CORING TO CONSERVE RESIDUAL WATER SATURATION AND ITS USE WHEN INTERPRETING ELECTRICAL LOGS

V. G. Mamyashev, B. U. Khairullin, L. A. Vylegjanina, T. V. Mamyashev
STC “Tyumenpromgeophyzika”, SibBurMash, SIC LOG, RUSSIA

Introduction

This paper describes efforts to increase the scope of geological information and the validity of analyses performed on preserved cores. A primary consideration in any coring program related to the development of oil and gas fields is how to preserve oil and water saturations within the rock while the core is cut and after it is brought to the surface. One of the effects of coring that limits accuracies of core analyses appears to be contamination of the core by drilling mud filtrate. Filtrate invasion can distort fluid saturations, cause wettability changes, and alter rock and fluid electrical properties.

To eliminate water-based mud (WBM) filtrate invasion and increase core data value, special coring technologies are used. Perhaps the most widespread technique for preserving water saturations in rocks during coring is the use of “non-filtration” oil-based muds (OBM). In West Siberian fields, by 1992, 105 evaluation wells had been cored using OBM. Unfortunately, high labour requirements, high coring costs, and safety and ecological concerns associated with the use of OBM make further development and application of this technology complicated.

Efforts to improve coring technologies using water-based mud (WBM) appear to be more promising for practical application. Kotyahov (1956) and Glumov (1967) have described successful WBM coring programs in which representative fluid saturations were obtained from low permeability formation cores.

Using WBM, coring fluid invasion into the core is unavoidable, but in certain conditions, instantaneous (momentary) linear-rate filtration under the drilling bit can be comparable with the instantaneous drilling rate (rate of penetration per one turn of the drilling bit). This means that the filtrate invasion front practically coincides with the bottom hole surface. Filtration through the sides of the core in the vicinity of the drill bit cutters is the same as under the drilling bit. Between the cutters and the core sampler, filtration changes to a dynamic regime and the filtration rate increases remarkably. The filtration regime becomes static when the rock gets into the core sampler. The filtrate invasion depth into core using WDM, Dr, has three components conforming to the enumerated filtration regimes:

$$Dr = L_1 * (V_1/V) + L_2 * (V_2/V) + A \qquad (1)$$

In equation 1, V_1 and V_2 are the linear rates of filtration into the formation for "under the bit" filtration regimes; L_1 and L_2 are distances between the lower rim of the coring bit and the last core formatting element and from this element to the lower rim of core sampler; V is the instantaneous drilling rate; and A is the ingress depth depending on the effect of static filtration. Rates V_1 and V_2 are functions of the pressure difference (DP) between the well and formation, WBM properties, permeability (k), and "dynamic" porosity ($Æ_d$) of rocks:

$$V_1(V_2) = f\,(a * lgDP, w_f, k, 1/Æ_d) \qquad (2)$$

In equation 2, DP is the pressure difference between the well and formation; a is an empirical constant for flow rates in regimes V_1 and V_2; and w_f is the specific water filtration capacity from WBM.

The greatest amount of total mud filtrate invasion takes place as the core is formed (coring), whereas the contribution to total filtrate invasion between the cutter and sampler is somewhat less. Within the sampler, the amount of additional filtrate invasion that occurs depends on the residence time in the WBM environment. Usually, the influence of this component is significant too.

Using equations 1 and 2 along with support from other analytical and experimental equations, it is possible to estimate how coring conditions will affect the potential for obtaining cores with preserved fluid saturation conditions. To restrict WBM filtrate invasion, the rate of drilling must be high, distances L_1 and L_2 must be as short as possible, and magnitudes DP and w_f must be minimised. We propose to eliminate flushing that occurs while the rock is in the core sampler by filling the sampler with a special insulating agent (imposing a condition such that $A = 0$).

