The Story of the Archie Equation

The Archie Equation
An empirically-derived relationship, which has been used since 1942 to estimate saturation in clean sandstones and carbonates.

$$S_w^n = \frac{a.R_w}{\emptyset^m.R_t} \Rightarrow S_w = \sqrt[n]{\frac{a.R_w}{\emptyset^m.R_t}}$$

RI – I - Resistivity Index: The ratio of water –bearing to true formation resistivity.

$$I = \frac{R_t}{R_o} \Rightarrow I = \frac{R_t}{F.R_w} \Rightarrow I = 1/S_w^n \Rightarrow I = S_w^{-n}$$

$$R_t = a\emptyset^{-m}R_wI \Rightarrow R_t = a\emptyset^{-m}R_wS_w^{-n} \Rightarrow logR_t = -mlog\emptyset + log(aRw) + logI$$

This can be solved graphically using log data from a water leg and the Pickett Plot.

Formation Factor: The relationship between porosity and resistivity of the formation.

Applied to the flushed zone
The basic formulae can be applied to the special case of the flushed zone, which results in an estimate of residual oil

$$S_{xo}^n = \frac{F.R_{mf}}{R_{xo}}$$

Determining "m" from the gradient

$$F = a/\emptyset^m \Rightarrow F = a\emptyset^{-m} \Rightarrow logF = -m * log\emptyset$$

when Sw = 1

$$S_w^n = \frac{F.R_w}{R_t} \Rightarrow F = R_o/R_w$$

$$R_o = F.R_w \Rightarrow S_w^n = \frac{R_o}{R_t}$$

This can potentially be measured on core samples, if we have preserved the pore fluid or it could be determined in-situ using Deep Induction logs and in-situ fluid analysis (ISFA).

Humble Equations for sandstones

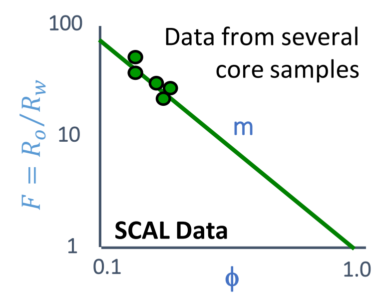
$F = 0.62/\emptyset^{2.15}$ $\quad$ $F = 0.81/\emptyset^2$

Parameters determined empirically by the Humble Oil Company. m is generally around 2, and typically decreases with better quality rock (m~1.0 for fractures, m~2.0 for intergranular pores, m>2.0 for vugs, m as high as 3 in tightly cemented carbonates)

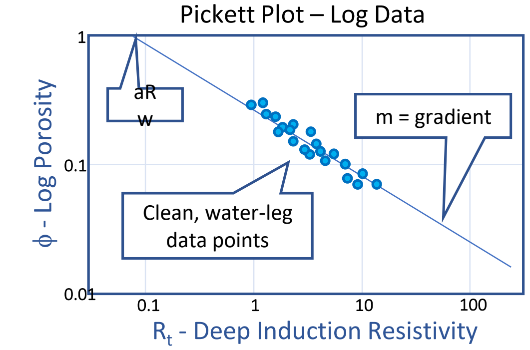
Determining "n" from the gradient

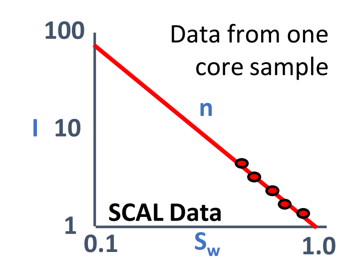
$$S_w^n = (R_o/R_t) \Rightarrow S_w = (R_o/R_t)^{1/n}$$

$$-nlog(S_w) = log(R_t/R_o)$$



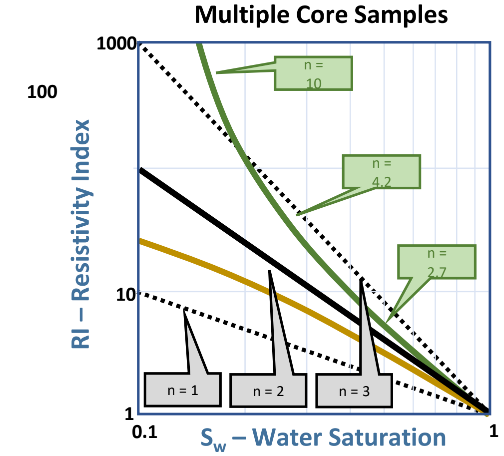
Pickett Plot – Log Data





n is dependent on wettability. It increases with oil wetness as the conductive brine phase is disrupted and resistivity increases. As a consequence, n can increase as a function of increasing grain surface rugosity, clay presence, increase in polar molecules in the oil and more.

Multiple Core Samples



Montaron & Han, 2009

Water-wet Archie rocks plot on a straight line, with a gradient of around 2. In shaly sands the clays result in increased conductivity (decreased resistivity), resulting in a decreased gradient (brown line). Strongly oil-wet reservoirs have much steeper gradients as a result of the increased resistivity, due to disruption of the water layer (green line).

a	= tortuosity factor	S_w	= Water Saturation
m	= cementation exponent	F	= Formation Resistivity Factor
n	= saturation exponent	I	= Resistivity Index
Φ	= porosity	R_t	= True Resistivity (equivalent to a deep resistivity log reading)
mf	= mud filtrate	R_0	= Resistivity of rock with only water (S_w = 1)
xo	= flushed zone	R_w	= brine resistivity

References

Archie, G. E. (1942, December 1). The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics. Society of Petroleum Engineers. doi:10.2118/942054-G

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