Seventy Years of Archie

London Petrophysical Society, One-day seminar,
The Geological Society, Burlington House, London
Thursday 6th December 2012

Talk	Time	Name	Talk Title	Affiliation	Slide pack
	09:00 - 09:30	Registration			
	09:30 - 09:45	LPS	Welcome	LPS	
	09:30 - 09:45	LPS	A message from the SPWLA	SPWLA	
1	10:00 - 10:30	Alan Johnson	Keynote; What did Archie actual present and why was it so radical?	Shell	
2	10:30 - 11:00	Adam Moss	Archie parameters - the basics	BG Group	a
	11:00 - 11:30	Coffee break			
3	11:30 - 12:00	Craig Lindsay	"Archie m & n from core – How, Why and What?"	Core Specialist Services Ltd	a
4	12:00 - 12:30	Jeffrey Hook	Uncertainty in Archie, what matters most	Consultant	a
	12:30 - 13:30	Lunch			
5	13:30 - 14:00	Paul Glover	Archie 'a' factor	University of Leeds	a
6	14:00 - 14:30	Michel Claverie	Unusual Archie results; right, wrong or unexpected, but explained.	Schlumberger	b
7	14:30 - 15:00	Geoff Page	"KISS: Alternatives to Archie – Direct volumetric measurements of Shc"	Baker Hughes	b
	15:00 - 15:30	Tea break			
8	15:30 - 16:00	Nick Colley	To Archie or not to Archie ?	BG Group	c
9	16:00 - 16:30	Ibrahim Milad	Uncertainties in water saturation model: Archie Equation - Single Well Case Study	BP	c
10	16:30 - 17:00	Mei Han	Probing the Archie Exponent under Variable Saturation Conditions	Schlumberger	b
	17:00 - 17:15	LPS	Discussion and Closing Remarks	LPS	
	17:30 - 20:30	President's Evening			

Slides will be available after the seminar, a) as seen; b) with some edits and/or omissions; c) sorry but not at all

What Did Archie Actually Present and Why was it so Radical

Alan Johnson; Principal Petrophysicist Shell UK Ltd. Aberdeen

Abstract

The presentation will look at Gus Archie's early career and his motivation for the investigations which led to the development for his famous equation in 1942. The types of data available at the time will also be reviewed together with the work of other investigators prior to Archie and how he integrated their results in his studies. The story will emphasise his key contribution in really quantifying what until then had been very much a qualitative field.

Archie's contribution in being the first to define the term Petrophysics as a discipline will also be discussed, with Archie's vision of how this encompassed the scope of interrelations between the different rock properties.

Archie Parameters, the Basics

Adam Moss, BG Group

I will discuss the Archie parameters and relate them to rock properties and pore-geometry. The Archie cementation and saturation exponents (m and n) are not just empirical coefficients, they link to fundamental rock properties such as grain size and packing, pore connectivity and surface area. These concept are illustrated using core analysis data from oil and gas reservoir rocks. The link between capillary pressure hysteresis and variable Archie saturation exponent is also presented along with a discussion on the effects of wettability.

“Archie m & n from core – How, Why and What?”

Craig Lindsay, Core Specialist Services Limited

Abstract

The presentation will briefly cover some of the basic of principals of what is measured in the lab when attempting to determine the Archie parameters (m and n). On the face of it these measurements are simple and straightforward. Maybe it’s not so simple?:

- What can go wrong?
- Will the lab make the measurements correctly?
- Are the measurements we requested relevant to our reservoir?

The author will cover a number of topics that don’t feature in a typical SCAL program – leaving it to the delegates to decide if they need to include such methods or not. I’ll be asking do you use these methods and was the lab data useful? Some new and novel methods will be mentioned – these are commonly not offered by commercial labs – why? How do we (should we) get commercial labs to adopt these potentially valuable (and very time saving!) methods?

