Wettability

What is Wettability

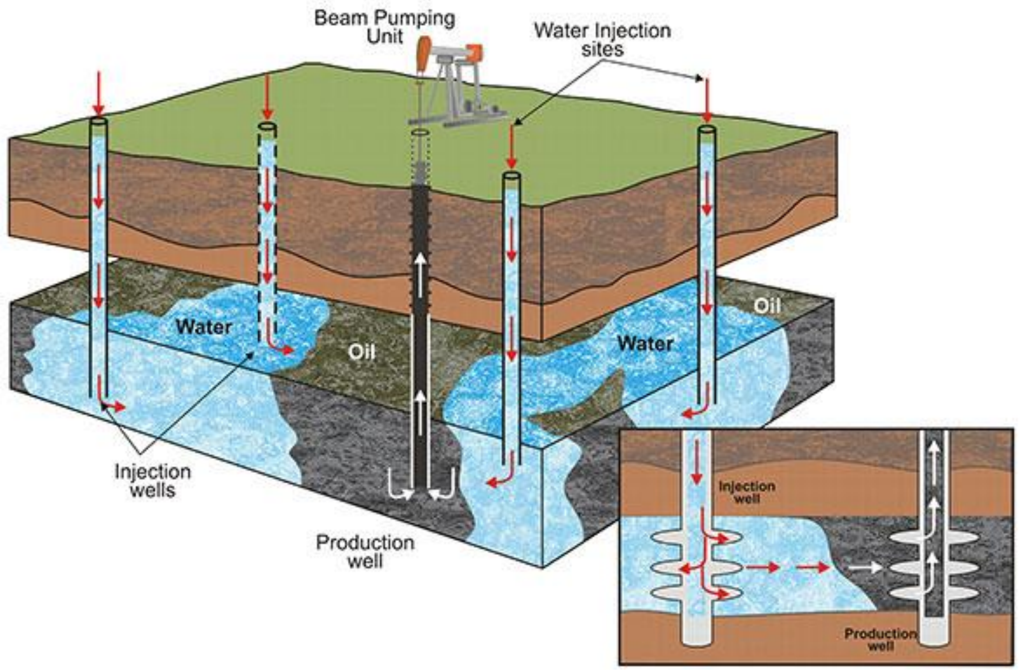
Wettability is the preference of a solid to be in contact with one fluid over another in a system of two or more immiscible fluids

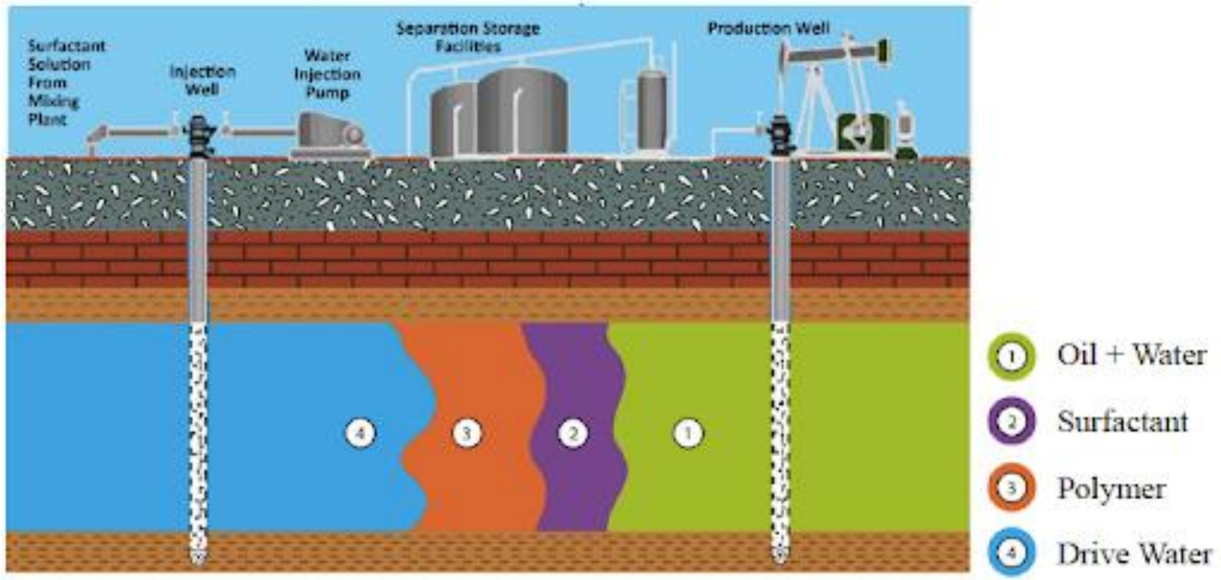
the tissue paper prefers to be in contact with water or the tissue paper "likes" the water (hydrophilic)

the fabric used in making umbrellas "does not like" to be contacted by water, which explains why rain droplets slide easily off of umbrellas (hydrophobic)

Importance of Wettability

Knowing the wettability is very important in understanding flow behavior when we are injecting water to displace oil.





