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PREDICTING THE BEHAVIOR OF WATER AND GAS CONING IN HORIZONTAL WELLS

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The applications of horizontal well technology in developing hydrocarbon reservoirs have been widely used in recent years. One of the main objectives of using this technology is to improve hydrocarbon recovery from water and/or gas-cap drive reservoirs. The advantages of using a horizontal well over a conventional vertical well are their larger capacity to produce oil at the same drawdown and a longer breakthrough time at a given production rate.

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. Coning can seriously impact the well productivity and influence the degree of depletion and the overall recovery efficiency of the oil reservoirs.

Delaying the encroachment and production of gas and water are essentially the controlling factors in maximizing the field's ultimate oil recovery. Since coning can have an important influence on operations, recovery, and economics, it is the objective of this paper to develop a computer program for calculating the critical oil (or gas) rate to avoid coning of unwanted fluids into production wells and to predict the behavior of water and gas coning in horizontal wells.

Keywords: *predicting, coning, horizontal well, critical rate, time to breakthrough*

INTRODUCTION

Water or gas coning can adversely affect oil production in oil reservoirs and gas production in gas reservoirs. In oil reservoirs, a large oil rate can cause upward coning of water or downward coning of gas into the well perforations. Once gas or water is produced, the oil rate decreases and the cost of water and/or gas handling is increased [1].

It is a common industry practice to reduce water coning in oil reservoirs by perforating vertical wells as far above the oil water contact (OWC) as possible and to produce the wells at or below the critical oil rate. Similarly, wells are often perforated low in the oil column away from the gas-oil contact (GOC) in gas-oil reservoirs. The benefits of this practice which are mixed in that limited perforations may increase the pressure gradient (the drawdown) near the well, which can exacerbate coning. There has also been success in reducing coning with polymers and gels [2]. A more recent and novel approach is to use downhole water-sink technology (DWS) where water is produced separately from the oil using dual packers [3]. The water production below the

OWC may reduce upward water coning so that the oil rate can be increased. In this paper, a computer program was developed for Calculating the critical oil production rate, the time to breakthrough, and Determining the optimum placement of the horizontal well above the WOC.

HORIZONTAL WELL CRITICAL RATE

Critical rate is defined as the maximum allowable oil flow rate that can be imposed on the well to avoid a cone breakthrough [4]. Joshi [5] proposed the following relationships for determining the critical oil flow rate in horizontal wells:

For oil water system:

$$q_{OC}=0.0246\,x\,10^{-3}\frac{(\rho_w-\rho_0)k_h[h^2-(h-D_b)^2]}{\mu_0\beta_0\ln(r_e/r'_w)}\ . \tag{1}$$

For gas oil system:

$$q_{OC}=0.0246\,x\,10^{-3}\frac{(\rho_0-\rho_g)k_h[h^2-(h-D_t)^2]}{\mu_0\beta_0\ln(r_e/r'_w)}\ . \tag{2}$$

Where:

$$r'_w=\frac{\left[r_{eh}\frac{L}{2a}\right]}{\left[1+\sqrt{1-[L/(2a)]^2}\right][h/(2r_w)]^{h/L}} \tag{3}$$

$$r_{eh}=\sqrt{\frac{43560A}{\pi}} \tag{4}$$

$$a=(L/2)\left[0.5+\sqrt{0.25+(2r_{eh}/L)^4}\right]^{0.5} \tag{5}$$

HORIZONTAL WELL BREAKTHROUGH TIME

Critical flow rate calculations frequently show low rates that, for economic reasons, cannot be imposed on production wells. Therefore, if a well produces above its critical rate, the cone will break through after a given time period. This time is called time to breakthrough [4].

Papatzacos et al. [6] proposed a relationship that is based on semi analytical solutions for time development of a gas or water cone and simultaneous gas and water cones in an anisotropic, infinite reservoir with a horizontal well placed in the oil column:

$$t_{BT}=\frac{22758.528\,h\phi\,\mu_0\,t_{DBT}}{(\rho_w-\rho_n)\,k_v}\,. \tag{6}$$

In case of water or gas cone:

$$t_{DBT}=1-(3q_D-1)\ln\left[\frac{3\,q_D}{3\,q_D-1}\right] \tag{7}$$

In case of simultaneous gas and water cones:

$$\ln(t_{DBT})=c_0+c_1\ln q_D+c_2\ln q_D^{\,2}+c_3\ln q_D^{\,3} \tag{8}$$

The coefficients of the above polynomial are given in Table 2.1 (Appendix 1).