Results

Appropriate requirements were successfully realised using prototype procedures and KIM equipment. The process insulates the rock from the moment when core enters the core sampler. As a result, within the core sampler, WBM is completely excluded, so capillary phenomenon and diffusion exchange are significantly decreased. Insulation is also provided by the core receiver designs. The core receivers have distances L_1 and L_2 less than or equal to 5 and 35 mm respectively. We have found that with L_1 = 5mm, L_2 = 35 mm, and an instantaneous drilling rate V of 1.2 m/hr or greater, the depth of WBM filtrate invasion into a core changes from the few millimetres to 10-18 mm depending upon the permeability of the rock. Hence, the fluid saturation in the central part of the core is preserved. During the drilling process, the core gradually fills the core sampler. The insulating agent is displaced in the opposite direction from the bottom of the hole. Core captured in the core sampler remains surrounded by the insulating agent until the core receiver is pulled from the well.

A series of KIM core receivers that insulate core within the core sampler from WBM invasion were developed and issued by SibBurMash. They insure that core within the core sampler is insulated, and also provide a hermetic seal at the bottom of the cored interval. They have been made for 67, 80, and 100 mm core diameters. Differences between hermetic receivers and isolating receivers lie in the additional rigging (ball valve) with the lower unit of the hermetic sampler. The valve provides forced core separation and seals the core sampler's entrance hole. The upper part of the tube is sealed in both core receiver types.

Depth of filtrate invasion during coring is determined at the wellsite using a special chemistry lab. Wellsite measurements provide indications of whether tighter controls are required to decrease depth of invasion into the core. Control methods are based on WBM injection indicators. There are two types of indicators used in this proposed technology. One is a fluorescence substance and the second is an additive that is not normally associated with WBM or formation water. The additive is easy to detect by analytical methods. The use of tritium as an indicator is well known. The depth of invasion can be determined when a florescence substance is added to the WBM by observing a freshly cut core face under ultra-violet light. The invaded zone shows up as a florescent ring around the periphery of the core. Quantitative evaluation of the effects of WBM filtration invasion is conducted on samples cut from the periphery zone (portion that fluoresces) and from the centre part of core. Water volumes are extracted from these samples for comparison. A sample of cubic form with 30 - 45 mm side length is cut from the central part of core immediately after the core is retrieved at the wellsite. This sample is encapsulated with paraffin wax for subsequent studies according to technologies developed for analysing core from wells drilled with oil-based mud. These coring and analysis procedures are described in methodical guidelines[3] that have been approved by the Expert-Technical Counsel of the GKZ Russian Federation.

To date in West Siberia, more than 30 wells have been cored using this technology. Common penetration with coring is 971 m. Overall, core recovery averages 91%, with recoveries from extremely unconsolidated and poorly cemented rock from Senonian and Senomanian formations averaging slightly lower at 82.5%.

The reliability of residual water saturations measured from core obtained by this insulating technology have been confirmed by comparing results from WBM-drilled insulated core with those obtained using OBM. An example is shown in Figure 1. Recovery of core containing preserved water saturations aids in the precise definition of reservoir residual water saturation S_{rw}. Measurements on these cores provide the possibility of substantiating reliable regimes in modelling S_{rw} by the centrifuge technique to relate water saturations to reservoir heights. We've been able to achieve tight correlations between specific resistance (r_{cor}) of insulated core and W, the ratio of water volume to total rock sample volume. For the rocks tested, the character of the relationship $r_{cor} = f(W)$ does not conform to the traditional form of the Archie-Dahnov equation. Instead, results appear to differ depending upon whether the rock is of reservoir or non-reservoir quality, as shown on Figure 2. This division is explained by differences in the silt content of the rocks that affects absorption properties and hence the electrical conductivity of pore water. Separate experiments for this rock confirmed an increase in electrical resistivity anisotropy with increasing oil and gas saturation, as well as confirmation of the influence of oil saturation on diffusive-adsorption activity[4]. The net result is the alteration of "n" within the resistivity equation, which slightly increases with decreases in the magnitude of W.

