February 2020

WHITE PAPER

ESal Engineered Salinity

THE SECRET IS IN THE WATER

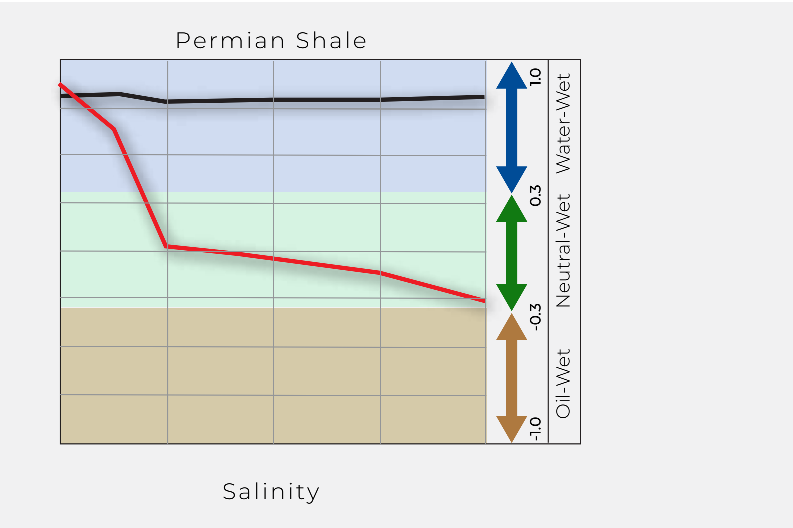
Wettability Measurements

How and Why?

You want a wettability measurement for your field, but what are you going to do with it and which technique should you use?

WETTABILITY MEASUREMENTS: HOW and WHY?

It is commonly accepted that wettability controls electrical properties, capillary pressure, relative permeability, waterflood behavior, ultimate recovery and EOR options in reservoirs, making it an important measurment (Anderson, 1986). For instance, the information is used to design drilling, completion and waterflood fluids. **But in the end, you want information that leads to profitable results which means avoiding negative outcomes and creating positive ones.**

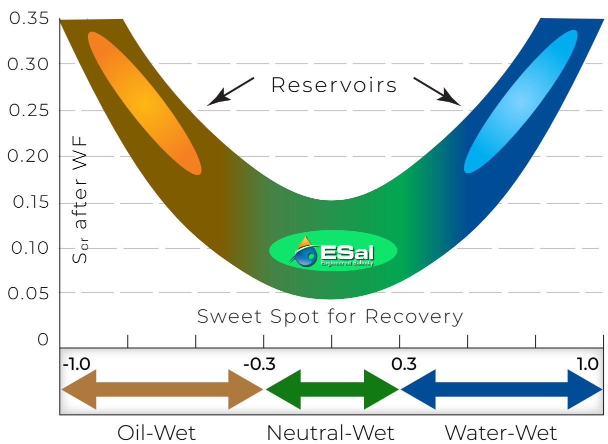


Most of us assume that the measured wettability is relatively stable and unchanged by normal operations, essentially an intrinsic property of the reservoir. At ESal LLC, we have learned that wettability can be changed by normal operations and this knowledge should be an essential component of operational decisions. The figure opposite shows the change in wettability with salinity for a Permian shale reservoir with two different Permian oils. Reservoir salinity is on the y-axis, and salinity is on the x-axis with lower values to the right. This shale reservoir is initially water-wet with either oil. In the first case, the wettability is insensitive to salinity (black line) and you will not affect reservoir wettability when using a wide range of salinity in your frac water.

In the second case the wettability is very sensitive to salinity (red line) and the salinity of your frac fluid matters. By using the right water in the second case, you can change the water-wet reservoir to neutral-wet and increase recovery.

This additional recovery occurs because the best oil drainage happens where oil and water move equally well, or neutral wettability. This condition strikes the balance between adhesion (oil-wet) and water block (water-wet).

The next figure shows this concept. The shaded crescent area shows the range of residual oil saturation (S_{or}) data from carbonate and sandstone rocks as the wettability changes. We can see both oil-wet and water-wet conditions do not allow the lowest residual saturations (best recovery) compared to neutral-wet conditions.



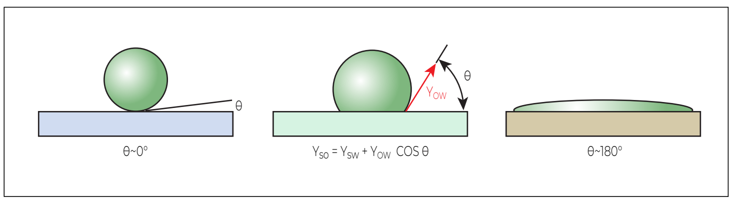
The difference in recovery can be substantial depending on the wettability condition and the positive economic outcomes in the shale case above are evident.

Now that we understand the importance of water and wettability, how do we measure wettability, and will that measurement help me recover more oil?

