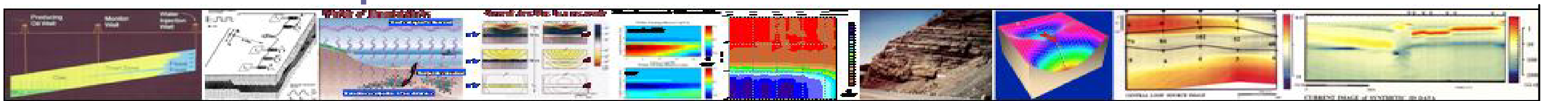
Water/Gas Flood Monitoring Using 4-D EM Measurements



KMS Technologies, KJT Enterprises, Inc.
PHOENIX GEOPHYSICS

Monitoring reservoirs while they are being flooded with gas or water (or others) can significantly improve the production output and facility usage because one can avoid flood breakthroughs before they happen. When using water or gas, there is in most cases a clear resistivity contrast between the swept and unswept area. The bulk resistivity of a rock depends on its porosity, pore fluid resistivity, and saturation. When the pore fluid within a rock changes from water to hydrocarbons (oil or gas), most physical properties of the rock change. Electrical resistivity is most affected. Replacement of oil by brine in a reservoir can cause a change in electrical resistivity of reservoir rock of as much as four orders of magnitude.

Considering that resistivity contrast is always involved with water or gas floods, electromagnetic (EM) measurements can be successfully applied to monitor reservoirs. EM methods have the potential to be used for water or gas flood monitoring because they can discriminate between water-saturated reservoirs (low resistivity) and hydrocarbon-saturated reservoirs (high resistivity).

Over the past decade, it became clear that surface geophysical measurements could be used for water or gas flood monitoring. During the last decade, electromagnetic method, hardware development and modeling have made significant progress. Today, new multichannel recording systems (MTEM) have greatly increased the dynamic range of EM data, and MTEM provides EM data of higher resolution and spatial coverage, and complex models can now be run in a reasonable time for commercial applications. Many 2D and 3D modeling study have been carried out to evaluate the influence of a water flood on surface EM measurements. In recent years, many successful TEM surveys have been carried out through out the world for hydrocarbon exploration and reservoir monitoring purposes. Such as gas storage monitoring in France, steam fronts monitoring (SAGD - steam assisted gravity drainage) in Canada, TEM mapping of hydrocarbon migration in Brazil, as well as recently rapid development of marine EM for oil and gas E&P applications by major international oil companies.

The electromagnetic technology would provide a low cost alternative to water or gas flood monitoring (at a fraction of seismic sensors and comparable to surface gravity). Surface sensors could be used initially and as the field gets developed and more wells become available the appropriate downhole sensors can be added. More effective reservoir monitoring and management is the result.

Product & Services

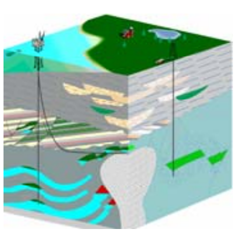
- Integrated off-shelf hardware system;
- Modeling, data processing & interpretation;
- Software development for modeling & data processing;
- Consulting service to oil or services companies or service companies;
- Technology training (data acquisition, modeling, data processing & interpretation, etc.);
- Small scale field demonstration test;
- Full field water flood monitoring service for oil companies.

PHOENIX GEOPHYSICS

3781 Victoria Park Avenue, Unit #3
Scarborough, Ontario
Canada, M1W 3K5

Telephone: 001 (416) 491-7340
Fax: 001 (416) 491-7378

E-Mail: mail@phoenix-geophysics.com
www.phoenix-geophysics.com



KMS Technologies

KJT Enterprises Inc.
6420 Richmond Ave., Suite 610
Houston, TX, 77057
USA
Tel.: +1.713.532.8144
Fax: +1.713.532.7776
Email: info@kmstechnologies.com
http://www.kjtenterprises.net

Case study I

- Feasibility for EM Measurements for water flood monitoring
- Study area: North America
- Depth: ~2,490 m (8,170 ft)
- Reservoir thickness: 41.75 m (137 ft)
- Reservoir porosity: 22.5%
- Reservoir water saturations: 0.7 and 0.81
- Oil saturated reservoir resistivity: 60 Ωm
- Water flooded reservoir resistivity: 4.0 Ωm

The objectives were to demonstrate that electromagnetic measurements can be used from the surface to monitor the water flood in a North America oilfield. The detailed objectives of the project are threefold:

- 2-D modeling (LOTEM-Long Offset TEM) of the reservoir for different flooding times
- 3-D modeling (LOTEM) of the reservoir for different flooding times
- Integration of the results and development of a path forward.

