Test Development, Service Life Prediction Models and Specifications

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November 15th 2017

Defining the Formation Factor

Definition

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- The formation factor can be defined as the ratio of the resistivity of a medium and the resistivity of the fluid in the medium
- Known in petrophysics as Archie's law
- Named after Gustavus (G.E.) Archie, who worked for Shell Oil Company
- Seminal work appeared in the 1940s
- Was quite useful for OK oil fields
- Since that time it has been adapted by many

Definition - II

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- The formation factor can also be thought of as the inverse of the product of porosity and connectivity

Determination from Electrical Tests

Computation from Different Tests

Obtaining the Correct Form For Specifications

- Jason is fanatical that we should have the right form
- The specification should be based on formation factor as this minimizes 'influences'

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Use of the Formation Factor for Relating to Other Transport Related Tests

RCPT
Diffusion
Absorption

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RCPT

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Resistivity and RCPT

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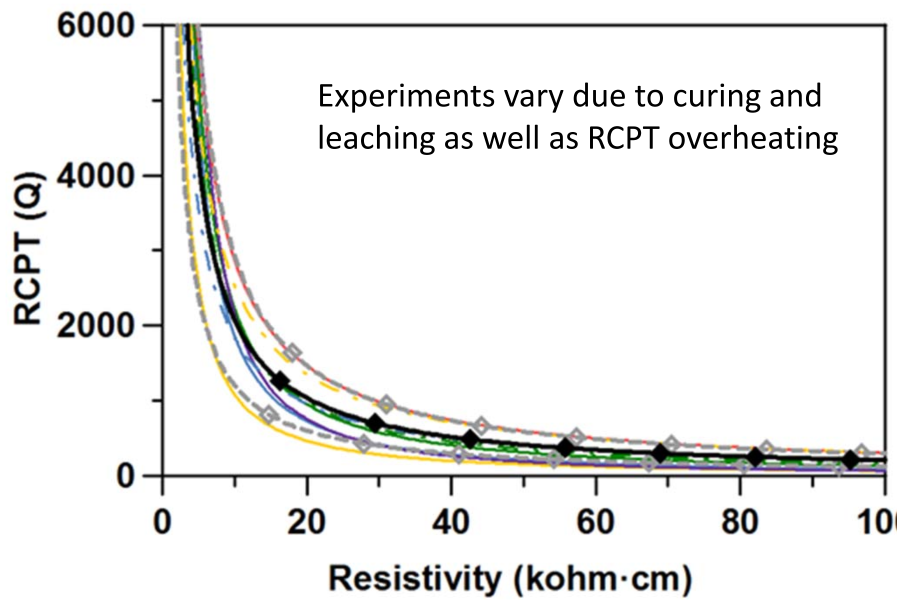
- We can fundamentally relate RCPT and resistivity

$$Q = \int_{0\,hr}^{6\,hr} I\,dt = \int_{0\,hr}^{6\,hr} \frac{V}{R}\,dt = \int_{0\,hr}^{6\,hr} \frac{V}{\rho}\frac{A}{L}\,dt = \mathrm{Q} = V\,\frac{A}{L}\,t\,\frac{1}{\rho} = 60V\,\frac{8107\,mm^2}{50.8\,mm}\,21{,}600\,s\,\frac{1}{\rho} = \frac{206{,}830\,V\,m\,s}{\rho}$$

- The differences from theory are likely influenced by storage (leaching and degree of saturation) and issues of heating with RCPT



