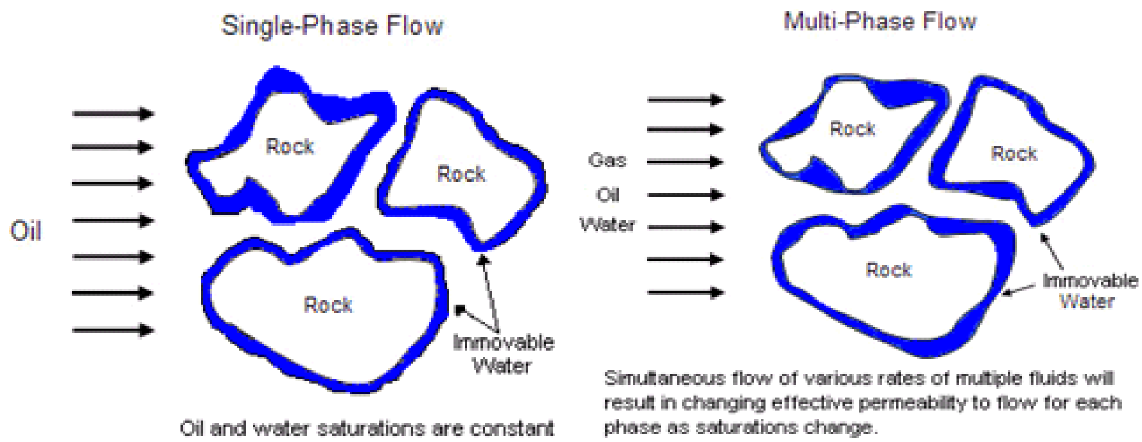
Relative Permeability

Subtopics:

Relative permeability is a concept used to convey the reduction in flow capability due to the presence of multiple mobile fluids. It is dependent upon pore geometry, wettability, fluid distribution, and fluid saturation history. Relative permeability measurements are conducted on core samples in a laboratory and are both time-consuming and expensive to produce. Consequently, relative permeability measurements are most often requested for projects where secondary and/or tertiary recovery is being considered.

In a single-phase system such as a dry gas or an under-saturated oil reservoir, the effective permeability of flow of the mobile fluid through the reservoir varies little during production because the fluid saturations do not change. However, when more than one phase is mobile, the effective permeability to each mobile phase will change as the saturations of the fluids change in the reservoir.



In a two-phase system, the fluids might consist of oil and water or oil and gas. In a three-phase system, all three fluid phases will occur. Each fluid, as it flows through the porous media, interferes with the fluids because capillary forces exist that reduce the flow rate of each individual phase in a non-linear fashion. Consequently, the sum of the relative permeability of each phase is always less than one.

$$k_{ro} + k_{rw} + k_{rg} < 1$$

Relative Permeability Terms and Equations

Typical phases seen in a reservoir are oil, water, and gas; and the effective permeability of each is designated as k_o, k_w, and k_g, respectively. The relative permeability for each phase is calculated by dividing the effective permeability to flow by the absolute permeability. The absolute permeability is the “Klinkenberg” or theoretical “air” permeability, which is measured by cleaning and completely drying a core sample and then measuring the effective permeability of flow to air. The units of relative permeability are dimensionless.

