UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT

Colorado School of Mines

Research Summary

Transient Drainage Volume of Fractured Horizontal Wells

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Outline

→ Conventional Wisdom of Well Spacing

→ Unconventional Wells

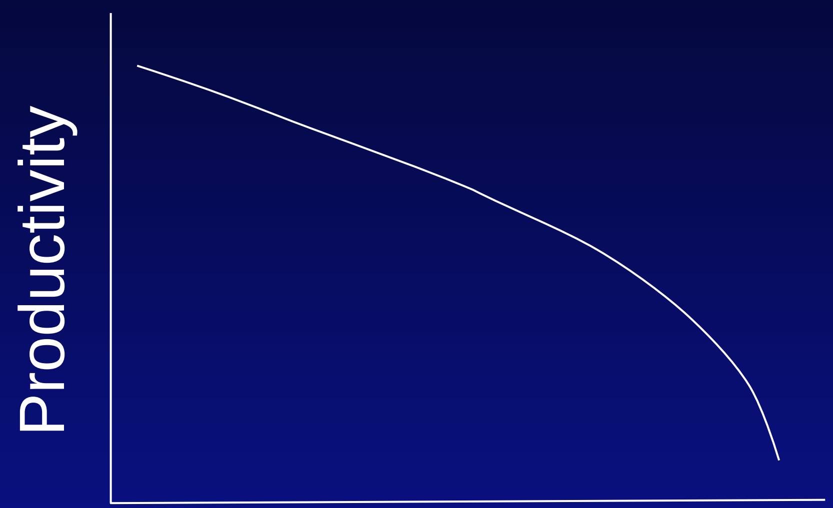
→ Well Spacing Problem for Unconventional Projects

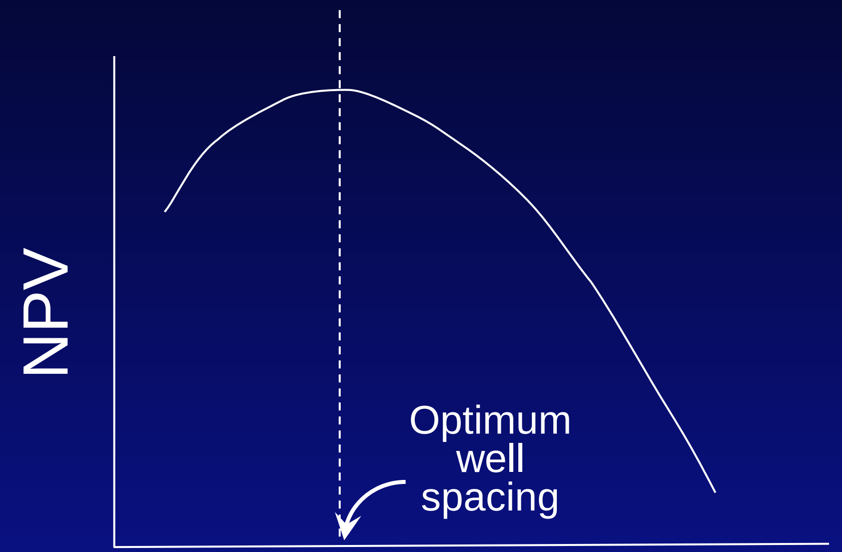
→ Transient Drainage Area

→ Conclusions

Conventional Wisdom

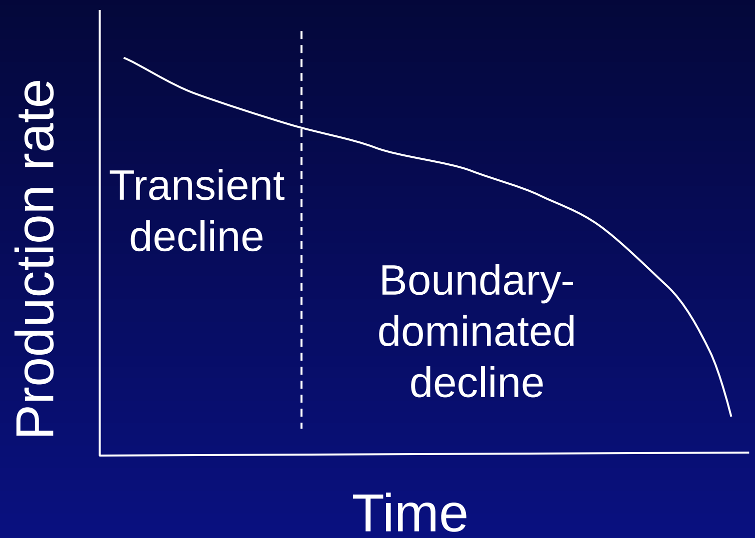
Well Spacing (Drainage Area) for Conventional Plays

