Production Simulation for Overpressure Gas Wells

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***Abstract*—In this paper, the simulation models of constant-volume closed overpressure gas reservoirs and water drive overpressure gas reservoirs were constructed basing on the pressure drop equations and the productivity equations, according to the features of overpressure gas wells and reservoirs. With these models, the pressure distributions of static fluid and flowing fluid in borehole were calculated respectively. The pressure distribution in borehole and formation of overpressure gas wells was simulated with computer and mathematical model techniques, through which the distortion and the variation process with pressure drop of reservoir rocks and overpressure gas well pressure, temperature, outflow, flow pattern etc. were both vividly described. The software, "Production Simulation System for Overpressure Gas Wells", was designed, which laid a foundation of the optimal control for single overpressure gas well and offered a more efficient method for the description of the production performance of overpressure gas reservoirs.**

Keywords-overpressure gas wells; gas reservoirs; pressure distribution; production performance; simulation

I. INTRODUCTION

In recent years, more and more rich overpressure gas fields were discovered and developed, for example, Kela 2 Gas Field in Tarim, carbonate formation in the east of South Sichuan province etc. There are many technical problems for the development of overpressure gas fields which we have to face and solve at first. Lots of problems have to be confronted in development process for overpressure gas reservoirs, as in [1], for example, the deformation analysis of rock stress sensitivity, aquifer influx calculation when the layer was subjected to reconsolidation, precise calculation for gas reservoir volume, forecast for high temperature and high pressure in layer, as in [2], the affection of condensate oil and sulfur in gas phase and so on, as in [3] to [5]. However, those problems seriously restrict rational and efficient development of overpressure gas reservoirs. Dynamic simulation and optimize control for single gas well are considered as a prerequisite to resolve those problems, as in [6]. This task group had accumulated abundant research experience of dynamic simulation and optimize control for ordinary gas well, HTHP gas well and condensate gas well. Being aimed at feature of overpressure gas wells, the fluid flow dynamics variation in formation and in borehole was imitated by computer simulation technique and mathematical technique. As the reservoir pressure drops, the variation process of overpressure gas well pressure, temperature, outflow, flow pattern etc. and the distortion process of reservoir rocks are vividly described in this paper. The system not only settles the fundament of optimal control for single overpressure gas well, but also offers a more efficient method to describe the production performance for overpressure gas reservoirs.

II. BOREHOLE PRESSURE SIMULATION

Pressure is the uppermost variable to control fluid flow dynamics change in borehole. Pressure has a close relation with not only the changes of other parameters in borehole, but also production equipment which includes design of bore frame. So, if only change process of borehole pressure is precisely described, the whole production process and design of production equipment would be reasonably controlled. It is special important to describe the pressure dynamic change for more complex overpressure gas wells. Generally speaking, because it is very difficult to send pressure gauge to bottom-hole for overpressure gas wells, bottom-hole pressure and formation pressure have to be calculated by wellhead pressure, as in [7].

In this paper, the pressure change along with well depth is represented by rectangle length and borehole pressure distribution form well-head to bottom-hole is simulated by computer simulation technique. Borehole pressure simulation includes static fluid pressure simulation and flow fluid pressure simulation in borehole.

A. Static Fluid Pressure Simulation in Borehole

When the gas well is closed, the gas column would stop flowing in borehole. The temperature and gas deviation factor along with well depth is negligible. Because the pressure from well-head to bottom-hole linearly varies with depth, static pressure distribution in borehole could be calculated form wellhead pressure as where *h* represents well depth, as in [7].

$$P = P_{ts} + \rho_g g h \tag{1}$$

Where, P is the pressure along with well depth, MPa. P_{ts} is static wellhead pressure, MPa. ρ_g is mixture density of gas, g/m^3. *h* is the depth of borehole, m.

B. Flow Fluid Pressure Simulation in Borehole

Suppose the gas well is vertical and the kinetic energy of flowing gas is negligible. Pressure distribution in borehole could be calculated from wellhead where borehole is divided into several segments. Fluid flow pattern in borehole is judged by pressure and correlation parameters in different well section. The fluid flow pattern includes single phase flow, mist flow, stratified flow, transition flow and dispersion flow. Where, P_{tf}

represents wellhead pressure, MPa . T_{wh} represents wellhead temperature, K . P_{wf} which would be calculated represents bottom-hole pressure, MPa .

