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MEASUREMENT OF THE FORMATION FACTOR ON DRILL CUTTINGS

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ABSTRACT

Drill cuttings can provide useful information for reservoir characterization. In addition to porosity and pore size distribution measurement by mercury porosimetry, we have shown in a previous paper (Egermann et al., 2002) that permeability was accessible. Using a small volume of cuttings (less than 10 cm^3), we were able to accurately determine permeability after saturating the cuttings with a viscous oil and interpreting the response to a pressure pulse.

In this paper, we present an original method to determine the formation factor of the rock from cuttings. The method is rather simple and quick to operate. It has been tested on rocks of different porosity and the results are in good agreement with core measurements.

The method consists in introducing the cuttings in a conductivity cell. The whole volume, inter-cuttings and pore volume, is initially saturated with a conductive fluid A. The overall conductivity that is measured depends on the rock conductivity and also on the conductivity of the fluid located in the inter-cuttings space. From the effective medium theory, the corresponding unknowns are the Formation Factor, FF, and the fraction of voids between the cuttings. The Formation Factor has been derived either by estimating the voids fraction from the total volume of cuttings used and the cell volume, or by adding a new independent conductivity measurement after the fluid A has been replaced by a fluid B in the inter-cuttings space only.

With this new type of measurement, we are able to quickly provide a complete set of data on a small volume of cuttings: porosity, grain density, permeability and formation factor. These measurements are not aimed to replacing core measurements but to provide additional information for reservoir characterization and log calibration when cores are not available.

INTRODUCTION

An early evaluation of the Formation Factor (FF) shortly after the drilling operations is very interesting to obtain a good estimation of the volume of hydrocarbons in place. The FF is defined as the ratio between the resistivity of the porous medium saturated with a conductive fluid (R_o) and the resistivity of this conductive fluid (R_w).

$$FF = \frac{R_o}{R_w}$$

Archie (1942) proposed to link the FF with the rock porosity using the following formula (called first Archie law) :

$$FF = a \times \phi^{-m}$$

where a is a parameter (close to unity) and m is called the cementation exponent.

The Resistivity Index (RI) is defined as the ration between the resisitivity of the porous medium at S_w (R_t) and the resistivity of the porous medium fully saturated (R_o).

$$IR = \frac{R_t}{R_o}$$

According to the second Archie law (1942), the RI is related to S_w

$$IR = S_w^{-n}$$

where n is the resistivity index.

In the classical process of interpretation, the logs provide R_t and ϕ along the well and the value of R_w is known from the resistivity measurements in the aquifer. From the two Archie's laws, it is then possible to evaluate the saturation profile along the well :

$$S_w = \left(a \times \phi^{-m} \times \frac{R_w}{R_t} \right)^{1/n}$$

When no core measurements are available, default values of m and n are often used to run the interpretation. This can lead to significant errors in the evaluation of the Sw profile and consequently to the hydrocarbon volume in place.

In this paper, we present a novel approach to derive the FF from measurements on drill cuttings. The general principle of the method is presented in the first part. It involves experimental conductivity measurements on cuttings and interpretation using the effective medium theory. The method is validated in the second part by comparison between the FF values derived from cuttings are compared with core measurements. The benefits of the method and its possible applications for exploration purpose are discussed in the last part.

FORMATION FACTOR FROM CUTTINGS

General principle

The method consists in introducing the cuttings in a conductivity cell. The whole volume, inter-cuttings and pore volume, is initially saturated with a conductive fluid A. The overall conductivity that is measured then depends on the rock conductivity and also on the fluid conductivity of the fluid located in the inter-cuttings space. From the effective medium theory, the corresponding unknowns are the Formation Factor (FF) and the fraction of voids between the cuttings. The Formation Factor is derived either by estimating the voids fraction from the total volume of cuttings used and the cell volume, or by adding a new independent conductivity measurement after the fluid A has been replaced by a fluid B in the inter-cuttings space only.

Experimental procedure

The set-up is conventional and similar to what is commonly used for conductivity measurements on core (Figure 1). It is mainly composed of a generator (1 KHz), an ampere meter, a voltmeter and a conductivity cell, where the cuttings are introduced. The conductivity measurement is performed with four electrodes because this technique was proven to be the most accurate (Sprunt et al., 1990).

The cleaned and dried cuttings are first introduced in the cell and then saturated with a conductive fluid A. Hence, the fluid A initially occupied both the inter-cuttings and the pore volume of the rock. The overall conductivity of the system is then measured, which is noted σ_A^*. This state is referred as A (Figure 2).

