Methods of mathematical statistics application in assessing the density of actual and forecasting distribution density of residual oil reserves

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Abstract. The authors propose a method for mathematical statistics application for residual reserves in deposits predicting. They propose a method for making residual the current reserves distribution model based on geological and physical characteristics of the reservoir analysis. The article takes the first step to justify the use of statistical methods in the conditions of operational facilities of the Romashkino and Tuymazy oil fields. One of the urgent problems associated with the effective oil fields development is not only a reliable estimate of the distribution density of residual reserves, but their forecast for the subsequent development as well. There are many ways to estimate residual reserves nowadays. All of them are, to one degree or another, based on residual oil saturation ratio estimating, which in the conditions of insufficient accuracy of geophysical methods, as well as their rise in price (carbon-oxygen logging, for example) or their limited application, calls for other approaches in the residual oil reserves value assessing, based, for example, on the field data. Logging methods have their limitations. Their application requires other approaches in residual reserves amount assessing. Having analyzed multiple studies results, such as, for example, field data, implemented in the SPSS program regression analysis, which allows statistical data the processing the authors propose the mathematical statistics methods application in assessing the density of the actual and forecasting the residual oil reserves’ distribution density. The mathematical modeling results for oil from a porous medium displacement process are presented for Romashkino and Tuymazy oil deposits.

1. Introduction

According to geological exploration studies in Aktash region, the authors [1-3] carried out a correlation analysis, on the basis of which the regression equations were derived. Considering the structure of the operational object of Aktash region, it can be noted that its geological model is characterized by a significant heterogeneity of the composing collectors, a significant difference in the collector properties of the allocated groups and a limited distribution area of productive sediments, which is a characteristic feature of the territory. Undoubtedly, all this was, on the whole, a complicating factor throughout the entire period of the area development.

The researchers [4-6] performed a detailed statistical analysis of the distribution features of the main parameters characterizing the filtration and reservoir properties of the each productive layer composing the terrigenous Devonian deposits within the Aktash area. The obtained results were tested at the
Romashkino and Tuimazy fields, where the correctness of the derived regression equation was confirmed.

2. Materials and methods
A single-factor correlation analysis and visualization of the various geological, physical, and field parameters influence on the residual $Q_{res}$ reserves value and the ultimate oil recovery was performed [6]. Further, the contribution of each of these components to the ultimate oil recovery value and residual reserves was evaluated in order to obtain a predictive regression equation.

For these purposes, the regression analysis implemented in the SPSS statistical data processing program is best suited [7].

To assess the significance (impact) of the various components on the residual reserves density a pairwise correlation analysis was performed first, i.e. the influence of each of the factors on the residual oil reserves value was studied with the aim of their further inclusion in the regression equation for the residual reserves development forecasting. In this case, the Pearson correlation coefficient and the significance coefficient were determined [8–9].

At the same time, the following geological, physical, and fishing factors were taken into account in the correlation analysis:

\[ H_{\text{nott}} – \text{net oil thickness, m}; \]
\[ IR_{\text{por}} – \text{porosity fragmentation variability}; \]
\[ IR_{\text{Roll}} – \text{oil saturation fragmentation variability}; \]
\[ IR_{\text{perm}} – \text{permeability fragmentation variability}; \]
\[ K_{cl} – \text{clay mass ratio, \%}; \]
\[ N – \text{the interlayers number in a pack}; \]
\[ G – \text{hydraulic conductivity}; \]
\[ K_{fl} – \text{flushing ratio, u.r.}; \]
\[ Q_{\text{init}} – \text{initial stock density, t/m}^3; \]
\[ K_{\text{perm}} – \text{average number of permeable intervals in the section, 1/m}; \]
\[ OWR – \text{oil water ratio, t/t}; \]
\[ N_{cl} – \text{relative clay ratio, u.r.}; \]
\[ K_{\text{bwr}} – \text{bound water ratio}. \]

Pairwise correlation calculation results are presented in table 1.