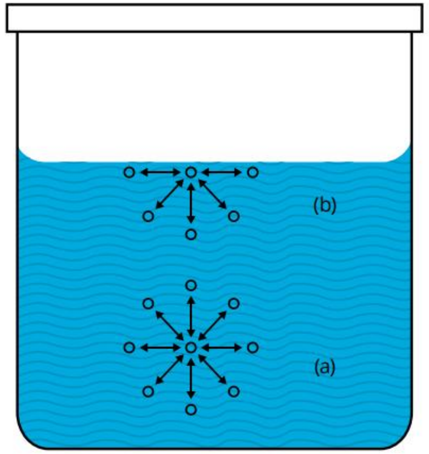
For example, if we are injecting water (waterflooding) in a water-wet rock (rock that likes water), the flow will be different from the case of an oil-wet rock. This is due to the low mobility of water in a water-wet rock as water wants to stick to the surface while the oil will be expelled out easily. Therefore, wettability can be considered as a flow or transport property that affects the flow in porous media

Surface and Interfacial Tension

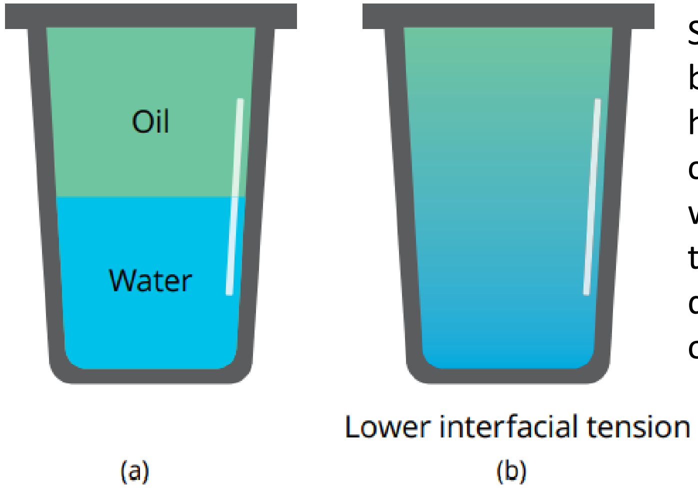
- Surface tension occurs between water and gas or between a solid and fluid (liquid or gas).
- Interfacial tension (IFT), on the other hand, takes place between two liquids, and the lower the interfacial tension between two fluids, the closer the fluids will become to being miscible (miscibility is the ability of two fluids to mix together).
- In either case, it is defined as the energy per unit area or the force per unit length [N/m], which can be expressed as [dyne/cm, where 1 dyne = 10-5 N] with the symbol σ

Table 7.1: Typical ST/IFT values for specific fluid pairs at ambient conditions.

System	σ [mN/m]
Air/mercury	480
Gas/oil	24
Gas/brine	72
Oil/brine	32



Schematic showing a beaker filled with water to a certain point, and then filled with air. Point (a) in the schematic shows a balanced water molecule while point (b) shows an imbalanced water molecule.



Schematic showing (a) a clear interface between oil and water which indicates higher interfacial tension when compared to (b) a hypothetical case with no visible interface which indicates that oil and water are partially miscible due to the low interfacial tension (since oil and water are immiscible).

