Relative Permeability Correlations

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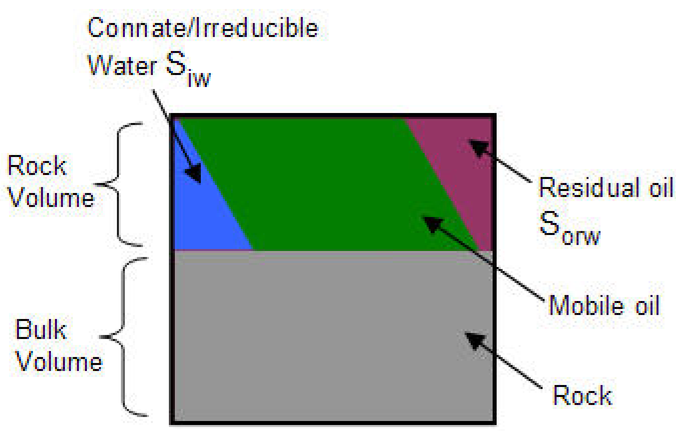
Two-Phase Correlations

In a two-phase system, the fluids consist of oil and water, oil and gas, or gas and water. An example of an oil-water system is shown below:



Corey

This model assumes the wetting and non-wetting phase-relative permeabilities to be independent of the saturations of the other phases and requires only a single suite of gas/oil-relative permeability data.

Water / Oil System

$$k_{ro} = \left[\frac{1 - S_o}{1 - S_{iw}}\right]^2 \left[1 - \left(\frac{S_o - S_{iw}}{1 - S_{iw}}\right)^2\right]$$

$$k_{rw} = \left[\frac{S_w - S_{iw}}{1 - S_{iw}}\right]^4$$

Gas / Oil System

$$k_{rg} = \left[\frac{S_g}{1 - S_{org}}\right]^2 \left[1 - \left(\frac{1 - S_g - S_{org}}{1 - S_{org}}\right)^2\right]$$

$$k_{ro} = \left[\frac{S_o - S_{org}}{1 - S_{org}}\right]^4$$

Gas / Water System

$$k_{rg} = \left[\frac{S_g}{1 - S_{iw}}\right]^2 \left[1 - \left(\frac{1 - S_g - S_{iw}}{1 - S_{iw}}\right)^2\right]$$

$$k_{rw} = \left[\frac{S_w - S_{iw}}{1 - S_{iw}}\right]^4$$

Honarpour

Developed using data from oil and gas fields in the continental US, Alaska, Canada, Libya, Iran, Argentina and the United Arab Republic.

Sandstone

Water Wet

$$k_{rw} = 0.035388\left[\frac{S_w - S_{iw}}{1 - S_{iw} - S_{orw}}\right] - 0.0108074\left[\frac{S_w - S_{orw}}{1 - S_{iw} - S_{orw}}\right]^{2.9} + 0.56556(S_w)^{3.6}(S_w - S_{iw})$$

Intermediate Wet

$$k_{rw} = 1.5814\left[\frac{S_w - S_{iw}}{1 - S_{iw}}\right]^{1.91} - 0.58617\left[\frac{S_w - S_{orw}}{1 - S_{iw} - S_{orw}}\right]^{2.9}(S_w - S_{iw}) + 1.2484\,\phi\,(1 - S_{iw})(S_w - S_{iw})$$

Any Wettability

$$k_{row} = 0.76067\left[\frac{\left(\frac{S_o}{1 - S_{iw}}\right) - S_{or}}{1 - S_{orw}}\right]^{1.8}\left[\frac{S_o - S_{orw}}{1 - S_{iw} - S_{orw}}\right]^{2.0} + 2.6318\,\phi\,(1 - S_{orw})(S_o - S_{orw})$$

$$k_{rog} = 0.98372\left[\frac{S_o}{1 - S_{iw}}\right]^{4}\left[\frac{S_o - S_{org}}{1 - S_{iw} - S_{org}}\right]^{2}$$

$$k_{rg} = 1.1072\left[\frac{S_g - S_{gc}}{1 - S_{iw}}\right]^{2} k_{rgro} + 2.7794\,S_{org}\left[\frac{S_g - S_{gc}}{1 - S_{iw}}\right] k_{rgro}$$

Limestone

Water Wet

$$k_{rw} = 0.0020525\left[\frac{S_w - S_{iw}}{\phi^{2.15}}\right] - 0.051371\left[\frac{S_w - S_{iw}}{k_{abs}^{0.43}}\right]$$

Intermediate Wet

$$k_{rw} = 0.29986\left[\frac{S_w - S_{iw}}{1 - S_{iw}}\right] - 0.32797\left[\frac{S_w - S_{orw}}{1 - S_{iw} - S_{orw}}\right]^{2}(S_w - S_{iw}) + 0.413259\left[\frac{S_w - S_{iw}}{1 - S_{iw} - S_{orw}}\right]^{4}$$