From this table it follows that the following factors are the most significant: initial net oil thickness $H_{\text{nott}}$, clay mass ratio $K_{cl}$, the number of interlayers in pack $N$, hydraulic conductivity $G$, flushing ratio $K_{fl}$, initial stock density $Q_{\text{init}}$, average number of permeable intervals in the section $K_{\text{perm}}$, relative clay factor $N_{cl}$, bound water ratio $K_{\text{bwr}}$.

Since $K_{cl}$ and $N_{cl}$ are related quantities, one of them can be neglected, given the different degree of significance ($N_{cl}>K_{cl}$). The coefficient of bound water $K_{\text{bwr}}$ depends on the relative clay content, therefore, it can also be neglected. The number of packs $N$ and the average number of permeable intervals in the section $K_{\text{perm}}$ are also related quantities that reflect heterogeneity (multilayer), and for the calculations taking into account their significance one can take the average number of permeable intervals in the section coefficient.

So, to obtain a regression equation for the relationship between the residual reserves density and geological field data, the authors used the following factors: hydraulic conductivity $G$, flushing ratio $K_{fl}$, net oil thickness $H_{\text{nott}}$, relative clay ratio $N_{cl}$, and the average number of permeable intervals in the section $K_{\text{perm}}$.

Regression analysis to obtain the corresponding equation was carried out in the SPSS program, the regression equation of the dependence of $Q_{\text{res}}$ on geological and production factors was derived for each pack individually and for the whole reservoir DI. As a result, the authors obtained the following regression equations.

\[ Q_{\text{res}}=0.001G – 0.028K_{\text{perm}} + 0.046H_{\text{nott}} – 0.084N_{cl} – 0.016K_{\text{perm}} – 0.033, \quad R^2 = 0.7 \] (1)
Table 1. Pairwise Correlation Results

| Factor   | Correlation coefficient | $Q_{res}$ |
|----------|-------------------------|-----------|
| $H_{thth}$ | Pearson Correlation      | 0.772(**) |
|          | Sig. (2-tailed)          | 0.000     |
| $IR_{por}$ | Pearson Correlation      | 0.012     |
|          | Sig. (2-tailed)          | 0.851     |
| $IR_{oil}$ | Pearson Correlation      | 0.063     |
|          | Sig. (2-tailed)          | 0.320     |
| $IR_{perm}$ | Pearson Correlation     | 0.014     |
|          | Sig. (2-tailed)          | 0.821     |
| $K_{cl}$  | Pearson Correlation      | -0.368(**) |
|          | Sig. (2-tailed)          | 0.00021   |
| $N$       | Pearson Correlation      | 0.195(**) |
|          | Sig. (2-tailed)          | 0.002     |
| $G$       | Pearson Correlation      | 0.732(**) |
|          | Sig. (2-tailed)          | 0.000     |
| $K_{perm}$ | Pearson Correlation      | -0.161(*) |
|          | Sig. (2-tailed)          | 0.011     |
| $Q_{init}$ | Pearson Correlation      | 0.805(**) |
|          | Sig. (2-tailed)          | 0.000     |
| $K_{perm}$ | Pearson Correlation      | -0.447(**) |
|          | Sig. (2-tailed)          | 0.000     |
| $OWR$     | Pearson Correlation      | 0.079     |
|          | Sig. (2-tailed)          | 0.557     |
| $N_{cl}$  | Pearson Correlation      | -0.419(**) |
|          | Sig. (2-tailed)          | 0.00014   |
| $K_{bwr}$ | Pearson Correlation      | -0.419(**) |
|          | Sig. (2-tailed)          | 0.000     |
** Correlation is significant at 1% ($p=0.01$).
* Correlation is significant at 5% ($p=0.05$).

In order to verify the calculated (forecasted) $Q_{res}$ value with the actual data, the sum of the residual reserves density for each pack and for the reservoir DI was calculated. The results are summarized in table 2.

