Fluid Saturation

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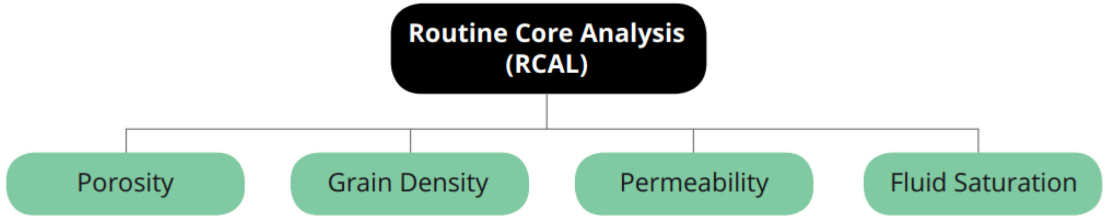
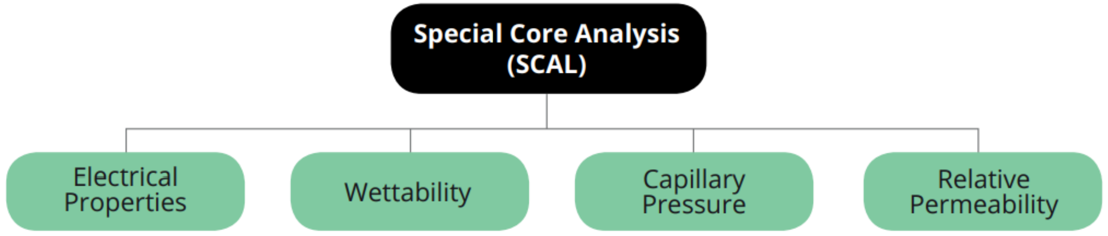
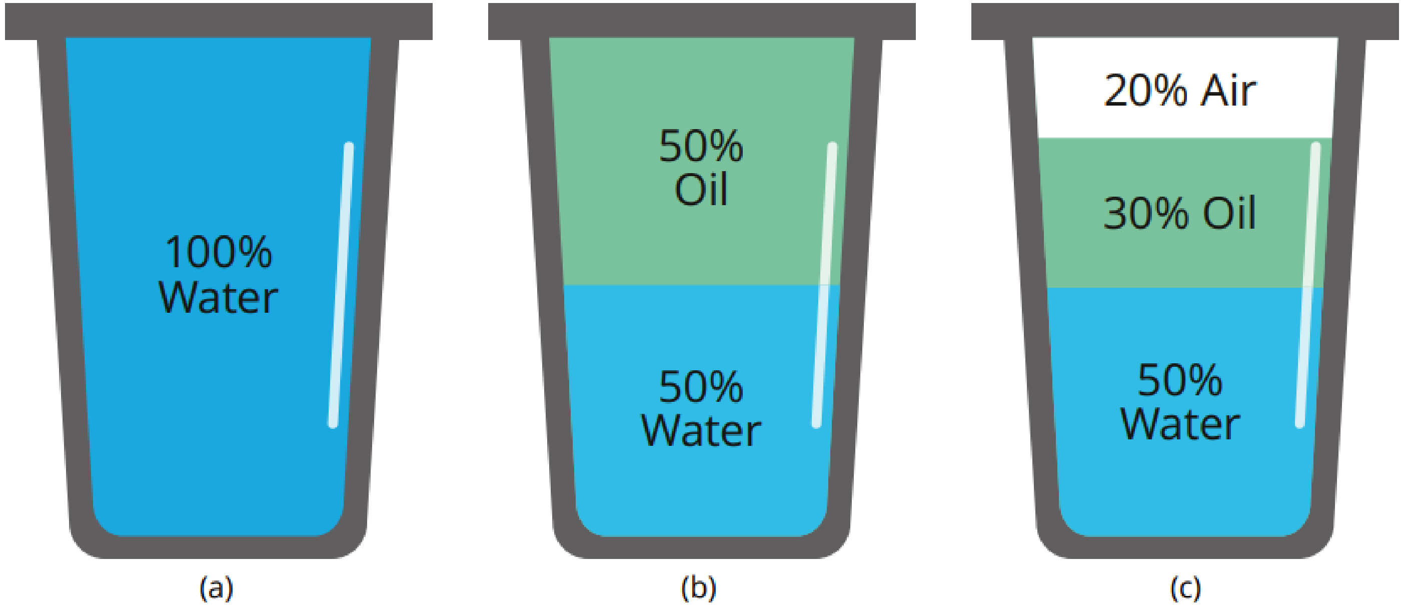
Review

