Lateral logging sounding and lateral logging complex effective inverse problem solving method

M. L. Myrontsov (Institute of Telecommunications and Global Information Space, National Academy of Sciences of Ukraine)

SUMMARY

Using the example of lateral logging sounding the possibility of assessing the influence of the adjacent beds and boundary effects on the real vertical resolution of the inverse problem solution is shown. An example of such solution to the inverse problem of the “BKZ+BK” complex for a real well material in a sedimentary rocks is given. The conclusions are made that: for the correct use of the algorithm for solving the inverse problem, it is necessary to have an estimate of the vertical resolution of the electrometry method as a whole; a real assessment of the influence of boundary effects on the measurement of the apparent resistance of the probes of the complex allows us to evaluate the effectiveness of the method; the use of the proposed residual functional allows us to change the effect of probes of different lengths on the final result and thereby allows to achieve satisfactory accuracy even when studying the geoelectric parameters of formations whose thickness is less than the length of the largest probes of the complex. 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 (Azimov et. al., 2019; Gomilko et. al., 1999; Gomilko and Trofimchuk, 2001; Kaliukh et. al., 2019; 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 et. al., 2014; 2019; Trofimchuk and Lovtsov, 1995). 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).

Electric logging (EL), as one of the main GIS methods, provides the researcher with a certain “average” value of specific resistivity (SR) – the so-called apparent resistivity (AR). Therefore, one of the components of the theory and methodology of electrometry of wells is the creation of an algorithm (solution of the inverse problem), which allows reconstructing the spatial distribution of the differential value SR using the measurement data. Moreover, the number of geoelectric parameters of the reservoir model cannot exceed the number of measured values against this reservoir, therefore, the spatial distribution is described using the model of a limited number of parameters. Obviously, to increase the granularity of the determination of the spatial distribution of the SR, an increase in the number of probes having different depths of investigation is necessary. However, this number is limited by design, technical and methodological features.

**Method**

In the case of a three-layer model of the medium, the number of unknown parameters of the model is three ($\rho_B$ – SR of the uninvaded zone of bed (in abbreviated form – SR of bed), $\rho_Z$ – SR of the invaded zone of bed (in abbreviated form – SR of zone) and $D/d$ – the ratio of the diameter of the zone to the diameter of the well) and, therefore, the solution of the inverse problem will only make sense for electrometry complexes having three or more probes.

Such a three-layer model successfully describes even thin-layered and anisotropic reservoirs, spurious and residual oil saturation reservoirs, anomalously low-resistance reservoirs, etc., which are commonly considered complex in the conditions of the Dnieper-Donets depression. To study such objects, the complex of lateral logging sounding (BKZ – consists of seven unfocused probes A0.4M0.1N, A1.0M0.1N, A2.0M0.5N, A4.0M0.5N, N6.0M0.5A, A8.0M1.0N, N0.5M2.0A (reverse A2.0M0.5N)) even in combination with the BK-3 (BK) three-electrode lateral logging probe and 71.6F or 6F1 (IL) focused induction logging probe is ineffective. It is also ineffective for some simpler objects (for example low-power formations with a capacity comparable to or shorter than the length of the largest probes of the complex) if the currently accepted approach to the quantitative interpretation of “BKZ + BK + IL” data is applied.

As a criterion for the proximity of the solution found with the desired true value it is customary to consider the minimization of the functional which in general terms can be written as:

$$ F(\rho_1^T, ..., \rho_n^T) = \frac{1}{n} \left( \sum_{i=1}^{n} \left( \frac{\rho_i^T - \rho_i^P}{\delta_i^T + \chi_i} \right) ^2 \right), $$

where is $n$ – the number of equipment probes; $\rho_i^T$ – calculated values of AR for the model under consideration; $\rho_i^P$ – actually obtained values of AR; $\delta_i$ – relative error of the probe; $\chi_i$ – absolute error of the $i$ th probe.
Figure 1 Well “North-Pokurskaya” (SR drilling fluid 1.2-1.3 Ohm·m): a – VIKIZ diagrams; b – the result of solving the inverse problem “BKZ + BK” for all $K = 1$; c – the result of solving the inverse problem “BKZ + BK” at $K_{4.0/0.5N} = 0$, $K_{4.0/0.10N} = 0$; g – diagram of spontaneous polarization (PS).

