from gas resources, from the very start, whereas, margins of the structure is mined using exclusively the flow of reservoir fluid under the deposits. The mechanism of manifestation of the second, mixed, type of deposits is somewhat different: first the main volume of the reservoir is drained, mainly by gas resources, and then – with decrease in stratum pressure – the influence of beyond-contour regions gradually activates. Deposits, characterized by the mixed drive, as dynamic systems, are relatively easy to regulate by changing the volume and direction of water pumped into the stratum, fluid extraction, etc.

In order to determine the influence of factors on oil recovery and ways of subsequent mining, we selected 49 exploited objects of mined offshore deposits of Azerbaijan, typical for the solution gas drive, and 75 deposits, characterized by the mixed drive. The solution gas drive is mainly seen in the objects of the Kerkmakin suite of the productive Azerbaijan stratum (Lower Plicoene) and horizons V, VII of the Balaxani suite, NKS (nadkermakinskaya sandy) and PK (podkermakinskaya) of the suites of the lower section of the productive layer are in most cases characterized by mixed mechanism of drainage (Table 1). Then, we conducted a detailed study of reasons why their reserves recovered to various extents (Bagirov et al., 2013; Dyshin et al., 2018). One of the elements of the research we performed was comparative analysis, which allowed us to determine the specifics of recovery of oil reserves of the offshore deposits, confined to various natural conditions.

The comparative analysis was performed based on the well-known and broadly recognised statistical method that implies using Student and Fisher criteria.

Within the distinguished groups of deposits of the same type based on the respective statistical criteria, we carried out a comparative analysis of the current...
and ultimate coefficients of oil recovery of offshore deposits for each of the mechanisms so as to determine the extents of their differences and various patterns of recovery of the reserves in the distinguished groups of the deposits (Bagirov et al., 2010; Abdullaeva 2010; Altunina et al., 2020).

Thus, by comparing the coefficients of each of the mechanisms with one another, we found significant differences, indicating that those objects are completely different by pattern of manifestation of the stratum energy (Table 2).

Table 2. The results of comparing the oil recovery factors of objects characterized by mixed and dissolved gas regimes

<table>
<thead>
<tr>
<th>Oil recovery factors</th>
<th>Natural drainage mechanisms</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mixed</td>
<td>Solution gas</td>
</tr>
<tr>
<td></td>
<td>mean dispersion</td>
<td>mean dispersion</td>
</tr>
<tr>
<td></td>
<td>( C_{\text{current}} )</td>
<td>student's Fisher's</td>
</tr>
<tr>
<td></td>
<td>0.48</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.28</td>
</tr>
</tbody>
</table>

The criteria were calculated with a degree of significance \( a = 0.05 \)

As we see in the data given above, both types of deposits, grouped by the pattern of manifestation of drainage mechanism, are characterized by significant change in the values of current coefficients of oil recovery. Therefore, if in offshore deposits, this value for the solution gas mechanism changes 0.10 to 0.44, for the mixed mechanism, its value ranges 0.20 to 0.60 (Fig. 1). Naturally, in case of other equal conditions (including mining systems), deposits of the both mechanisms with low coefficients of oil recovery indicate passivity of the stratum energy, whereas high coefficients of oil recovery suggest its activity. As is known, according to the principle of representativeness in nature, mixed drive is more active than the solution gas drive. To determine the regions of distribution of the activity degree, we developed a combined graph of current coefficients of oil recovery (Fig. 1).

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**Table 1.** Information on the results of the development of objects of offshore fields in Azerbaijan, characterized by the regime of dissolved gas and mixed modes

<table>
<thead>
<tr>
<th>Drives</th>
<th>Number of objects</th>
<th>Initial reserves, mln t.</th>
<th>Cumulative oil production from the beginning of development, mln t.</th>
<th>Oil recovery factors</th>
<th>Residual reserves, mln t.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>balance. recov.</td>
<td>balance. recov.</td>
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<td></td>
<td>balance. recov.</td>
</tr>
<tr>
<td>Solution gas drive</td>
<td>49</td>
<td>260.4</td>
<td>87.1</td>
<td>0.23</td>
<td>0.33</td>
</tr>
<tr>
<td>Mixed drive</td>
<td>75</td>
<td>421.9</td>
<td>226.7</td>
<td>0.48</td>
<td>0.54</td>
</tr>
</tbody>
</table>

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**Fig. 1.** The graph of the distribution of the current oil recovery factor for objects characterized by a mixed and gas dissolved in oil modes.
One of the main differences in oil extraction from the deposits is that regardless of the perfection of the exploration system and duration of its intense introduction, the reserves of those deposits are impossible to recover completely. This phenomenon is associated with natural representativeness of the collectors, which have various effects on the exploration process. At the same time, the stratum parameters manifest non-autonomously, but rather in complex interaction. Furthermore, their significance in the mining process is not constant and is subjected to certain changes in processing time. Thus, a mined stratum, as a hydrodynamic system, is a quite complex body, the internal structure of which is relevant to determine from both scientific and practical standpoints. Without consideration of those tasks, it is impossible to determine causes of slow, or by contrast intensified, realization of offshore oil deposits.