- Petrophysics can be divided into core and wireline petrophysics
- Core petrophysics that requires conducting laboratory experiments on core samples brought from the reservoir to the surface
- Wireline petrophysics, which involves using logs to determine properties
- Rock samples are extracted from the reservoir through cuttings or coring, can be subjected to two categories of laboratory analysis: routine core analysis and special core analysis





Concept of Fluid Saturation



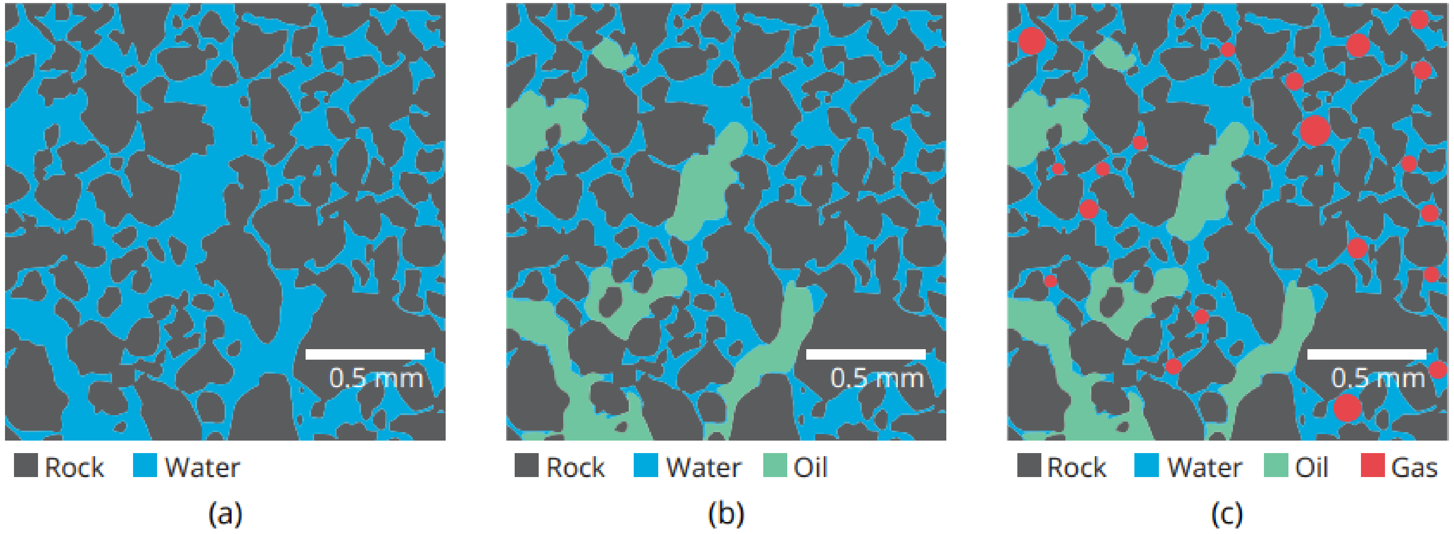
$$S_w = \frac{V_w}{V_p} \qquad S_o = \frac{V_o}{V_p} \qquad S_g = \frac{V_g}{V_p}$$

$$\frac{V_w + V_o + V_g}{V_p} = S_w + S_o + S_g = 1$$

Sw is the water saturation [dimensionless],
Vw is the volume of water in the pore spaces [cm3],
So is the oil saturation [dimensionless],
Vo is the volume of oil in the pore spaces [cm3]
Sg is the gas saturation [dimensionless],
Vg is the volume of gas in the pore spaces [cm3]
Vp is the pore volume [cm3]

Schematic showing identical glasses filled with different fluids: (a) the glass is filled with 100% water, representing Sw = 1, (b) the glass is filled with 50% water and 50% oil, representing Sw = 0.5 and So = 0.5, and (c) the glass is filled with 50% water, 30% oil, and 20% air (gas), representing Sw = 0.5, So = 0.3, and Sg = 0.2

