Petroleum and Mining Engineering College

Department of Petroleum Reservoir Engineering Third stage

Petroleum Product Engineering

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Water and Gas Coning

Coning is a term used to describe the mechanism underlying the upward movement of water and/or the down movement of gas into the perforations of a producing well or the open hole interval. Coning can seriously impact the well productivity and influence the degree of depletion and the overall recovery efficiency of the oil reservoirs. The specific problems of water and gas coning are listed below.

1- Costly added water and gas handling.
2- Reduced efficiency of the depletion mechanism.
3- The water is often corrosive and its disposal costly.
4- Loss of the total field overall recovery.

Delaying the encroachment and production of gas and water are essentially the controlling factors in maximizing the field's ultimate oil recovery.

The coning is primarily the result of movement of reservoir fluids in the direction of least resistance, balanced by a tendency of the fluids to maintain gravity equilibrium. The analysis may be made with respect to either gas or water. Let the original condition of reservoir fluids exist as shown schematically in figure -16, water underlying oil and gas overlying oil.

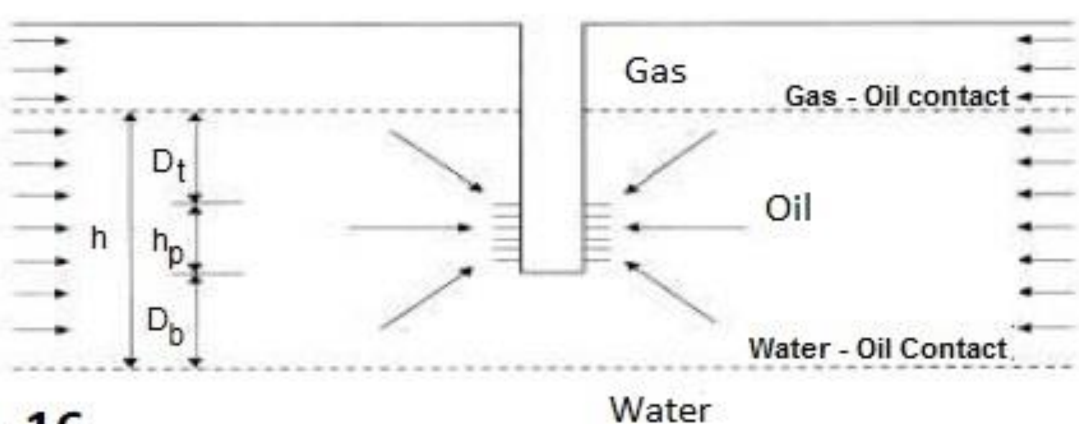


Fig. 16

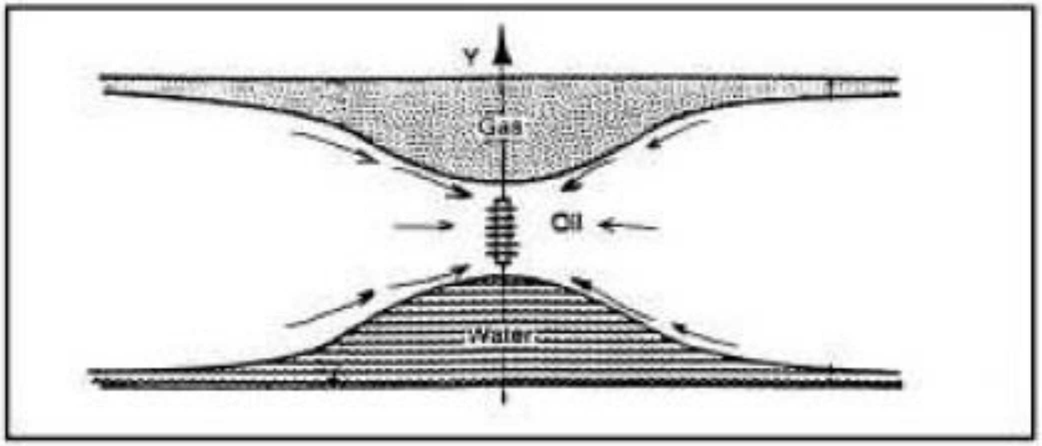


Fig.17 : Gas and Water coning

There are essentially three forces that may affect fluid flow distributions a round the well-bores. These are:

1- Capillary forces.
2- Gravity forces.
3- Viscous forces.