In our tests, the fluid A originally in the inter-cuttings space is then replaced by another conductive fluid B, without displacement the fluid A inside the cuttings. Practically, this operation has been achieved by several techniques : miscible displacement of the fluid A bt the fluid B, gravity drainage of the fluid A and replacement by the fluid B, capillary desorbtion of the fluid A and replacement by the fluid B. The overall conductivity of the system is then measured, which is noted σ_B^*. This state is referred as B (Figure 2).

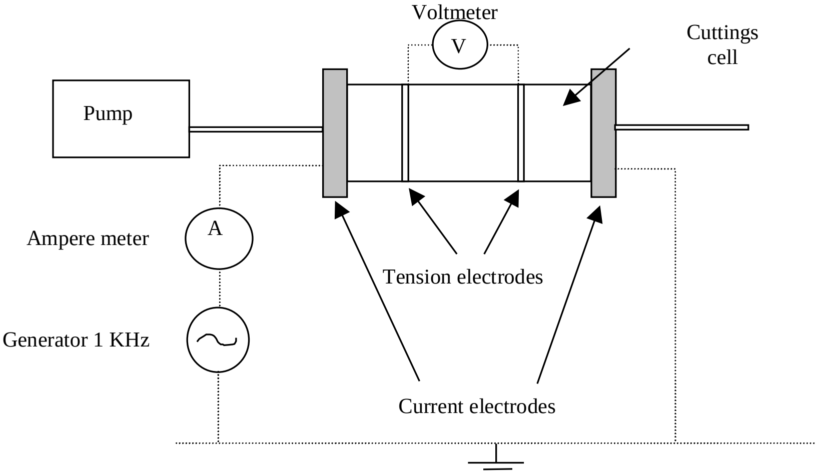

Figure 1: experimental set-up

When brines are used for fluids A and B, the fluid conductivities can be directly deduced from tables (Worthington et al., 1990). In a more general case, it is also possible to use a conductimeter prior to the experiment. We note σ_A and σ_B the conductivities of the fluids A and B.

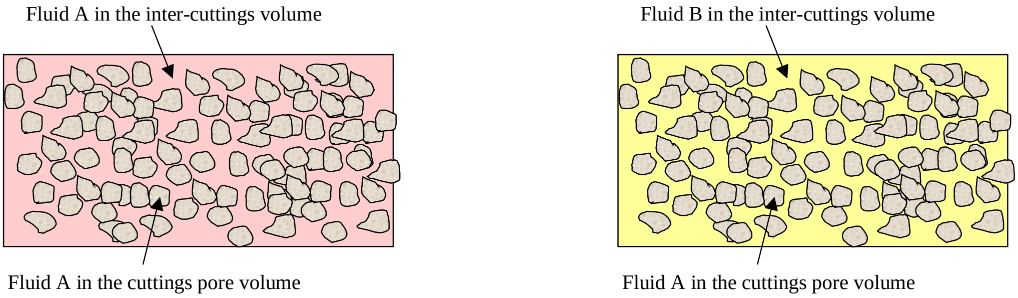

Figure 2: principle of the measurement (states A and B)

Interpretation of the experimental results

The experimental results can be interpreted using the effective medium theory (Bruggeman, 1935, Berryman, 1990). We consider that the whole space is occupied by two kinds of media 1 and 2, the inter-cuttings fluid and the saturated cuttings. The volumic fraction of cuttings (the medium 2) is noted y. The conductivities of the two media are noted σ_1, σ_2 and the global conductivity is noted σ^*.

Self-consistent approach

According to a first approach called self-consistent, the following equation can be written:

$$(1-y)\times\frac{\sigma_1-\sigma^*}{\sigma_1+2\sigma^*}+y\times\frac{\sigma_2-\sigma^*}{\sigma_2+2\sigma^*}=0$$

The above equation can then be applied for the two states (A and B), where the conductivity was measured. If the index 1 refers to the inter-cuttings volume and index 2 refers to the cuttings volume, we can then deduce two independent equations:

State A :

$$\sigma_1 = \sigma_A \qquad \sigma_2 = \sigma_A/\mathrm{FF} \qquad \sigma^* = \sigma_A^*$$

$$(1-y)\times\frac{\sigma_A - \sigma_A^*}{\sigma_A + 2\sigma_A^*} + y\times\frac{\sigma_A/\mathrm{FF} - \sigma_A^*}{\sigma_A/\mathrm{FF} + 2\sigma_A^*} = 0 \qquad (1)$$