$$k_{ro} = \frac{k_o}{k},\ k_{rw} = \frac{k_w}{k},\ k_{rg} = \frac{k_g}{k}$$

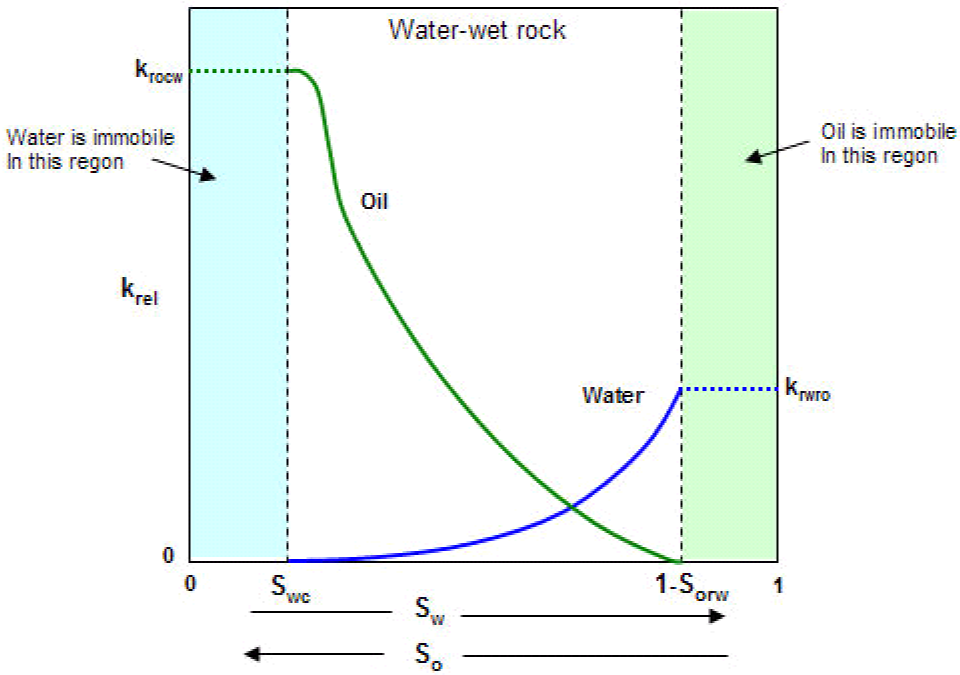
Wettability

Wettability in a reservoir is a measurement of the ability of a fluid to coat the rock surface. Wettability and heterogeneity have a significant impact on the shape of the relative permeability curves. The wetting fluid relative permeability curve is concave upwards whereas the non-wetting fluid has an “s” shape. In the case where there is no interfacial tension between the fluid phases, the relative permeability curves simplify to straight lines between the endpoints.

Water-Wet Relative Permeability Curves (Oil and Water)

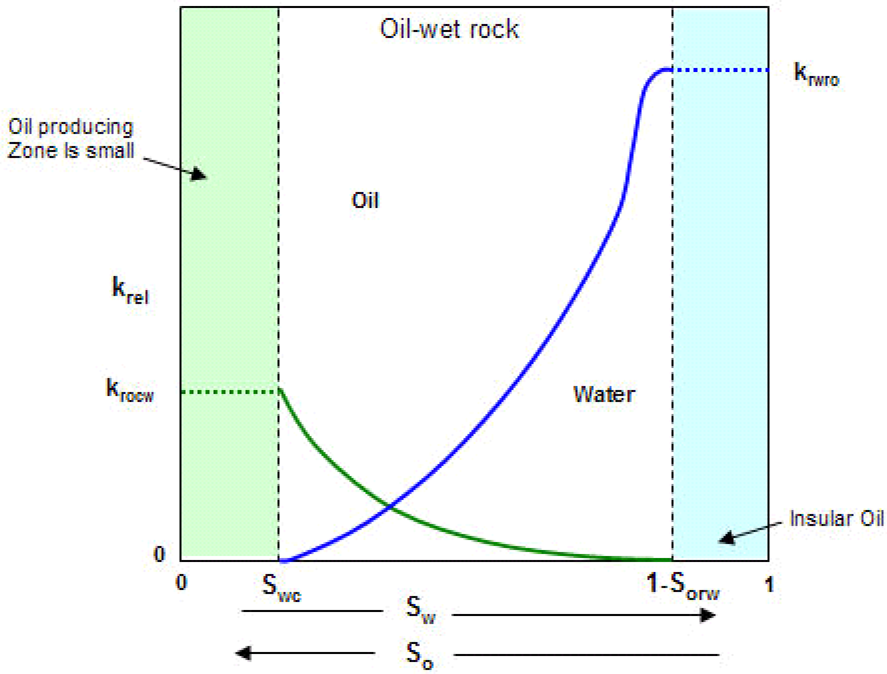
A schematic of oil-water relative permeability curves in a water-wet reservoir is shown below. In water-wet rock, a water layer wets the rock surface and acts like a lubricant for the oil located in the central parts of the pores.

