Introduction to

Effective Permeability
and
Relative Permeability

Review: Absolute Permeability

- **<u>Absolute permeability:</u> is the permeability of a porous medium saturated with a single fluid (e.g. S_w=1)**
- **Absolute permeability can be calculated from the steady-state flow equation (1D, Linear Flow; Darcy Units):**

$$q = \frac{k\,A\,\Delta p}{\mu\,L}$$

Multiphase Flow in Reservoirs

Commonly, reservoirs contain <u>2 or 3 fluids</u>

- **Water-oil systems**
- **Oil-gas systems**
- **Water-gas systems**
- **Three phase systems (water, oil, and gas)**

To evaluate multiphase systems, must consider the <u>effective</u> and <u>relative</u> permeability

Effective Permeability

<u>Effective permeability</u>: is a measure of the conductance of a porous medium for one fluid phase when the medium is saturated with more than one fluid.

- The porous medium can have a distinct and measurable conductance to each phase present in the medium
- Effective permeabilities: **(k_o, k_g, k_w)**

Amyx, Bass, and Whiting, 1960; PETE 311 Notes

Effective Permeability

- **Oil**

$$q_o = \frac{k_o \, A \, \Delta\Phi_o}{\mu_o \, L}$$

- **Water**

$$q_w = \frac{k_w \, A \, \Delta\Phi_w}{\mu_w \, L}$$

- **Gas**

$$q_g = \frac{k_g \, A \, \Delta\Phi_g}{\mu_g \, L}$$

Steady state, 1D, linear flow equation (Darcy units):

q_n = volumetric flow rate for a specific phase, n

A = flow area

$\Delta\Phi_n$ = flow potential drop for phase, n (including pressure, gravity and capillary pressure terms)

μ_n = fluid viscosity for phase n

L = flow length

Modified from NExT, 1999; Amyx, Bass, and Whiting, 1960; PETE 311 NOTES

Relative Permeability

Relative Permeability **is the** **ratio** **of the effective permeability of a fluid at a given saturation to some base permeability**

- **Base permeability is typically defined as:**
  - absolute permeability, k
  - air permeability, k_{air}
  - effective permeability to non-wetting phase at irreducible wetting phase saturation [e.g. $k_o(S_w=S_{wi})$]
  - because definition of base permeability varies, the definition used must always be:
    - confirmed before applying relative permeability data
    - noted along with tables and figures presenting relative permeability data