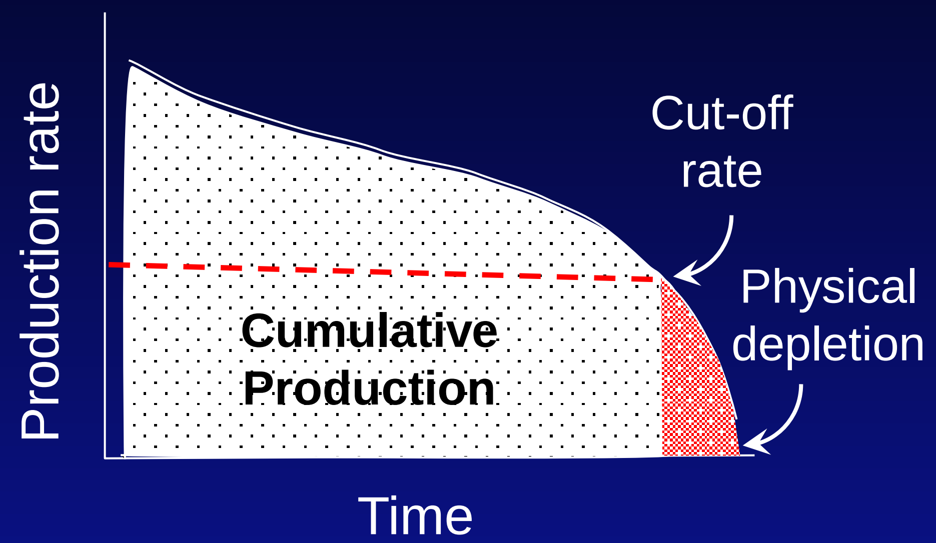




Conventional Wisdom

Well Spacing (Drainage Area) for Conventional Plays





Most conventional wells reach cut-off rate during boundary dominated flow

At the cut-off rate, the drainage area is close to physical depletion

Conventional Wisdom

Well Spacing (Drainage Area) for Conventional Plays

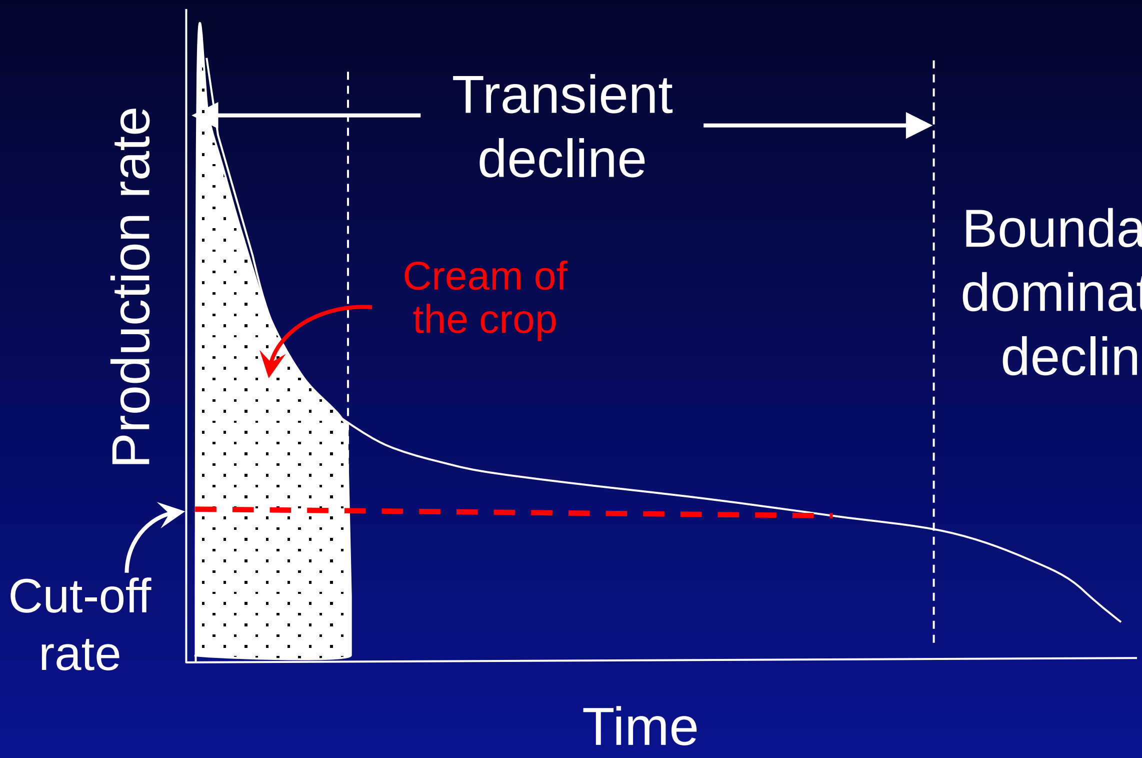
Tighter well spacing accelerates the recovery of reserves, which is favored by project economics

The incremental gain in productivity becomes smaller as the well spacing becomes tighter

For conventional wells, well project economics and well spacing is dictated by physical depletion conditions