Concept of Fluid Saturation



Schematic showing a cross section of a rock at the microscopic scale: (a) all the pore spaces are filled with water (Sw = 1), (b) the pore spaces are filled with water and oil (Sw + So = 1), and (c) the pore spaces are filled with water, oil, and gas (Sw + So + Sg = 1)

- shows an example of a microscopic rock slice illustrating water, oil, and gas saturations in the pore spaces
- Similar to porosity, fluid saturation is important to estimate the amount of hydrocarbons in a reservoir
- However, it is important to distinguish between porosity and fluid saturation. Porosity tells us the maximum storage capacity of a medium, while fluid saturation depicts the exact amount of fluid occupying the pore spaces of the same medium

Example

A core sample with a pore volume of 15 cm3 contains water, oil, and gas. The water volume within the sample is 6.3 cm3, while the oil volume is 5.4 cm3. What is the gas saturation?

Solution

The water saturation can be found using

$$S_w = \frac{V_w}{V_p} = \frac{6.3}{15} = 0.42$$

The oil saturation can be found using

$$S_o = \frac{V_o}{V_p} = \frac{5.4}{15} = 0.36$$

The gas saturation can then be found using

$$S_w + S_o + S_g = 1$$

$$S_g = 1 - S_w - S_o$$

$$S_g = 1 - 0.42 - 0.36 = \mathbf{0.22}$$

Measuring Fluid Saturation

Fluid saturation measurements can be classified into two types:

direct

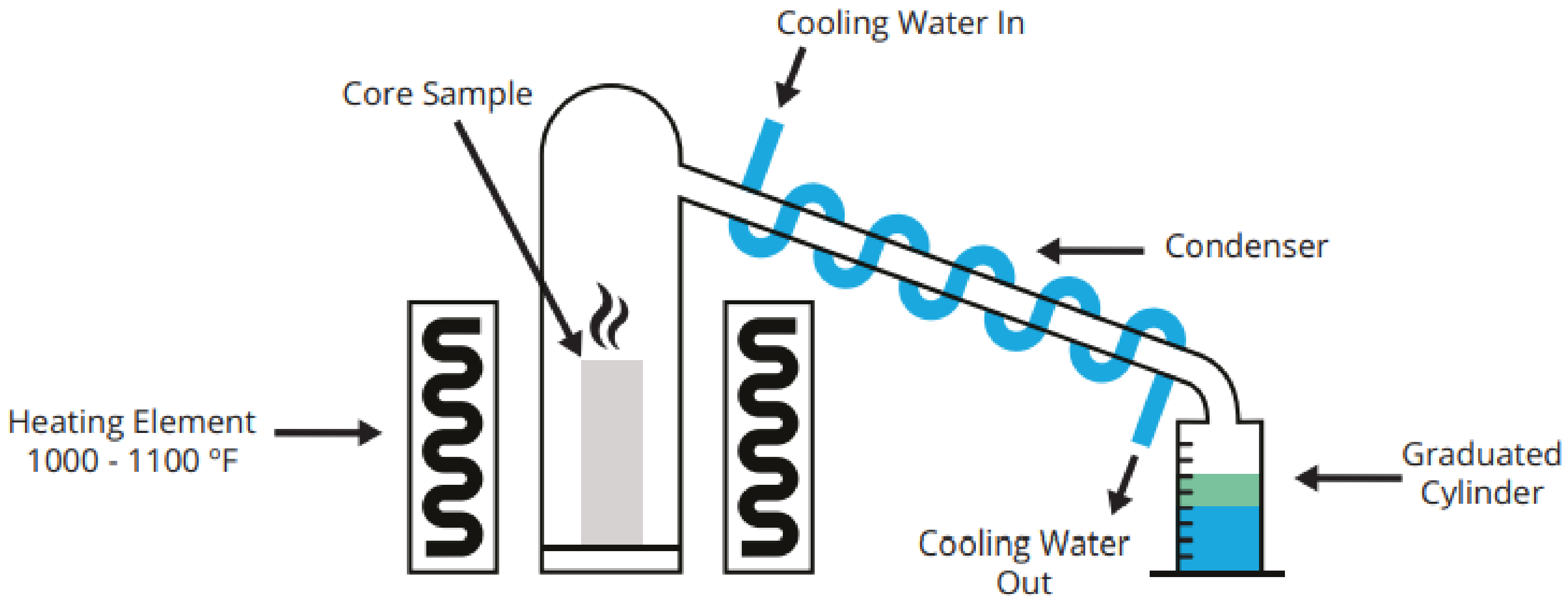
- include conventional core analysis techniques such as extraction methods (retort distillation and Dean-Stark method)