Adhesion Tension

- Cohesive forces are forces of attraction between similar molecules while adhesive forces are forces of attraction between different molecules

if we want to analyze a droplet of water on a solid surface that is static, then we can analyze the forces acting on the horizontal plane of point A of that system:

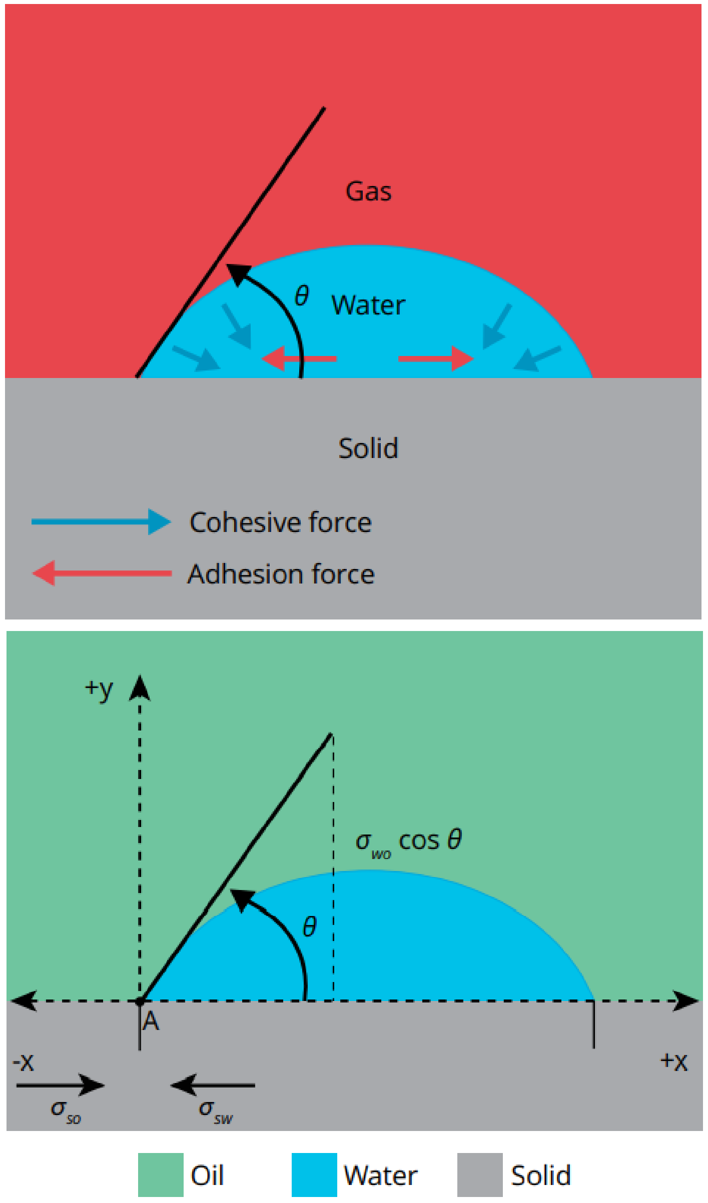
$$\Sigma f_x = \sigma_{so} - \sigma_{sw} + \sigma_{wo} \cos\theta = 0$$

where Σf x are the forces in the horizontal plane, σsw is the surface tension between the solid and water [N/m], σso is the surface tension between the solid and oil [N/m], σwo is the interfacial tension between water and oil [N/m], and θ is the contact angle between the water droplet and the surface

Adhesion tension can be defined as the difference between two solid-fluid surface tensions:

$$A_T = \sigma_{sw} - \sigma_{so} = \sigma_{wo} \cos\theta$$

$$\cos\theta = \frac{\sigma_{sw} - \sigma_{so}}{\sigma_{wo}} = \frac{A_T}{\sigma_{wo}}$$



Classification of Wettability

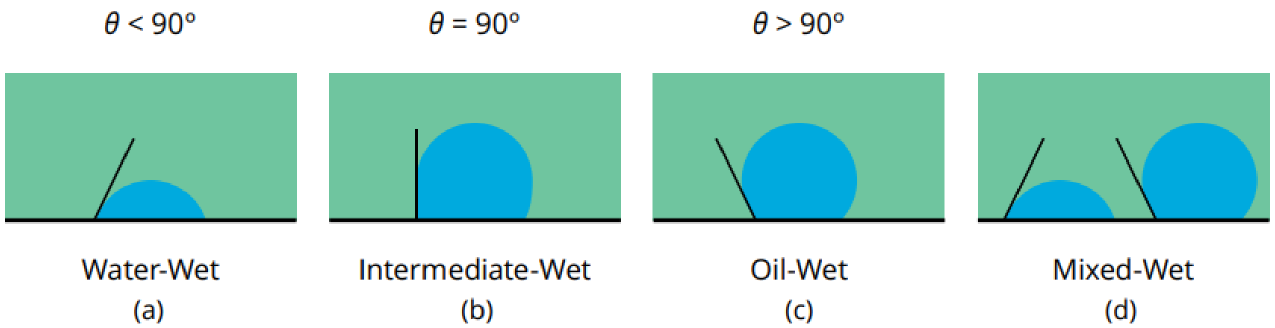


Table 7.2: Wettability classification based on the contact angle of the water droplet on a rock surface.