Craig Lindsay has a 2:1 BSc. Honours in Geology from Liverpool University, UK, followed by 30 years in the core analysis industry. Initially at Core Lab from 1981-2001 working at wellsite and in routine, SCAL, IR spectroscopy and formation damage, latterly as project co-ordinator and data evaluator. Followed by 8 years at Helix RDS consultancy in project management of all core related projects including petrophysical and RE data evaluation / integration, now self-employed (March 2010) providing consultancy services to a portfolio of operators from small to majors. Currently serving as President of the Society of Core Analysts - a Chapter at Large of the SPWLA.

Uncertainty in Archie' Equation, what matters most

Jeffrey Hook, JaysHeath Ltd

Abstract

The precision with which a set of data (from a single core plug through a set of wireline logs to a complete reservoir) can be evaluated depends on the validity of the interpretation model used and the precision with which the parameters in the model can be determined.

The assumptions underlying the use of Archie's equation will be considered and circumstances in which they may not be valid may be indicated.

There are at least six parameters, four constants (tortuosity factor, a, cementation exponent, m, saturation exponent, n, and water resistivity, R_w) and two variables (porosity and true formation resistivity) in Archie's equation. The significance of the various interpretation parameters used in the estimation of water saturation from Archie's equation will be considered by simple error propagation techniques and their relative importance indicated. For some parameters typical uncertainties associated with their measurement will be indicated.

From an analysis of this type it is possible to allocate resources of time, effort and money to best reduce the uncertainty in the evaluation of a reservoir.

Archie 'a' factor

Prof. Paul W.J. Glover
School of Earth and Environment, The University of Leeds, UK

Abstract

Archie`s first law, as it is often used is incorrect in so much as it contains a parameter a which is not justified theoretically. However, paradoxically this empirical form of Archie`s law often performs better than the theoretically correct original version. The choice may seem trivial, but is extremely important because the difference between the cementation exponent values calculated using the theoretically correct form of the first Archie`s law and the empirical form can lead to an underestimation of reserves by at least 20% for typical reservoir parameter values. Clearly, the accuracy of cementation exponent calculations should be of prime importance, especially with reservoirs becoming smaller, more heterogeneous and difficult to produce. We have examined the apparent paradox, and conclude that while the theoretical form of the law is correct, it is the data that we have been analysing with Archie's law has been in error. There are at least three types of systematic error that are present in most measurements; (i) a porosity error, (ii) a pore fluid salinity error, and (iii) a temperature error. Each of these systematic errors is sufficient to ensure that a non-unity value of the 'a' parameter is required in order to fit the electrical data well. Fortunately, the traditional inclusion of this parameter in the fit has compensated for the presence of the systematic errors in the electrical and porosity data, leading to a value of cementation exponent that is correct. The exceptional case is those cementation exponents that have been calculated for individual core plugs. We make a number of recommendations for reducing the systematic errors that contribute to the problem and suggest that the value of the 'a' parameter may now be used as an indication of data quality.

Unusual Archie results; right, wrong or unexpected, but explained.

Michel Claverie, Schlumberger

Abstract

We present a few examples of anomalous Archie water saturation in fresh water reservoirs, in thinly laminated sands and in carbonate reservoirs; we identify the origins of the anomalies and provide solutions for measuring the correct saturation profile.

“KISS: Alternatives to Archie – Direct volumetric measurements of Shc”

Geoff Page, Baker Hughes

Abstract

Archie’s equation is based on a complex non-linear empirical correlation between water conductivity, pore structure and volume, and a bulk rock measurement Rt. Any addition of clay complicates the issue. The methodology does not actually calculate (or see) hydrocarbon at all – it is inferred.

After 70 years of new technology is there a better, simpler, method now available that gives a direct measurement of hydrocarbon volume??

Alternatives that will be considered include:

- Electrical
- Core
- Sigma
- Elemental composition
- Density and/or Neutron
- Magnetic Resonance

We will look at some of the advantages and disadvantages of each method, and consider if after 70 years Archie is still the best??..............

