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Rise in Core
Wettability Characterization Technique

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Outline

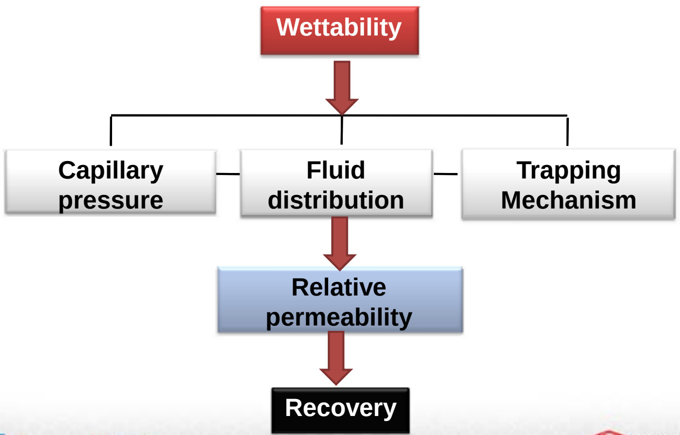
Wettability

- Wettability is defined as the relative preference of a solid surface to be coated by a certain fluid in a system.
- The reservoir rock wetting preference influences many aspects of reservoir performance:
  - Controls the fluid flow directly,
  - Affect the location and distribution of fluids,
  - Affect Oil Trapping Mechanism.

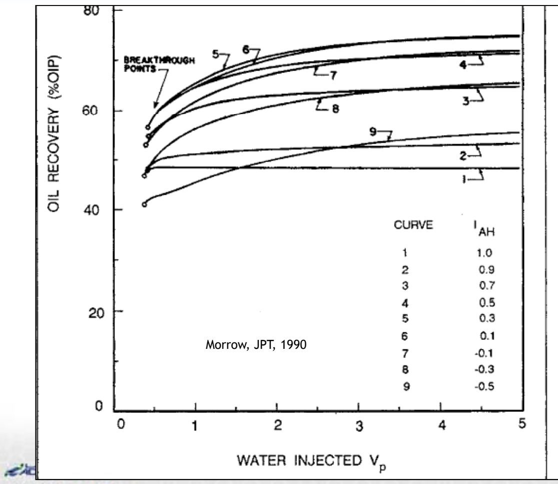
Range and Alteration of Wettability

- Reservoir wettability is affected by the:
  - Minerals in the pores as well as their distribution.
  - Adsorption or deposition of oil constituents on the rock surface.
  - The oil composition, as black-oil composition determines the solubility of the polar components.
  - Reservoir Conditions of temperature, pressure and saturation history.

Why Wettability is Important



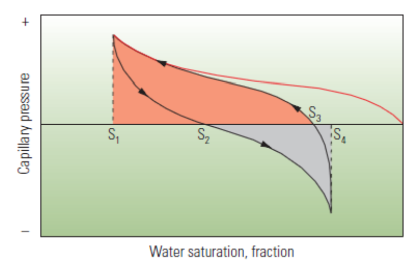
Performance of Waterflooding

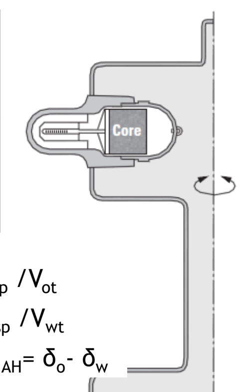


Measurement Techniques

- Industrial wettability measuring techniques include:
  - Amott Wettability Methods,
  - USBM Wettability Method,
  - Combined Amott-Harvey & USBM Methods, and
  - Contact Angle Methods.
- Limitations:
  - Imprecise in Wettability bands.
  - Very Demanding Experimental Setup.
  - Very Demanding Experimental Procedure
  - USBM test cannot determine whether a system has fractional or mixed wettability.