Spragg et al. 2015

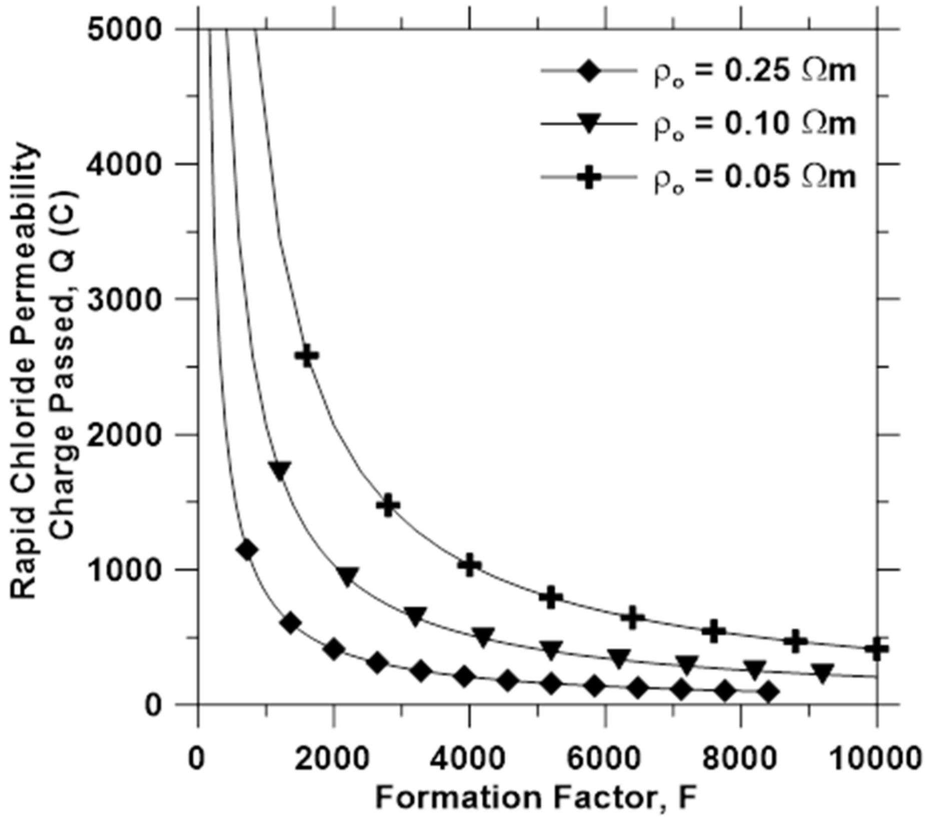
F Factor and RCPT

- More fundamentally however the F-Factor can be related with the pore solution conductivity and RCPT

$$Q = V\,\frac{A}{L}\,t\,\frac{1}{\rho_0}\frac{1}{F}$$

$$Q = 60V\,\frac{8107\,mm^2}{50.8\,mm}\,21{,}600\,s\,\frac{1}{\rho_o}\frac{1}{F}$$

$$Q = \frac{206{,}830\,V\,m\,s}{\rho_o}\,\frac{1}{F}$$



Weiss et al. 2016

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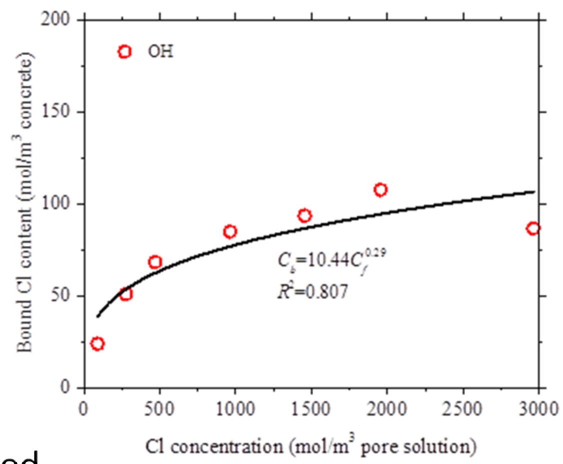
F Factor and $D_{Apparent}$

- Frequent criticism of F-Factor - it doesn't include binding
- While this is true (neither does any electrical measure) it can be shown that F Factor can easily be combined with a binding isotherm to predict performance
- Nernst Plank

$$\frac{\partial(\varphi S_l c_i + c_b)}{\partial t} = -\mathrm{div}(\mathrm{J}_i) = -\mathrm{div}\left\{-\frac{D_i^0}{F}\left[\mathrm{grad}\, c_i + c_i \mathrm{grad}(\ln \gamma_i) + \frac{z_i F}{RT} c_i \mathrm{grad}\psi\right]\right\};$$

