Synthetic simulation of NTEM-sounding signals on the target horizon of the White Tiger oilfield

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Abstract. Based on the prior information on the White Tiger oilfield cross-section, an attempt has been made to apply synthetic simulation of the NTEM-sounding signals to predict the reservoir’s saturation type and to evaluate the NTEM signals’ response.

1. Introduction

White Tiger is a major oilfield on the southern shelf of Vietnam, situated 120 km from the port city of Vung Tau, the main production unit of the Vietsovpetro enterprise.

The geological cross-section of the field is represented by pre-Neozoic crystalline basement rocks and Neozoic terrigenous rocks in the sedimentary cover with Oligocene, Neogene and Quaternary sand-aleurite and clay rocks (Figure 1).

![Figure 1. Geological cross-section of the producing horizon at the wells BT-126, BT-19, BT-9.](image)

The target producing horizons of the White Tiger oilfield are upper Oligocene, lower Oligocene and basement rocks. The research uses the data on BT-126 well [1]. Besides, a cumulative cross-section has been plotted for BK-126, BT-19, BT-9 in Surfer 12 software. The pay horizons are reser-
voirs situated in the following sediments: upper Miocene (O1), lower Miocene (O2) and fractured basement rocks (F).

2. Materials and methods
The basis of the NTEM method is a study of the character of the electro-magnetic field generated in the earth by an abrupt change in the current flowing in the generator. An abrupt current cut-off in the generator’s loop results in inductive currents that propagate vertically from the day surface down the earth as the current lines density is reduced. The study of the geo-electric characteristics of the cross-section with NTEM sounding provides information on the reservoir’s properties and its saturation type [2].

The saturation prediction is implemented by converting the electrical resistivity (ER) value obtained with NTEM method into the water-saturation factor (Fw), using the Dakhnov-Archi petrophysical function. The aim has been to generate a synthetic NTEM signal and to evaluate its response to the parameters of the geological model change i.e. to the target horizons’ saturation. Besides, it has been required to evaluate the NTEM response to the saturation of the stratum (fractured and cavernous reservoirs) by synthetic simulation for the White Tiger oilfield specific conditions.

There have been a few stages in the synthetic simulation.
1. Collecting prior information (well logging, structural parameters).
2. Developing a standard geoelectric model based on the prior information.
3. Solving the primal problem and evaluating the NTEM signals’ response.
4. Generating noisy primary data.
5. Solving the inverse problem (inversion).
6. Comparing the results of the primal problem solution and the inversion results.

The research deals with the first three stages, the last three stages being currently in process.

The geoelectric model of the cross-section is a sequence of geoelectric horizons of fixed thickness and resistivity. The input data (Table 1) includes: structural frame, electric resistivity (ER) and target horizons’ parameters Fp, Fw, and Heff.

Table 1. Reservoir parameters of the producing horizons of the White Tiger oilfield.

| Producing horizons | Parameters | Heff (m) | Fp (%) | Reservoir resistance (Ohm) |
|--------------------|------------|----------|--------|---------------------------|
| Upper Oligocene (O1) | 34 | 12.5 | 100 |
| Lower Oligocene (O2) | 96 | 10 | 95 |
| Basement (B) | 30 | 5.5 | 1200 |

Reservoir parameters Kp и Kw are calculated as weighted mean values by the geophysical-geological model, Heff is calculated as a sum of the reservoir intervals.

The target-reservoir stratums’ resistance is found using the petro-physical function [4,5].

3. Research results and analysis
Based on the lateral logging results, an averaged geoelectric NTEM model of the sedimentary cover of the White Tiger oilfield has been constructed. The geoelectric model for the cross-sections of up to 5 km deep mostly consists of 9 to 10 geoelectric horizons (Figure 2).
A set of geoelectric models has been drawn-up for different saturation levels of the reservoir horizon (Figure 3).

In order to find the ER value for the target horizon, the petro-physical function of Dakhnov-Archi is used [3]:

$$K_W = \left( \frac{a.b.R_W}{R'' - K''_W} \right)^{\frac{1}{m}}$$  \hspace{1cm} (1)

The $m$ factor defines the pore space type:
- $m = 2.96$ – porous reservoir;
- $m = 1.3$ – cavernous-porous reservoir;
- $m = 1$ – fractured reservoir.

The changes of the resistance values have been defined for different saturation levels in the above reservoir types.

On the basement cross-section with fractured and cavernous reservoirs, ER changes significantly from very small to very big values (from 21.8 Ohm.m to 1,084 Ohm.m).

On the resistivity profile of the lower Miocene, ER changes slightly, from 92 to 130 Ohm.m.
On the resistivity profile of the upper Oligocene, ER changes slightly, from 71 Ohm.m to 104 Ohm.m.

Based on the formalized physical-geological models (PGM), synthetic curves have been calculated for the source signal of the electromotive forces (EMF), as well as apparent resistance transforms $R_T$ with cumulative longitudinal conductivity $S_T$ (Figure 4) have been plotted. For example, a set of synthetic curves has been calculated for different saturation levels of the basement fractured reservoirs ($m = 1$).

- PGM1 is a physical-geological reservoir model with Fw=10%;
- PGM2, Fw = 50% is a physical-geological reservoir model with Fw=50%;
- PGM3, Fw=100%, is a physical-geological reservoir model with Fw=100%.

To calculate the NTEM signals’ response to the saturation types, signal divergence nomograms have been plotted (Figure 5).

The NTEM signal divergence has been calculated for a time span of 5,000ms. Every resistance level has its saturation Fw of 10 – 100 %.

Two reservoir types have been studied: cavernous (with $m=1.3$) and fractured (with $m=1$).

The nomogram shows the percentage model divergence (1%). It is possible to detect reservoirs with the saturation Fw = 90 – 100 %. For the fractured reservoirs, the NTEM divergence with carbon saturation is higher and reaches 17 %. For the terrigenous lower Miocene reservoirs, the NTEM signal divergence is low in case of the saturation change, with the maximum being 0.55%. The divergence of 0.3% has been taken as an alarm level.

The response of the terrigenous upper Oligocene reservoirs to the saturation change is higher than that of the lower Oligocene rocks, being 2.4%.

**4. Discussion**

Based on the preliminary analysis of the geological-and-geoelectric structure of the target horizons of the White Tiger oilfield, the response of the NTEM signals has been defined for the reservoirs of different saturation- and pore-space types in the upper Oligocene and basement rocks. The synthetic NTEM signal divergence for the pay horizons’ reservoirs shows the NTEM signal response to the presence of caverns and fractures in the basement rocks. The divergence of the non-noisy NTEM signals between the models with carbon saturation and the ones with water saturation is 17%. The comparison of the models with the saturation Fw = 10% - 100% shows that the higher the water saturation, the lower the reservoir’s electric resistivity is.
5. Conclusion

The use of the NTEM method in defining the target horizons’ signal response has been researched for the White Tiger oilfield. The synthetic simulation of the NTEM signals based on the prior information has made it possible to develop a standard geoelectric model and evaluate the NTEM signal response for the reservoirs with different saturation- and pore space values. The method is based on a complex analysis and can be used to detect the reservoirs and predict the change in their filtration-capacity properties, which in turn helps to estimate their potential for hydrocarbons.

References

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