Taking this into account, we compared the developed models of oil recovery of the offshore oil deposits, characterized by solution gas and mixed drives. The objective of the oil recovery modeling was solved through multidimensional correlation-regression analysis using computer technology. Therefore, the matrix of the deposits with mixed mechanism includes average values of 11 traits: effective thickness of strata ($x_1$), porosity of rocks ($x_2$), permeability of the collectors ($x_3$), sandiness of rocks ($x_4$), oil density ($x_5$), oil viscosity ($x_6$), segmentation of the deposits ($x_7$), amount of cementing substance ($x_8$), water cut of the products ($x_9$), rates of the extraction at the start of mining ($x_{10}$), density of network of wells ($x_{11}$). For the deposits drained through the solution gas drive, – other than the parameters indicated above – the matrix was additionally given average values of the following features: difference in pressure during the mining of the objects ($x_{12}$), saturation pressure ($x_{13}$), volumetric coefficient of oil ($x_{14}$), stratum temperature ($x_{15}$) and gas factor ($x_{16}$) (Magerramov et al., 2021).

The program produced the following oil recovery models and coefficients of multiple correlation:

For the objects characterized by the solution gas drive

$$y_1 = 0.13378 + 0.05735(x_1) + 0.1487 \sqrt{(x_2)} + 0.015(x_3) - 0.00706(x_8) - 0.0839(x_9) + 0.0342(x_{11})-0.01344(x_{12})^{1/3}$$

$R_{\text{mni}} = 0.72$

For the objects characterized by the mixed drive

$$y_2 = 1.024 - 0.655(x_4) + 5.334 - \frac{1}{\varepsilon x_5} + 0.212(x_6)^{-1} - 0.457(x_7) + 3.126(x_8) + 1.714(x_{10})$$

$R_{\text{mni}} = 0.76$

It has to be noted that the structure of equations includes only those features that had significant (positive or negative) effects on oil recovery. The other features, which were considered insignificant, are not represented in the equation.

To demonstrate the pattern (positive or negative) of the influence of the parameters of the mixed deposits with different drives, we developed a scheme of their manifestation (Fig. 2).

As we see from the figure above, the extraction of oil reserves with the solution gas drive is positively influenced by such parameters as efficiency of the strata thickness, porosity of the rocks, permeability of the collectors and density of network of wells. Segmentation of the deposits, viscosity of oil, difference in pressure during the mining of the objects all have a negative influence.

For the deposits, exploited in the conditions of manifestation of the mixed drive, the traits that take positive effects on the exploration were as follows: permeability of the collectors, water cut of the products, rates of extraction at the start of the mining. Negative factors for such deposits were effective thickness of the strata, viscosity of oil and segmentation of the deposits.

Effective thickness, as a significant parameter, is included in both regression equations, although its influence on oil recovery in the conditions of the mechanisms we compared is not entirely clear. If the increase in its value had a positive effect on mining of the solution gas drive-drained reserves, its increase had negative effect on the mixed drive objects. Geological-economic analysis of long-mined deposits revealed that in the solution gas mechanism, yield decrease in the wells over the process of mining is associated with decrease in gas resources dissolved in oil, related to the stratum pressure falling below the saturation level. Experience of the mining demonstrates that increase in the length of the filter by additional perforation always gave positive results. An example may be the objects of the Kirkmakin suite on the deposits of the Central Absher-on, where even at the late stage of the exploration, involvement of additional interval of effective thickness allowed significantly increasing the average daily yield of oil. As with deposits with mixed drive, the increase in the filter in the region was always accompanied by the risk of inclusion of water-containing seams in the mining, which are usually quite aggressive in such deposits. Furthermore, in such deposits, opening of the stratum with extremely large filters was often accompanied by plugging, which complicated the drainage of the entire perforated interval (Magerramov et al., 2021; Manzhaei et al., 2021).
Porosity of the rocks, as a positive factor for oil recovery, was incorporated only in the model of the deposits with the solution gas drive, and permeability of the collectors was included into both regression equations, and, as expected, positively influenced the oil recovery. We should assume that increase in conductivity of the stratum provides mobility of oil in a porous environment, though its significance in various manifestations of the mechanism varied.

