CHFR-Slim

Through-tubing, behind-casing formation resistivity
Applications

- Location of bypassed hydrocarbons
- Reevaluation of existing fields
- Monitoring of reservoir saturation
- Monitoring of gas-oil-water contacts
- Primary formation evaluation in cased holes

Benefits

- Rig time savings from more efficient operations
- Identification of unswept reserves
- Optimized sweep efficiency for improved production
- Better input for decisions on recompletions and sidetrack placement
- Maximized total hydrocarbon recovery
- Savings in time and cost by eliminating need to pull tubing

Features

- Deep-reading resistivity measurement behind casing
- Through-tubing capabilities
- Redundant electrode contacts to ensure data quality in perforated or corroded intervals
- Quality measurements, even with small amounts of scale and corrosion
- Ability to measure through most cements without environmental corrections
- Measurement independent of wellbore fluids
- Dynamic measurement range for evaluation of low-porosity, low-salinity formations
- Accurate saturation measurement in low-permeability formations with deep mud-filtrate invasion

Formation resistivity measurement technology for cased holes

The Schlumberger CHFR-Slim* tool, one of the ABC* Analysis Behind Casing technologies, provides deep-reading resistivity measurements from behind steel casing. Its enhanced hardware and measurement principles improve the operational efficiency of cased hole resistivity measurements, and its small diameter allows it to be run through tubing.

The abilities to detect and evaluate bypassed hydrocarbons and to track fluid movement in the reservoir are fundamental to improving production and increasing reserves. Measuring resistivity behind casing has been recognized as a necessary component of these capabilities since the first openhole resistivity log was recorded in 1927; however, advanced electronics and electrode design are only now making these challenging measurements possible.

Making the measurement

The CHFR-Slim tool introduces a current that travels up and down the casing before returning to the surface electrode. This current follows a path similar to the current from openhole laterolog tools, as shown in the figure to the right.

While most of the current remains in the casing, a very small portion escapes into the formation. Electrodes on the tool measure the voltage difference created by this leaked current, and that difference is proportional to the formation conductivity.

Typical formation resistivity is about 1 billion times that of steel casing. During the resistivity measurement, the current escaping to the formation causes a voltage drop in the casing segment. Because casing has a resistance of a few tens of microhms and the leaked current is typically on the order of several milliamperes, the potential difference measured by these tools is in the nanovolt range (one-billionth of a volt).

The measurements are performed while the tool is stationary. To obtain the contact between the tool and the casing that is essential to the CHFR-Slim measurements, the small electrodes on the sonde are designed to scrape through small amounts of casing scale and corrosion to establish good electrical contact. The tools use four levels of voltage electrodes in sets of three with 120° spacing. This 12-electrode configuration allows faster operation.
and provides redundant measurements to help ensure data quality in perforated or corroded intervals. For quality control, the electrode-casing contact is measured at each station. Scale that has formed in amounts that prevent adequate electrical contact can be removed using the Schlumberger Scale Blaster® engineered approach to scale removal.

Low-resistivity (1- to 5-ohm-m range) cements that are typically found in oil wells do not impact cased hole resistivity measurements, but measurements made behind cements having unusually high resistivity require environmental corrections.

Because its electrodes make direct contact with the casing, the tool is able to work in all wellbore fluids. Thus the tool is not limited to conductive borehole fluids and can operate in wells with oil, oil-base muds, or gas in the casing.

**A range of saturation measurements**

The depth of investigation of the resistivity measurement is between 7 and 32 ft (2 and 10 m), which is more than an order of magnitude deeper than that of pulsed-neutron saturation measurements.

The dynamic range of measurements also allows evaluations in reservoirs with low porosity and formation salinity. Resistivity and nuclear measurements can be combined for an enhanced saturation evaluation that is equivalent to an openhole interpretation.

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**Case study: Faster logging with equivalent results (Indonesia)**

The CHFR-Slim tool uses proven Schlumberger technology and makes an average station time in just 1 min. The result is an effective logging speed of 240 ft/hr.

Measurements made with the tool match openhole resistivity data quality, as shown below by the logs from a well in Indonesia. The 240-ft/hr logging speed allowed the job to be completed overnight.