- Binding

$$c_b = \alpha \cdot {c_{Cl}}^{\beta}$$



Qiao et al. to be submitted

Chloride Diffusion

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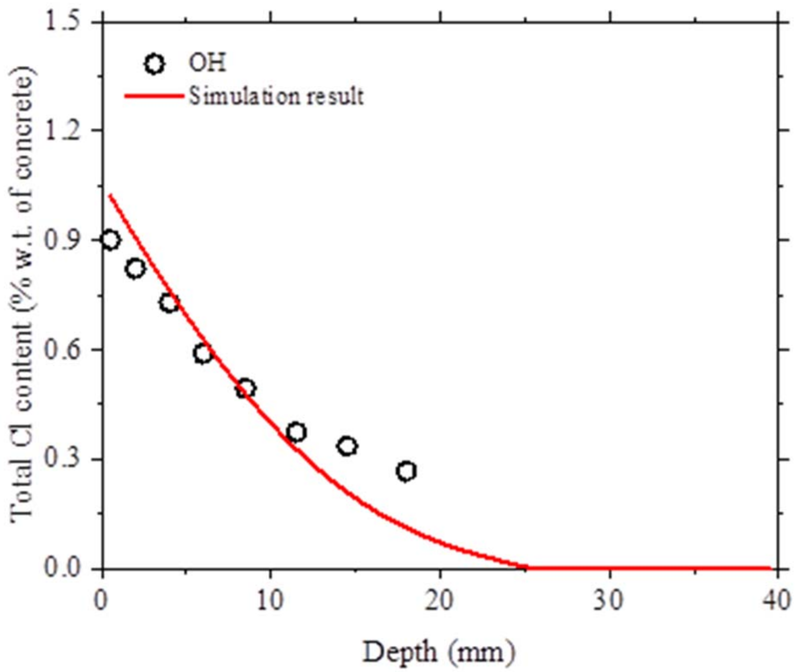
- Here we see that combining the F-Factor and binding is very powerful
- This does a good job at predicting chloride ingress
- This is much faster than ASTM 1556
- Further binding is a qualification test and F is a QC/QA test



Qiao et al. to be submitted

Use of the Formation Factor for Relating to Other Transport Related Tests

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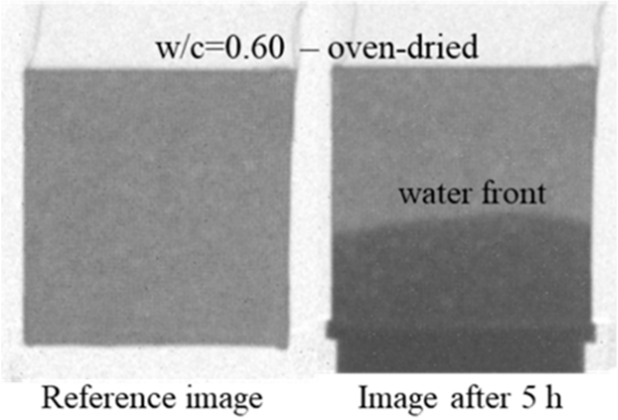
F Factor and Absorption

- The Formation Factor can be related to other transport properties directly.
- In a recently submitted paper we demonstrate that the mass of absorbed water (M) is related to ($F^{-0.5}$)
- Derived from first principles

$$M(t) = \frac{A\rho R_i}{2}\sqrt{\frac{\varepsilon P_{cap}}{\mu}}\sqrt{\frac{1}{F}}\sqrt{t}$$



Moradllo et al. submitted

Absorption

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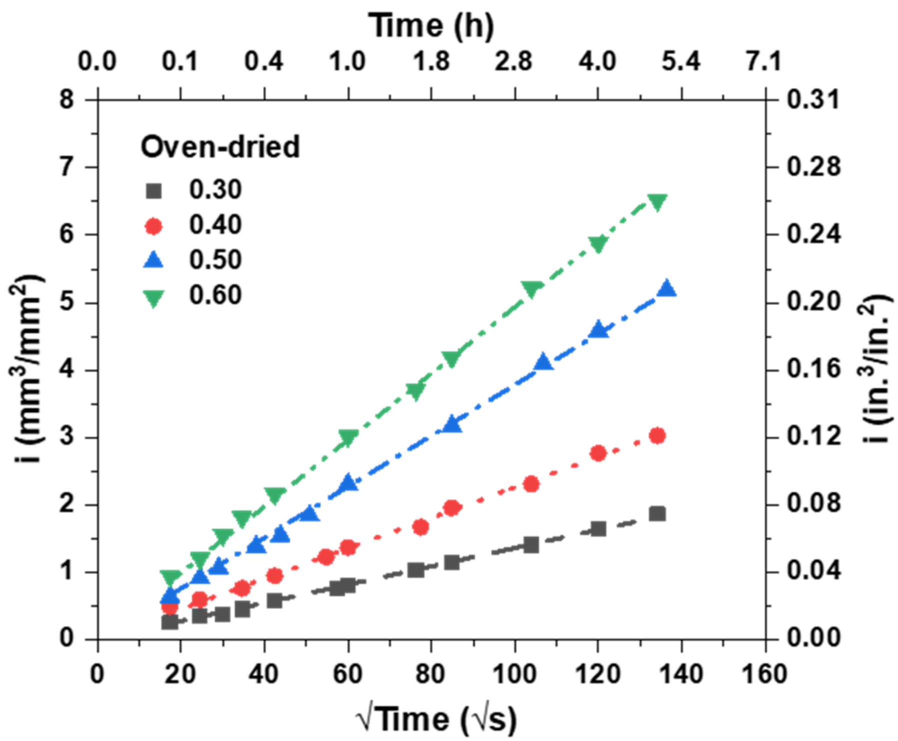

