

**Introduction to  
Effective Permeability  
and  
Relative Permeability**

# Review: Absolute Permeability

- **Absolute permeability**: 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 2 or 3 fluids

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

To evaluate multiphase systems, must consider the effective and relative permeability

# Effective Permeability

**Effective permeability**: 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: **( $k_o$ ,  $k_g$ ,  $k_w$ )**

# Effective Permeability

- Oil

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

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

$q_n$  = volumetric flow rate for a specific phase,  $n$

- Water

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

$A$  = flow area

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

- Gas

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

$\mu_n$  = fluid viscosity for phase  $n$

$L$  = flow length

# 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,  $k_{\text{air}}$
  - 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

# Relative Permeability

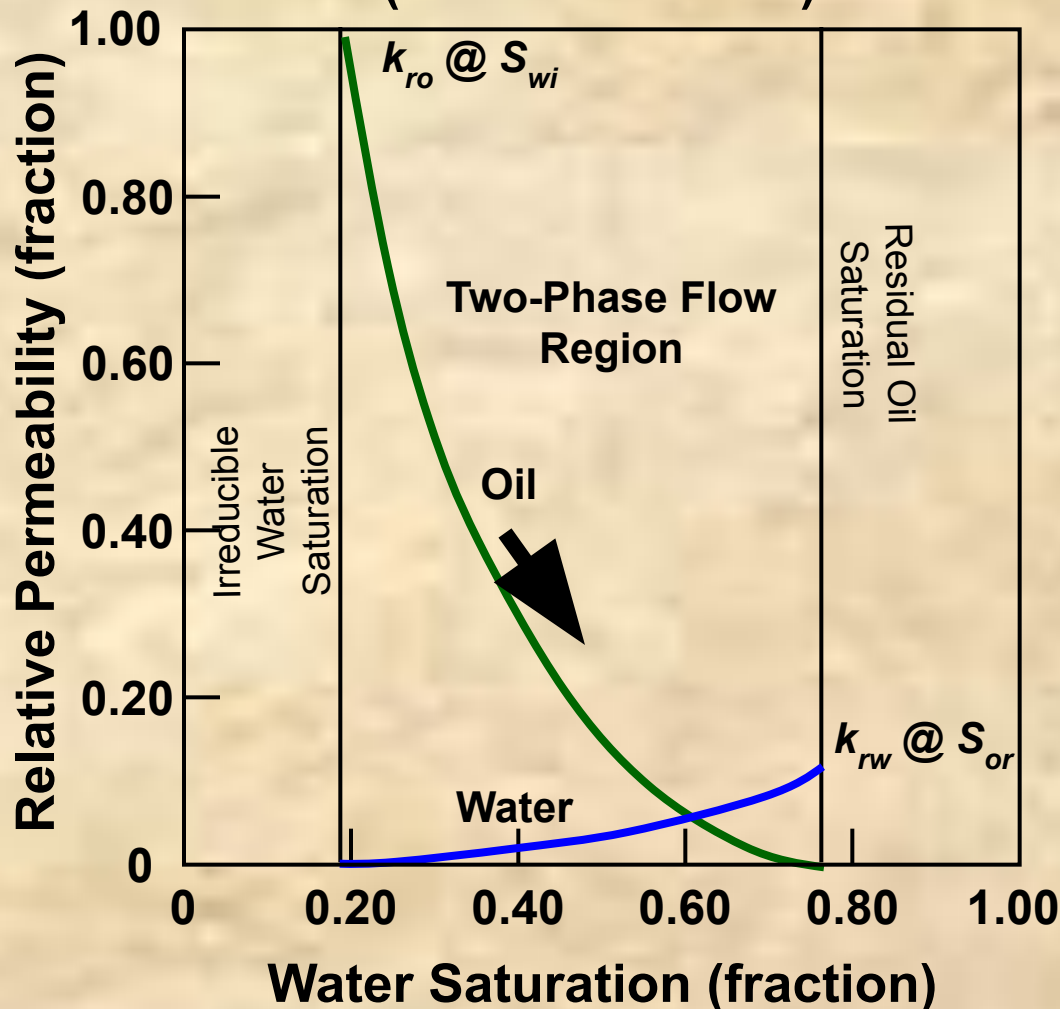
- **Oil**  $k_{ro(0.5,0.3)} = \frac{k_{o(0.5,0.3)}}{k}$
- **Water**  $k_{rw(0.5,0.3)} = \frac{k_{w(0.5,0.3)}}{k}$
- **Gas**  $k_{rg(0.5,0.3)} = \frac{k_{g(0.5,0.3)}}{k}$