Amott-Harvey Method



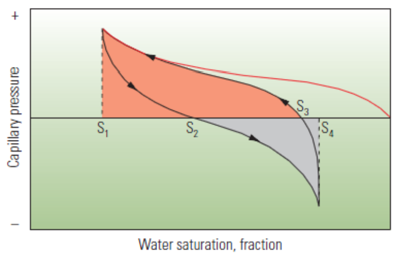


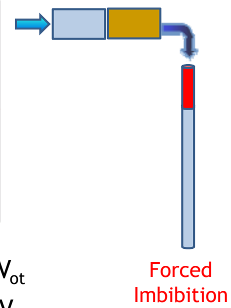
water-wet index: $\delta_w = V_{osp} / V_{ot}$

oil-wet index: $\delta_o = V_{wsp} / V_{wt}$

Amott-Harvey wettability index: $I_{AH} = \delta_o - \delta_w$

Amott-Harvey Method





water-wet index: $\delta_w = V_{osp} / V_{ot}$

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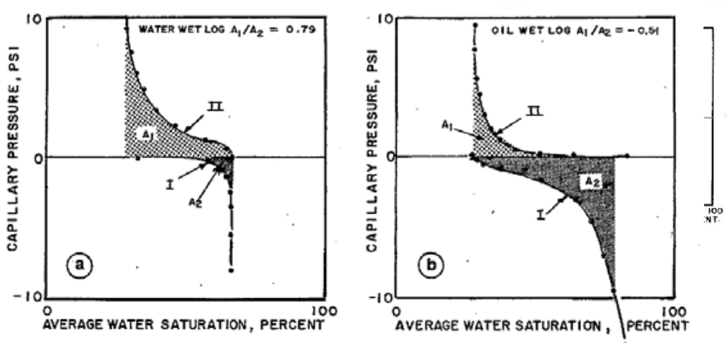
Amott-Harvey Index: $I_{AH} = \delta_o - \delta_w$

Advantages and Disadvantages

- Advantage:
  Relatively quick method (days).
- Disadvantages:
  Insensitive near neutral wettability.
  Measures Wettability by an Index

USBM Wettability Index



$$W = \log(A_1 / A_2)$$

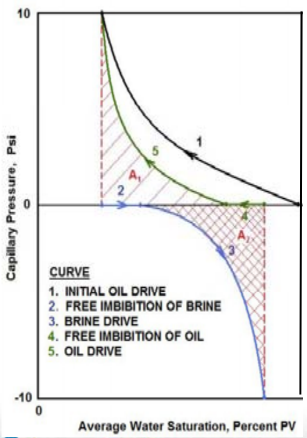
A_1 and A_2 are the areas under the oil- and brine-drive curves respectively.

If W > 0, water-wet; W < 0, oil-wet; W ≈ 0, neutrally wet.

Advantages and Disadvantages

- Advantage:
  - USBM is more sensitive to near neutral wettability.
- Disadvantages:
  - Time Consuming
  - USBM WI = - ∞ to ∞
  - Insenstive to fractional or mixed wettability.
  - Expensive

Modified Amott - USBM Method



Procedure of five steps :
(1) Initial Oil Drive,
(2) Brine Spontaneous Imbibition,
(3) Brine Drive,
(4) Oil Spontaneous Imbibition
(5) Oil Drive.

USBM WI: The areas under the brine-and oil-drive curves.

While,
Amott WI: Volumes of free and total water and oil displacements.

Call for New Technique

- Drawbacks of existing techniques call for the inventing a new technique to characterize wettability that has the following attributes:
  - (a) Sound Theoretical Background
  - (b) Simpler experimental setup,
  - (c) Conducted with less experimental effort,
  - (d) Determine all bands of wettability,
  - (e) if Possible, measure contact angle rather than a wettabiilty index.

