Petroleum and Mining Engineering College
Department of Petroleum Reservoir Engineering
Third stage

Petroleum Product Engineering

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8:30 Am

Water Coning

Meyer, Gardner, and Pirson proposed a similar expression for determining the critical oil rate in the water coning system shown schematically in figure -16.

The proposed relationship has the following form:

$$Q\ max = 0.001535 * \left[\frac{\rho_w - \rho_o}{\ln\left(\frac{r_e}{r_w}\right)}\right]\left(\frac{K_o}{\mu_o B_o}\right)[h^2 - (h - D_b)^2] \ldots\ldots\ldots (12)$$

Example (1-2):

Resolve example (1-1) assuming that the oil zone is underlaid by bottom water. The water density is given as 63.76 lb/ft. the well completion interval is 15 ft as measured from the top of the formation (no gas cap) to the bottom of the perforations.

Solution:

The critical oil flow rate for this water-coning problem can be estimated by applying equation (12). The equation is designed to determine the critical rate at which the water cone "touches" the bottom of the well to give.

$$Q\ max = 0.001535 * \left[\frac{\rho_w - \rho_o}{\ln\left(\frac{r_e}{r_w}\right)}\right]\left(\frac{K_o}{\mu_o B_o}\right)[h^2 - (h - D_b)^2] \ldots\ldots\ldots (12)$$

Qo max = 0.001535 [((63.76/62.4)-(47.5/62.4))/ ln(660/0.25)] (93.5/0.73*1.1) [40^2- -15^2]

Qo max = 8.13 STB/day

Simultaneous Gas and Water coning

If the effective oil-pay thickness h is comprised between a gas cap and a water zone figure -17, the completion interval h_p must be such as to permit maximum oil-production rate without having gas and water simultaneously produced by coning, gas breaking through at the top of the interval and water at the bottom.

This case is of particular interest in the production from a thin column underlaid by bottom water and overlaid by gas.]

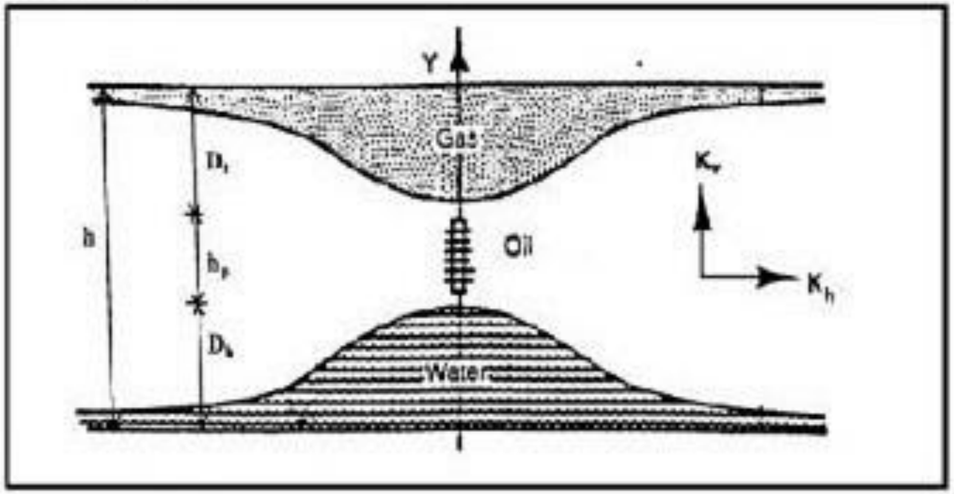

Fig.17 : **The development of Gas and Water coning**

For this combined gas and water coning, Pirson (1977) combined equation (11) and (12) to produce the following simplified expression for determining the maximum oil-flow rate without gas and water coning:

$$Qomax = Qow + Qog \quad .... (13)$$

$$Q\ max = 0.001535 \left(\frac{K_o}{\mu o\ B_o}\right)\left[\frac{(h^2 - hp^2)}{\ln \frac{r_e}{r_w}}\right](\rho w - \rho o)\left[\frac{\rho o - \rho g}{\rho w - \rho g}\right]^2 + (\rho_o - \rho_g)\left(1 - \frac{\rho_o - \rho_g}{\rho_w - \rho_g}\right)^2 \quad \text{............} \quad (14)$$

The following data are available:

Horizontal and vertical permeability, i.e., $k_h = k_v = 110$ md

Oil relative permeability, $k_{ro} = 0.85$

Oil effective permeability, $k_o = 93.5$ md

Oil density, $\rho_o = 47.5$ lb/ft^3

Water density, $\rho_w = 63.76$ lb/ft^3

Gas density, $\rho_g = 5.1$ lb/ft^3

Oil viscosity, $\mu_o = 0.73$ cp

Oil formation volume factor, FVF, $B_o = 1.1$ bbl/STB

Oil column thickness, $h = 65$ ft

Perforated interval, $h_p = 15$ ft

Depth from GOC to top of perforations, $D_t = 25$ ft

Well-bore radius, $r_w = 0.25$ft

Drainage radius, $r_e = 660$ ft

Calculate the maximum permissible oil rate that can be imposed to avoid cones breakthrough, i.e., water and gas coning.