Where $P_1 = P_{\mathrm{tf}}$, $T_1 = T_{\mathrm{wh}}$.

(1) Pressure drop (ΔP) is calculated by first casing section (ΔH).

The first value of $\Delta P^{(0)}$ is set when $H_1 = 0$.

① $\overline{P}$ (MPa), $\overline{T}$ (K) and $\overline{Z}$ are calculated in ΔH .

Where, $\overline{P}$ represents average pressure. $\overline{T}$ represents average temperature. $\overline{Z}$ represents average natural gas deviation factor.

②Subject to （ $\overline{P}$ 、 $\overline{T}$ ）, parameters which include μ_{g} , R_{s} , B_{o} , μ_{o} , μ_{w} , μ_{L} , δ_{L} , ρ_{g} , V_{sL} , V_{sg} , V_{m} , are calculated.

Where, μ_{g} represents natural gas viscosity. R_{s} represents natural gas solubility in oil. B_{o} represents oil volume coefficient. μ_{o} represents oil viscosity. μ_{w} represents water viscosity. μ_{L} represents liquid viscosity. δ_{L} represents gas-liquid surface tension. ρ_{g} represents gas density. V_{sL} represents liquid velocity. V_{sg} represents gas velocity. V_{m} represents gas-liquid velocity.

③ N_{FR} , λ_{L} , L_1 , L_2 , L_3 and L_4 are calculated.

Where, N_{FR} represents Furude coefficient. λ_{L} represents non-spondylolisthesis liquid holdup. L_1 , L_2 , L_3 and L_4 are non-dimensional limit number.

④Judging fluid flow pattern.

⑤Calculating liquid holdup (H_{L}).

⑥Calculating ρ_{m} and ρ_{n} .

Where ρ_{m} represents gas-liquid density. ρ_{n} represents non-spondylolisthesis gas-liquid density.

⑦Calculating friction resistance coefficient in diphase (f_{m}).

⑧Calculating ΔP . $\Delta P = \dfrac{10^{-6}(\rho_{\mathrm{m}} g + \dfrac{f_{\mathrm{m}} V_{\mathrm{m}}^2 \rho_{\mathrm{n}}}{2d})}{1 - \dfrac{\rho_{\mathrm{m}} V_{\mathrm{m}} V_{\mathrm{sg}}}{\overline{P} \times 10^6}} \times \Delta H$.

⑨comparing ΔP to $\Delta P^{(0)}$.

If $\left| \dfrac{\Delta P - \Delta P^{(0)}}{\Delta P} \right| > 0.01$, it should go to ①as $\Delta P^{(0)} = \Delta P$ and continue iteration until satisfy the accuracy.

If $\left| \dfrac{\Delta P - \Delta P^{(0)}}{\Delta P} \right| < 0.01$, it should go to ① as $H_1 = H_1 + \Delta H$, $P_1 = P_1 + \Delta P$, $T_1 = T_1 + \alpha \Delta H$ (α represents geothermal gradient)and calculate next section.

(2)There should keep on calculating every section until $H_1 = H$. $P_{\mathrm{wf}} = P_1$ will be gotten.

III. Formation Fluid Pressure Simulation

At the first, according to the accumulation features, overpressure gas reservoirs was divided into constant-volume closed overpressure gas reservoirs and water drive overpressure gas reservoirs. The most important basis which analyzes flow dynamic process of overpressure gas reservoirs is rock stresses sensitivity of reservoir strata, as in [8] and [9]. A quantity of simulation experiments for depletion-drive development show that overpressure gas reservoir rock will express strong stresses sensitivity in the development process, as in [10] and [11]. The effect that net overburden pressure acts on porosity and permeability is named stress sensitivity of porosity and stress sensitivity of permeability, as in [12].

In order to more vividly describe rock stresses sensitivity of reservoir strata and analyze dynamic changeable process of gas reservoirs, rock stresses sensitivity of reservoir strata and pressure dynamic changeable process are imitated by computer simulation technique.

A. The Simulation Model of Porosity Sensitivity

As formation effective stress rises, reservoir rock suffers reconsolidation that causes rock pore volume rapidly decreasing, as in [13].