After carrying out the 2-dimensional modeling it became apparent that controlled source electromagnetic methods have better volume focusing and higher signal-to-noise ratios than DC or MT methods. One of such a method is the LOTEM methods.

We carried out a 2-dimensional TEM modeling study to evaluate the influence of a water flood on surface EM measurements. After we modeled a controlled source electromagnetic system (LOTEM) and found a configuration (with high coupling to resistive reservoir parameter changes caused by water flooding) where the influence of the reservoir flooding can be measured in 20-30% signal changes. The results showed a clearly visible response in the electric field components. The signals are in the mV range and can readily be measured.

Fig. 2 shows the time lapse display 3 different times after current switching across the section. The time lapse value is displayed as percentage change. In Fig. 3 we have contoured the percentage change which is the difference between a hydrocarbon saturated and flooded reservoir. The vertical axis is in time. In the LOTEM section (Fig. 3) we can also observe little changes past 2 seconds signal recording timer after transmitter shut off. We have still included most of the time range despite that most signal changes occur before 10 seconds. We can see a good consistency across the section. On the right side of the display, we see a pinch out (a break on the right side of the profile). This could be caused by thinning of the reservoir layer below a certain threshold thickness value. We are reaching a threshold given by the total conductance of the brine saturated reservoir in this area.

summary the findings are:

- Natural source electromagnetics has too low signal levels to track the resistive reservoir changes at this oilfield;
- Controlled source electromagnetics can detect the reservoir resistivity changes and
    - o resolve the resistive reservoir units.
    - o obtain sufficient signal levels to record time lapse changes with commercial systems.

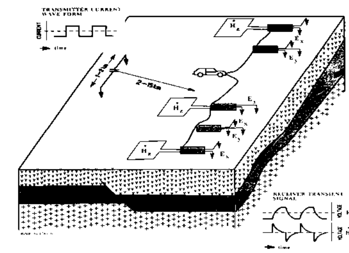


Fig. 1: Typical LOTEM system layout showing transmitter and receivers along an acquisition array (Right).

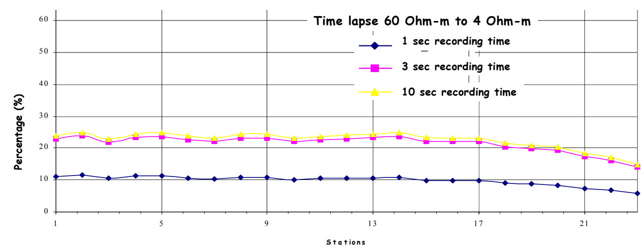


Fig. 2: Percentage change of the electric field measurements for a hydrocarbon saturated and flooded reservoir. The different represent different times after current switching for the electric field in y-direction.

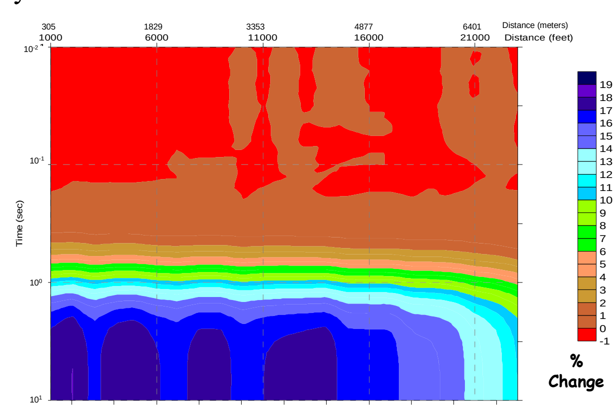


Fig. 3: Contour plots of the percentage difference (electric fields in y-direction) between oil saturated and flooded reservoir. On the vertical scale is time.

Case study II

- Problem: Gas storage reservoir boundary change monitoring
- Study area: on-shore, near Paris
- Depth: ~ 500 m
- Reservoir thickness: ~ 25 m
- Reservoir: sandstone (porosity 30%)
- Reservoir fluid: gas and brine

For this study, a multi-channel transient electromagnetic (MTEM) system was used to detect hydrocarbons and to monitor their movement within the reservoir. Figure 4, an example of a typically strong resistivity contrast, shows part of a resistivity log from a well in the underground gas storage reservoir used in our experiment. Gas is present at a depth of 490 m and resistivity increases from approximately 20 Ohm-m in the rocks above the reservoir to approximately 400 Ohm-m in the gas-saturated reservoir.