Wettability State	θ [°]
Water-wet	<90
Intermediate-wet	≈90
Oil-wet	>90

1) Water-wet, where the rock surface prefers to be coated with water and thus the rock has a high affinity towards water, allowing water to spread on the surface (Figure a). This means that the contact angle will be less than 90° as the water spreads on the surface

2) Intermediate-wet or neutral-wet, where the surface has an almost equal tendency to be coated by one of the fluids (either oil or water) (Figure b). This means that the contact angle is around 90° as the surface has equal affinity towards both oil and water.

3) Oil-wet, where the rock prefers to be in contact with oil, opposite to the water-wet case (Figure c). In this case, the contact angle will be greater than 90° as the surface prefers to be in contact with oil over water

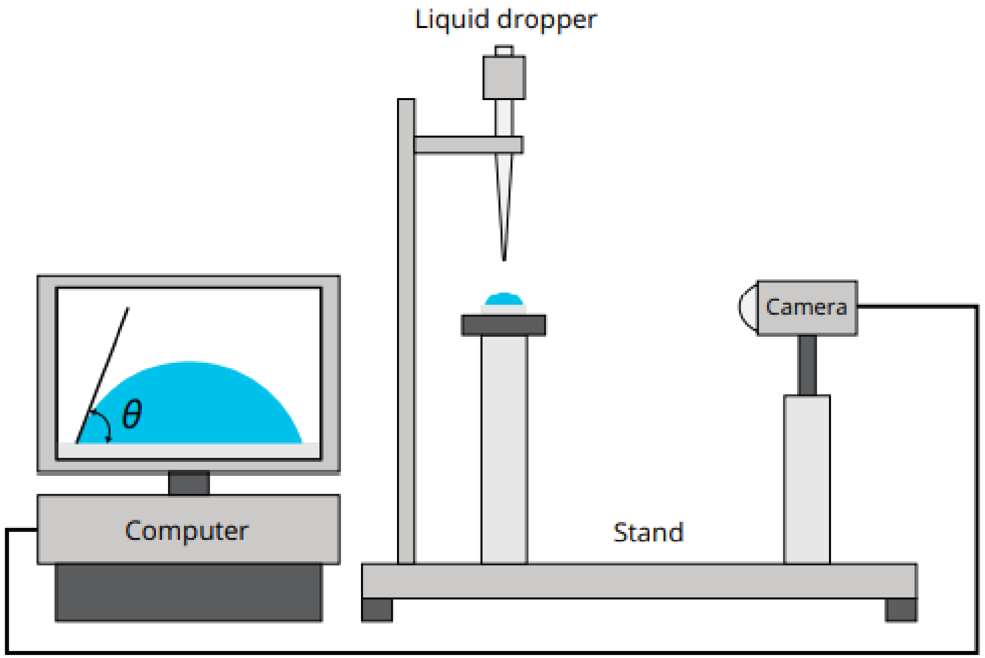
4) Mixed-wet, where parts of the rock prefer to be in contact with oil and the other parts prefer to be in contact with water (Figure d). Mixed wettability can also be referred to as fractional wettability and the contact angle will vary depending on the region of the rock.

Flow Sequence/Cycle

- The flow sequence in porous media can be classified into two main types: drainage and imbibition.
- Drainage means the decrease in the wetting phase while imbibition is the increase in the wetting phase.
- For example, the flow of water into a water-wet tissue paper is an imbibition process as the wetting phase (water) increases in the medium.
- In the reservoir, when the oil migrates from the source rock to the reservoir, assuming that a water-wet reservoir, the process is termed as drainage;
- when water is injected in the same reservoir, assuming it maintains its initial water-wet state, to displace oil, the process is termed as imbibition.

Measuring Wettability

Contact Angle



Schematic of the experimental apparatus to measure the contact angle. In this system, the contact angle of a water droplet surrounded by air is measured.

Table 7.3: Expected contact angle values for specific fluid pairs on a clean glass surface.