Unconventional Wells

Production from Unconventional Wells

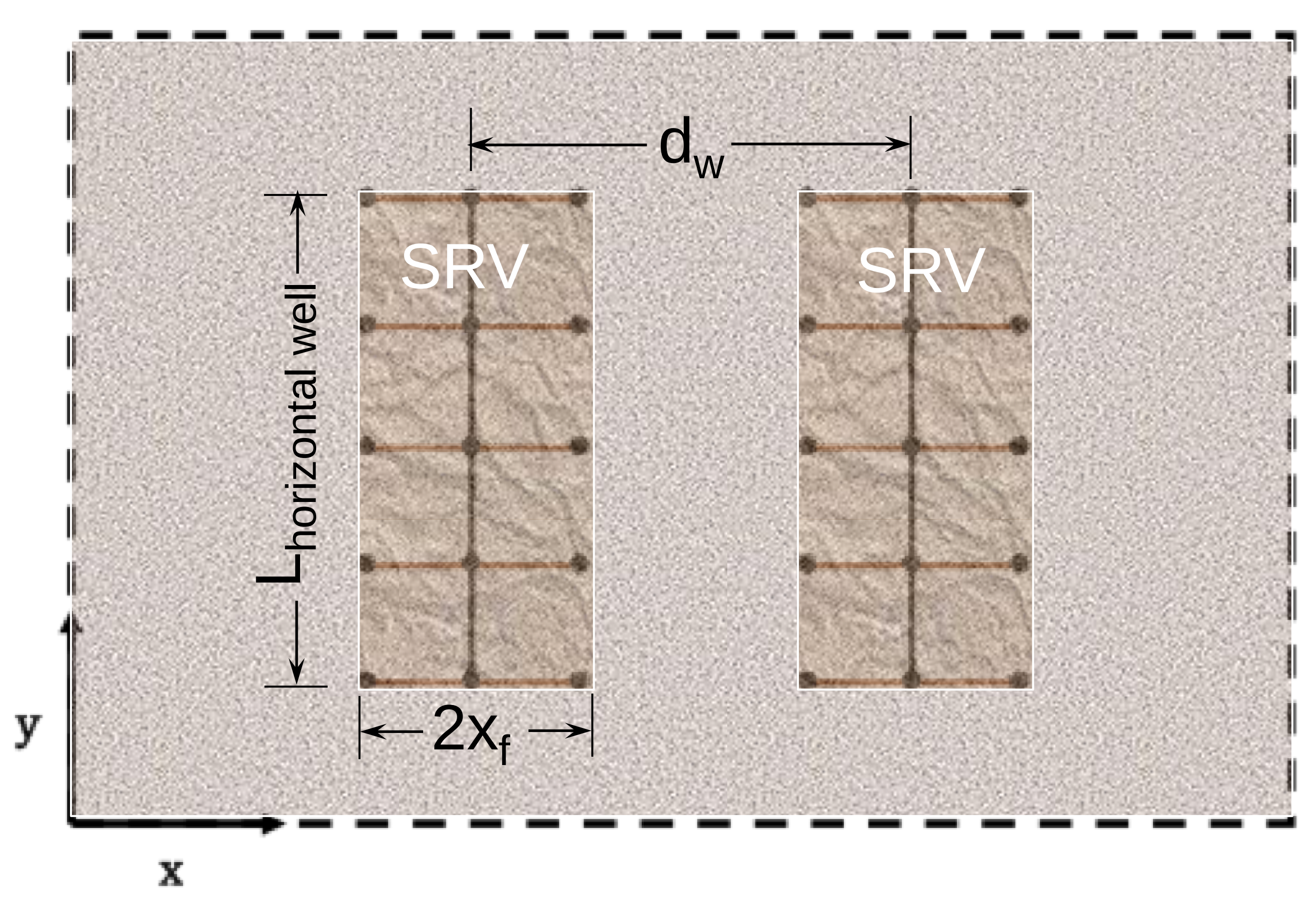


Most unconventional wells reach cut-off rate during transient flow

Project economics are dictated by economic depletion

Well Spacing Problem

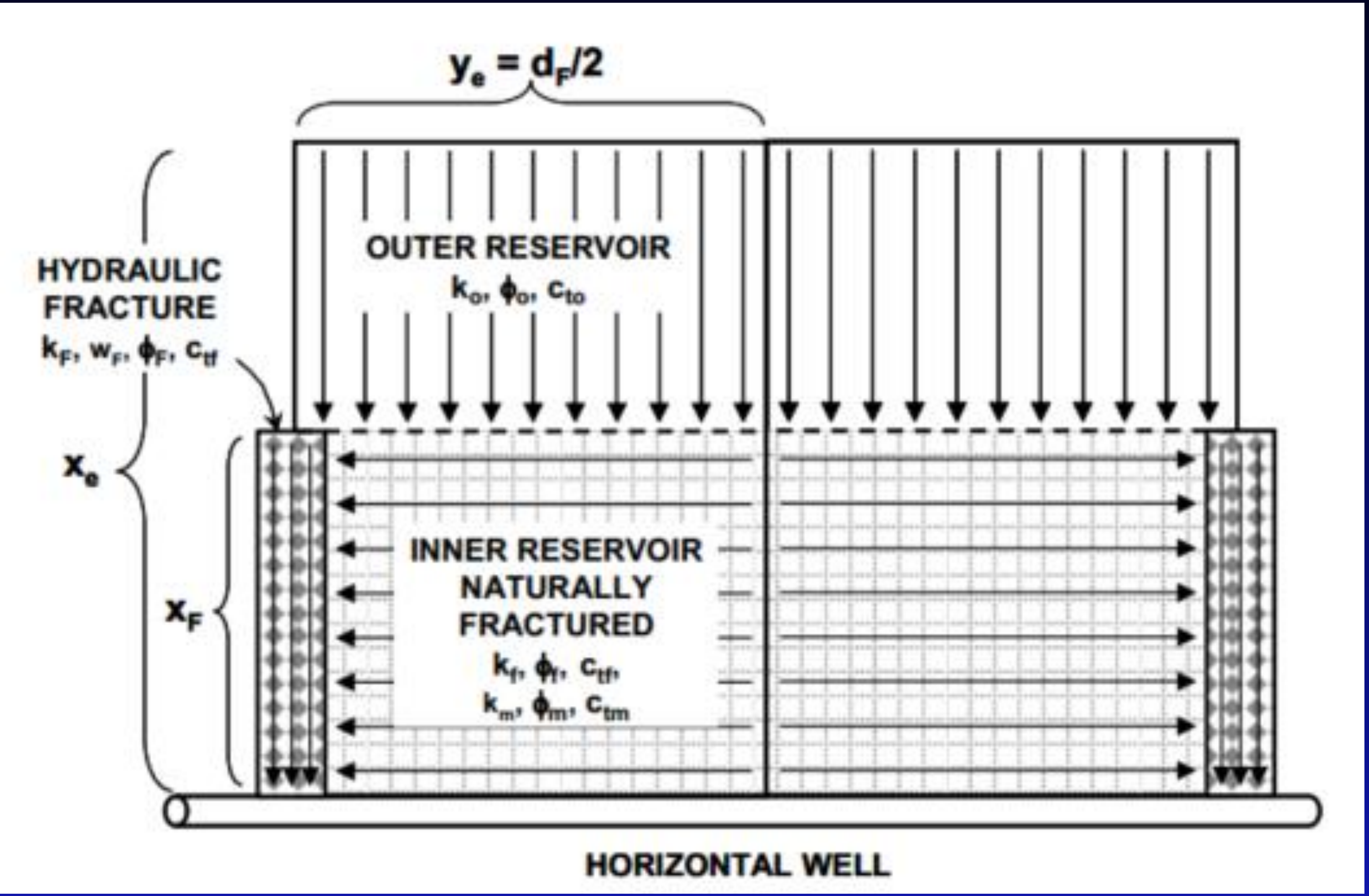
Well spacing is one of the most important factors affecting the economics of unconventional development projects



Drainage area of fractured horizontal wells is a function of well spacing and the size of the SRV

Transient Drainage Area

Linear flow model



Transient Drainage Area

Dimensionless transient linear flow equation

$$P_D = \sqrt{\frac{\pi t_D}{1+\omega}} \exp\left(-\frac{y_D^2 (1+\omega)}{4t_D}\right) - \frac{\pi y_D}{2} erfc\left(\frac{y_D}{2\sqrt{\frac{t_D}{1+\omega}}}\right)$$