It is very important to establish "log-core" relationships between the formation-specific electrical resistivity (r_t) and the water content (W) for reliable water saturation definition. These may be established for each separate formation if sufficient data is available describing the resistivity (r_t) of homogeneous intervals (beds) from logs and the water content (W) from core analyses. These "log-core" relationships have been established for some formations. They have provided estimates of water saturation (W) for oil-gas reservoirs from their specific resistivity. For geological prospecting and evaluating small reservoirs and oil and gas deposits within West Siberia, generalized relationships were developed. For example, some relationships that have been developed for the Surgut oil and gas region include the following:

$$lg\ W = 0.22*(lg\ r_t)^2 - 1.06 * lg\ r_t + 1.96, \text{ intervals of AS beds} \quad (3)$$
$$lg\ W = 0.18*(lg\ r_t)^2 - 1.05 * lg\ r_t + 1.87, \text{ intervals of BS beds} \quad (4)$$
$$lg\ W = 0.15*(lg\ r_t)^2 - 1.05 * lg\ r_t + 1.72, \text{ intervals of JS beds} \quad (5)$$

Comparing relationships $r = f(W)$ from "core-core" and "log-core" analyses allows one to establish the dependence of the specific resistivity (r_t) of the formation on the insulated core resistivity (r_{cor}). This dependence is common for all sediment formations in West Siberia, and may be presented as:

$$r_t = r_{cor} / [(0.03* T + 0.4) \pm 0.2] \quad (6)$$

where T is the formation temperature (°C) and r_{cor} is the resistivity measured under laboratory conditions (20 °C). Equation 6 allows estimation of "log-core" relationships where "core-core" data is available from insulated core but when insufficient information is available for developing "log-core" correlations (insufficient r_t and W data).

Discussion

Insulated coring technology works particularly well for lower-permeability formations. Advantages diminish when coring highly permeable formations ($k >$ 500-700 mD) especially in highly water-saturated regions and in the vicinity of oil-water or gas-water contacts. Incorrect core saturations may also result when samples are taken from formations with abnormally high formation pressure and high gas content. Experience has shown that gas expansion upon core retrieval can displace residual water from the core. This phenomenon has been observed only in rocks with low permeability ($k < 3\text{-}5$ mD). In higher permeability cores, this effect becomes negligible. For those cases in which some of the pore water is displaced upon retrieval, some benefit can still be derived from the preserved core. The water loss has no considerable effect on the specific resistivity of pore water or on the resistivity relationship, $\rho = f(W)$.

Conclusion

In conclusion, the insulated coring technology and use of cores obtained with WBM in this manner offers about the same type of information as cores cut with OBM but with fewer adverse effects from the coring fluid.

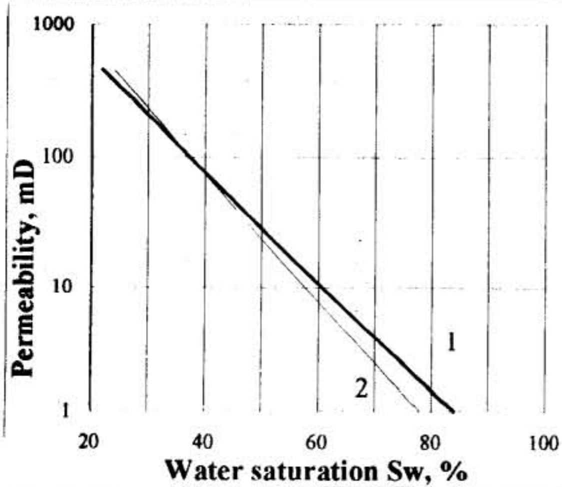

Fig.1 Comprasion data by samples coring with using WBM (1) and OBM (2).

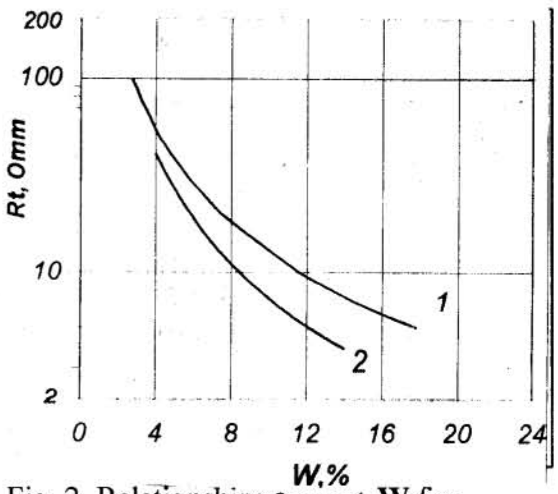

Fig. 2 Relationships ρ_{cor} and **W** for Reservoir (1) and non reservoir (2) rocks.

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