We can expand on the above basic visualization of coning by introducing the concept of:

- Stable cone.
- Unstable cone
- Critical production rate.

Defining the conditions for achieving the maximum water-free and/or gas-free oil production rate is a difficult problem to solve. Engineers are frequently faced with the following specific problems:

1- Predicting the maximum flow rate that can be assigned to a completed well without the simultaneous production of water and/or free-gas.
2- Defining the optimum length and position of the interval to be perforated in a well in order to obtain the maximum water and gas-free production rate.

Critical rate Q_{oc} is defined as the maximum allowable oil flow rate that can be imposed on the well to avoid a cone breakthrough. The critical rate would correspond to the development of a stable cone to an elevation just below the bottom of the perforated interval in an oil-water system or to an elevation just above the top of the perforated interval in a gas-oil system. Fig.14,Fig.15

There are several empirical correlations that are commonly used to predict the oil critical rate, including the correlations of:

1- Meyer , Gardner and Pirson Methods.
2- Craft and Hawkins Method.
3- Chaney et al. Method

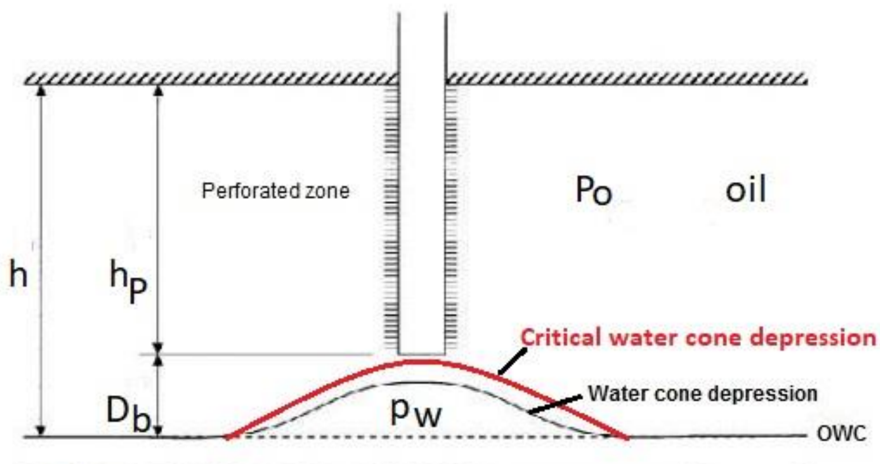


Fig.14

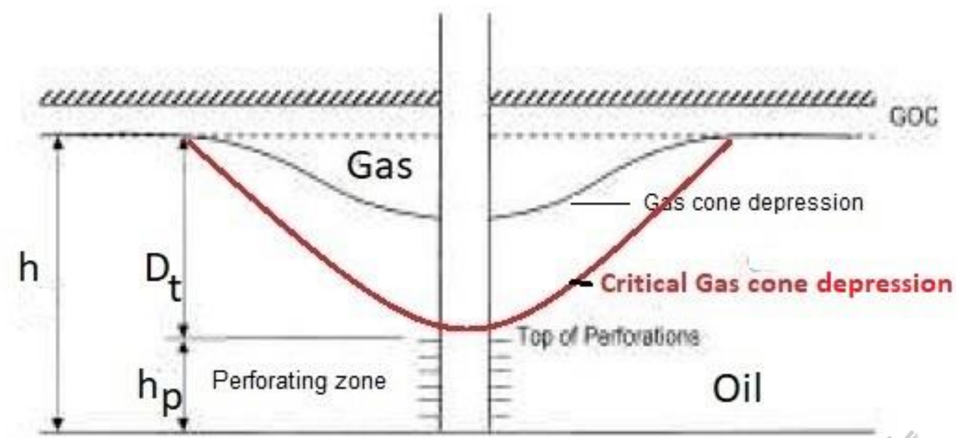


Fig.15

1- Meyer and Gardner and Pirson Methods

Meyer, Gardner, and Pirson suggest that coning development is a result of the radial flow of the oil and associated pressure sink around the well-bore. In their derivations, Meyer, Gardner, and Pirson assume a homogeneous system with a uniform permeability throughout the reservoir, i.e., $k_h = k_v$. It should be pointed out that the ratio k_h/k_v is the most critical term in evaluating and solving the coning problem. They developed three separate correlations for determining the critical oil flow rate:

- Gas coning
- Water coning
- Combined gas and water coning.