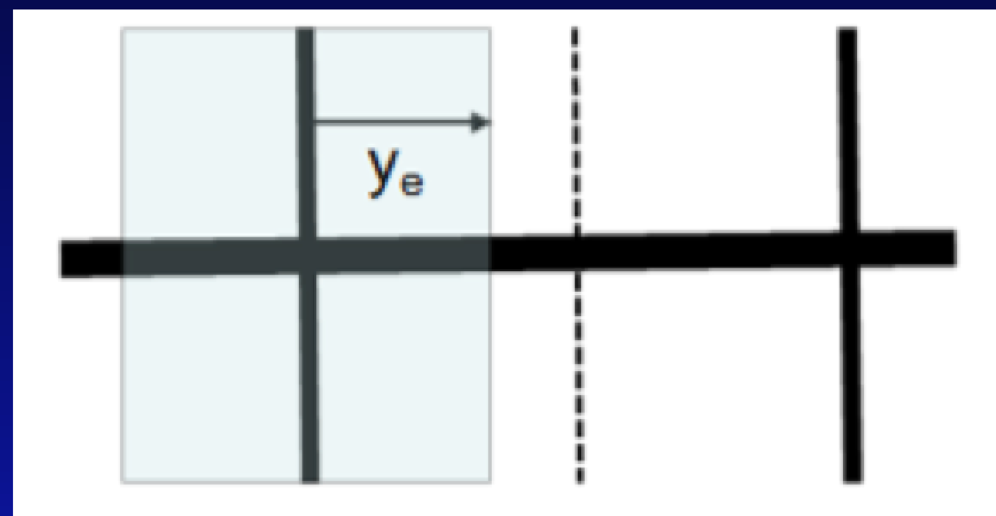
$$P_D = \frac{kh}{141.2 qB\mu}(P_i - P)$$

$$t_D = \frac{2.637 \times 10^{-4} kt}{\phi \mu c_t x_f^2}$$

$$y_D = \frac{y}{x_f}$$

$$\omega = \frac{(\phi c_t)_m h_m}{(\phi c_t)_f h_f}$$

ω : storativity ratio



Transient Drainage Area

Let y_e denote the point beyond which the pressure does not change with time

During transient flow, $y_e = f(t_m)$

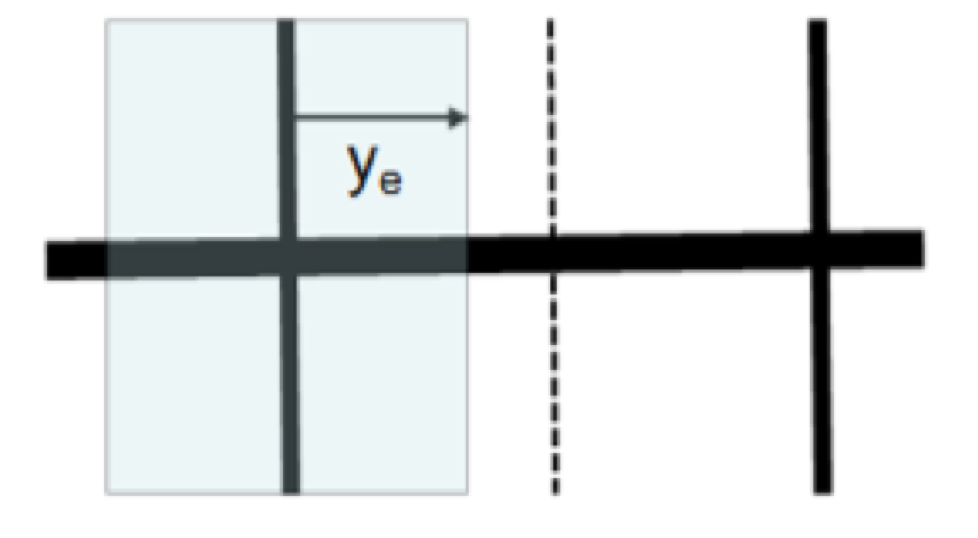
The time t_m is found by differentiating the linear flow solution twice and setting equal to zero

$$t_D = \frac{y_{eD}^2 (1+\omega)}{2}$$

$$t_m = \frac{y_e^2 (1+\omega)}{2\eta}$$

$$y_e = \sqrt{\frac{2\eta t_m}{(1+\omega)}}$$

$$h = \frac{2.637 \times 10^{-4} k}{f c_t m}$$



Transient Drainage Area

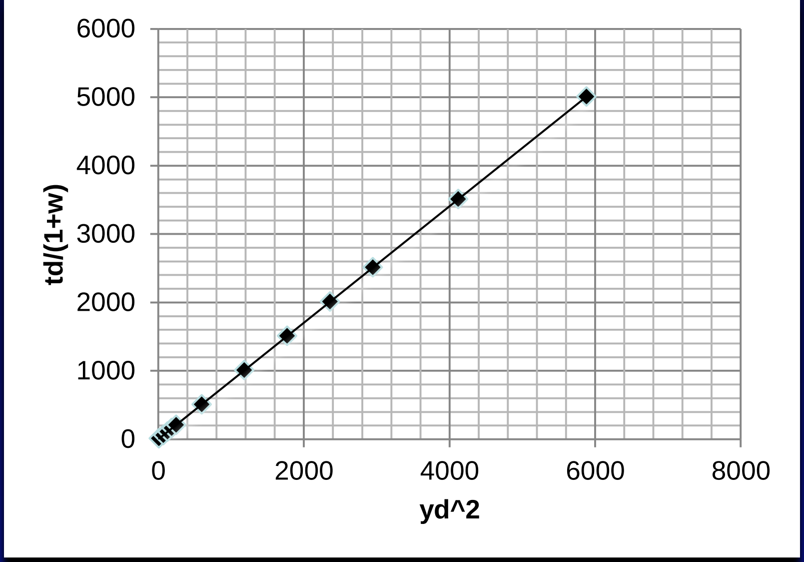
When the pressure from transient linear flow equation becomes equal to the pressure from pseudosteady state linear flow equation:

$$P_{wD} = \frac{2\pi t_D}{1+\hat{\omega}} + \frac{\pi}{6}\left(y_{eD} - \frac{w_D}{2}\right) + \frac{\pi}{3C_{FD}}$$

$$P_{wD} - \bar{P}_D = \frac{\pi}{6}\left(y_{eD} - \frac{w_D}{2}\right) + \frac{\pi}{3C_{FD}}$$

$$P_D = \sqrt{\frac{\pi t_D}{(1+\omega)}} \exp\left(-\frac{y_D^2(1+\omega)}{4t_D}\right) - \frac{\pi y_D}{2} erfc\left(\frac{y_D}{2\sqrt{\frac{t_D}{(1+\omega)}}}\right) = \frac{\pi}{6} y_D$$