$S_o = 0.5$   
 $S_w = 0.3$   
 $\therefore S_g = 0.2$



# Relative Permeability Functions

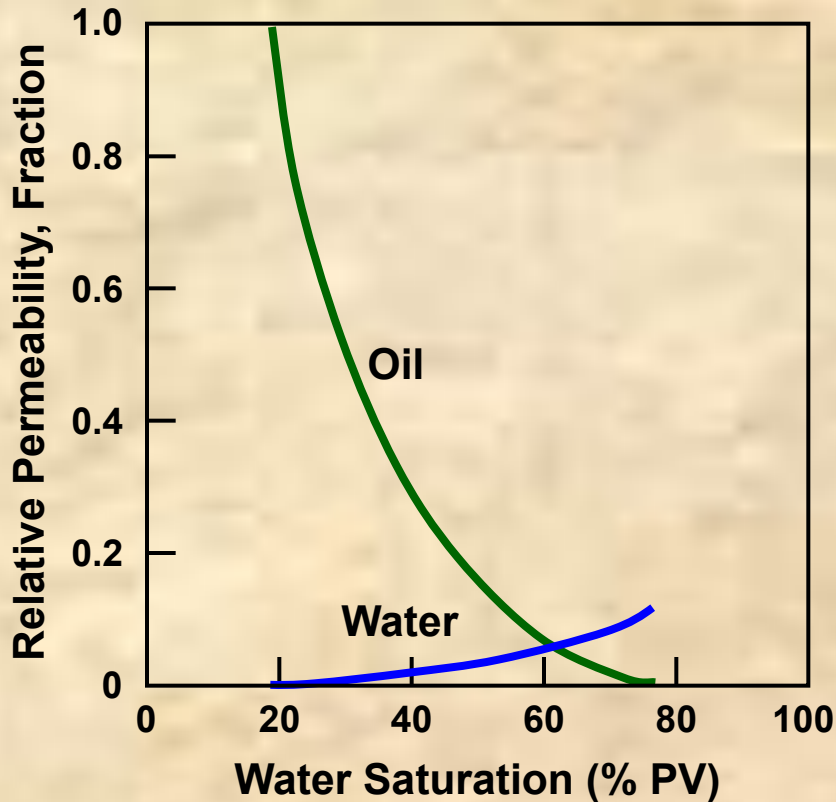
Imbibition Relative Permeability  
(Water Wet Case)



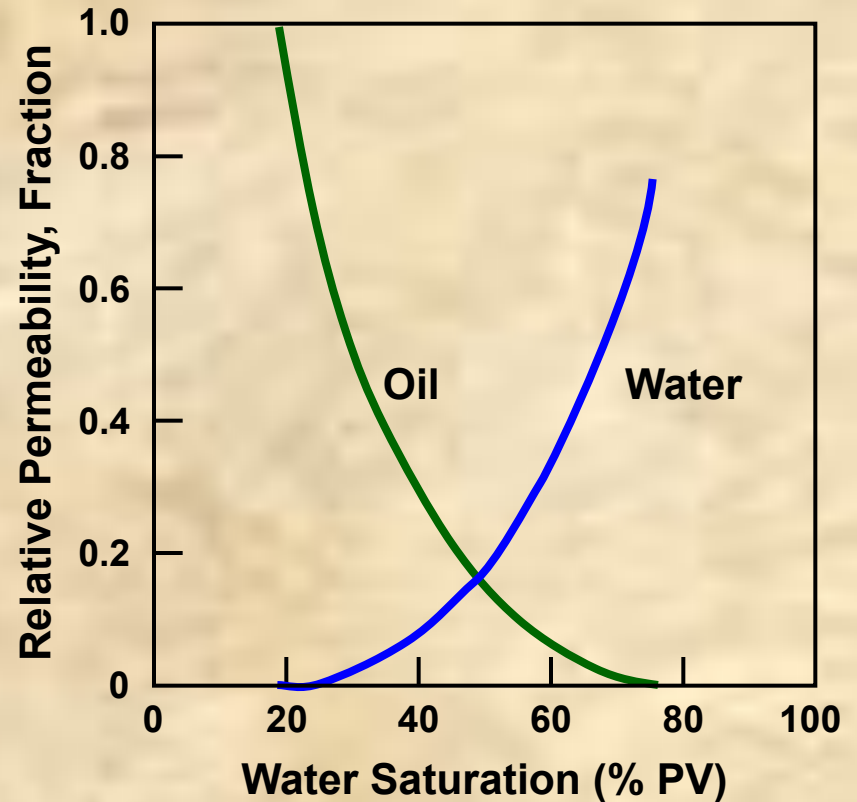
- Wettability and direction of saturation change must be considered
  - drainage
  - imbibition
- Base used to normalize this relative permeability curve is  $k_{ro} @ S_{wi}$
- As  $S_w$  increases,  $k_{ro}$  decreases and  $k_{rw}$  increases until reaching residual oil saturation



# 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 saturation

# Factors Affecting Relative Permeabilities

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

# 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.**

# **Applications of Relative Permeability Functions**

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