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An Integrated Approach for Saturation Validation: A Case Study

J.Nandy, *ISMU, Dhanbad, India,* ***A.Ghosh*,*** *Schlumberger, Mumbai, India,* ***R.Guru,****ONGC Ltd., Mumbai,*
S.Malik, *Schlumberger, Mumbai, India,* ***K.M.Sundaram,*** *ONGC Ltd., Mumbai.*

Summary

Water saturation determination from well logs is a critical parameter for hydrocarbon exploration. Conventional methods of water saturation determination using resistivity log is still a popular industry practice. However, there are different ways of resistivity independent saturation determination. Present case study involves an approach using sonic data for saturation determination in an integrated manner, which can give a robust answer with reduced uncertainties.

Introduction

The present case study involves an offshore well in the East Coast deep-water in India. The reservoir analyzed is a gas bearing reservoir with no gaswater contact (GWC) penetrated in the well. The well section has had acoustic well-log data in addition to other conventional logs and electrical images.

The litho-facies is blocky as well as finely laminated sandstone facies. The current work is spurred by a desire to investigate if acoustic based methods could result in valid and robust water saturation computation. The aspiration is that the work is applicable in cases where variation in intercalated or inter-laminated clay volumes could mask the signature of fluid saturations or fluid-type changes on resistivity and thus brings about the clarity in contacts definition. In present study, an integrated approach has been used by using saturation from substitution in elastic modulii in addition to conventional resistivity based saturation analysis.

The body of the paper discusses the work flow involved and the results obtained. As will be seen presently, results are quite encouraging and promise not only the alternative validating mechanisms but also detection of hydrocarbon saturation using nonresistivity well-logs in deep-water environment.

Theory and Methodology

Effective grain properties from the clean zones:
Effective medium theories which model dry frame properties and saturated frame properties rely on grain properties while not explicitly modeling grain to grain contact elasticity.

In order to account for all factors including above, an effective G_{grain}^{clean} and an effective G_{grain}^{clean} have been obtained as follows.

For clean zones the following relationships have been used.

$$G_{dry}^{clean} = G_{grain}^{clean}(1-\phi_t)^{c/(1-\phi_t)} \quad \ldots. (1)$$

$$K_{dry}^{clean} = K_{grain}^{clean}(1-\phi_t)^{c/(1-\phi_t)} \quad \ldots. (2)$$

Where Φ_t is total porosity and c is a constant independent of total porosity.

G_{grain} clean has been evaluated as intercept of line fitted to log G_{bulk} vs (1/1- Φ_t)*log (1- Φ_t) plot, on G_{bulk} axis and c has been evaluated as the slop of that line.

Since VP/VS of dry gas bearing rock is a constant (Brie at all 1995), the implication is that K_{dry}/G_{dry} has to be independent of Φ_t and therefore

$K_{dry}/G_{dry} = K_{grain}/G_{grain}$

From the values reported for VP/VS in dry gas bearing sandstone (Brie at all 1995), K_{grain}/G_{grain} is deduced to be 1.14, and hence

$K_{grain}clean = 1.14 * G_{grain}clean$ …….(3)

Dry frame properties with shale present

K_{grain} has been computed as

K_{dry} has been computed as

Where $p = p_c + p_s$ (Keys and Xu, 2002)

Where c stands for compliant pores and s stands for stiff pores.

When the calculations were carried out it was noted that when V_{clay} was less than 25% p_s was << p_c. The compliant pore volumetrics p_c having been modeled from clay bound water and stiff pore volumetrics from $N_t - N_c$. Clay bound water has been computed as minimum of clay bound water from petrophysical inversion through a least square optimization and implemented through a robust multimineral model of rock and micro porosity from micro porosity bin of NMR T2 inversion. Total porosity has been considered from averaging N_t by the afore mentioned petrophysical processing result and density NMR combination derived method. From the above modeling of p it has been seen that since p_s is low and can be ignored, p is modeled by $p=c/(1-N_t)$ itself. Consequently K_{dry} has been modeled as

Where 'c' obtained from clean reservoir data as discussed in the foregoing has been used.

It is worth noting here that the methodology discussed (namely obtaining 'c' and G^{grain}_{clean}) from clean formation leads to most likely values of G^{grain}_{clean} to be used. Thus preferring this over $K_{dry} = G_{dry} * (K^{grain}_{clean} / G^{grain}_{clean})$ has been deliberate, since K_{grain}/G_{grain} has derived from $(K^{clean}_{grain} / G^{clean}_{grain})$, even when volume of clay is low, whereas 'c' is applicable for a clayey formation is still close to 'c' obtained from analysis of cleanformation, where V_{clay} is less than 25%.

Fluid properties

The properties of mud filtrate and formation water at formation temperature and pressure conditions have been computed from standard correlations. The gas composition is known and accordingly the compressional modulus has been computed.

Computation of K_{fluid}

The value of K_{fluid} has been computed as follows:

or,

So, finally K_{fluid} can be written as

Where A can be defined as