- S_{wc} is the connate or irreducible water saturation. This is the water saturation below which water is not mobile because of capillary forces. The relative permeability of water at water saturations below S_{wc} is zero.
- S_{orw} is the residual oil saturation or critical oil saturation. This is the oil saturation below which the oil is immobile, that is, its relative permeability is zero.



Oil-Wet Relative Permeability Curves (Oil and Water)

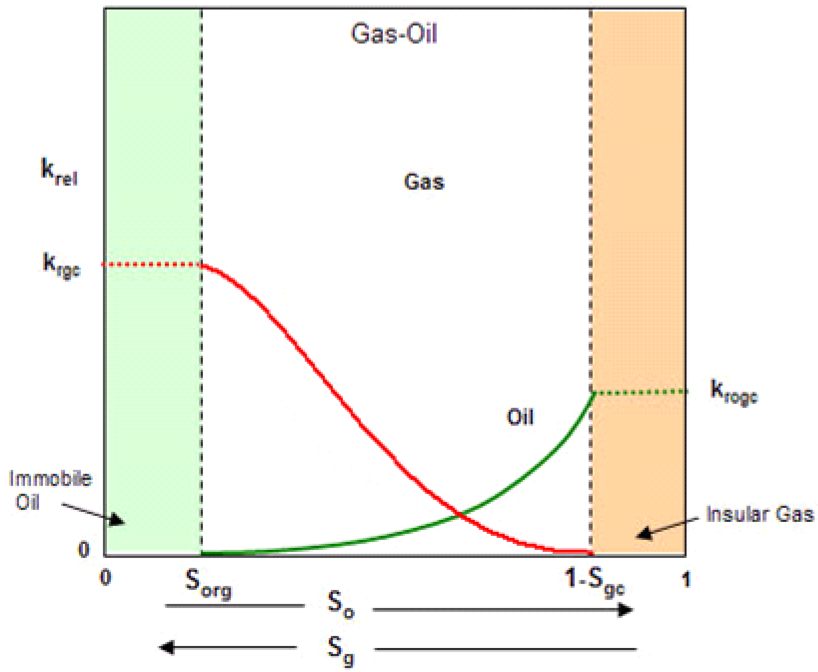
The figure below displays a schematic of water-oil relative permeability curves in an oil-wet reservoir rock. In oil-wet rock, oil wets the pore surfaces and water occupies the central regions of the pores. Typically, the irreducible water saturation in oil-wet reservoir rock is lower than that in water-wet rock.



Gas-Oil Relative Permeability Curves

The schematic below displays a set of gas-oil relative permeability curves. In this case, the wetting phase, the oil phase, impedes the flow of gas. The water saturation in the reservoir rock is taken to not exceed its irreducible value. This means that the water is not mobile, but exists in the pore space and simply reduces the available pore space that the gas and oil can occupy.

- S_{gc} is the critical gas saturation. This is the minimum saturation for gas to become mobile.
- S_{org} is the residual oil saturation to gas. This is the immobile oil when gas is the displacing fluid.
- k_{rogc} is the relative permeability of oil at the critical gas saturation.
- k_{rgc} is the relative permeability of the gas at the residual oil saturation.



Normalized Relative Permeability

When using water-oil relative permeability, there is a second term that is often encountered. This is “normalized” relative permeability. Normalized relative permeability defines the oil relative permeability at the critical water saturation (water becomes mobile) as a value of one (1.0), and defines the absolute permeability as the effective at the critical water saturation.