Wettability is measured by various techniques, but all are macro-scale expressions of the nano-scale forces. The common macro-scale measurements include contact angles, spontaneous or forced imbibition, capillary pressure, and interfacial tension. The table below summarizes some of the important aspects of the commonly used techniques.

Technique	Quant.	Qual.	Time	Temp.	Pressure	Expense	Core	Cuttings
Amott	X		10 d	N	N	high	Y	N
USBM	X		1-3 d	N	N	high	Y	N
Contact Angle	X		1-2 hr	Y	Y	high	Y	N
Imbibition		X	60-90 d	Y	N	med	Y	N
Capillary Pressure		X	1 d	N	N	med	Y	N
Chromatographic	X		1 d	Y	Y	high	Y	N
Modified Flotation	X	X	1 d	Y	N	low	Y	Y
NMR	X		1 d	Y	Y	high	Y	N
FESEM		X	1 d	N	N	high	Y	Y
Interfacial Tension		X	1 d	N	N	med	----	----

The methods can be divided into static and dynamic. For instance, interfacial tension and contact angles are generally measured under static conditions. Interfacial tension is measured between the fluid phases, and the relationship between the fluids and solid phase are often calculated.



Contact angles directly measure fluid-rock relations. As shown above, the drop of oil that spreads across the surface (large contact angle) is seen as 'wetting the surface' and that surface is termed oil-wet (120-180°).

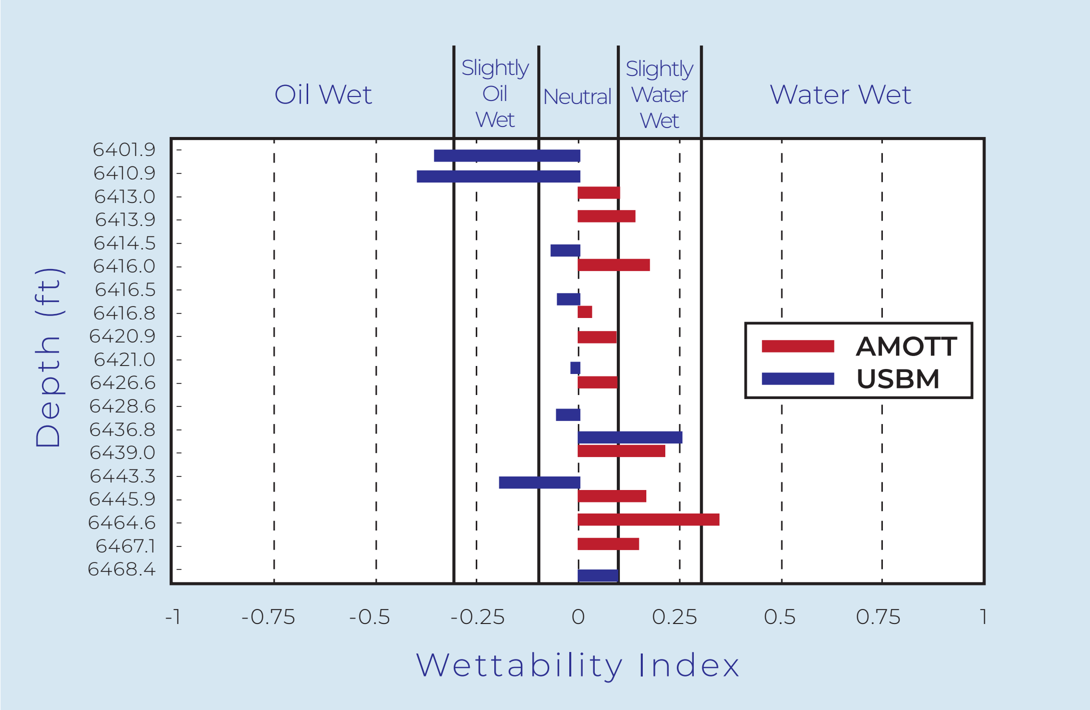
The rock will preferentially imbibe oil compared to water. In contrast, a drop of oil that beads up on the surface (low contact angle), means the surface is water-wet because the oil can barely attach to the surface (0-75°). In this case, rock will preferentially imbibe water displacing oil. The surface forces being measured are very sensitive to contaminants in the oil or water, impurities in the rock plate, temperature and pH, so measurements need to reproduce reservoir conditions as much as possible (Shedid and Ghannam, 2004).

Dynamic methods, which are more relevant to oil movement under drive, measure the balance of forces as fluids move through the rock. This complex process involves processes such as resistance at pore throats to each fluid (dependent on the size of those pore throats and fluid wetting them) and the rheology of the fluids. For instance, oil-wet pore throats will allow oil flow easily while restricting water flow and vice versa. A combination of both are required for maximum oil drainage (neutral wettability).

Examples of the dynamic methods include imbibition, the Amott method that uses imbibition followed by forced displacement, and the U.S. Bureau of Mines (USBM) method that uses capillary pressure data obtained from forced displacement by centrifugation.