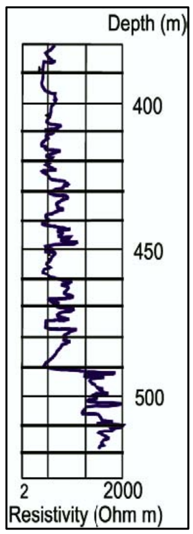


Fig. 4: Part of a resisivity log from St. Illiers la Ville (Wright, et al., TLE2002)

The location of our experiment was 30 km west of Paris. The reservoir contains the maximum amount of gas in October, when the gas-water contact is at its lowest level, and the least amount in April, when the gas-water contact is highest. As resistive gas is replaced by more conductive salt water, the resistivity of several million cubic meters of reservoir rock changes. The data were obtained in an experiment that ran from 1992 to 1998. Two MTEM surveys were carried out in 1994 and 1996 at an underground gas storage reservoir at St. Illiers la Ville, France. The reservoir is a 30% porosity sandstone anticline about 25 m thick at a depth of about 500 m. In summer, gas is pumped in, the gas pressure rises, and the gas-water contact falls; in winter, gas is extracted, the gas pressure decreases, and the gas-water contact rises. The position of the contact is known from constant monitoring at more than 40 wells. The surveys had two objectives: first, to attempt to detect the reservoir directly from the data and, second, to detect the movement of the gas-water contact between the two survey times. A recent breakthrough in the understanding of the system has allowed both objectives to be achieved.

After processing, data were sorted into common-offset gathers to allow sections of the subsurface to be produced. Sections of a 1000-m common-offset gather for the differentiated 1994 data are shown in Fig. 5 (Left) and for the differentiated 1996 data on the right. (Fig. 5). Results for the two surveys are remarkably similar. What is particularly interesting is that the lateral extent of the green event at about 4 ms corresponds almost exactly to the known horizontal limit of the reservoir gas bubble. The only other possible explanation for such an arrival is the effect of pipes in the area. We believe the effect of the pipes is negligible for two reasons to do with the geometry.

The differencing (Fig. 6) shows a distinct positive anomaly across the area where the response from the reservoir was seen in Fig. 5 (Left & right). The positive nature of the anomaly is consistent with more gas and greater pressure existing in the reservoir in 1994 than in 1996. An anomaly is seen only where we expect to see it; there are no significant anomalies visible outside the region of the reservoir. Figures 5 and 6 show that the movement of hydrocarbons in a reservoir can be monitored with MTEM. We have demonstrated that MTEM can be used both for direct hydrocarbon detection and for monitoring fluid movement in a reservoir. The potential applications for this method are considerable. A major application would be in areas where potential hydrocarbon-bearing structures have been found using seismic methods and the drilling risk needs to be reduced. In these areas MTEM can discriminate between water and hydrocarbons. MTEM could find by-passed hydrocarbons in existing fields and monitor carbon dioxide sequestration. The method can readily be adapted for use offshore, for example in the North Sea & GOM. With a magnetic dipole source instead of the electric dipole source used in this test, it would be possible to search for conductors and could then be used to search for water.

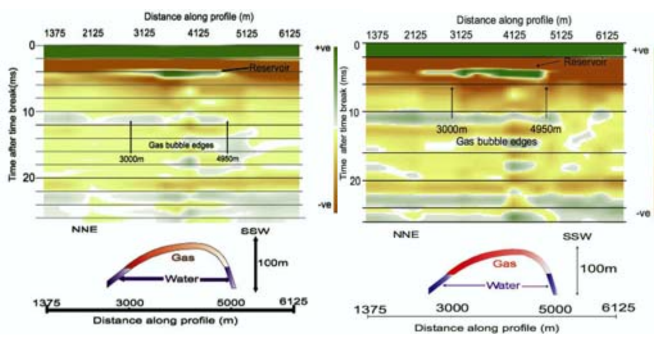


Fig. 5: A 1000-m common-offset section of the derivative of the approximate earth impulse response for the 1994 (Left) and 1996 (Right) data (Wright, et al., TLE, 2002).

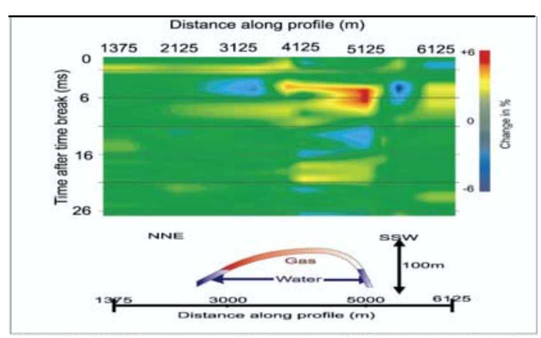


Fig. 6: A 1000-m common-offset section of 1996 approximate impulse responses subtracted from 1994 approximate impulse responses (Wright, et al., TLE, 2002).