The CHFR-Slim tool’s fast logging speed is the direct result of the new measurement technique. First, while current in the casing is flowing past the electrodes, a small amount of current is introduced opposite the casing current. This action reduces the sensitivity of the measurement to the resistance of the casing. Second, the casing resistance measurement (or calibration step) is made during the formation resistivity measurement, but at a different frequency.

The combined effect of these improvements is the elimination of a separate casing resistance measurement. Station measurement time is reduced by half, and logging speed is doubled. Measurement quality is the same for both tools.

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**These CHFR-Slim measurements, which were acquired at 240 ft/hr and saved the operator daylight rig time, closely match the openhole resistivity log of this well.**
Case study: Extending field economic life (Bakersfield)

The CHFR* tool provides an excellent means of identifying bypassed hydrocarbons before the decision is made to abandon a well or field. This information can have a significant impact on field economics.

In Bakersfield, California, a well in a field with a water-injection program was abandoned when the water rate reached uneconomic levels at 1,600 B/D. Years later the well was reevaluated using the CHFR tool.

As shown on the right, the logs confirmed that the interval below X720 ft had watered out. They also showed hydrocarbons in the interval between X680 and X700 ft.

A plug was set at X710 ft, and the interval between X680 and X697 ft was perforated. Following the workover procedure, the well produced oil at 300 B/D.

Two other wells in the field were also logged with the CHFR tool with similar success. The decision to reevaluate the three wells proved very profitable for the operator because of the commercially significant volume of oil produced.
**Case study: Reservoir monitoring (UAE)**

To monitor fluid movement and injection performance in a large Middle Eastern carbonate oil reservoir, CHFR tools were run in time-lapse mode across a reservoir being waterflooded with seawater.

A CHFR-Slim tool was run back to back with a CHFR-Plus tool. Repeatability was excellent between the two tools, and their measurements compared favorably with those from a previous CHFR-Plus run, as well as with the original openhole resistivity log data.

In this example CHFR-Slim data are used for time-lapse monitoring, demonstrating the excellent repeatability that is critical for detecting subtle movements of reservoir fluids.

**Case study:Logging for primary evaluation (Mexico)**

The CHFR-Slim tool can provide primary formation evaluation data in new wells for which there are no openhole resistivity data.

In the Mexico log displayed below right, well control issues prevented the acquisition of openhole log data across the primary reservoir. The operator needed to identify sandstone intervals that could be perforated to maximize gas production while minimizing water production.

Traditional cased hole neutron-gamma ray logs alone are inadequate to clearly identify gas-bearing sands. After the casing was set, the CHFR-Slim tool was run with other ABC* Analysis Behind Casing services, including ECS* Elemental Capture Spectroscopy, CHFP* Cased Hole Formation Porosity, and CHFD* Cased Hole Formation Density services. The combination of resistivity, lithology, porosity, and density information enabled clear identification of the sands.

*CHFR stands for Computerized Horizontal Reservoir Scanner.*
Accuracy and precision

The accuracy of CHFR-Slim measurements depends on the thickness and resistivity of the cement. For typical oilfield cements with resistivities of a few ohm-meters, the accuracy of the measurement prior to a cement correction is around 10% at 1 ohm-m and improves to better than 3% above 10 ohm-m. Applying environmental corrections to the log data can improve the accuracy of the measurement if the cement parameters are well known.

The precision of the CHFR-Slim measurements depends on the signal-to-noise ratio of the voltage measurements. At low resistivities (high conductivities), the precision of the measurement is better than ±1%. However, at high resistivities and in large casing sizes, the precision may be closer to ±7% (at 100 ohm-m). The precision can be improved by increasing the station time.
## CHFR-Slim Tool Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Diameter (in. [mm])</td>
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<tr>
<td>Length (ft [m])</td>
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<tr>
<td>Weight (lbm [kg])</td>
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<td>Max. temperature (°F [°C])</td>
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<td>Max. pressure (psi [kPa])</td>
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<td>Max. well deviation</td>
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<td>Stationary measurement (min)</td>
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<td>Resistivity range (ohm-m)</td>
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<td>Accuracy</td>
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<tr>
<td>Precision</td>
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