RIC Technique

- New Rise In Core Wettability Characterization Technique is proposed.
- Based on a New Liquid/Liquid/rock Washburn equation.
- Estimates Wettability in terms of Contact Angle.
- Proved the RIC Concept Considering Repeatability and Uncertainty using Berea SS Core Samples.
- Compared to Industry standard techniques using Carbonate Core Samples.

Modifying Washburn Equation

- The Washburn equation

$$m^2 = \frac{C \cdot \rho^2 \cdot \gamma_{LV} \cdot \cos\theta}{\mu} \cdot t$$

- Where:

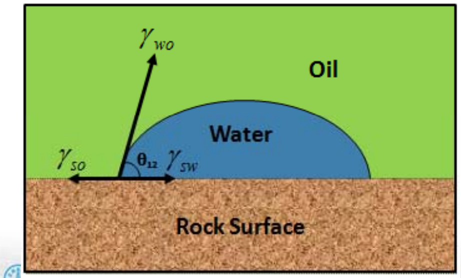
$$C = \left[\frac{r\left(\pi R_k^2\right)^2 \phi^2}{2} \right]$$

- This version of the Washburn equation enables to describe the contact angles of air/liquid/rock systems. (Wolfrom et al., 2002).

Washburn Eq for Oil/Water System

- Note that Young equation for liquid/liquid/rock systems can be described as (Tiab, 2004),

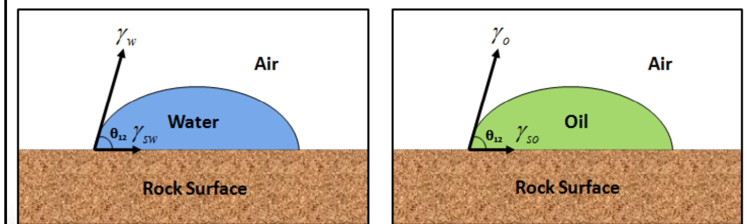
$$\cos\theta_{wo} = \frac{\gamma_{so} - \gamma_{sw}}{\gamma_{wo}}$$



Washburn Eq for Oil/Water System

- Evaluating γ_{sw} and γ_{so} using Figures b and c, and substituting in Equation 3, results in,

$$\cos\theta_{wo} = \frac{(\gamma_{oa}\cos\theta_{oa}) - (\gamma_{wa}\cos\theta_{wa})}{\gamma_{wo}}$$



(b) (c)

Washburn Eq for Oil/Water System

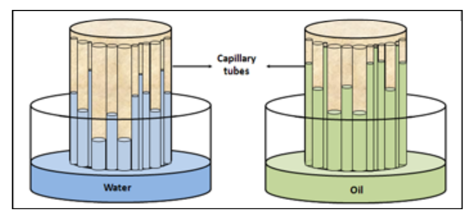
- Cancelling out similar terms, results in,

$$\cos\theta_{wo} = \frac{\left(\frac{m^2 \cdot \mu_o}{C\rho_o^2 t}\right) - \left(\frac{m^2 \cdot \mu_w}{C\rho_w^2 t}\right)}{\gamma_{wo}}$$

- Air behaves as strong non-wetting phase in both of oil/air/solid and water/air/solid systems.
- Equal air/oil and air/water capillary forces would result if the differences between $\gamma_{air/oil}$ and $\gamma_{air/water}$ are ignored (assumption).

Washburn Eq for Oil/Water System

- Considering Water/Air and Oil/Air Systems in certain porous media



- For equal capillary forces, both water and oil will rise in pores according to their densities,