Gas coning

Consider the schematic illustration of the gas-coning problem shown in figure - 15. Meyer, Gardner, and Pirson correlated the critical oil rate required to achieve a stable gas cone with the following well penetration and fluid parameters:

- Difference in the oil and gas density.
- Depth D_t from the original gas-oil contact to the top of the perforations.
- The oil column thickness h.

The well perforated interval h_p in a gas-oil system, is essentially defined as:

$$h_p = h - D_t$$

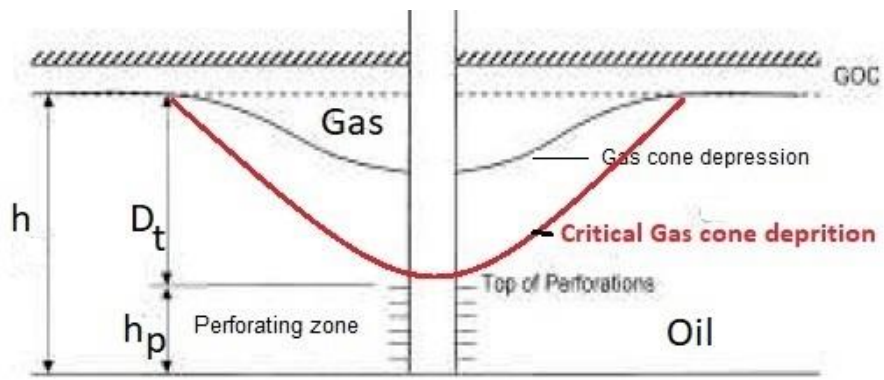
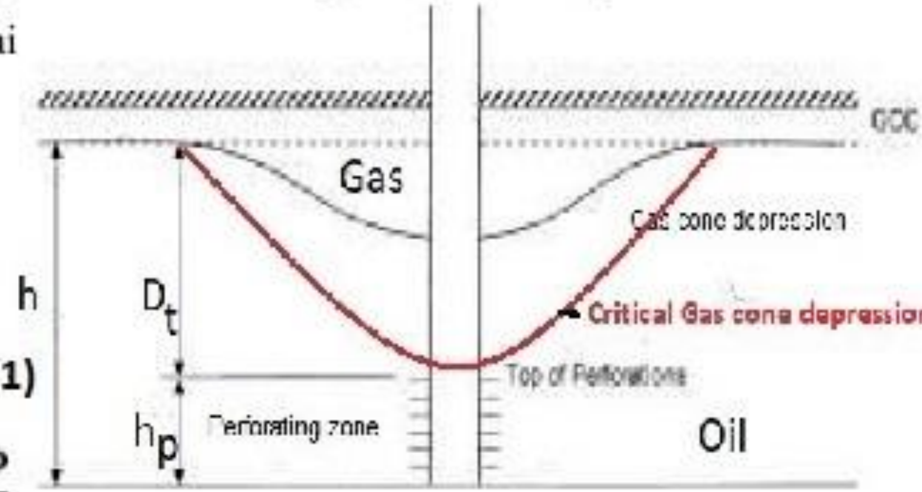


Fig.15

Meyer, Gardner, and Pirson propose the following expression for determining the oil critical flow rate in a gas-oil system:

Summary of assumptions for gas-oil system:

1. Capillary forces usually have negligible effect on coning and will be neglected.
2. No gas drive, that means GOR remai



Φ = Potential = H

For any point, calculate H

$$\Phi = g \quad + \frac{Po - P_g}{\rho_o} \quad \cdots (1)$$

$$\Phi = H * g \rightarrow H = \frac{\Phi}{g}$$

Hgas = z + Pg / (ρgas *g) .... (2)

Hoil = z + Po / (ρoil *g) ....(3)

Since Pc = zero i.e., Po = Pg (where Pc = Pg-Po = zero)

& Hg = constant (i.e., no gas drive).