$$P_D = \sqrt{\frac{\pi t_D}{(1+\omega)}} \exp\left(-\frac{y_D^2(1+\omega)}{4t_D}\right) - \frac{\pi y_D}{2} erfc\left(\frac{y_D}{2\sqrt{\frac{t_D}{(1+\omega)}}}\right) - \frac{\pi}{6} y_D = 0$$



$$t_D = 0.8516 y_D^2 (1+\omega)$$

$$t_m = \frac{y^2(1+\omega)}{1.175\eta}$$

Transient Drainage Area

$$t_D = 0.5 y_{eD}^2 (1+\omega)$$

$$t_D = 0.8516 y_D^2 (1+\omega)$$

$$y_D = 0.77 y_{eD}$$

y_D = Drainage distance

y_{eD} = Distance of investigation

If we substitute y_D in the transient linear flow equation;

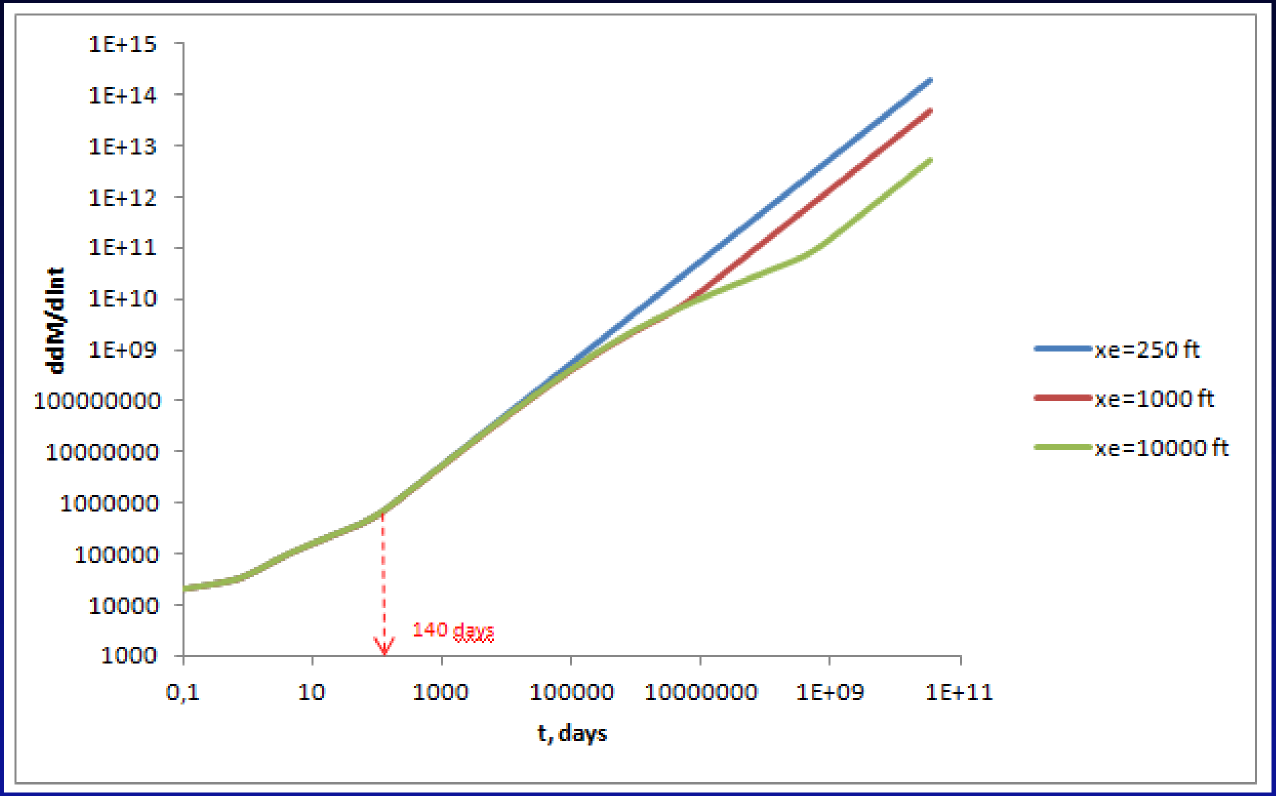
$$P_D = \sqrt{\frac{\pi t_D}{1+\omega}} \exp\left(-\frac{y_D^2(1+\omega)}{4t_D}\right) - \frac{\pi y_D}{2} erfc\left(\frac{y_D}{2\sqrt{\frac{t_D}{1+\omega}}}\right)$$