To Archie or not to Archie ?

Nick Colley, BG Group

Abstract

Two case studies of a non-Archie formation are presented. The different results for Sw computed by different methods are compared and discussed, and the influence of SCAL results is demonstrated. The subsequent petrophysical dilemma is discussed but, sadly, not solved.

Uncertainties in water saturation model: Archie Equation - Single Well Case Study.

Ibrahim B. Milad, Petrophysicist, Iraq SPU.

ABSTRACT

The example reservoir has been producing for more than 50 years. It has significant intervals which remain unswept and swept intervals that had seen significant saline aquifer or injected fresh water influx. Recently, new wells were drilled though such intervals that also acquired NMR and cased hole sigma logs that offered the opportunity to compare water saturations from a number of methods.

This paper assesses and compares the uncertainties of the Archie model, watered out intervals, compared to unswept hydrocarbon intervals. This uncertainty is mainly due to implementation of the input parameters from drainage experiments on core, but the impact of imbibation and variable water salinity has also been tested.

The accuracy of the Archie saturation model depends on the accuracy of log measurements and parameters used in the model. Accurate water saturation is one of the requirements of estimating oil in place. Typically this can be performed using deep resistivity logs and Archie equation in the example reservoir, as it consists of mainly thick clean sand units with saline connate water. This approach becomes more complex in swept intervals because of the imbibition of water and uncertain water salinity.

In this study, which focuses on one well, the change in the salinity of the watered out zone is not significant, however, the analysis showed higher uncertainty throughout the swept zone.

Utilize SCAL rock electrical properties measurements under drainage condition, adding up significant uncertainty in the residual oil saturation in the swept zone. SCAL ahead and behind the flood front is recommended to control the uncertainty around the saturation model in the swept zone and get the residual oil saturation right for reserves calculations.

Probing the Archie Exponent under Variable Saturation Conditions

Mei Han and Bernard Montaron, Schlumberger.

Abstract

A variety of n values have been reported in sandstones and carbonates. The deviation from n=2 may be due to pore geometry, heterogeneity and rock wettability. In this presentation, we review three experimental and theoretical studies that permit to improve the understanding of this complex behaviour.

Han et al. (2008) measured the electrical responses on different water wet sandstones and carbonates. On a clay free rock Fontainebleau sandstone, during drainage, the measured RI-Sw curves indicate a saturation exponent n close to 2 in the saturation range Sw > 20%. However, below this saturation threshold, a bending down deviation is observed. Based on the numerical simulation, they explained the bending down behaviour by the dominance of water film conduction, which locates at the grain surface roughness when Sw < 20%. On carbonate samples with bimodal pore size distribution they observed not only the bending down deviation but also the bending up behaviour. They argued that the electrical behaviour depends strongly on the spatial distribution and connection of the micro-porosity.

Kumar et al. (2011) furthered the comprehension on rock complex resistivity response by advanced imaging techniques. They coupled 3D micro-tomography imaging, high-resolution SEM analysis, and insitu observations of fluid distribution. On the Fontainebleau sandstone, they observed that at low Sw water films in those clean sands concentrate at or on the perimeter of grain contacts but rarely at the smooth grain surface. 3D images analysis shows the grain contacts span the rock structure. Their simulation results showed that taking into account the conductivity of thin water film within grain contacts results in a match to the measured bending down behaviour of RI - Sw curves. They also applied the analysis on carbonates under different wettability conditions. The results emphasized the influence of the micro-porosity conductivity on the saturation exponent determination at low Sw range.

The above behaviour observed in sandstone and carbonate can be modelled by the connectivity equation, introduced by Montaron (2007 & 2009). It leads to a simple analytical model that fits remarkably well the experimental data. Finally including in the connectivity model a moderate amount of oil-wetness in the reservoir rock leads to a complete model. The analytical models proposed match the electrical conductivity behaviour observed for clean non-reservoir sandstone rocks as well as carbonates.