System	θ [°]
Air/mercury	140
Gas/oil	0
Gas/brine	0
Oil/brine	30

Measuring Wettability

Amott Index

$$I_w = \frac{S_w(B) - S_w(A)}{S_w(C) - S_w(A)}$$

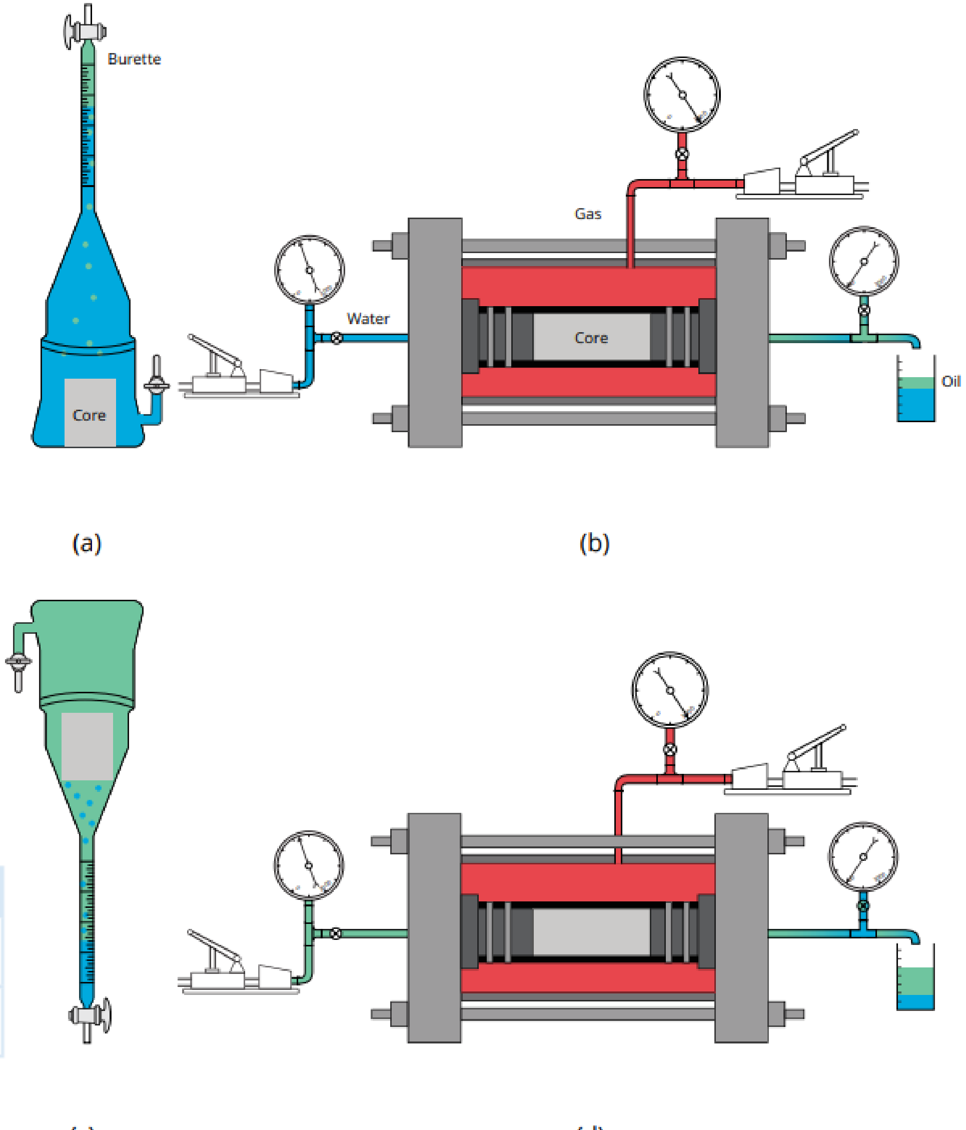
$$I_o = \frac{S_o(D) - S_o(C)}{S_o(E) - S_o(C)}$$

Amott index (I A) is the difference between the water and oil indices as shown below

$$I_A = I_w - I_o$$

Table 7.4: Expected Amott index values for different wettability states.

	Water-wet	Intermediate-wet	Oil-wet
Amott index (I_A)	0.3 – 1.0	-0.3 – 0.3	-1.0 – -0.3



(a) (b) (c) (d)

Iw and Io are the Amott indices for water and oil respectively,

Sw(A) is the initial water saturation present in the core sample before water spontaneous imbibition,

Sw(B) is the water saturation after spontaneous water imbibition (Figure a),

Sw(C) is the water saturation after forced water injection (Figure b),

So (C) is the oil saturation after forced water injection (Figure b),

So (D) is the oil saturation after spontaneous oil imbibition (Figure c),

So (E) is the oil saturation after forced oil injection (Figure d).