$$\rho_w\, g\, h_w = \rho_o\, g\, h_o$$

Modified W/O Washburn Equation

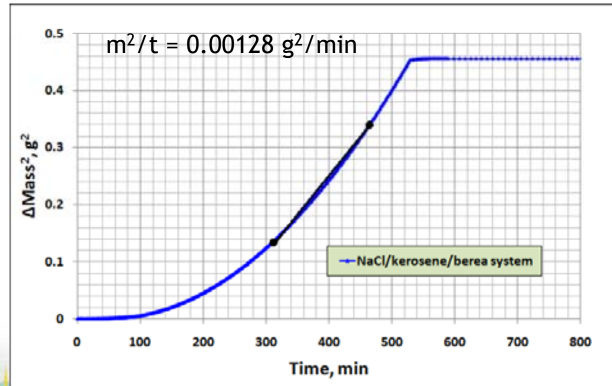
- Water or oil penetration of the porous media at any time is function of the balance between gravity and capillary forces, resulting in,

$$\cos\theta_{wo} = \frac{(\mu_o \cdot \rho_w^2) - (\mu_w \cdot \rho_o^2)}{\rho_o^2\, \rho_w^2 \cdot C \cdot \gamma_{wo}} \cdot \frac{m^2}{t}$$

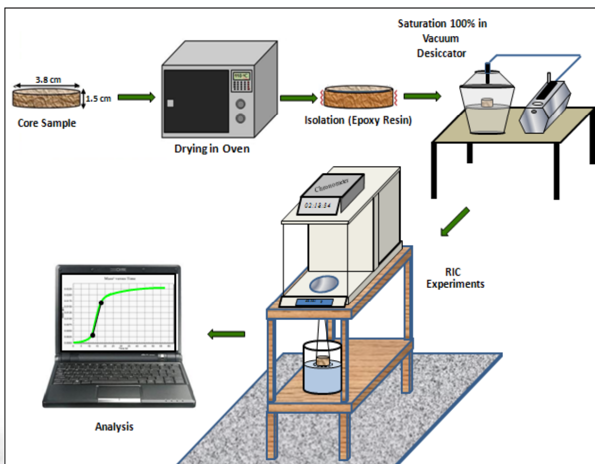
- Where,
- The constant, C, characterizes the porous media;
- The term m^2/t could be the slope of the imbibition curves (m^2 vs. time) of both oil/water/solid system.

Water/Oil Imbibition Experiment

$$\cos\theta_{wo} = \frac{(\mu_o \cdot \rho_w^2) - (\mu_w \cdot \rho_o^2)}{\rho_o^2\, \rho_w^2 \cdot C \cdot \gamma_{wo}} \cdot \frac{m^2}{t}$$



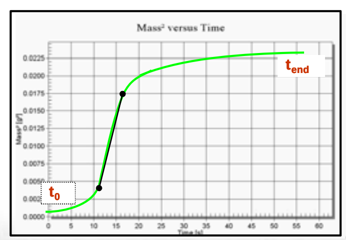
Experimental Setup

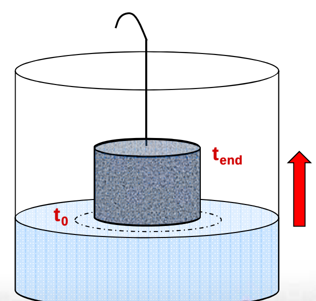


RIC Experiments for C Determination

- RIC dodecane/air/rock imbibition experiment performed to determine the m^2/t.

$$C = \frac{\mu}{\gamma_{LV} \cdot \rho^2 \cdot \cos\theta} \cdot \frac{m^2}{t}$$

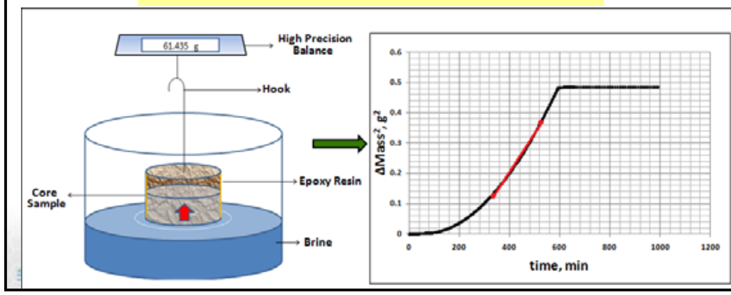




RIC Experiments for Wettability

- Liquid/Liquid/rock Washburn equation
- RIC is performed with brine/oil system.