There are two standpoints about decline rate that rock pore volume decreases with fluid pressure. One standpoint is that the decline rate of pore volume gradually increases with drops of pore pressure. The other standpoint is that the decline rate of pore volume acutely increases at first and gradually decreases later, as in [14].

On the basis of the porosity varied model as effective stress, two decline rates of pore pressure are simulated in this paper

$$\varphi_{\mathrm{e}} = \varphi_0 c P_{\mathrm{e}}^{-m} \tag{2}$$

Where φ_{e} is porosity under effective overburden pressure. φ_0 is original formation porosity. P_{e} is effective overburden pressure, MPa . *c* is coefficient. *m* is index.

B. The Simulation Model of Permeability Sensitivity

Permeability of reservoir rock rapidly decreases with drops of fluid pressure. On the basis of the permeability varied model as effective stress, change law of permeability is simulated in this paper.

$$K = K_0 c P_{\mathrm{e}}^{-m} \tag{3}$$

Where K is permeability under effective overburden pressure, $10^{-3} \mu m^2$. K_0 is permeability under original formation pressure, $10^{-3} \mu\mathrm{m}^2$.

C. The Simulation Model of Constant-volume Closed Gas Reservoirs.

The development process of constant-volume closed overpressure gas reservoirs are ordinarily divided into three sections. The first section is elastic development section that the pressure wave hasn't arrived boundary. The second section is that the pressure wave has arrived formation boundary and hasn't become stability condition. The third section is that all formation pressure equably decreases after pressure wave arriving boundary.

Reconsolidation of mudstone and shale around and elastic water influx of limited closed edge water are ignored to constant-volume closed gas reservoirs. The simulation model of constant-volume closed overpressure gas reservoirs is built in this paper.

- Pressure Drop Equation of Constant-volume Closed Gas Reservoirs

$$\frac{p}{Z}=\frac{p_i}{Z_i}\left(\frac{1-G_P/G}{1-C_e\Delta p}\right) \tag{4}$$

Where p is present formation pressure, MPa. p_i is original formation pressure, MPa. Z is gas compressibility factor under present pressure. Z_i is gas compressibility factor under original formation pressure. G_P is accumulation produced gas volume, m^3. G is the original geological reserve of gas, m^3. C_e is effective compressibility in formation.

- Gas Well Productivity Equation of Constant-volume Closed Gas Reservoirs

Based on the value of gas reservoir formation pressure, the development process of overpressure gas reservoirs is divided into two sections in this paper. The first section is overpressure stage (pressure coefficient ≥ 1.5) and this stage is described by trinomial productivity equation. The other section is high pressure stage ($1.2 \leq$ pressure coefficient < 1.5) and this stage is described by binomial productivity equation.

$$\begin{aligned}&\bar{p}_R^2-p_{wf}^2=aq+bq^2+cq^3 \quad \text{pressure coefficient} \geq 1.5\\ &\bar{p}_R^2-p_{wf}^2=aq+bq^2 \quad 1.2 \leq \text{pressure coefficient} \leq 1.5\end{aligned} \tag{5}$$

Where q is gas production, m^3/d. $\bar{p}_R$ is average formation pressure, MPa. p_{wf} is bottom-hole pressure, MPa. *a*, *b* and *c* are productivity equation coefficients.

D. The Simulation Model of Water Drive Gas Reservoirs

When the volume of edge water in overpressure gas reservoirs is comparatively large, water influx of gas reservoirs must be considered in development process. The simulation model of overpressure gas reservoir with water drive is established in this paper.

- Pressure Drop Equation of Water Drive Gas Reservoirs

$$\frac{p}{Z}=\frac{p_i}{Z_i}\left(\frac{1-G_P/G}{1-C_e\Delta p-\dfrac{W_e-W_PB_W}{GB_{gi}}}\right) \tag{6}$$

Where W_e is accumulation gas water influx, m^3. W_P is accumulation produced water volume, m^3. B_W is volume factor of formation water. B_{gi} is original volume factor of gas.

Water influx is calculated by unsteady water flow model of Van-Hurst and limited water model of Fetkovich.