This approach has proven itself in solving the problems of multi-probe infrared in which the measured apparent conductivity by probes of different lengths is reduced to the same value of vertical resolution by solving the Fredholm equation of the first kind of convolution type. But the EL task (in contrast to the IL problem) is nonlinear and therefore requires a different approach.

Consider instead of (2) a functional of the form:

$$F(\rho^T_1, ..., \rho^T_n) = \sum_{i=1}^n K_i \left( \frac{\rho^T_i - \rho^T_{i-1}}{p_i} \right)^2,$$

(2)

where are $K_i$ – the weights of each probe of the complex which may vary by the interpreter.
In the point-wise version of the inverse problem solution (in contrast to the layered one) we believe that the logging data at each point corresponds to the logging data obtained in the reservoir of infinite power, and for this data we solve the one-dimensional inverse problem. After solving the inverse problem already along the curve \( \rho_H \), if necessary, we set the boundaries (we divide the studied interval into layers) and for each layer we determine values \( \rho_B, \rho_Z \) and \( D/d \).

Examples

Let us now consider a point-wise the “BKZ + BK” inverse problem solution for real well material (Fig. 1) for a well which we will arbitrarily call “Severo-Pokurskaya”. We will compare the results with high-frequency induction logging isoparametric sensing data (VIKIZ: VK1-VK5 curves correspond to probes of length 0.5, 0.71, 1.0, 1.41, 2.0 m).

\( R'z \) and \( R'b \) are the SR of the zone and the reservoir obtained under the assumption that the entire interval is the penetration interval, and \( R''b \) is the SR of the reservoir obtained under the assumption that the entire interval is impermeable. Comparison of Fig.1.b and Fig.1.c allows us to conclude that the reservoir pressure (defined under the assumption of lack of penetration) differs significantly from the reservoir determined on the assumption of penetration of the entire study interval.

Indeed, under the assumption of the presence of penetration and its absence, the reservoir properties almost coincide with the presence of an eight-meter probe in the complex. When the two longest unfocused probes of the BKZ complex are excluded then the SR reservoir, assuming no penetration, becomes a kind of "middle" between the SR of the zone and the SR of the bed in the presence of penetration.

Therefore in the presence of large probes and with increasing penetration (which is crucial in this case) the “BKZ + BK” complex is the most sensitive to the SR of the bed. A change in the SR of the penetration zone in this case turns out to be a smaller effect.

Generally speaking this fact complicates the interpretation process since without additional material, as follows from the obtained result, we cannot unambiguously establish the permeability of the interval. Indeed each of the two results presented is obtained correctly with its own error value and which practically do not differ from each other. It is such results, as shown in Fig. 1.b, indicate that the invaded zone is present but has a small radius. That is the influence of changes in the SR zone (on the value of the measured SR) is leveled by its small size. This is also confirmed by VIKIZ data (at intervals where it is not determined by other methods of penetration: the diameter of the penetration zone \( D/d \) is 1.5-2.5 and at intervals where guaranteed penetration is present it is 2.5-6.0).

In such cases when it is really possible to distinguish between the intervals “with” and “without” penetration without additional methods proceed as follows. We solve the inverse problem under the assumption that there is penetration over the entire interval (we determine \( R'z \) and \( R'b \)) and under the assumption that the interval is impermeable (we determine \( R''b \)). Then we divide the studied interval by auxiliary methods into intervals with and without penetration, and on the first we consider the solution \( R'z \) and \( R'b \) and on the second – \( R''b \). Intervals with penetration are allocated according to auxiliary methods.

An increase in accuracy is expected when other electrometry probes are added to the “BKZ + BK” complex for example at least one IL probe. A similar approach without loss of generality is also possible in solving the inverse problem for other electrometric complexes of oil and gas wells.

Conclusions

For the correct use of the solution algorithm it is necessary to have an estimate of the vertical resolution of the method as a whole i.e. have an assessment of the capabilities of the combination of
the solution algorithm and the real impact of the boundary effects on the measurement of the AR probes of the complex. However, the use of functional (2) allows to change the influence of probes of various lengths on the final result and thereby allows satisfactory accuracy to be achieved even when studying geoelectric parameters of beds whose thickness is less than the length of the largest probes of the electrometric complex. The work results for the “BKZ + BK + IK” complex were introduced into the production process of LLC “Pridneprovsk Mining and Chemical Corporation” and SE “Ukrspetzgeologiya”.

Acknowledgements

The publication contains the results of studies conducted by President’s of Ukraine grant for competitive projects (F44, Grant for young doctors of sciences, 2019).

References