Amyx, Bass, and Whiting, 1960

Relative Permeability

- **Oil** $$k_{ro(0.5,0.3)} = \frac{k_{o(0.5,0.3)}}{k}$$

- **Water** $$k_{rw(0.5,0.3)} = \frac{k_{w(0.5,0.3)}}{k}$$

- **Gas** $$k_{rg(0.5,0.3)} = \frac{k_{g(0.5,0.3)}}{k}$$

S_o =0.5

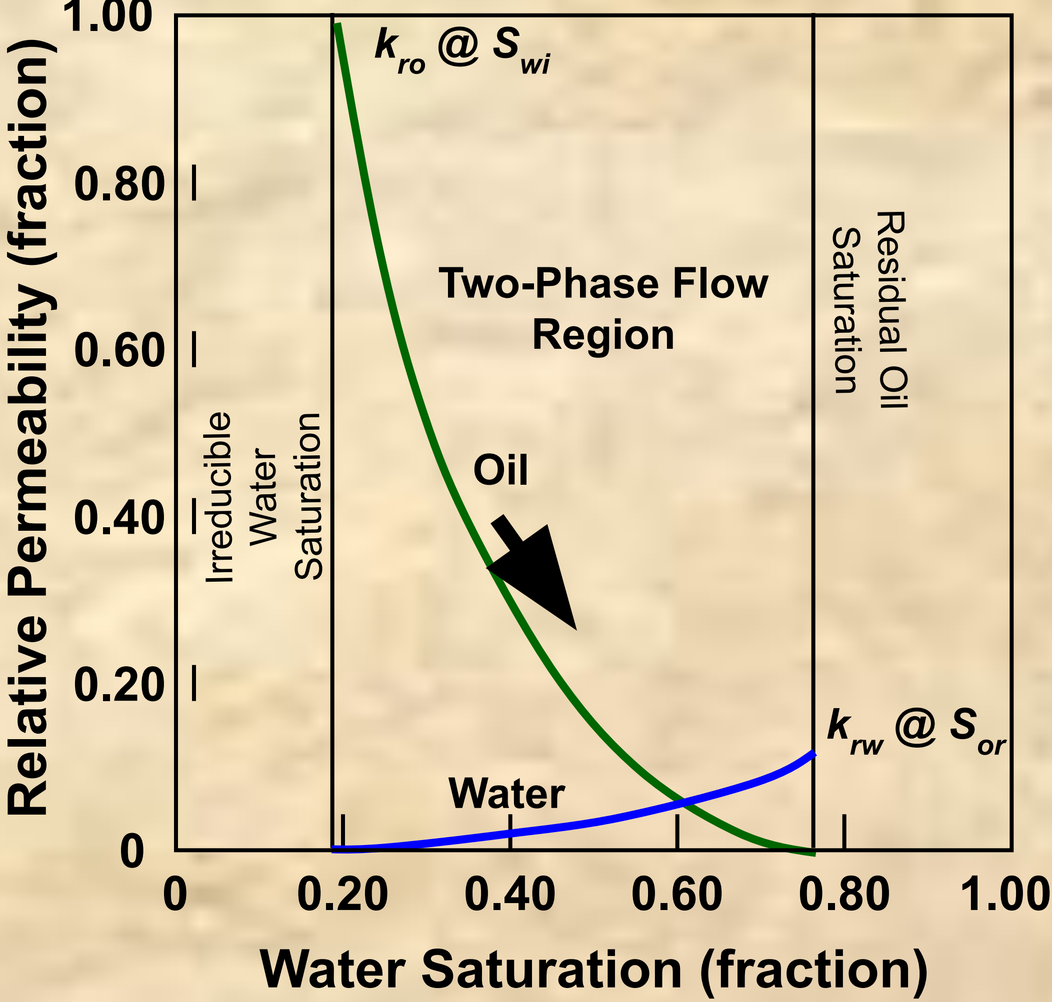
S_w =0.3

$\therefore S_g$ = 0.2

Modified from Amyx, Bass, and Whiting, 1960

Relative Permeability Functions

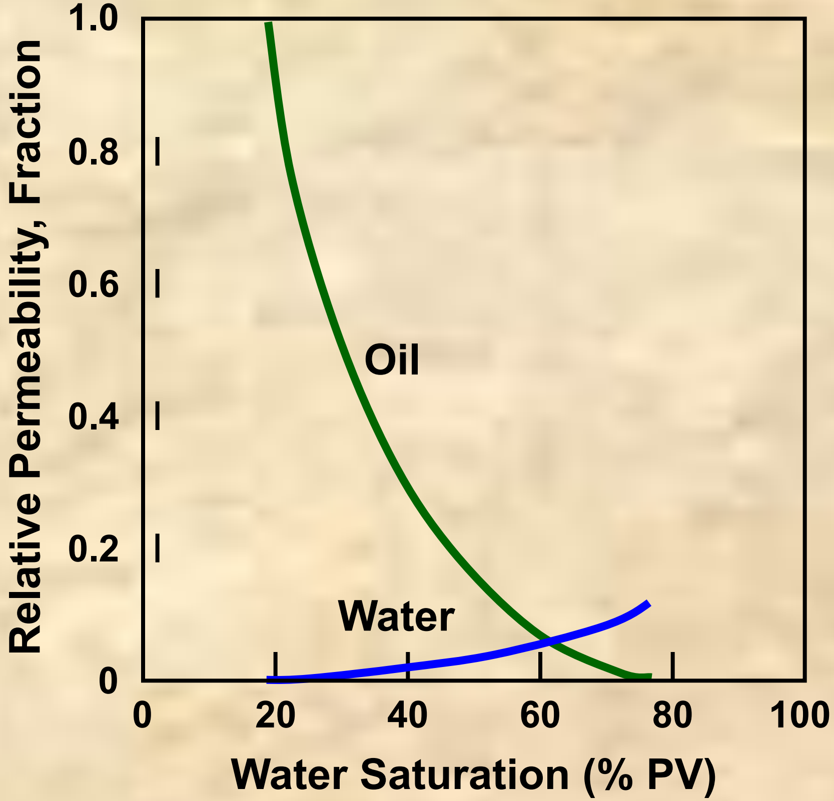
Imbibition Relative Permeability (Water Wet Case)