Solution:

Apply equation (14) to solve for the simultaneous gas-and water coning problem, to give:

$$Q_{max} = 0.001535\left(\frac{K_o}{\mu_o B_o}\right)\left[\frac{(h^2 - hp^2)}{\ln\frac{r_e}{r_w}}\right](\rho w - \rho o)\left[\frac{\rho o - \rho g}{\rho w - \rho g}\right]^2 + (\rho_o - \rho_g)\left(1 - \frac{\rho_o - \rho_g}{\rho_w - \rho_g}\right)^2 \quad \dots\dots\dots (14)$$

Qomax =0.001535(93.5/0.73*1.1)[(65²-15²)/(ln(660/0.25)]
[((63.76/62.4)-(47.5/62.4))((47.5/62.4)-(5.1/62.4))/((63.76/62.4)-(5.1/62.4)))²+((47.5/62.4)-(5.1/62.4))(1-((47.5/62.4)-(5.1/62.4))/((63.76/62.4)-(5.1/62.4)))²]

Qomax = 17.1 STB/day

Pirson derives a relationship for determining the optimum placement of the desired h_p feet of perforation in an oil zone with a gas cap above and a water zone below. Pirson proposes that the optimum distance D_t from the GOC to the top of the perforations can determined from the following expressed:

$$D_t = (h - hp)\left[1 - \left(\frac{\rho_o - \rho_g}{\rho_w - \rho_g}\right)\right] \quad \dots(14)$$

Where the distance D_t is expressed in feet.

Example (1-4):

Using the data given in example (1-3), calculate the optimum distance for the placement of the 15 foot perforations.

Solution:

Applying equation (14) gives:

$$D_t = (65 - 15)\left[1 - \frac{47.5 - 5.1}{63.76 - 5.1}\right] = 13.9 \text{ ft}$$

Completion Efficiency

Generally, there are difference types of well completions; the cased-hole completion has advantage characterize the open-hole completion by:

1- Excessive gas or water production can be controlled more easily.
2- Can be selectively stimulated.
3- Adaptable to multiple completion techniques.

The advantage of cased-hole completion comes in account of loss in well potential to produce with maximum rate because of casing and perforation. Also it is not unusual during drilling, completion, or work-over operations for materials such as mud filtrate, cement slurry, or clay particles to enter the formation and reduce the permeability around the well-bore which cause potential loss. This effect is commonly referred to as "well-bore damage" and the region of altered permeability is called the "skin zone" this zone can extend from a few inches to several feet from the well-bore as shown in figure -18 , it express by positive skin factor (s = +). Many other wells are stimulated by acidizing or fracturing, which in effect increases the permeability near the well-bore, expressed by negative skin factor (s = -). Figure - 19 shows pressure profile through porous media.

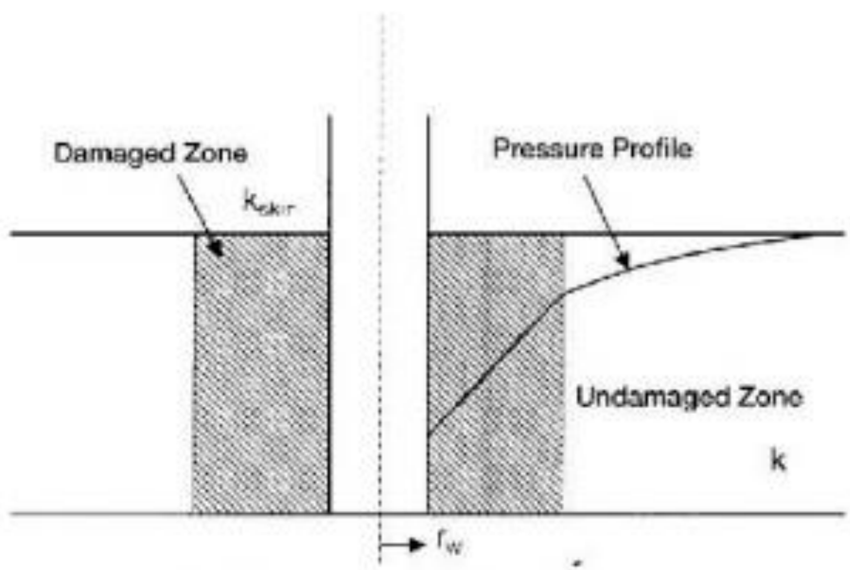

Figure –18: near well bore skin effect.