For eg.(2) , solving for Pg →

(Hg – z) * ρg *g = Pg ....(2-a)

& also eq.(3) becomes:-

$(Ho - z) * \rho o * g = Po$ ………(3-a)

Since $Pc = zero \rightarrow Po = Pg$

Then eq. (2-a) = eq. (3-a)

$(Hg - z)\ \rho g * g = (Ho - z)\ \rho o * g$ ……….(4)

Solve eq. (4) for Ho

$Ho = Hg * (\rho g/\rho o) + z\ [(\rho o - \rho g)/\rho o]$ ……. (5)

Where Hg is constant

Derivative equation (5) respect to **Ho**

$dHo = [(\rho o-\rho g)/\rho o]\ dz$ …….(6)

Darcy's law $Q = k\ A\ \Delta P / \mu\ L$ (for linear flow)'

Solving for oil flow:

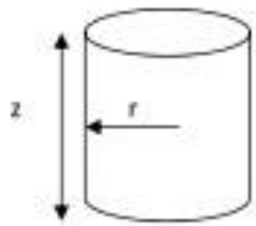
$Q \rightarrow Qo$

$k \rightarrow ko$

$L \rightarrow dr$

$\mu \rightarrow \mu o$

Radial area $\leftrightarrow A = 2\pi rz$



$\Delta P = \rho o\ g\ dHo$

Where $P = \rho\ g\ H$

Then Darcy's law →

$Qo = 2\pi\ \rho o\ g\ (ko/\mu o)\ z\ r\ (dHo/dr)$ ……. (7)

Substitute the value of (dHo) [i.e. eg.(6) in eq.(7)]

For radial flow

$Qo = 2\pi\ (\rho o - \rho g)\ g\ (ko/\mu o)\ z\ r\ (dz/dr)$ ………. (8)

$$Q\ \max = \int_{r_w}^{r_e} \frac{d}{r} = 2\ (\rho_o - \rho_g)\ g \left(\frac{K_o}{\mu_o}\right) z r \int_{(h-D_t}^{h} z d \quad \text{..........(9)}$$

$$Q\ \max = \pi g \left[\frac{\rho_o - \rho_g}{\ln\left(\frac{r_e}{r_w}\right)}\right] \cdot \left(\frac{K_o}{\mu_o}\right)[h^2 - (h - D_t)^2] \ldots\ldots (10)$$

Or in field units

$$Q\ \max = 0.001535 \cdot \left[\frac{\rho_o - \rho_g}{ln\left(\frac{r_e}{r_w}\right)}\right] \cdot \left(\frac{K_o}{\mu_o B_o}\right)[h^2 - (h - D_t)^2] \ldots\ldots (11)$$

Q_o max = maximum oil production rata without gas coning (critical rate), STB/day

ρ_o = oil density, gram/ cm³

ρ_g = gas density, gram/ cm³

r_e = drainage area radius, ft

r_w = well-bore radius, ft

k_o = oil permeability, md

μo = oil viscosity, cp

Bo = oil formation volume factor, bbl/STTB

h = thickness of oil zone (producing zone), ft

D_t = Depth from the original gas-oil contact to the top of the perforations, ft

h_p = Completion interval (Perforated interval), ft.

Example (1-1):

A vertical well is drilled in an oil reservoir overlaid by a gas cap. The related well and reservoir data are given below:

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

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

Oil density, $\rho_o = 47.5$ lb/ft³

Gas density, $\rho_g = 5.1$ lb/ft³

Oil viscosity, $\mu_o = 0.73$ cp

Oil formation volume factor, $B_o = 1.1$ bbl/day

Oil column thickness, $h = 40$ 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

Using Meyer, Gardner, and Pirson relationships, calculate the critical oil flow rate.

Solution

The critical oil flow rate for this gas-coning problem can be determined by applying equation (11). The following two steps summarize Meyer, Gardner, and Pirson methodology.

Step 1. calculate effective oil permeability, k_o

$k_o = k_{ro}\, k = 0.85 * 110 = 93.5$ md

Step 2. solve for Q_{oc} by applying equation (11)

$$Q_{max} = 0.001535 \cdot \left[\frac{\rho_o - \rho_g}{\ln\left(\frac{r_e}{r_w}\right)}\right] \cdot \left(\frac{K_o}{\mu_o B_o}\right)[h^2 - (h - D_t)^2] \ldots\ldots (11)$$

Q_{oc}=Qo max=0.001535[((47.5/62.4)-(5.1/62.4))/ln(660/0.25)](93.5/073*1.1) [40^2-$(40-25)^2$]

Q_{oc}=Qo max= 21.20 STB/day