indirect

- include electrical properties and capillary pressure

Measuring Fluid Saturation

Extraction Method : Retort Distillation



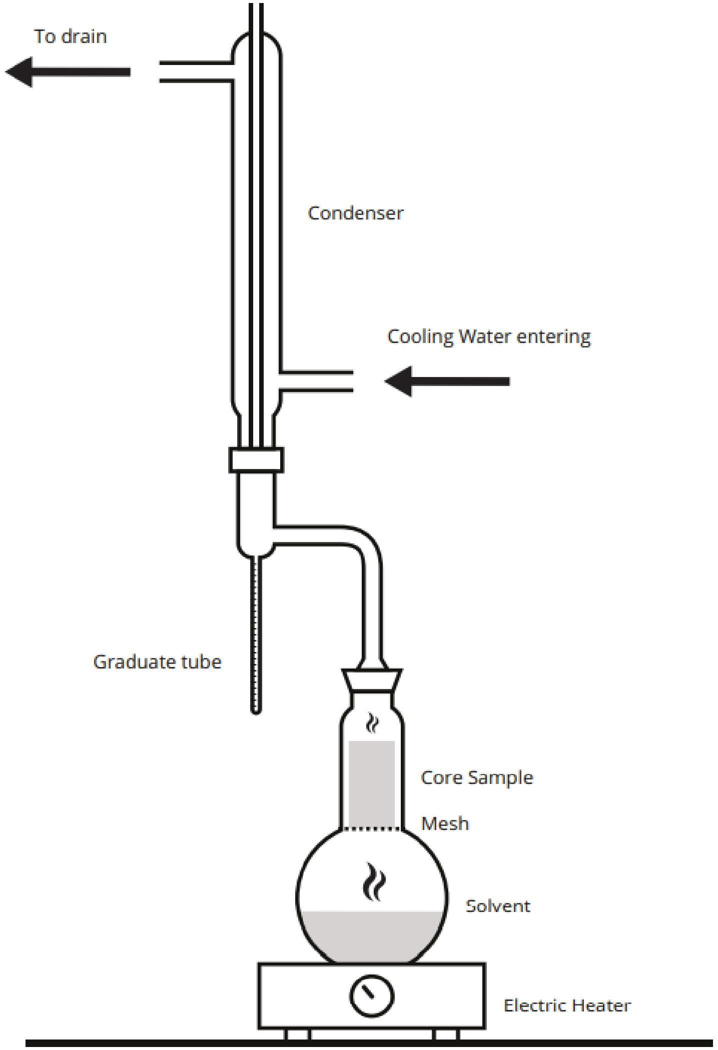
Schematic showing the experimental set-up for the retort distillation extraction method.

- a core sample is placed in a chamber and heated to around 1100 °F (≈593 °C).
- This is to evaporate all the fluids in the system (oil and water).
- The vapors will rise and reach a condensing tube where cold water is being circulated.
- The vaporized liquids will condense back to liquid form and will be collected in the graduated cylinder after passing through the condensing tube
- The advantages of the retort distillation method are that it can directly measure oil and water saturations, and is a relatively fast method (usually takes less than one hour)
- The main disadvantage of this method is that subjecting the core to very high temperatures can damage it