State B :

$$\sigma_1 = \sigma_B \qquad \sigma_2 = \sigma_A/\mathrm{FF} \qquad \sigma^* = \sigma_B^*$$

$$(1-y)\times\frac{\sigma_B - \sigma_B^*}{\sigma_B + 2\sigma_B^*} + y\times\frac{\sigma_A/\mathrm{FF} - \sigma_B^*}{\sigma_A/\mathrm{FF} + 2\sigma_B^*} = 0 \qquad (2)$$

By combining (1) and (2), it is then possible to eliminate y in the equation and FF can be easily calculated from a secondary degree polynomial equation:

$$(K_B - K_A)X^2 + \left[K_B\left(2\sigma_A^* - \sigma_B^*\right) - K_A\left(2\sigma_B^* - \sigma_A^*\right)\right]X + 2\sigma_A^*\sigma_B^*(K_A - K_B) = 0$$

where $K_A = \left(\frac{\sigma_A + 2\sigma_A^*}{\sigma_A - \sigma_A^*}\right)$ $\quad K_B = \left(\frac{\sigma_B + 2\sigma_B^*}{\sigma_B - \sigma_B^*}\right)$ $\quad X = \sigma_A/\mathrm{FF}$

It is also possible to use only equation (1) or (2) if y is known from another direct measurement. By definition, y is equal to the ratio between $V_{cuttings}$ and V_{cell}. $V_{cuttings}$ can be easily obtained using a pycnometer and V_{cell} is known from the cell dimensions. In the following, the two above means for calculating the FF from the self-consistent theory are called procedure 1 (two states A and B needed) and 2 (only one state, A or B, needed).

Derivative approach

According to a second approach called derivative, the following equation can be written (same notation as in the self-consistent approach section):

$$\left(\frac{\sigma_2 - \sigma^*}{\sigma_2 - \sigma_1}\right)\left(\frac{\sigma_1}{\sigma^*}\right)^{1/3} = 1 - y$$

The above equation can then be applied for the two states (A and B), where the conductivity was measured:

State A :

$$\left(\frac{\sigma_A/\mathrm{FF} - \sigma_A^*}{\sigma_A/\mathrm{FF} - \sigma_A}\right)\left(\frac{\sigma_A}{\sigma_A^*}\right)^{1/3} = 1 - y \qquad (3)$$

State B :

$$\left(\frac{\sigma_A/\mathrm{FF} - \sigma_B^*}{\sigma_A/\mathrm{FF} - \sigma_B}\right)\left(\frac{\sigma_B}{\sigma_B^*}\right)^{1/3} = 1 - y \qquad (4)$$

By combining (3) and (4), it is then possible to eliminate y in the equation and FF can be easily calculated from a secondary degree polynomial equation:

$$(K_A - K_B)X^2 - \left[K_A\left(\sigma_A^* + \sigma_B\right) - K_B\left(\sigma_B^* + \sigma_A\right)\right]X + K_A\sigma_A^*\sigma_B - K_B\sigma_B^*\sigma_A = 0$$

where $$K_A = \left(\frac{\sigma_A}{\sigma_A^*}\right)^{1/3}, \; K_B = \left(\frac{\sigma_B}{\sigma_B^*}\right)^{1/3} \text{ and } X = \sigma_A/FF$$

It is also possible to use either equation (3) or (4) if the value of y is calculated directly as in procedure 2 (previous section). In the following, the two above means for calculating the FF from the derivative theory are called procedure 3 (two states A and B needed) and 4 (only one state, A or B, needed).

COMPARISON WITH CORE MEASUREMENTS

The different procedures of FF measurement were tested on crushed core cuttings to have a reliable reference on core. The tests have been conducted on 8 samples of different porosities (11% to 40%) and lithologies (sandstones and carbonates).

