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Electrometry effective inverse problem solving method

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SUMMARY

A new fast inverse problem solving method of multi-probe electrometry of wells is proposed, which allows taking into account the quantitative contribution of measuring each probe to the final result. The algorithm for solving the inverse problem has been developed and implemented in software. It is shown that the proposed approach can also significantly improve the vertical resolution of the method as a whole. An example is given of comparing various results of solving the inverse problem of lateral logging sounding and lateral logging when changing the contribution of the measurement of each probe to the final result. It is concluded that the use of a quick method for solving the minimization of the residual functional combined with the ability to take into account the contribution of each probe of the multi-probe electrometric complex to the final result of solving the inverse problem makes it possible to increase the accuracy of quantitative interpretation. It is also shown how the developed algorithm and the corresponding software created make it possible to increase the accuracy of determining the geoelectric parameters of reservoirs. The results of the work were introduced into the production of a number of commercial geophysical organizations.
Introduction

Modern scientific research at the Institute of Telecommunications and the Global Information Space has a broad focus. They have a wide scientific spectrum. But they also have a different focus. Among the works containing serious practical results, the following works should be singled out first of all (Baum et. al., 2014; Kaliukh et. al., 2015; Korchenko et. al., 2019; Okhariev and Trysnyuk, 2019; Trysnyuk et. al., 2019). Among the works containing fundamental and applied results. The following should be highlighted (Trofimchuk, 2002; Trofymchuk et. al., 2013; 2017; 2018; 2019). In this paper, a description of the numerical method and the results obtained using it are presented. This work relates to well logging and is a continuation of the works (Myrontsov, 2019a; 2019b).

Method

The effectiveness of a particular the inverse problem solving method is determined by the choice of the method for determining probe measurement data for the selected medium parameters; the choice of the “proximity” parameter of the calculated probe readings and real ones; by choosing a method for selecting model parameters for the selected "proximity" parameter. These questions can be rephrased accordingly as:
- the choice of a method for solving the direct problem (finite differences, finite elements, integral currents, semi-analytical solution, etc.);
- the type of functionality that will be minimized when solving the inverse problem (previously this item looked like “the choice of the nearest palette clearly”);
- a method of an iterative process for solving the inverse problem.

![Figure 1](image-url)

**Figure 1** Three-layer model of the reservoir of finite thickness (h): $\rho_B$ – specific resistivity (SR) of uninvaded zone of the bed, $\rho_W$ – SR of drilling mud (SR of the well), $\rho_Z$ – SR of invaded zone of the filtrate of the drilling fluid, $D/d$ – ratio of the diameter of the penetration zone to the nominal diameter of the well.
Without loss of generality we considered a three-layer model of the reservoir (Fig. 1).

To begin with, a table was constructed linking the values of the vector components from the range of values of geoelectric model parameters with the vector components from the range of values of measurement data.

![Figure 1](image1.png)

**Figure 2** Well “Test-1” (SR drilling fluid 1 Ohm·m): a, b – diagrams of the SR probes of the complex; c – is the result of the inverse problem, if all \( K=1; g = K_{A0.4M0.5N} = 0, K_{A0.4M0.5N} = 0; d - K_{A8.0M1.0N} = 0 \) but \( K_{7F1.6} = 1 \).

Having selected the necessary parameters \( \rho_z, (D/d)^{\frac{1}{j}}, \rho_B \) for the reservoir of infinite thickness, we solved the direct resistivity logging (RL) problem for the BKZ geometry, then for the BK geometry and formed a new row of the table in the form of values:

\[
\rho_z^{j}, \rho_B^{j}, \rho_{A0.4M0.1M}^{j}, \ldots, \rho_{A8.0M1.0M}^{j}, \rho_{BK-3}^{j}.
\]

As a rule it is customary to build such a table on a bi-logarithmic scale. After completion of its formation it became possible to implement an algorithm for the simplest solution of the inverse problem.

In the process of sorting the rows of the table, one is selected for which the given complex SR most closely match the actually measured parameters.

The values \( \rho_z^{j}, (D/d)^{\frac{1}{j}}, \rho_B^{j} \) from this line will be the desired parameters of our model. Enumeration can be implemented automatically and the criterion of "coincidence" will look like minimizing the functionality:
\[
F(p^T_1,\ldots,p^T_n) = \left[ \sum_{i=1}^{n} K_i \left( \frac{p^T_i - p^P_i}{p_i^P} \right)^2 \right], \tag{1}
\]

where is \( n \) – the number of probes of the complex; \( p^T_i \) – calculated values of apparent resistivity (AR) for the considered model; \( p_i^P \) – the actual values of the AR; \( K_i \) – weighting coefficients of each probe of the complex which can be changed including by the interpreter.

**Examples**

In Fig. 2.a,b – diagrams of probes of the “BKZ + BK” complex for a model well are presented. For convenience it is called “Test-1”. Fig. 3.c shows the result of solving the inverse problem for all the probes of the complex (\( \forall i: K_i = 1 \)) for this well (Rz, Rb – the desired model parameters, R’z, R’b – the result of solving the inverse problem).

As expected: there is a distortion of the shape of the curves in the vicinity of the positions of the horizontal boundaries of the layers; significantly distorted SR values of compacted high-resistivity layers; SR of distorted layers of increasing penetration, which are the sole for high resistance, are distorted; significantly distorted parameters of the reservoir (SR zone and SR reservoir) lowering penetration.

At the same time satisfactorily (for water-saturated (\( \rho_B = 4.5 \) Ohm ∙ m, \( \rho_Z = 20 \) Ohm ∙ m, \( D/d = 5 \)) almost perfectly) the parameters of productive reservoirs of increasing penetration (the roof of which are not high-resistivity layers) are distinguished.

If the inverse problem of four-meter and eight-meter probes is excluded from the process of solving the inverse problem (Fig. 2.g), the situation unexpectedly improves. The parameters of all the layers are guaranteed satisfactorily determined by the curves of the desired parameters.

The only drawback is the significant distortion of the curves in the vicinity of the horizontal boundaries of the layers. It turned out that this drawback is very easily eliminated by attaching to the complex just one IL probe. In this case we chose the 7F1.6 probe. The resulting solution with an added IL probe (Fig. 2.d) is almost devoid of distortion of the curves in the vicinity of the horizontal boundaries of the reservoirs compared to the previous result. This clearly demonstrates the benefits of sharing RL and IL data.

Immediately we note the fact that the vertical resolution of both the “BKZ + BK” and “BKZ + BK + IL” complexes is somehow determined by the vertical resolution of the BKZ. This should be remembered when choosing weights while minimizing (1). And especially remember when solving the inverse problem for contrasting thin-layer layers.

**Conclusions**

The use of a quick way to solve the minimization of the residual functional( combined with the ability to take into account the contribution of each probe of the multi-probe electrometric complex to the final result of solving the inverse problem) made it possible to create a fast and highly effective method for quantitative interpretation of electric wells data.

Namely the complex BKZ, "BKZ + BK", "BKZ + BK + IL". The developed algorithm and the corresponding software created can improve the accuracy of determining the geoelectric parameters of oil and gas reservoirs. The results of the work were introduced at LLC “Pridneprovsk Mining and
Chemical Corporation”, LLC “NADRA Geophysical Equipment” and is used in the current work of SE “Ukrspetzgeologiya”. The work continues to study the areas of existence of stable solutions and areas of equivalent solutions of the inverse problem.

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References