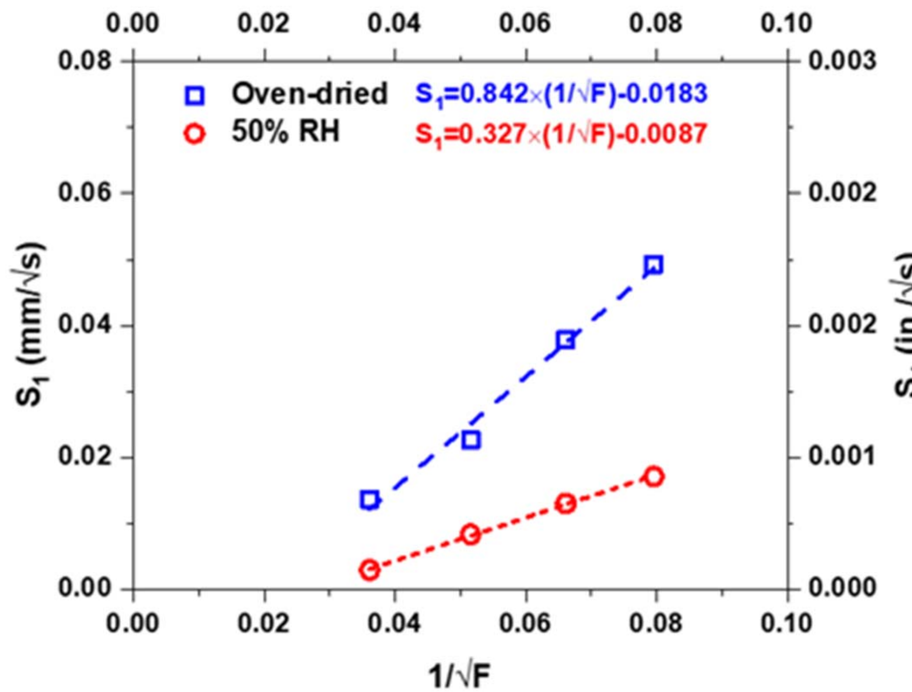

Moradllo et al. submitted

Conclusions

- F-Factor is a physical representation of the pore structure – Inverse of (Porosity * Connectivity)
- F – Factor is the ratio of resistivities (Bulk/Solution)
- F – Factor is related to many current tests

Four Step Approach Toward Performance

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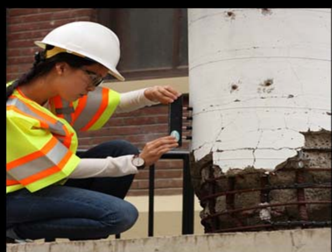


Assess Performance w/ Standard Tests

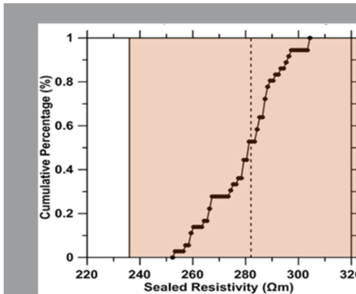
Tests should be:
- easy to perform
- economical
- repeatable

Convert Test Results to Fundamental Properties

Example:
- Measure ρ
- Account for Pore Solution
- Determine F- Factor

Relate Properties w/ Exposure Conditions

Use Exposure, Material Properties, and Models to Estimate Performance



Establish Performance Grade and Measure

Set Performance Limits and Use Tests to Measure to Insure That You Received What you Specified

Barde et al. 2007