We have

$$P_D = \frac{\pi}{6} y_D$$

Transient Drainage Area

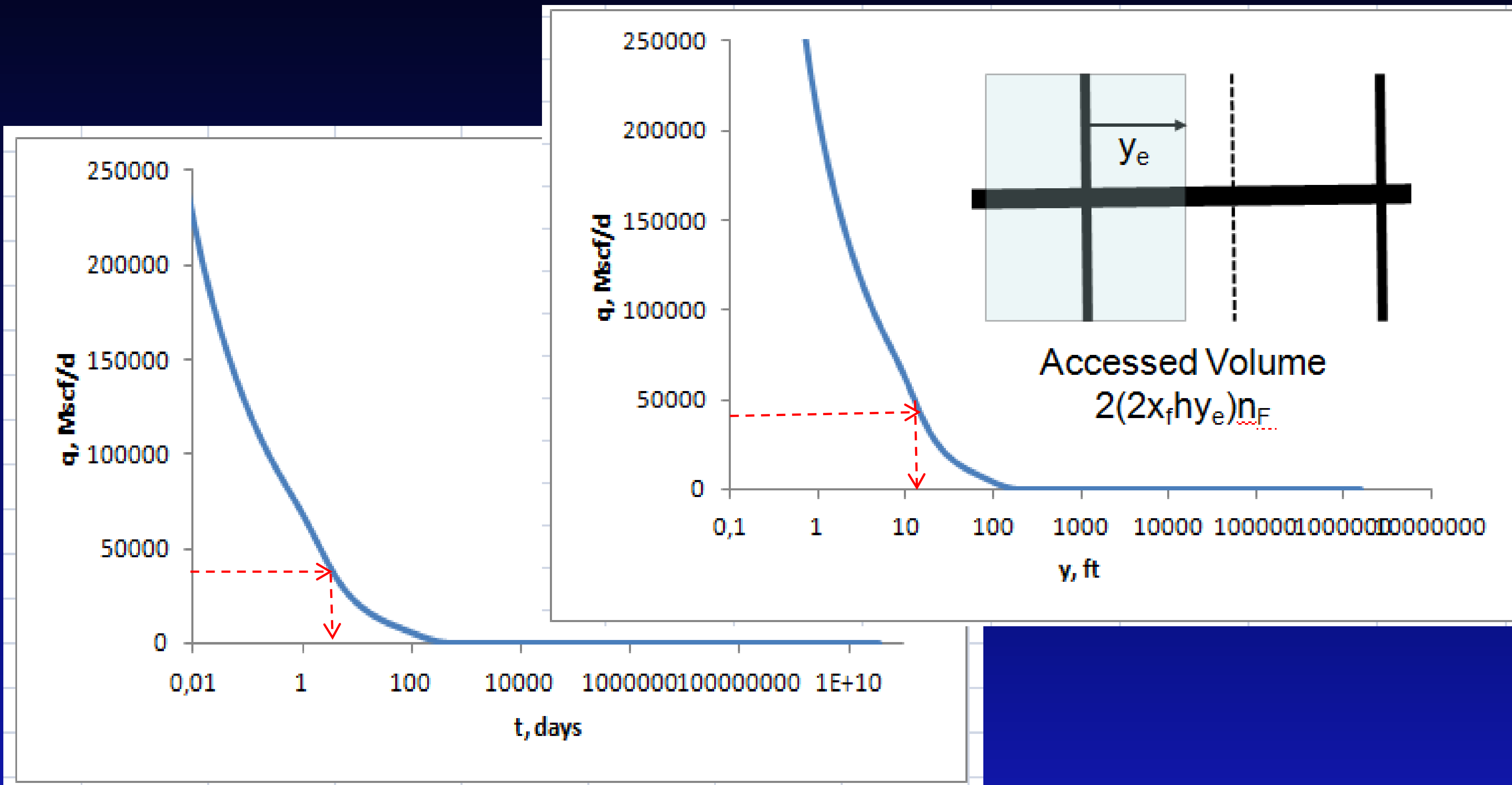
Example: Reaching physical boundaries



Stabilization Time and the Effect of the Outer Reservoir for the Dual-Porosity Inner Reservoir (k_o = 0.0001 md)

Transient Drainage Area

Drainage Volume under Constant Pressure Production



Transient Drainage Area

The same approach can be applied to find the accessed reservoir volume beyond SRV