Case study III

- Problem: Hydrocarbon migration mapping
- Study area: Sergipe-Alagoas Basin, Brazil
- Depth: ~ 600 to 800 m
- Reservoir: Aptian sandstone and conglomerates
- Reservoir fluid: oil and brine
- Reservoir sequence: controlled by faults

The motivation for the work described in this article was to study the near-surface electromagnetic response of hydro-carbon reservoirs at a representative Brazilian onshore basin. Transient electro-magnetic (TEM) measurements were carried out in December 1999 over three known oil fields in Sergipe-Alagoas Basin (Figure 2) as part of a joint project with CENPES/Petrobrás (the research center of the Brazilian state oil company) to investigate the possibility of mapping hydro-carbon alteration plumes over reservoirs at Sergipe-Alagoas Basin.

Within a sedimentary basin, hydrocarbon reservoirs are frequently overlain by an associated alteration plume. That plume is assumed to be formed by hydrocarbons continually moving toward the surface through available permeability, faults, and microfractures. Below the water table, the small amount of hydrocarbons dissolved in water tends to reduce the contrast in resistivity readings with respect to the host formation conductive minerals such as pyrite, pyrrhotite, and clays. Differences in anomalous recordings are larger when near-surface rocks are porous.

Fig. 7 is a diagram of the basic concept. In this study, SIROTEM-MK3 measurements were carried out at 49 single loop (100 and 50 m) sites over seven days. The period ranged from 10^{-1} to 30 ms. The stations were acquired along and between four northwest-southeast striking regional profiles.

Fig. 8 shows the time slice for the apparent resistivity at 0.7 ms which is representative of the whole period. To help in the interpretation, we plotted in Fig. 8 the main faults identified by previous seismic interpretation and available data from producing and dry wells. Fig. 4 indicates two areas of high conductivity. Both correlate quite well with the known oil fields, indicating that there are near-surface alteration zones. Indeed, almost all producing wells are within the anomalous zones. On the other hand, almost all dry wells are outside the anomalies and over resistive zones. Pyrite halos over hydrocarbon reservoirs of Sergipe-Alagoas Basin have already been described in Petrobrás internal reports. These halos were interpretated as the main reason for the conductive anomalies identified in this work. The fault pattern super imposed on the time slice map (Fig. 8) indicates unmistakably structural control for the hydrocarbon seepage; i.e., the conductive anomalies are bounded by the main faults in the studied area.

The identification of electromagnetic anomalies associated with alteration plumes over reservoirs illustrates the importance of the TEM surveys during the reconnaissance phase of petroleum exploration of onshore Brazilian basins. In this study area, for instance, a great number of dry wells could have been avoided if TEM information had been incorporated into the predrill evaluation.

Due to the successful results, TEM reconnaissance surveys are being planned in the near future at mature and frontier basins. The latter are intended to identify prospective blocks prior to a new bid round.

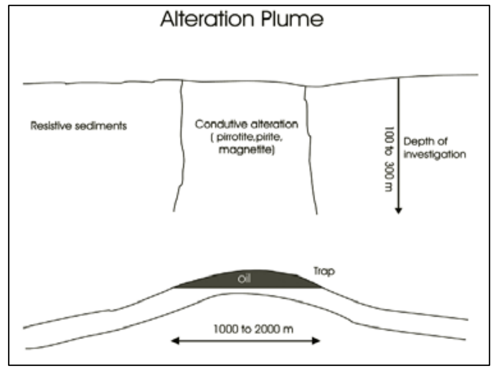


Fig. 7: Schematic diagram of the adopted geophysical model (modified from Smith and Rowe) (Menezes, et al., TLE, 2003).

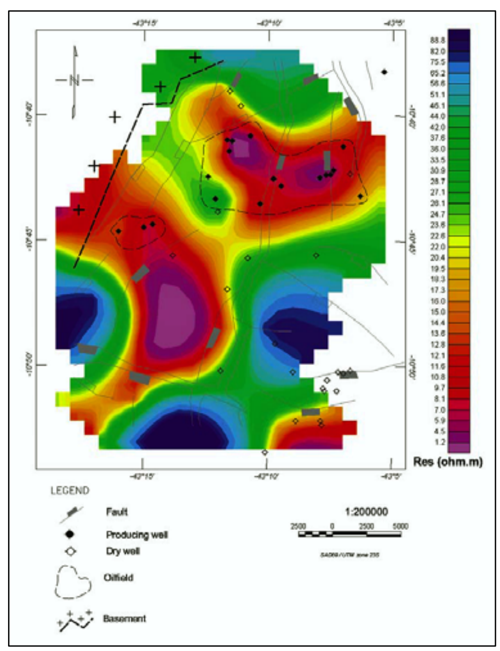


Fig. 8: Time slice of apparent resistivity at 0.7 ms. Producing and dry wells are posted. Fault pattern from previous seismic interpretation is superimposed (Menezes, et al., TLE, 2003).