Oil viscosity negatively affected the oil recovery factor in any conditions of the stratum. Obviously, the higher the viscosity of oil, the harder is to filtrate it in stratum conditions (Magerramov, 2021; Vershinina et al., 2015; Kalinina et al., 2002).

Segmentation of the strata, similarly to viscosity, is included in both models and has a negative pattern. It has to be noted that in any natural conditions of the objects in the process of mining, the segmentation of the strata complicates the even re-distribution of energy resources on its volume, does not allow the frontal movement of water-oil contact or pushing fluids to the faces of pits by extending gas bubbles. Therefore, the negativity of manifestation of frequency of layering of the exploited object is obvious.

Although the water cut of the stratum was only reflected in the equation for the mixed drive, its positive influence on the extraction of the reserves was seen in all natural conditions, if the flooding was even and gradual. In the Azerbaijan deposits characterized by the solution gas drive, in the process of mining, there was seen a high percentage of water, which is also a positive factor of oil extrusion.
High rates of extraction at the beginning of the mining of the deposits with the mixed mechanism promote the intensification of the influence of out-of-contour regions, related to drop in stratum pressure. The greater the extraction from those deposits at the beginning of the mining, the greater section of curved dynamics of oil extraction on stages III and even IV, and therefore, the greater the coefficients of oil recovery. From the solution gas deposits, the greater extraction there was at the beginning of the exploration, the lower was the oil recovery. This is explained by the fact that extremely large extractions were provided by unjustifiably outrunning expenditure of stratum energy. Expenditure of the energy of solved gas as early as at the starting stage of the exploration has negative effects on mobility of oil in porous environments at later stage, which decreases the recovery of reserves.

Density of network of wells had the effect on the oil recovery of the deposits characterized by the solution gas mechanism, while having no significant effect for the mixed mechanism. For the deposits with the solution gas drive, it was associated with impossibility of creation of a common cone of depression in the process – into each exploited well, the oil was introduced only from a particular region of the deposits with a respective radius. Thus, in the stratum, there remain zones that had not been subjected to exploitation, which is reflected in maps of oil saturation for the area. Therefore, densification of well network promotes extraction of various amounts of oil from various parts of the stratum. Geological-economic analysis and experience of mining such deposits allows one to state that without additional drilling of new wells, current level of oil recovery would have been significantly lower. And in deposits with mixed mechanism, after introduction of the object into exploitation, create a common cone of depression was created for the wells of the main fund, which – by naturally changing over time – has extended. Each new well, drilled in the region instead of one withdrawn from exploitation, can only compensate initial losses of oil. Further densification of the well network, usually, leads to re-distribution of the overall extraction between wells due to mutual influence between the wells which emerges in such natural conditions.

Difference in pressure during mining and rates of extraction at the beginning of the mining are actually interrelated parameters, and their influence on exploration of reserves is identical. Difference in pressure had no significant effect on exploration of mixed drive deposits, whereas the deposits with the solution gas drive were affected negatively. Indeed, the greater the energy of stratum that was used at the beginning of mining (leading to large-scale decrease in stratum pressure), the more complicated was the realization of initial oil reserves at the late stage of mining (Bagirov, 2003; Kalinina et al., 2002; Zhdanov, 2017).

Such features as sandiness of collector rocks, the amount of cementing substance, saturation pressure, volumetric oil coefficient, temperature of stratum played no significant role during mining of both types of objects.

Oil density, as a parameter influencing the mobility of oil, nonetheless, is not included in the structure of the equations. The reason for this is first of all that the oil density is in close positive interaction with oil viscosity (which, as indicated, was included in both equations), and secondly, the influence of the parameter on oil recovery was insignificant in other provinces.

It has to be noted that the gas factor, despite not being involved in the models of oil recovery, was significant for deposits with the solution gas drive during exploration. This parameter did not play such a significant role for deposits with the mixed drive.

Conclusions

1. We collected and systematized the material for offshore deposits of Azerbaijan, drained by mixed and solution gas drives.
2. Using criteria of Student and Fisher, there was complex comparative analysis of the current and final coefficients of oil recovery of offshore deposits, exploited during various regimes.
3. We determined the degree of difference and various patterns of recovery of reserves in the distinguished groups of deposits.
4. We determined threshold values of passiveness and activity of manifested stratum energies.
5. We developed models of oil recovery of offshore deposits objects of both mixed and solved gas drives, which allowed the more objective prediction of their oil recovery.
6. We performed comparative analysis of the influence of stratum parameters on oil recovery of offshore deposits according to types of manifestation of the mechanisms in them, which allows the timely correction of the process of oil extraction and which may be used during development of projects of mining and further development of those deposits.
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