Measuring Fluid Saturation

Extraction Method : **Dean-Stark**

- This method is also known as Soxhlet extraction or solvent extraction
- For this experiment, a core sample is placed at the top of a solvent flask
- The solvents used are usually toluene (hydrocarbon solvent) or a mixture of toluene and methanol.
- The solvent is heated to around 230 °F (110 °C, the boiling point of toluene)
- Once the vapor goes upward, it will reach the condensing tube with circulating cooling water
- Both fluids (water and solvent) will drop down in the graduated cylinder
- We cannot measure the oil volume/saturation from the Dean-Stark method directly, as the solvent mixes with oil
- The advantage of the Dean-Stark method is that it does not damage the core, and the core sample can be used for future analysis. The disadvantages are that the experiment is time-consuming as it usually takes about 48 hours



Schematic showing the experimental set-up for the Dean-Stark extraction method

Measuring Fluid Saturation

Material Balance

As mentioned earlier, the Dean-Stark method can only measure the water volume. In order to find the oil volume and saturation, we need to use material/mass balance

First, we know that the weight of the saturated core (assuming it contains oil and water) prior to extraction is equal to

$$W_s = W_d + W_w + W_o$$

Ws is the saturated weight [g],
Wd is the dry weight of the sample that can be obtained after the extraction process [g],
Ww is the weight of the water in the core sample [g],
Wo is the weight of the oil in the core sample [g]

We can say that the weights of water and oil in the core sample are equivalent to their densities multiplied by their volumes, as shown below:

$$W_s = W_d + \rho_w V_w + \rho_o V_o$$

ρw is the density of water [g/cm3],
Vw is the volume of water in the core [cm3],
ρo is the density of oil [g/cm3],
Vo is the volume of oil in the core [cm3].

We know that:

$$V_w + V_o + V_g = V_p$$

Vg is the volume of gas in the core [cm3],
Vp is the pore volume of the core [cm3].

Since we only have oil and water, then :

Measuring Fluid Saturation

Material Balance

Since we only have oil and water, so :

$$V_w + V_o = V_p$$

For simplicity, let us assume:

$$V_o = x$$

Then, we can rewrite

$$V_w = V_p - x$$

Then, we can substitute

$$W_s = W_d + \rho_w(V_p - x) + \rho_o x$$

After that, we can rearrange the equation to obtain:

$$W_s - W_d - \rho_w V_p = x(\rho_o - \rho_w)$$

Now, we can solve for x and replace it with Vo :

$$V_o = \frac{W_s - W_d - \rho_w V_p}{\rho_o - \rho_w}$$

Finally, we can divide both sides by the pore volume to find the oil saturation:

$$S_o = \frac{W_s - W_d - \rho_w V_p}{V_p(\rho_o - \rho_w)}$$

We can cross-check the water saturation value obtained from the Dean-Stark method using the following simple term:

$$S_w = 1 - S_o$$

Sw is the water saturation [dimensionless]
So is the oil saturation [dimensionless].

Example

A core sample containing only water (ρw = 1 g/cm3) and oil (ρo = 0.87 g/cm3) has a 13.6% porosity, 3 inch length, and 1.5 inch diameter. Its saturated weight was measured to be 144.3 g, and its dry weight was measured to be 133.2 g. Calculate the water and oil saturations.

Solution

First, the dimensions of the sample need to be converted to cm so that the units are consistent. Since 1 inch = 2.54 cm:

$$D = 1.5 \text{ in} = 1.5 \times 2.54 = 3.81 \text{ cm}$$

$$L = 3 \text{ in} = 3 \times 2.54 = 7.62 \text{ cm}$$

Then, the bulk volume of this core needs to be calculated. Since this is a cylinder:

$$V_b = \pi r^2 L$$

$$V_b = \pi \times \left(\frac{3.81}{2}\right)^2 \times 7.62 = 86.87 \text{ cm}^3$$

We now find the pore volume:

$$V_p = \phi V_b$$

$$V_p = 0.136 \times 86.87 = 11.81 \text{ cm}^3$$

Since this rock contains only oil and water, the oil saturation can now be found using **Equation 5.14**:

$$S_o = \frac{W_s - W_d - \rho_w V_p}{V_p(\rho_o - \rho_w)} = \frac{144.3 - 133.2 - 1 \times 11.81}{11.81(0.87 - 1)} = \mathbf{0.462}$$

The water saturation can then be found using **Equation 5.15**:

$$S_w = 1 - S_o$$

$$S_w = 1 - 0.462 = \mathbf{0.538}$$

Example

A Dean-Stark apparatus was used to determine fluid saturations of a sandstone cylindrical core plug, which measures 2 cm in diameter and 4.5 cm in length. The initial weight of the core plug prior to extraction was 76.63 g. The volume of water recovered from the core plug was 1.42 cm3. The weight of the core plug after it was dried was 73.94 g. The porosity of the core plug was determined to be 23.1%, and the densities of reservoir water and oil were 1.04 g/cm3 and 0.82 g/cm3, respectively. Determine the initial fluid saturations in the core plug.