Any Wettability

$$k_{row} = 1.2624\left[\frac{S_o - S_{orw}}{1 - S_{orw}}\right]\left[\frac{S_w - S_{iw}}{1 - S_{iw} - S_{orw}}\right]^{2}$$

$$k_{rog} = 0.93752\left[\frac{S_o}{1 - S_{iw}}\right]^4\left[\frac{S_o - S_{org}}{1 - S_{iw} - S_{org}}\right]^2$$

$$k_{rg} = 1.8655\,S_g\left[\frac{S_g - S_{gc}}{1 - S_{iw}}\right]k_{rgro} + 8.0053\left(S_{org}\right)^2\left[\frac{S_g - S_{gc}}{1 - S_{iw}}\right] - 0.025890\left(S_g - S_{gc}\right)\left[\frac{1 - S_{iw} - S_{org} - S_{gc}}{1 - S_{iw}}\right]^2\left[1 - \frac{1 - S_{iw} - S_{org} - S_{gc}}{1 - S_{iw}}\right]^2\left[\frac{k_{abs}}{\phi}\right]^{0.5}$$

Generalized Corey

Similar to the Corey correlation, but developed for a wider range of rock and wettability characteristics. This correlation can be used to change the endpoints of water-oil and gas-liquid relative permeability curves while still retaining the shape of the curves.

Gas / Oil System

$$k_{rog} = k_{rocw}\left[\frac{S_o - S_{iw} - S_{org}}{1 - S_{iw} - S_{org}}\right]^{n_{og}}$$

$$k_{rgo} = k_{rgro}\left[\frac{S_g - S_{go}}{1 - S_{gc} - S_{iw} - S_{org}}\right]^{n_g}$$

Gas / Water System

$$k_{rg} = k_{rgcw}\left[\frac{S_g - S_{gc}}{1 - S_{gc} - S_{iw}}\right]^{n_g}$$

$$k_{rw} = k_{rwgc}\left[\frac{S_w - S_{iw}}{1 - S_{iw}}\right]^{n_w}$$

Water / Oil System

$$k_{ro} = k_{rocw}\left[\frac{1 - S_w - S_{orw}}{1 - S_{iw} - S_{orw}}\right]^{n_{ow}}$$

$$k_{rw} = k_{rwro}\left[\frac{S_w - S_{iw}}{1 - S_{iw} - S_{orw}}\right]^{n_w}$$

Three-Phase Correlations

Three-phase relative permeability can be generated from the two-phase relative permeability curves of the oil-water system and the relative permeability curves of the gas-oil system. The two-phase curves represent the end curves when either the gas saturation or water saturation equals zero.

Stone I

This probability model estimates three-phase permeability data from laboratory measured two-phase data. It uses the channel flow theory in porous media to obtain a simple result for determining the relative permeability to oil in the presence of water and gas flow. The model implies that water-relative permeability and water-oil capillary pressure in three-phase systems are functions of water saturation alone, irrespective of the relative saturations of oil and gas. Similarly, the gas-phase relative permeability and gas-oil capillary pressure are the same functions for gas saturation in the three-phase system as in the two-phase gas-oil system.

Stone I is widely used in the industry as the benchmark for oil simulation. It is a better predictor than Stone 2 in low oil saturation regions, is more appropriate for water-wet systems, and is not suited for intermediate wet systems.

$$S_o^* = \frac{S_o - S_{orw}}{1 - S_{iw} - S_{orw}}$$

$$S_w^* = \frac{S_w - S_{iw}}{1 - S_{iw} - S_{orw}}$$

$$S_g^* = \frac{S_g}{1 - S_{iw} - S_{orw}}$$

$$k_{ro} = k_{rocw}\, S_o^* \left[\frac{k_{row}(@\, S_w)}{k_{rocw}(1 - S_w^*)}\right]\left[\frac{k_{rog}(@\, S_g)}{k_{rocw}(1 - S_g^*)}\right]$$

Stone II

Stone's Model II is a modified version of Stone I. It is a better predictor than Stone 1 in high-oil saturation regions. It is more appropriate for water-wet systems and is not suited for intermediate wet systems.

$$k_{ro} = k_{rocw}\left[\left(\frac{k_{row}}{k_{rocw}} + k_{rw}\right)\left(\frac{k_{rog}}{k_{rocw}} + k_{rg}\right) - \left(k_{rw} + k_{rg}\right)\right]$$

Baker

Baker's three-phase model is based on saturation-weighted interpolation between the two-phase relative permeability values. It is well suited for intermediate wet or oil-wet systems.

$$k_{ro} = \frac{(S_w - S_{iw})(k_{rocw}) + \left(S_g - S_{gc}\right)(k_{rog})}{(S_w - S_{iw}) + \left(S_g - S_{gc}\right)}$$