Table 2. Comparison table of calculated and actual values of the residual reserves density

| Pack | $\Sigma Q_{res,calc}, \text{t/m}^2$ | $\Sigma Q_{res,act}, \text{t/m}^2$ | $Q_{res,calc}$ average, $\text{t/m}^2$ | $Q_{res,act}$ average, $\text{t/m}^2$ |
|------|-----------------------------------|-----------------------------------|----------------------------------------|----------------------------------------|
| 4    | 10.39                             | 10.75                             | 0.179                                  | 0.185                                  |
| 7    | 7.59                              | 6.81                              | 0.194                                  | 0.174                                  |
| 9    | 4.76                              | 4.03                              | 0.198                                  | 0.17                                   |
| 11   | 13.94                             | 11.92                             | 0.244                                  | 0.209                                  |
| 13   | 13.69                             | 11.3                              | 0.240                                  | 0.198                                  |
| 23   | 4.03                              | 4.11                              | 0.287                                  | 0.294                                  |
| DI   | 49.11                             | 48.94                             | 0.197                                  | 0.196                                  |

In addition, the obtained regression equations (1) can be used to predict the terrigenous Devonian reserves development at the initial stage of oil field development under given initial conditions: with known hydraulic conductivity, flushing coefficient, oil-saturated thickness, relative clay content and average number of permeable intervals in the section.

In addition to the residual reserves density, the reservoir depletion degree is evidenced by the oil recovery coefficient. Therefore, it is very important to predict the final oil recovery factor ($ORF$) at the
initial stage of field development. For this purpose, the authors derived the appropriate regression equations for each pack and for the DI formation. After a preliminary assessment of the geological and physical factors influence (significance) on this indicator, the most significant (influencing) factors on the oil recovery factor are: net oil thickness $H_{noth}$, number of packs $N$, hydraulic conductivity $G$, amount of water produced per pack $Q_{waterpack}$, flushing factor $K_{fl}$, initial reserves density $Q_{init}$, average number of permeable intervals in the section $K_{perm}$, the recovered oil amount of selected pack $Q_{oilpack}$.

$$
ORF = 0.001 H_{noth} + 0.0008 G - 0.069 K_{perm} + 0.121 K_{fl} + 0.195
$$

Basing on the results, the comparative curves of the calculated and actual values of the oil recovery factor were compiled (Figure 1).

![Figure 1.](image)

**Figure 1.** Dependence of the estimated oil recovery factor and the actual oil recovery factor on the flushing ratio

Figure 1 shows graphs reflecting the dynamics of the dependence of the calculated and actual oil recovery factor on the $K_{fl}$ flushing ratio for the “merger site”, from which it follows that the maximum oil recovery factor can be achieved with the values $K_{fl} = 2.0$, which is in good agreement with the available field production data.

To test the universality of the results, it was decided to derive a similar regressive equation for the dependence of $Q_{res}$ on various geological and production factors in the conditions of the Tuymazy oil field (block XII) for the DI layer of the terrigenous Devonian.

### 3. Results and Discussion

After that, in order to assess the suitability of the equation (1) for calculating the $Q_{res}$ for Devonian terrigenous sediments in the Aktash area, the field data for the Tuymazy oil field were used in the equation (1), which was derived to determine the $Q_{res}$ from the DI reservoir.

According to the reconciliation results table 3 was compiled.

| Layer    | $z$, t/m² (Tuymazy oil field) | $\Sigma Q_{resact}$, t/m² (Tuymazy oil field) | $\Sigma Q_{recale}$, t/m² (Aktash oil field) |
|----------|-------------------------------|---------------------------------------------|---------------------------------------------|
| DI amount| 38,59                         | 37,37                                      | 50,239                                      |
| The average deviation, % | 3,0                           | -                                          | 34,4                                        |
The data in table 3 shows that the average deviation of the calculated $Q_{res}$ from the actual $Q_{res}$ obtained using the regression equation derived for the Tuymaz oil field (1) is 3.0%.

The obtained result allows concluding that the obtained regression equations are inapplicable outside the relevant conditions.

4. Conclusion

Basing on the research results the following conclusions can be drawn.

1. In the conditions of the Devonian terrigenous sediments the regression equations were obtained that can be used to calculate the current residual reserves density, as well as to make their forecast;
2. The equation obtained for the terrigenous deposits of the Romashkino oil field can be used to calculate the residual reserves density for similar deposits of other areas or the Ural-Volga region deposits, taking into account the geological, physical and field factors characteristic of these conditions.

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