Table 1: comparison results between FF from cuttings and from core

Nom	K md	ϕ %	FF 1	FF 2	FF 3	FF 4	FF core
V8	491	18.4	27.4	22.1	11.5	28.1	21.3
Bri	19.9	20.6	28.7	21.7	11.5	29.7	22.8
LavB	0.05	13.3	132.4	92.4	12.1	34.1	78.2
GDV2	96.5	22.2	20.8	16.4	9.8	18.8	16.5
LavJ	515	27.9	17.7	14.4	7.1	9.9	11.9
St Max	1610	40.4	8.7	7.9	5.2	6.1	6.0
Can1	0.31	11.3	99.1	69.6	13.7	58.7	79.7
Berea	230	19.7	31.9	24.6	9.4	16.5	15.3

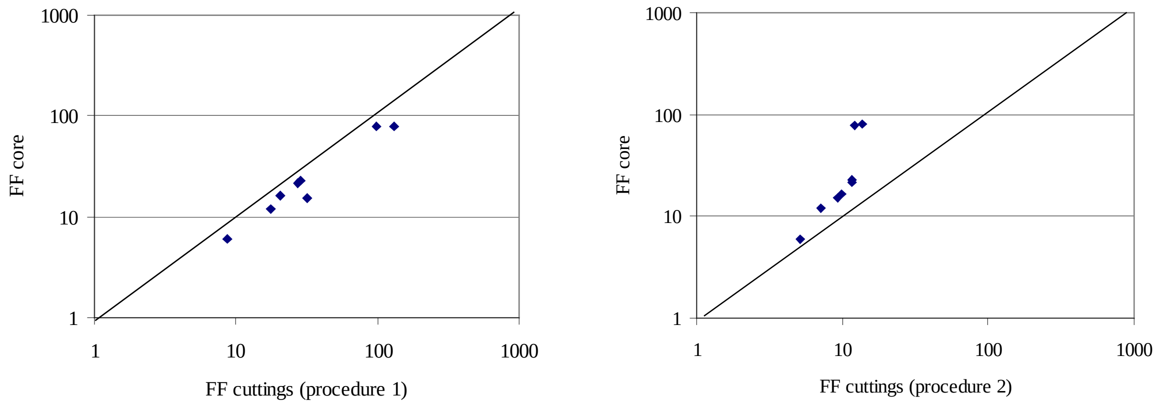

Figure 3: comparison with core measurement using self similarity approach

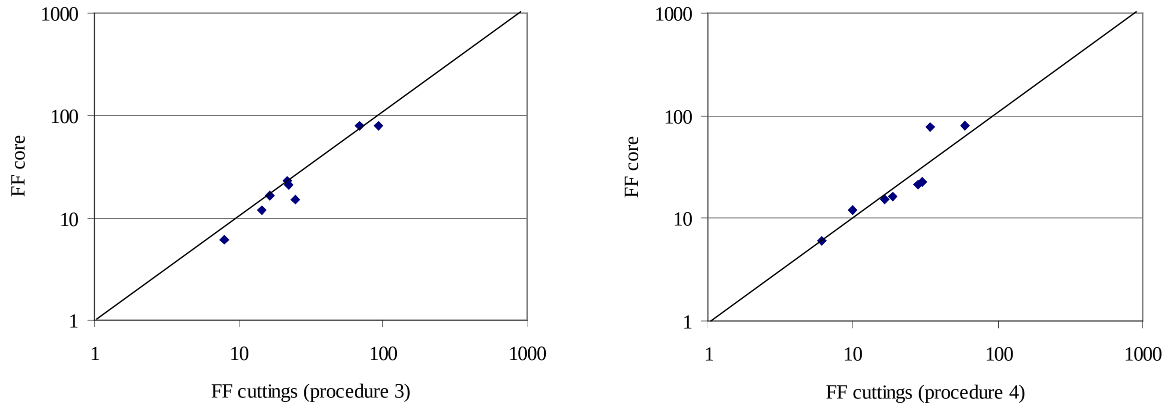

Figure 4: comparison with core measurement using derivative approach

All the results are gathered in Table 1 and the comparison with core measurement is plotted in Figure 3 for the self-consistent approach and in Figure 4 for the derivative approach. It can be observed that we obtain a good general correlation with the core measurements whatever the procedure used. Nevertheless, the correlation coefficient is better, when two independent conductivity measurements are integrated in the interpretation process (procedures 1 and 3), when the derivative approach is used.

CONCLUSION

With this new type of FF measurement, we are able to quickly provide a complete set of data from drill cuttings shortly after the drilling operations: porosity, grain density, permeability and formation factor. All the measurement methods are simple enough to be conducted on or in the vicinity of the field, leading to an early, accurate appraisal of the petrophysical formation evaluation. These measurements are not aimed to replacing core measurements but to provide additional information for reservoir characterization and log calibration when cores are not available.

NOMENCLATURE

σ_i: conductivity of fluid i
σ_i*: global conductivity of state i
y: volumetric fraction of cuttings
k: absolute permeability
ϕ: porosity

FF: Formation Factor
RI: Resistivity Index
m: cementation exponent
n: resistivity index

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