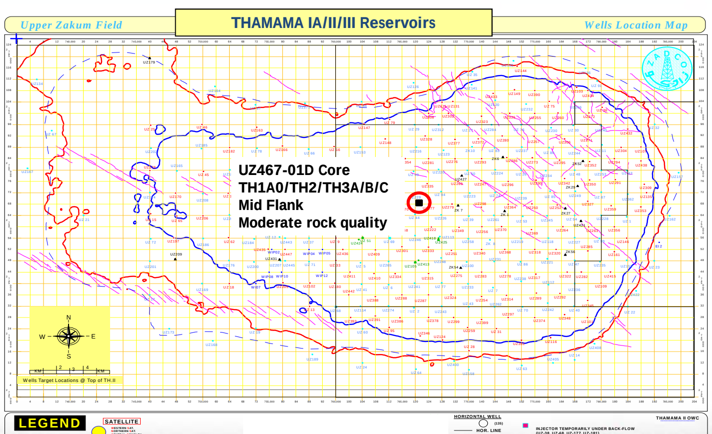
$$\cos\theta_{wo} = \frac{(\mu_o \cdot \rho_w^2) - (\mu_w \cdot \rho_o^2)}{\rho_o^2\ \rho_w^2 \cdot C \cdot \gamma_{wo}} \cdot \frac{m^2}{t}$$



Core Samples

- Cores samples from across the well, but mostly in the crest of the reservoir.
- Core are cut from the proximity of other cores samples to be cut for Amott-Harvey/USBM Wettability Measurements by a third party.

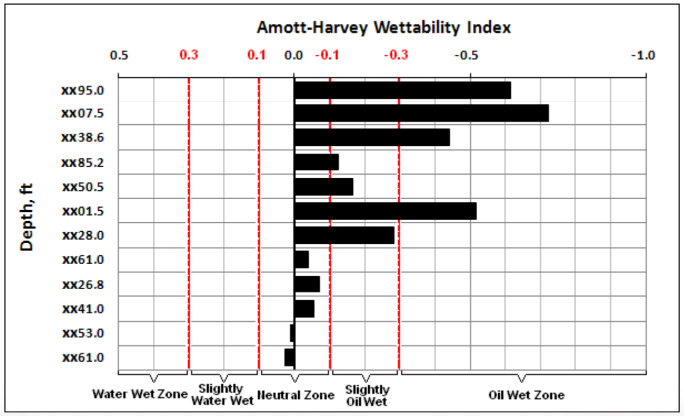
Location of UZ467



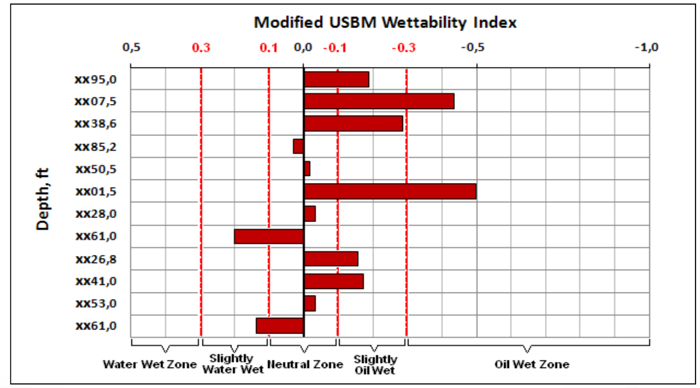
Twin Carbonate Core Samples

Formation	Twin Cores	
	Depth, ft	Depth, ft
YZ1A	XX95	XX94.8
YZ1A	XX07.6	XX07.3
YZ1A	XX38.6	XX38.4
YZ2	XX85.2	XX85.8
YZ2	XX50.5	XX50.3
YZ2	XX01.5	XX02.0
YZ3A	XX28.0	XX28.5
YZ3A	XX61.0	XX61.8
YZ3C	XX26.0	XX26.6
YZ3C	XX41.0	XX40.8
YZ3C	XX53.0	XX52.6
YZ3C	XX61.0	XX61.4