Unsteady water flow model of Van-Hurst:

$$W_e=C_V\sum_0^t \Delta p_e Q_D(t_D) \tag{7}$$

Where C_V is water influx factor. t_D is dimensionless time. $Q_D(t_D)$ is dimensionless water influx. Δp_e is effectively formation pressure drop on internal boundary of gas reservoir (the average gas reservoir), MPa.

Limited water model of Fetkovich:

$$W_e=V_aC_e(p_i-\bar{p}_a) \tag{8}$$

Where $\bar{p}_a$ is average pressure of water, MPa. V_aC_e is water influx factor about water.

Gas Well Productivity Equation of Water Drive Gas Reservoir

The gas well productivity equation of water drive gas reservoir is the same as the gas well productivity equation of constant-volume closed gas reservoir.

IV. THE DESIGN OF "PRODUCTION SIMULATION SOFTWARE FOR OVERPRESSURE GAS WELLS" AND EXAMPLE

The basic idea of computer simulation, which is used by numerical analysis and computer simulation, completes some kinds of processes and operational aspect. Then, the important information of statistics and strategic decision is obtained by computer simulation. In this paper, the pressure distribution in borehole and in formation for overpressure gas wells has been imitated by computer technique and mathematical technique. So, the software, "Production Simulation Software for Overpressure Gas Wells", was designed. The main function of this software includes borehole pressure simulation and formation fluid pressure simulation. The software structure and function are description in Fig. 1.

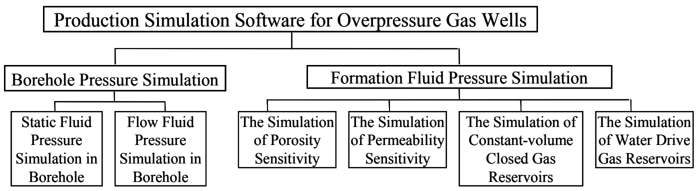

Figure 1. The software structure and function for production simulation of overpressure gas wells

For example, one overpressure gas well in one gas field was used to illustrate the process of production simulation. The overpressure gas reservoir where the gas well locates in contains edge water and condensate oil. The depth of gas reservoir is 3722m. The original reservoir pressure is 69.3MPa. The original reservoir pressure coefficient is 2.12. The temperature in middle of gas reservoir is 106℃. The reservoir effective thickness is 11.7m. The effective permeability is $1.62\times10^{-3}\mu m^2$. The radius of well is 0.07m and the supply radius is 870m. The relative density of natural gas is 0.661. The relative density of condensate oil is 0.796. The relative density of formation water is 1.002. The gas-water interfacial tension is $0.76N \cdot m$. The tubing diameter is 0.062m and gas tap diameter is 3mm. The wellhead temperature is 29℃. The skin factor is -5.31. The gas production is $115\times104m^3/d$. The oil production is 0.23t/d. The water production is 0.06t/d.

First, input parameters of the gas well and let rectangular length represent pressure changes. Then the borehole simulation picture for fluid flow pressure distribution in anytime would be calculated by computer and fluid flow pattern in borehole also would be judged at the same time in Fig. 2. Meantime, the change picture for formation pressure, bottom-hole pressure and wellhead pressure as time would also be calculated in any time stage in Fig. 3.

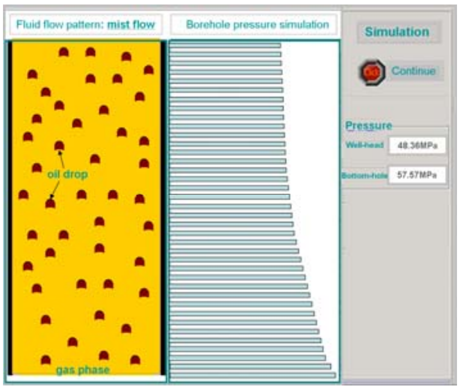

Figure 2. Fluid flow pattern and pressure simulation picture in borehole for any time

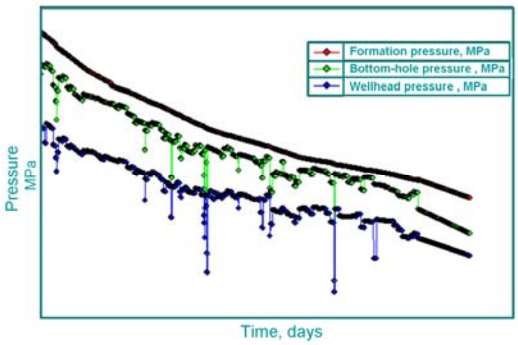

Figure 3. The change picture for formation pressure, bottom-hole pressure and wellhead pressure as time