Example

A core sample initially contained S_w = 25%. The core was placed in an Amott cell surrounded by water for a few days. After extracting the core, it was found that the water saturation increased to 68%. When the core sample was placed in the core holder and water was injected at a high flow rate, the water saturation in the core after water injection was found to be 72%. When the core sample was placed in an Amott cell surrounded by oil, very little oil imbibition occurred and the water saturation decreased to 71%. When the core sample was placed in the core holder and oil was injected to displace the water, the water saturation reduced to 32%. Based on the data collected, what is the wettability of the core sample?

Solution

First, the water and oil saturations in the problem have to be identified. They are as follows:

$$S_w(A) = 0.25 \quad S_w(B) = 0.68 \quad S_w(C) = 0.72$$
$$S_o(C) = 1 - 0.72 = 0.28 \quad S_o(D) = 1 - 0.71 = 0.29 \quad S_o(E) = 1 - 0.32 = 0.68$$

Then, using **Equation 7.4,** the Amott water index can be found:

$$I_w = \frac{S_w(B) - S_w(A)}{S_w(C) - S_w(A)} = \frac{0.68 - 0.25}{0.72 - 0.25} = 0.915$$

Similarly, using **Equation 7.5,** the Amott oil index can be found:

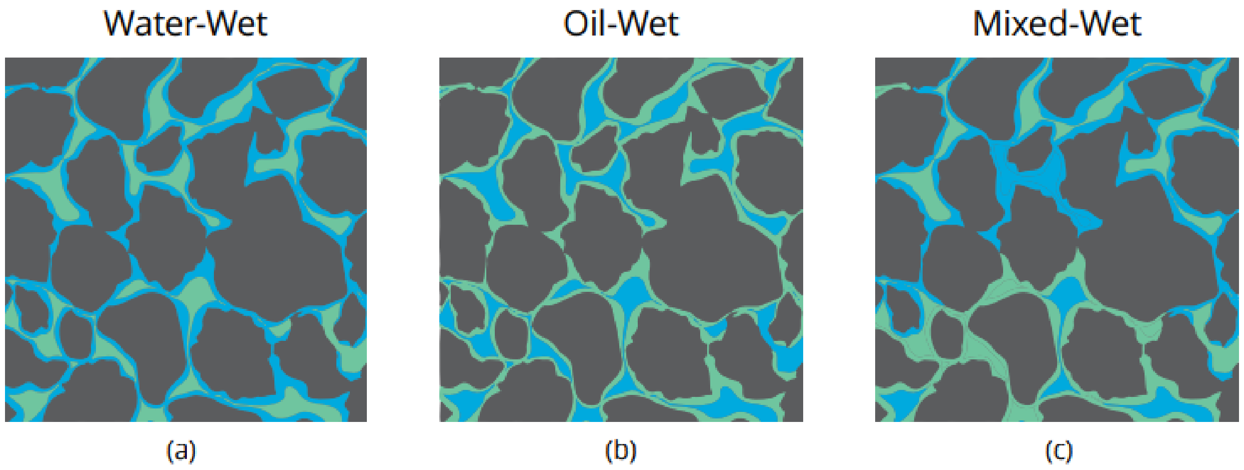
$$I_o = \frac{S_o(D) - S_o(C)}{S_o(E) - S_o(C)} = \frac{0.29 - 0.28}{0.68 - 0.28} = 0.025$$

Finally, the Amott index can be found using **Equation 7.6:**

$$I_A = I_w - I_o = 0.915 - 0.025 = \mathbf{0.890}$$

This value of the Amott index falls in the range of water-wet. Therefore, the core sample is **water-wet.**

Applications of Wettability



Possible water and oil distribution in
(a) a water-wet system where oil (green) remains in the center of the pores and fills the large pores,
(b) an oil-wet system where water (blue) remains at the center of the pores and fills the large pores while the oil surrounds the water, and
(c) a mixed-wet system where oil has displaced water from some surfaces but is still trapped at the center of the water-wet regions

- When dealing with reservoir rocks, wettability helps in understanding the saturation distribution in the reservoir at the pore-scale
- Different wettability states will have different saturation distributions at the pore-scale.
- In addition, the amount of oil recovered by water injection is mainly dictated by the wettability of the rock.