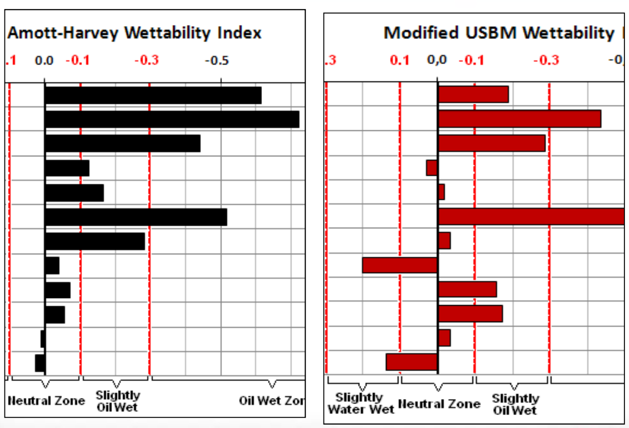
Amott-Harvey Wettability Index



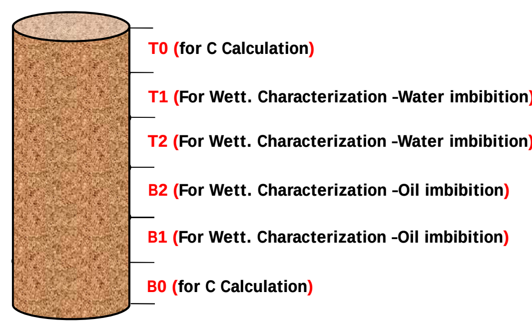
USBM Wettability Index



Amott-Harvey vs USBM Wettability Index

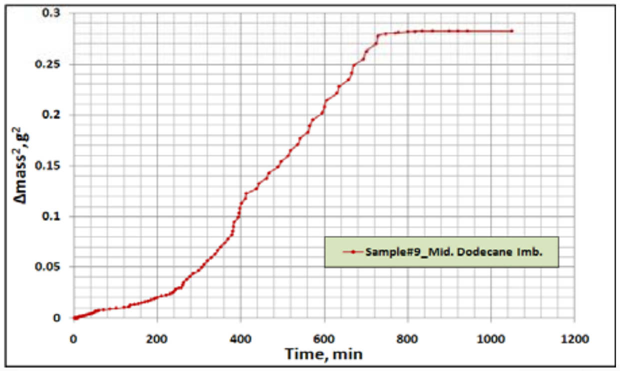


RIC Wettability Determination



Determination of C

Dodecane/Air/Carbonate_Plug_1

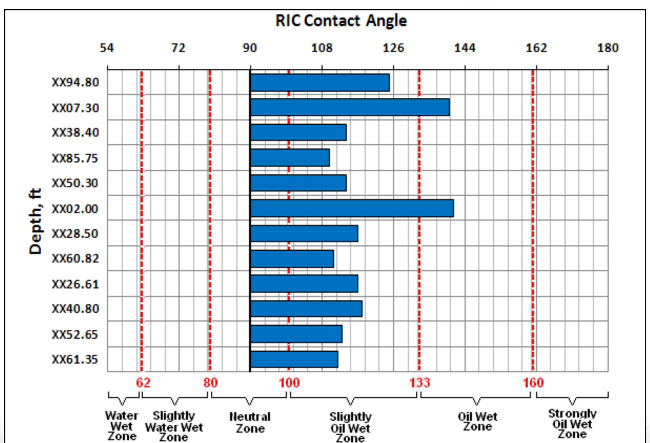


Wettability Measurement

Top- (Water imbibition)			
C / Slope	Min	Max	Average
Min	119.10	115.91	117.27
Max	120.91	117.48	118.94
Average	119.73	116.45	117.85