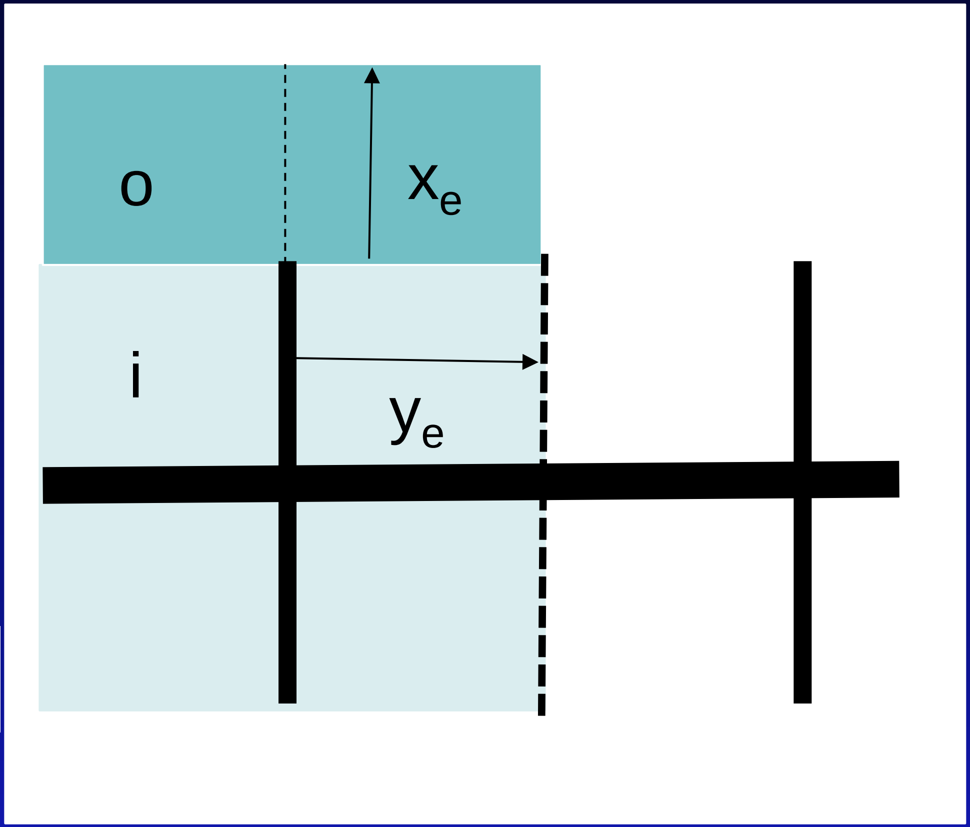
$$t_{om} = \frac{x_e^{\,2}}{2h_0}$$

$$x_e = \sqrt{2\eta_o t_{om}}$$

$$h_o = \frac{2.637 \times 10^{-4} k_o}{(\phi c_t)_o \mu}$$

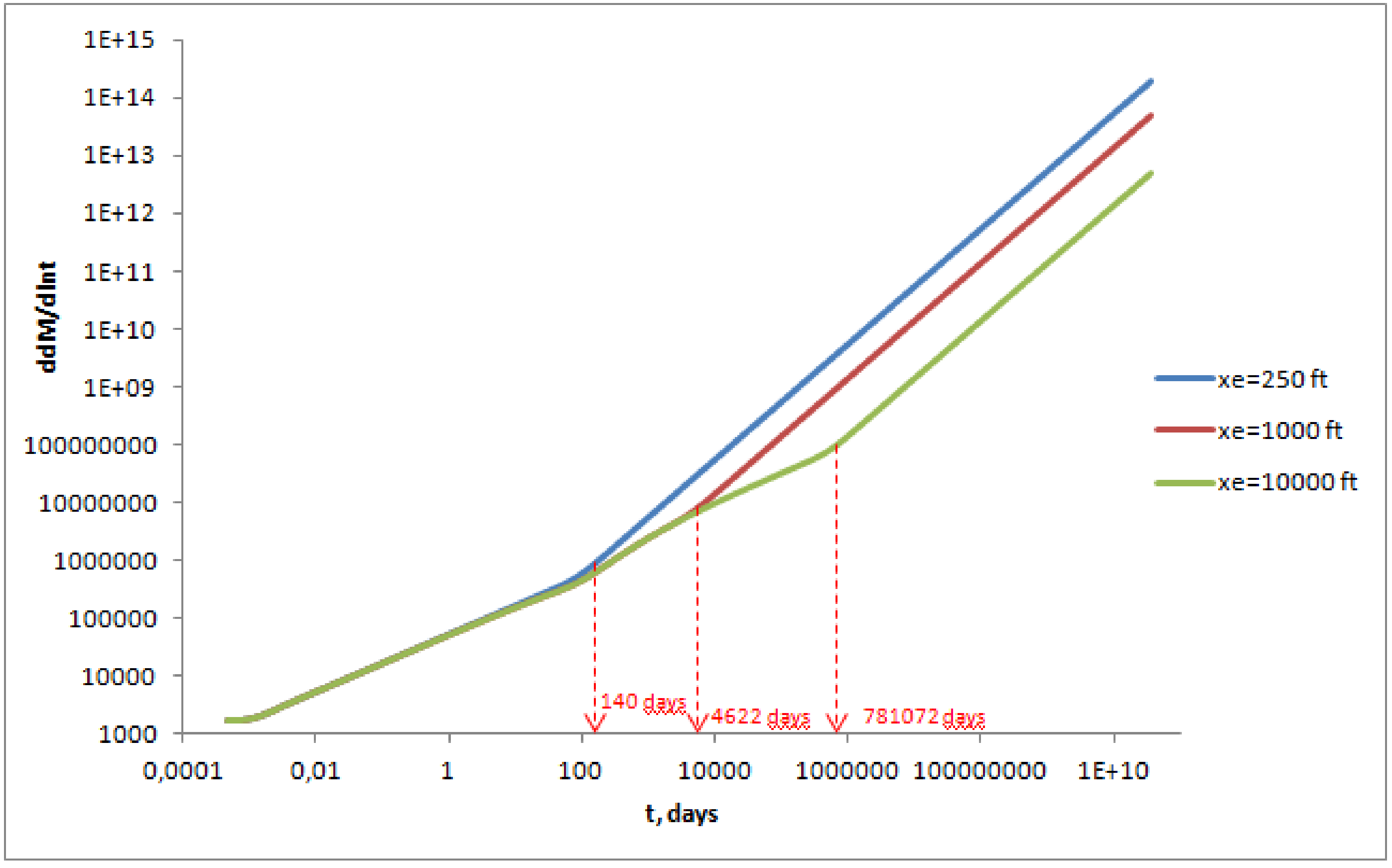
Total Accessed Volume:

$$4(x_f)(h)(y_e)(n_F) + 4(x_e)(y_e)(h)(n_F)$$

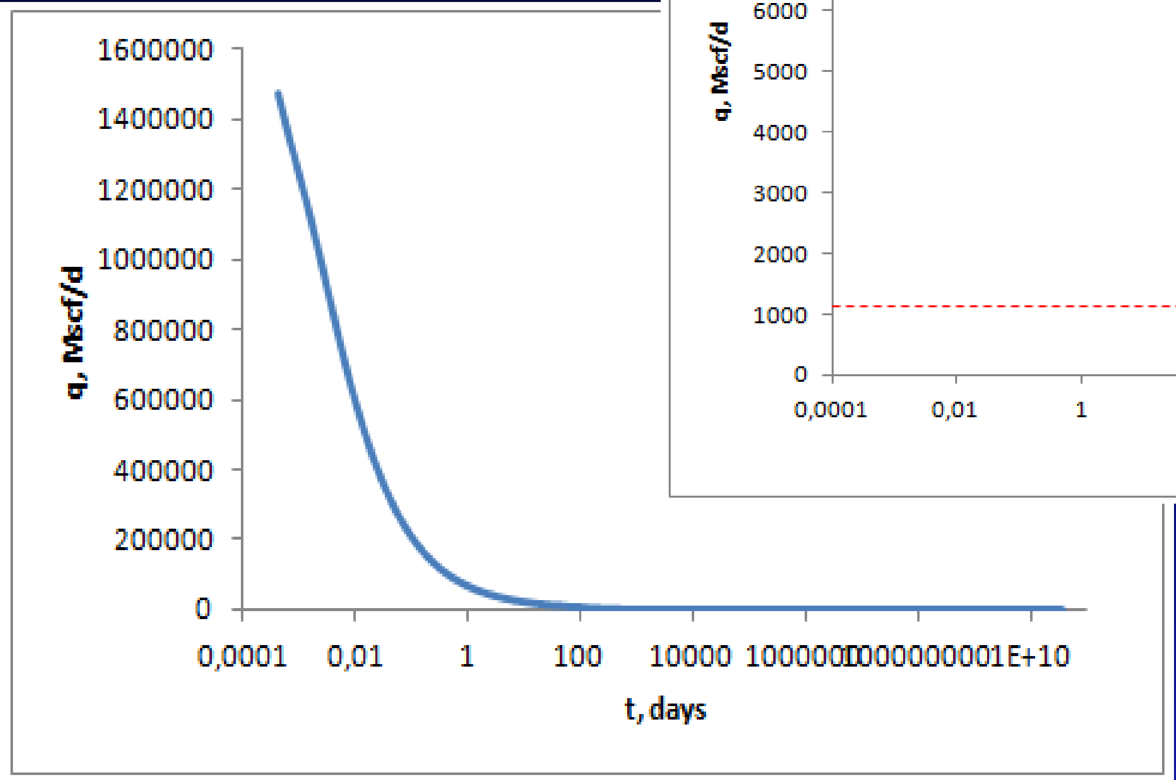


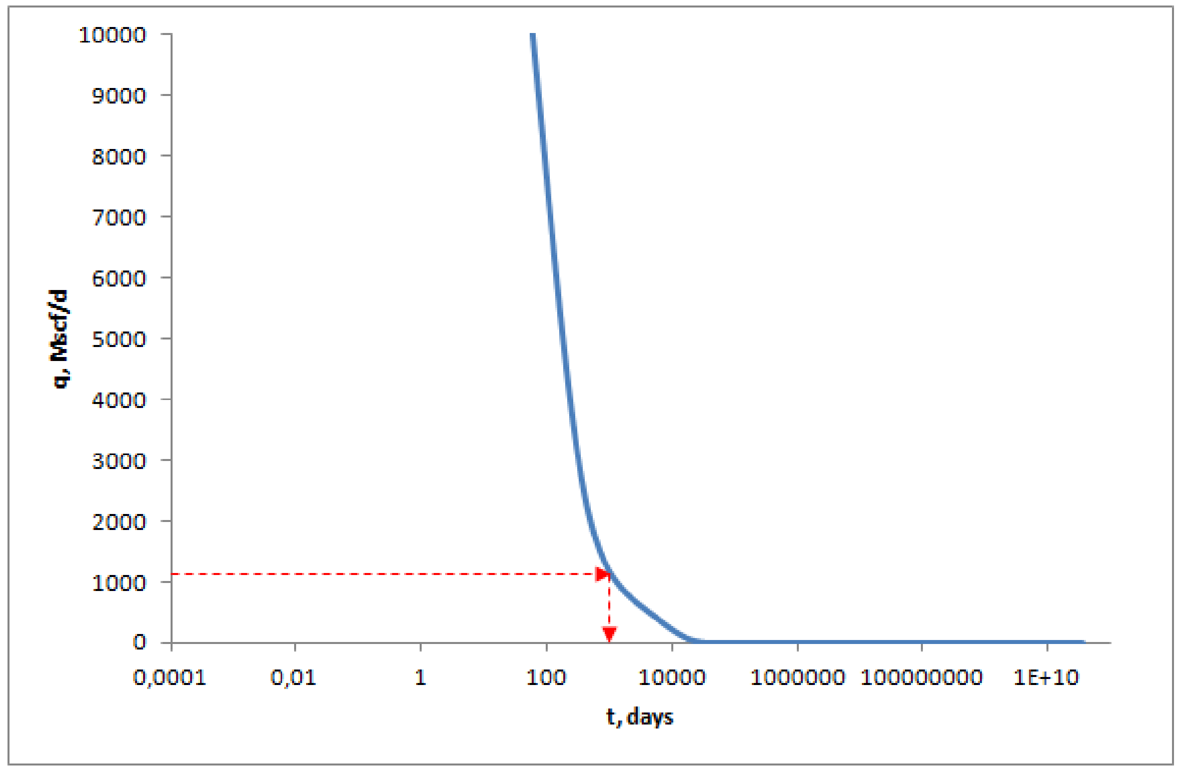
Transient Drainage Area

Example: Reaching physical boundaries (k_o = 0.1 md)



Transient Drainage Area





If we assume an economic cut-off rate of 1200 Mscf/d, we can reach that rate 980 days after the beginning of production.

Transient Drainage Area

We know that, the flow starts from the outer reservoir 140 days after the beginning of production.

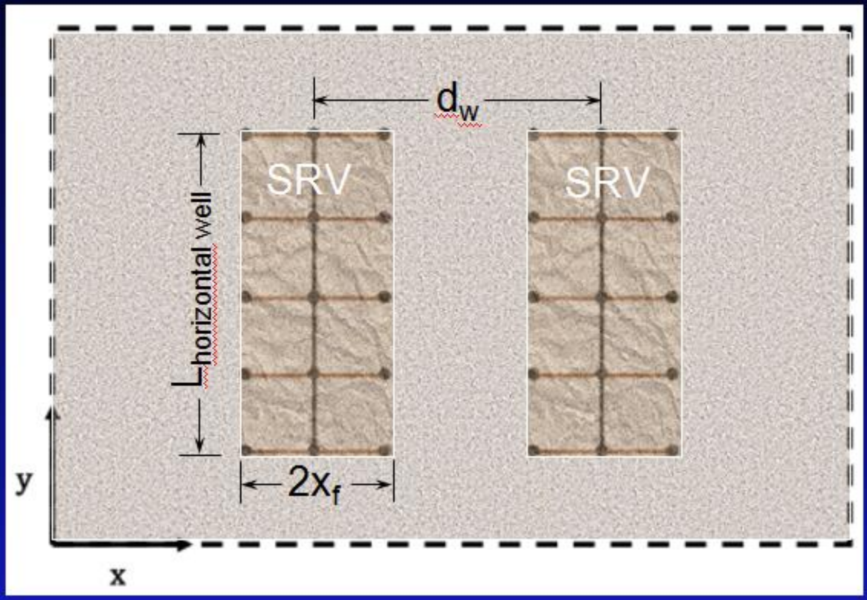
So, there will be flow from the outer reservoir for 980-140 = 840 days ≈ 20160 hours.

Then,

$$y = \sqrt{\frac{5.274 \times 10^{-4} k_m t}{\phi_m \mu_m c_{t_m}}} = \sqrt{\frac{5.274 \times 10^{-4} (0.1)(20160)}{(0.08)(0.013)(0.01)}} = 320 \ ft$$

320 ft of outer reservoir is accessed.

dw = 2(320+xf)



Transient Drainage Area

Accessed Volume Calculation:

→ For Inner Reservoir:

$$4(x_f)(h)(y_e)(n_F) = 4(250)(250)(100)(15) = 375000000 \ ft^3$$

→ For Outer Reservoir:

$$4(x_e)(y_e)(h)(n_F) = 4(320)(100)(250)(15) = 480000000 \ ft^3$$

→ Total:

$$375000000 + 480000000 = 855000000 \ ft^3 = 855 MMScf$$

Conclusions

The drainage area of unconventional wells are dictated by transient decline

Well spacing considerations are not usually related to physical depletion and recovery factors

Using the accessed reservoir volume corresponding to a given economic cut-off rate is a practical approach to optimize well spacing