Solution

First, the bulk volume of this core needs to be calculated. Since this is a cylinder:

$$V_b = \pi r^2 L$$

$$V_b = \pi \times \left(\frac{2}{2}\right)^2 \times 4.5 = 14.14 \text{ cm}^3$$

Now, we find the pore volume:

$$V_p = \phi V_b$$

$$V_p = 0.231 \times 14.14 = 3.27 \text{ cm}^3$$

Since the volume of water is given, the water saturation can be found using **Equation 5.1**:

$$S_w = \frac{V_w}{V_p} = \frac{1.42}{3.27} = \mathbf{0.43}$$

To find the oil saturation, we need to calculate the volume of oil.

First, we calculate the weight of water:

$$W_w = V_w \rho_w = 1.42 \times 1.04 = 1.48 \text{ g}$$

We can use this to find the weight of oil using **Equation 5.5**:

$$W_s = W_d + W_w + W_o$$

$$W_o = W_s - W_d - W_w$$

$$W_o = 76.63 - 73.94 - 1.48 = 1.21 \text{ g}$$

Note that the assumption made here is that the weight of gas is insignificant.

The volume of oil can then be found:

$$V_o = \frac{W_o}{\rho_o} = \frac{1.21}{0.82} = 1.48 \text{ cm}^3$$

The oil saturation can be found using **Equation 5.2**:

$$S_o = \frac{V_o}{V_p} = \frac{1.48}{3.27} = \mathbf{0.45}$$

Thereafter, the gas saturation can simply be found using **Equation 5.4**:

