Gas Rate Equation

$$q_g = C \int_{p_{wf}}^{p_R} \frac{1}{\mu_g B_g} dp$$

$$q_g = C^* \int_{p_{wf}}^{p_R} \frac{p}{\mu_g Z} dp$$

where

$$C = \frac{2\pi a_1 kh}{\ln(r_e/r_w) - 0.75 + s}$$

$$C^* = C\left(\frac{T_{sc}}{p_{sc} T_R}\right)$$

$a_1 = 1/(2\pi \cdot 141.2)$ **for field units**

$a_1 = 1$ **for pure SI units**

Gas Condensate Rate Equation

1. **Gas well deliverability can be accurately determined using a simple rate equation**

$$q_g = C \int_{p_{wf}}^{p_R} \left(\frac{k_{rg}}{B_{gd}\mu_g} + \frac{k_{ro}}{B_o\mu_o} R_s \right) dp$$

$$q_g \simeq C \int_{p_{wf}}^{p_R} \left(\frac{k_{rg}}{B_{gd}\mu_g} \right) dp$$

$$C = \frac{2\pi a_1 k h}{\ln(r_e/r_w) - 0.75 + s}$$

2. **The multiphase pseudopressure function can be easily calculated from producing GOR (composition) and PVT properties.**

3. **The effect of reduced gas permeability (condensate blockage) is incorporated in the pseudopressure function.**

4. **All other well terms (well geometry, damage skin, etc.) are accounted for in the "productivity" constant C.**

5. **The pseudopressure method works for radial, vertically fractured, and horizontal wells.**

Three Flow Regions

1. **Gas condensate wells producing with BHFP below the dewpoint have up to three flow regions.**

2. ***Region 1* has a constant flowing composition (GOR) where both gas and oil flow simultaneously. Most of the deliverability loss is caused by reduced gas permeability in Region 1.**

3. ***Region 2* is where condensate accumulates but has no mobility. Some additional deliverability loss occurs in Region 2, particularly for rich gas condensates.**

4. ***Region 3* is the outer region where reservoir pressure is greater than the dewpoint and only gas flows.**

5. **The multiphase pseudopressure function is calculated in three parts, based on the three flow regions.**

Total

$$\Delta p_p = \int_{p_{wf}}^{p_R} \left(\frac{k_{rg}}{B_{gd}\mu_g} + \frac{k_{ro}}{B_o\mu_o} R_s \right) dp =$$

Region 1

$$\int_{p_{wf}}^{p*} \left(\frac{k_{rg}}{B_{gd}\mu_g} + \frac{k_{ro}}{B_o\mu_o} R_s \right) dp \quad +$$

Region 2

$$\int_{p*}^{p_d} \frac{k_{rg}}{B_{gd}\mu_g} dp \quad +$$

Region 3

$$k_{rg}(S_{wi}) \int_{p_d}^{p_R} \frac{1}{B_{gd}\mu_g} dp$$

Region 1 pseudopressure is calculated using a modified Evinger-Muskat approach. Region 2 uses the $k_{rg}(S_o)$ relationship, and $S_o(p)$ estimated from the liquid dropout curve from a CVD experiment. Region 3 is treated the same as for single phase gas.

Region 1 Flow Characteristics

1. **The *flowing* composition (GOR) within Region 1 is constant throughout. That means that the single-phase gas entering Region 1 has the same composition as the produced wellstream mixture.**

   Conversely, if we know the producing wellstream, then we know the flowing composition within Region 1.

   Furthermore, the dewpoint of the producing wellstream mixture equals the reservoir pressure at the outer edge of Region 1.

2. Region 1 is the main source of deliverability loss in a gas condensate well. Gas relative permeability is reduced due to condensate buildup.

The size of Region 1 increases with time. For steady-state conditions, the condensate saturation in Region 1 is determined (as a function of radius) *specifically* to ensure that all liquid that condenses from the single-phase gas entering Region 1 has sufficient mobility to flow through and out of Region 1 without any net accumulation.

Calculation of Region 1 Pseudopressure

1. **The Region 1 pseudopressure integral is solved using the modified Evinger-Muskat approach. At pressures $p<p^*$ the PVT properties R_s, B_o, r_s, B_{gd}, μ_o, and μ_g are found directly.**

2. **Next, the equation defining producing GOR**

$$R_p = R_s + \left(\frac{k_{rg}}{k_{ro}}\right)\left(\frac{\mu_o B_o}{\mu_g B_{gd}}\right)(1 - r_s R_p)$$

is used to calculate k_{rg}/k_{ro} as a function of pressure,

$$\frac{k_{rg}}{k_{ro}}(p) = \left(\frac{R_p - R_s}{1 - r_s R_p}\right)\frac{\mu_g B_{gd}}{\mu_o B_o}$$

where PVT properties are known as a function of pressure.

3. **It is readily shown that the last equation can be expressed in terms of the oil relative volume of the flowing gas during a constant composition expansion, $V_{roCCE}=V_o/(V_g+V_o)$,**

$$\frac{k_{rg}}{k_{ro}}(p) = \left(\frac{1}{V_{roCCE}} - 1\right)\frac{\mu_g}{\mu_o}$$

4. **As shown by Evinger and Muskat, relative permeabilities k_{rg} and k_{ro} can be expressed directly as a function of the ratio k_{rg}/k_{ro} (when both phases are mobile).**

   This means that we can evaluate k_{rg} and k_{ro} directly as a function of pressure in the Region 1 pseudopressure integral, $k_{rg}(p) = f[k_{rg}/k_{ro}(p)]$ and $k_{ro}(p) = f[k_{rg}/k_{ro}(p)]$.