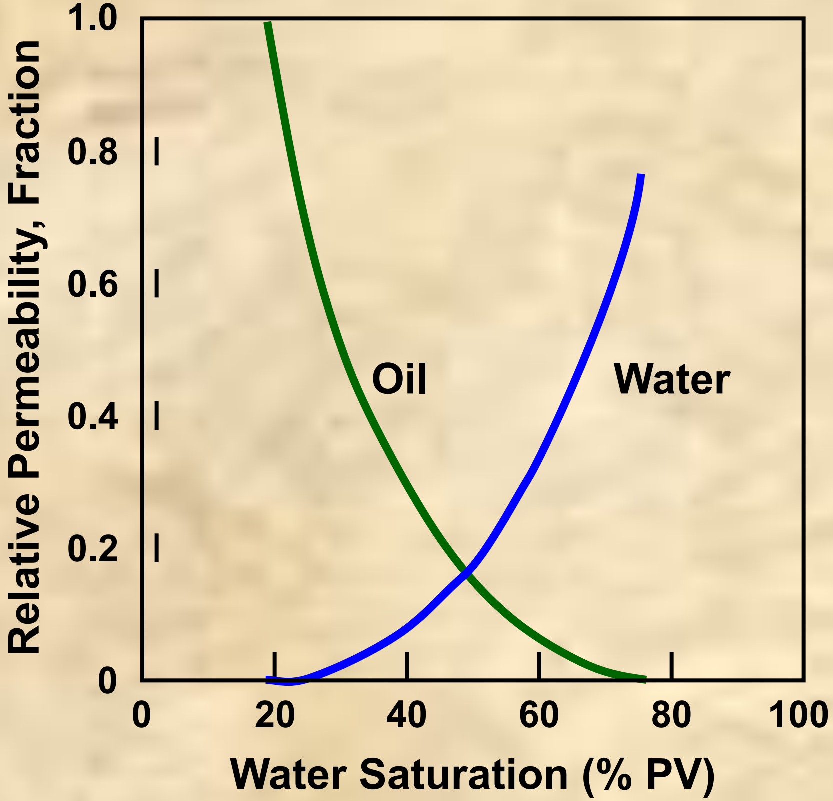
- **Wettability and direction of saturation change must be considered**
  - **drainage**
  - **imbibition**
- **Base used to normalize <u>this</u> relative permeability curve is k_{ro} @ S_{wi}**
- **As S_w increases, k_{ro} decreases and k_{rw} increases until reaching residual oil saturation**

Modified from NExT, 1999

Effect of Wettability for Increasing S_w



Strongly Water-Wet Rock



Strongly Oil-Wet Rock

Modified from NExT, 1999

- Water flows more freely
- Higher residual oil

Factors Affecting Relative Permeabilities

- Fluid saturations
- Geometry of the pore spaces and pore size distribution
- Wettability
- Fluid saturation history (i.e., imbibition or drainage)

After Standing, 1975

Characteristics of Relative Permeability Functions

- Relative permeability is unique for different rocks and fluids
- Relative permeability affects the flow characteristics of reservoir fluids.
- Relative permeability affects the recovery efficiency of oil and/or gas.

Modified from NExT, 1999

Applications of Relative Permeability Functions

- Reservoir simulation
- Flow calculations that involve multi-phase flow in reservoirs
- Estimation of residual oil (and/or gas) saturation