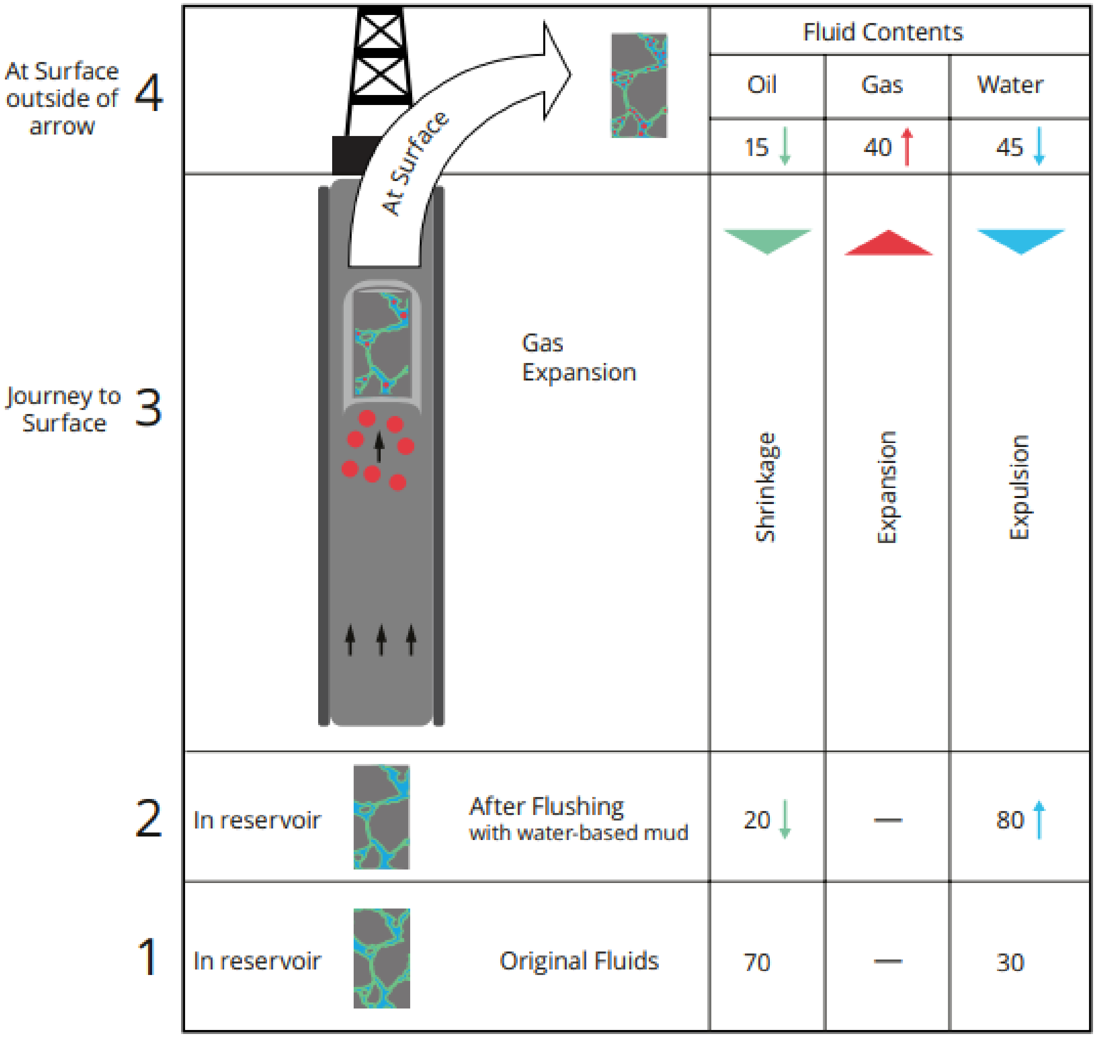
$$S_w + S_o + S_g = 1$$

$$S_g = 1 - S_w - S_o$$

$$S_g = 1 - 0.43 - 0.45 = \mathbf{0.12}$$

Limitations of Using Extraction Methods to Evaluate Reservoir's Saturation

It is difficult to evaluate the reservoir's saturation using the conventional core analysis (extraction methods) because of two main reasons: drilling muds and fluid properties.



Schematic showing the change in fluid saturation in a core sample from the initial reservoir condition until it reaches the surface. The numbers displayed are arbitrary numbers that are only used to explain the concept.

Summary

Definition of Fluid Saturation and its importance to the petroleum industry

Parameter	Symbol	Definition	Importance
Fluid saturation	S_i (where i can be water, oil, or gas)	The fraction of pore volume occupied by the fluid.	We use fluid saturation to quantify the volume of oil and/or gas in the reservoirs.

- Fluid saturation is a percentage that indicates how much fluid the pore space inside a rock contains, which is defined as the volume of fluid in a rock divided by its pore volume.
- In reservoir rocks, the fluids are usually hydrocarbons or water. Some extraction methods used to measure fluid saturation include retort distillation and the Dean-Stark method. In both of these methods, the fluid is extracted from the rock sample and then measured.
- The Dean-Stark method can only measure water saturation, unlike retort distillation that can measure both oil and water saturations. Therefore, material balance analysis is used to supplement the Dean-Stark method to calculate the oil saturation as well.
- Drilling muds make it difficult to evaluate the reservoir's saturation using extraction methods because they interfere with the saturation of the extracted samples.
- Similarly, extreme temperatures and pressures while extracting the core samples also cause changes within them, due to which the extraction methods cannot accurately determine the saturation within the reservoir

Homework

Question 1

Solvent extraction was used in order to measure the fluid saturation in a core. The following data are given for the core:

- Length: 3.5 inches
- Diameter: 2 inches
- Porosity: 22.9%
- Initial weight of the core: 487.6 g
- Final dry weight of the core: 455.9 g
- Water volume measured: 14.23 cm^3
- Water density: 1.04 g/cm^3
- Oil density: 0.80 g/cm^3

Calculate the fluid saturations.

Question 2

A core contains only oil and water within it. Find the water and oil saturations by using the following data:

- Dry weight: 168.3 g
- Saturated weight: 203.2 g
- Weight of the core after water removal: 184.1 g
- Diameter: 3.62 cm
- Length: 6.92 cm
- Water density: 1.03 g/cm^3
- Oil density: 0.79 g/cm^3