OPTIMUM PLACEMENT OF THE HORIZONTAL WELL ABOVE THE WOC

The optimum placement of the horizontal well above the WOC can be determined by applying the following expression:

$$D_b^{opt}=h\,\beta_{opt} \tag{9}$$

$$\beta_{opt}=c_0+c_1\ln q_D+c_2\ln q_D^{\,2}+c_3\ln q_D^{\,3}\,. \tag{10}$$

Where:

$$q_D=20333.66\,\mu_0\beta_0 Q_0/\left[L\,h(\rho_w-\rho_n)\sqrt{k_v k_h}\right]. \tag{11}$$

The coefficients of the above polynomial are given in Table 2.2 (Appendix 1).

RESULTS AND DISCUSSIONS

The rock, fluid, and the related reservoir properties of a bottom-water drive reservoir are given below in Table 1.

Once the data is input into the program, all the above calculations are carried out. The calculated critical rate is 52 bbl/STB. This is a low rate and for economic reasons, cannot be imposed on production wells. Therefore, if a well produces above its critical rate, the cone will break through after a given time period (time to breakthrough). From calculations, this time is 316 days at total flow rate of 1000 STB/day. the optimum placement of the horizontal well above the WOC is 28.25 ft.

Table 1

Input data

Length, ft.	1640
Well radius, ft.	0.3
Initial oil column thickness, ft.	50
Oil viscosity, cp	0.73
Oil formation volume factor, bbl/STB	1.1
Oil density, lb/ft^3	47.5
Water density, lb/ft^3	63.76
Horizontal permeability, md.	60
Vertical permeability, md.	15
Drainage radius of horizontal well, ft.	1489
Porosity, fraction	0.15
Gas density, lb/ft^3	9.1
Connate water saturation, fraction	0.25
Residual oil saturation, fraction	0.3

CONCLUSIONS

A computer program was developed to achieve the following objectives:

1. calculating the critical oil production rate in horizontal wells;
2. calculating the time to breakthrough;
3. determining the optimum placement of the horizontal well above the WOC.

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Nomenclature

ρ = density, lb/ft^3

k_h = horizontal density, md

k_v = vertical density, md

D_b = distance between the horizontal well and the WOC, ft

D_t = distance between the horizontal well and GOC, ft

r_w = wellbore radius, ft

Q_{oc} = critical oil rate, STB/day

L = length of the horizontal well

APPENDIX 1

Table 2.1

Coefficients for Breakthrough Time (Equation 8)

Ψ	c_0	c_1	c_2	c_3
0.2	-2.9494	-0.94654	-0.0028369	-0.029879
0.4	-2.9473	-0.93007	0.016244	-0.049687
0.6	-2.9484	-0.9805	0.050875	-0.046258
0.8	-2.9447	-1.0332	0.075238	-0.038897
1.0	-2.9351	-1.0678	0.088277	-0.034931
1.2	-2.9218	-1.0718	0.091371	-0.040743
1.4	-2.9162	-1.0716	0.093986	-0.042933
1.6	-2.9017	-1.0731	0.094943	-0.048212
1.8	-2.8917	-1.0856	0.096654	-0.046621
2.0	-2.8826	-1.1103	0.10094	-0.040963

Table 2.2

Coefficients for Optimum Well Placement (Equation 10)

Ψ	c_0	c_1	c_2	c_3
0.2	0.507	-0.0126	0.01055	-0.002483
0.4	0.504	-0.0159	0.01015	-0.000096
0.6	0.503	-0.0095	0.00624	-0.000424
0.8	0.502	-0.0048	0.00292	-0.000148
1.0	0.5	-0.0001	0.00004	0.000009
1.2	0.497	0.0042	-0.0026	0.000384
1.4	0.495	0.0116	-0.00557	-0.000405
1.6	0.493	0.0178	-0.00811	-0.000921
1.8	0.49	0.0231	-0.0102	-0.001242
2.0	0.488	0.0277	-0.01189	-0.001467