These large-scale methods generate a single value that represents thousands and thousands of individual interactions. Geometry of pores and pore throats, history of wetting and saturation of oil and water all influence the measurement. The agreement between dynamic methods is not always good.

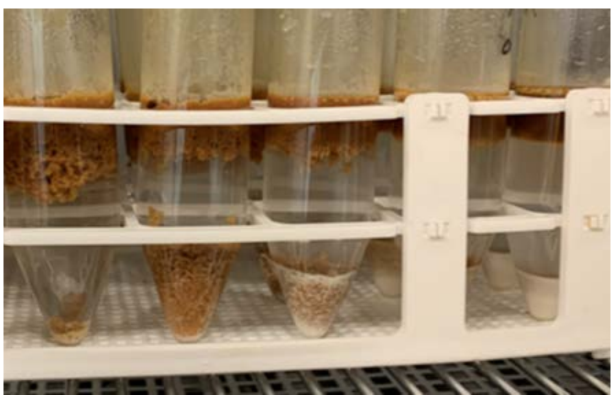
This figure shows the difference in wettability using Amott and USBM for samples from the Ghawar reservoir (Okasha et al. 2007). We can see that the values are not the same, with Amott giving neutral to slightly water-wet while USBM gives neutral to slightly oil-wet.



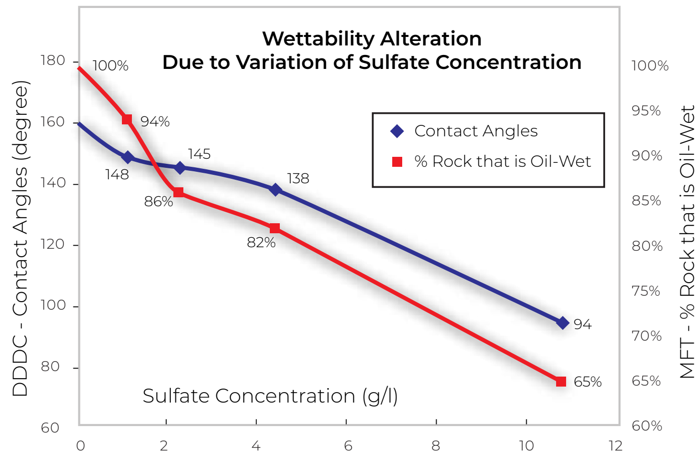
Techniques that measure wettability at a smaller scale include field effect scanning electron microscope (FE-SEM), nuclear magnetic resonance (NMR), interfacial tension and modified flotation. The first three techniques require significant investment in specialized equipment and expertise.

FE-SEM and NMR are direct observations of wettability while interfacial tension is an indirect measurement of wettability. Flotation, or more correctly modified flotation (MFT) (Mwangi, 2018), is a direct measurement. While flotation in general is only qualitative, MFT is quantitative.

MFT is a flotation technique where water and oil are added to powdered rock, mixed and allowed to separate. Grains that sink are water-wet, and grains that adhere to the oil phase and float are oil-wet. The technique physically separates the grains which can then be weighed to produce a quantitative value. The results are expressed in units of the standard wettability index (I_w), equivalent to the Amott wettability index where -1 is fully oil-wet and +1 is fully water-wet. The analytical resolution of the measurements is ±0.025-0.050 wettability units. The technique requires that the particles be separated by flotation (surface forces > gravitational forces) and that there is maximum contact between fluids and rock.



At ESal, we have chosen modified flotation because of its accuracy and speed of results. A typical salinity series is shown in the photo above where the salinity in each sample is different. The photo shows as the salinity is changed the amount of water-wet rock decreases until almost all the rock is oil-wet floating.



The MFT measurements are compared to contact angle measurements for the same system in the figure above. The results show that the two methods give almost identical results over a wide range of wettability.

So back to the beginning - you want a wettability measurement. Which technique will you use and what will you do with it? Salinity sensitivity of your reservoir can greatly impact your recovery as represented earlier. **Do you know how sensitive your reservoir is to changes in injection or completion water salinity?**

If not, what tests are being employed to measure this for your assets? The adoption of ESal's modified flotation tests will give you that answer quickly and at low cost.

The choice is yours, use about 50 Amott tests or one set of MFT tests to get the information you need to recover more oil. MFT can help you better understand your water problem, design waterflood and completion fluids, evaluate spatial heterogeneity of reservoir wettability or even the wettability of your frac sand. In our next white paper, we will share our experience with case examples of altering wettability in a variety of both conventional and unconventional reservoirs and the impact on recovery. **Follow us on LinkedIn** so you don't miss out on our future papers. If you want an efficient and economic method of significantly improving recovery, ESal is the answer for you.

References

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Why ESal is right for you

High Return:
An additional 5-15% more of the original oil in place (OOIP) from your field

Quick Results:
Increased production in as little as 6 months after deployment

Seamless:
No change in normal operations

Versatile:
Works in carbonate or clastic reservoirs

Increase Reserves:
Successful pilot test can be used to increase reserves

Improve Well Performance:
Reduce Plugging, Scaling and Corrosion

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