Bottom- (Oil Imbibition)			
C / Slope	Min	Max	Average
Min	117.30	114.33	115.61
Max	124.29	120.40	122.06
Average	118.92	115.75	117.11

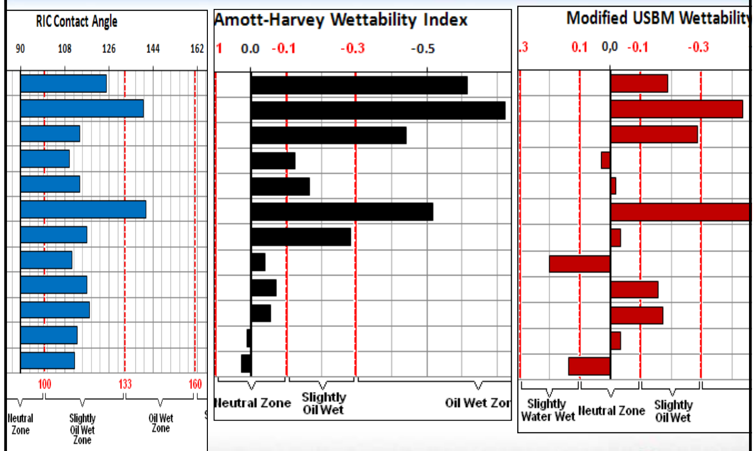
RIC Wettability of Twin Core Samples



RIC vs Amott-Harvey and USBM

Reservoir Formation	Reservoir Depth, ft	Amott-Harvey Index	Wettability Classification	USBM Index	Wettability Classification	Reservoir Depth, ft	RIC Contact Angle	Wettability Classification
YZ1A0	XX95.00	-0.614	Oil Wet	-0.188	Slight Oil Wet	XX94.80	125	Slight Oil Wet
YZ1A0	XX07.50	-0.722	Oil Wet	-0.434	Oil wet	XX07.30	140	Oil wet
YZ1A0	XX38.60	-0.442	Mod Oil Wet	-0.285	Slight Oil Wet	XX38.40	114	Slight Oil Wet
YZ2	XX85.20	-0.124	Slight Oil Wet	0.03	Neutral Wet	XX85.75	110	Slight Oil Wet
YZ2	XX50.50	-0.168	Slight Oil Wet	-0.017	Neutral Wet	XX50.30	114	Slight Oil Wet
YZ2	XX01.50	-0.516	Oil Wet	-0.499	Oil wet	XX02.00	141	Oil wet
YZ3A	XX28.00	-0.282	Slight Oil Wet	-0.035	Neutral Wet	XX28.50	117	Slight Oil Wet
YZ3A	XX61.00	-0.041	Neutral Wet	0.2	Slight Water Wet	XX60.82	111	Slight Oil Wet
YZ3C	XX26.80	-0.071	Neutral Wet	-0.157	Slight Oil Wet	XX26.61	117	Slight Oil Wet
YZ3C	XX41.00	-0.055	Neutral Wet	-0.173	Slight Oil Wet	XX40.80	118	Slight Oil Wet
YZ3C	XX53.00	0.010	Neutral Wet	-0.033	Neutral Wet	XX52.65	113	Slight Oil Wet
YZ3C	XX61.00	0.026	Neutral Wet	0.138	Slight Water Wet	XX61.35	112	Slight Oil Wet

RIC vs Amott vs USBM



Way Forward

- Investigate if the Constant, C, (Pore Mean Diameter) could be used to infer rock types.
- Conduct more RIC experiments in Carbonate Cores from Wells drilled in the Transition Zone
- Refine the experimental setup and experimental procedure.
- Extend the Current Experimental Setup and procedure to reservoir conditions.