V. CONCLUSIONS

(1) Because of high pressure in borehole, it is very difficult to send pressure gauge towards bottom-hole. Generally speaking, bottom-hole pressure is calculated by wellhead pressure which is read by wellhead gauge. The pressure distribution of static fluid and flowing fluid in borehole has been calculated by computer simulation technique in this paper. Meanwhile, fluid flow pattern in borehole is also judged.

(2) Rock stresses sensitivity of overpressure gas reservoir has analyzed in this paper. Basing on the pressure drop equations and the productivity equations, the simulation models of constant-volume closed overpressure gas reservoirs and water drive overpressure gas reservoirs have been established. Rock stresses sensitivity of reservoir strata and pressure dynamic changeable process are imitated by computer simulation technique and mathematical simulation technique.

(3) The software, "Production Simulation Software for Overpressure Gas Wells", was designed. The software not only analyzes single well dynamic for overpressure gas well, but also settles the fundament of optimal control for single overpressure gas well and offers a more efficient method to describe the production performance for overpressure gas reservoirs.

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REFERENCE

[1] W.P. Steven, and Robert R B, Overpressured Gas Reservoirs. Texas, CA: Society of Petroleum Engineers Inc, 1997.

[2] D.J. Hammerlindl, "Predicting gas reserves in abnormally pressured reservoirs", Fall Meeting of the Society of Petroleum Engineers of AIME. New Orleans, Louisiana, pp. 652-659, October 1971.

[3] A.T. Becerra, Analysis of Abnormally Pressured Gas Reservoirs. Texas, CA: PhD dissertation, 1993.

[4] T.F. Begland, and W.R. Whitehead, "Depletion performance of volumetric high-pressured gas reservoirs," SPE Reservoir Engineering. vol.4, pp. 279-282, August 1989.

[5] A.T. Bourgonyne, "Shale water as a pressure support mechanism in super pressure reservoirs," Abnormal Subsurface Pressure Symposium. Baton Rouge, Louisiana, pp. 787-805, May 1972.

[6] Z.B. Liu, L.Z. Lu, and J.Z. Zhao, "Experiment and model of rock stress sensitivity for abnormal high pressure gas reservoirs," Natural Gas Industry, vol.25, pp. 124-126, February 2005.

[7] S.L. Li, Natural Gas Egineering. Beijing, CA: Petroleum Industry Press, 2000

[8] Q.Y. Mei, "Study and application of performance prediction method for overpressure gas reservoir," Southwest Petroleum University. Chengdu, pp. 1-56, June 2006.

[9] W.Z. Tian, "The new method of material balance and production decline for abnormally high pressure gas condensate reservoirs," Southwest Petroleum University. Chengdu, pp. 1-64, June 2005.

[10] T.W. Jiang, M.L. Tang, and X.J. Xiao, "Study on stress sensitivity of the particular low permeability reservoir in Dina 2 gas field of Tarim Basin," Acta Sedimentologica Sinica, vol. 25, pp. 949-953, December 2007.

[11] X.H. Wang, and Y. Song, "Transforming laws of rock compressibility," Journal of Oil and Gas Technology, vol. 29, pp. 42-44, January 2007.

[12] W.L. Gao, "Evaluation for rock compression coefficient stresses sen jiang sitivity of high pressure cas reservoirs in Dina 2," Petroleum Geology and Engineering, vol. 21, pp. 75-76, January 2007.

[13] J.X. Huang, S.M. Peng, and S.W. Huang, "Research of reservoir property stress sensibility of abnormal high pressure gas reservoir," Journal of Xi ' an Shiyou University, vol. 23, pp. 621-624, August 2005.

[14] S.L. Yang, X.Q. Wang, and D.G. Wang, "Experiment and model of rock stress sensitivity for abnormal high pressure gas reservoirs," Natural Gas Industry, vol. 25, pp. 107-109, February 2005.