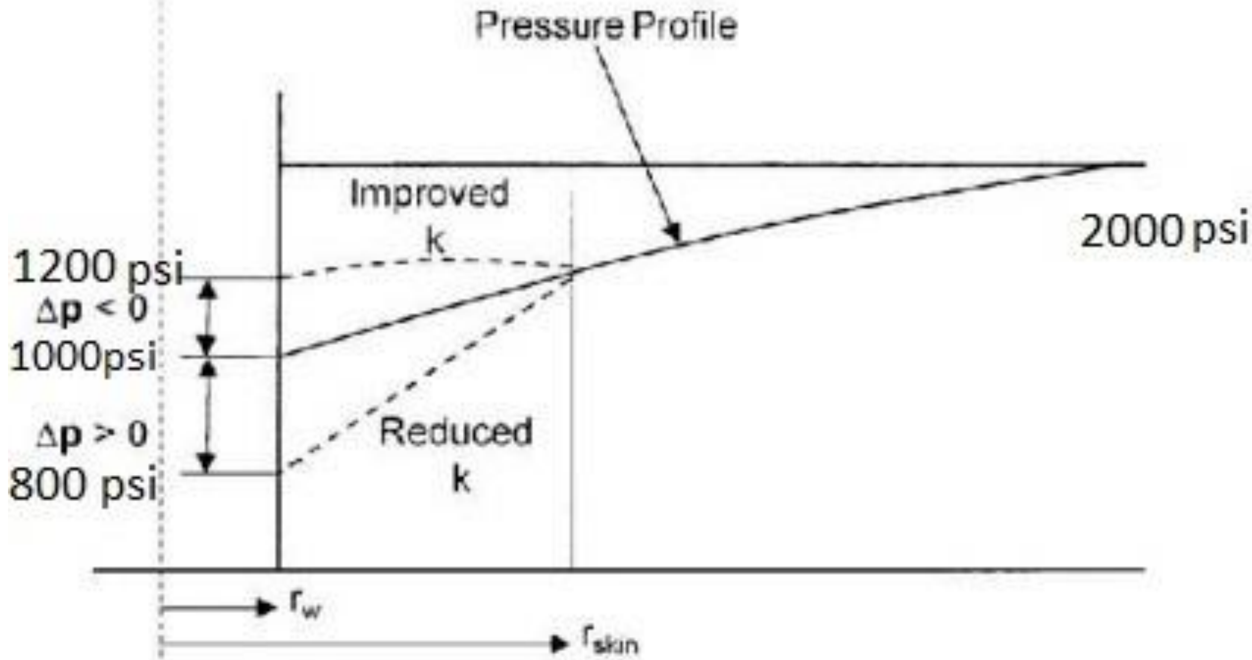

Figure -19 : pressure profile, reprehensive of positive and negative skin effects.

According to the above factors that cause pressure loss, there are many skin factors as following:

$$St = S_{fm} + S_c + S_{pp}$$

Where;
S_{fm} = Formation skin factor due to alteration formation characteristics (permeability).

Many wells either have a zone of reduced permeability near the well-bore resulting from drilling or completion operations or have been stimulated by acidizing or hydraulic fracturing.

Those factors that cause damage to the formation can produce additional localized pressure drop during flow. This additional pressure drop is referred to as Δp_{skin}. On the other hand, well stimulation techniques will normally enhance the properties of the formation and increase the permeability around the well-bore, so that a decrease in pressure drop is observed. The resulting effect of altering the permeability around the well-bore is called the skin effect.

compares the difference in the skin zone pressure drop for three possible outcomes:

- First outcomes: $\Delta p_{skin} > 0$, indicates an additional pressure drop due to well-bore damage, i.e., $k_{skin} < k$ and $s = +$.
- Second outcomes: $\Delta p_{skin} < 0$, indicates less pressure drop due to well-bore improvement, i.e., $k_{skin} > k$ and $s = -$.
- Third outcomes: $\Delta p_{skin} = 0$, indicates no changes in the well-bore condition, i.e., $k_{skin} = k$ and $s = 0$.