

Production Composition Model of Fractured Horizontal Wells in Shale Gas Reservoirs

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Abstract. Multi-stage fractured horizontal wells play an important role in developing shale gas reservoirs by significantly improving productivity. With the introduction of nonlinear desorption into matrix governing equations, a numerical model is developed to study the production composition of fractured horizontal wells in shale gas reservoirs. The results show that the production composition is majorly influenced by matrix permeability of inner zone, and spacing of secondary fractures.

1. Introduction

Shale gas is an unconventional natural gas resource which is hard to develop, and its commercial development requires multi-stage fracture and high investment. It is of great theoretical and practical significance to develop production composition model to investigate the contribution of desorption in every development stage.

2. Introduction of nonlinear desorption

2.1. Productivity Equation

Multi-stage fractured horizontal well is important for efficient exploitation of shale reservoirs, especially the horizontal well with SRV, which tremendously increases the productivity of shale gas producers. With the use of Laplace transformation, the productivity equation of multi-stage fractured horizontal wells can be expressed as follows:

$$\bar{q}_D = \frac{\sqrt{sf(s)}}{2\pi s} \frac{1 - e^{-\gamma_{FD}}}{\gamma_{FD}} \frac{\frac{\sqrt{s\eta_D}}{\xi} \{ \cosh[\sqrt{sf(s)} \cdot y_{FD}] - s_c \frac{\gamma_{FD}}{(1 - e^{-\gamma_{FD}})} \} + \sqrt{sf(s)} \sinh[\sqrt{sf(s)} \cdot y_{FD}]}{\frac{\sqrt{s\eta_D}}{\xi} \sinh[\sqrt{sf(s)} \cdot y_{FD}] + \sqrt{sf(s)} \cosh[\sqrt{sf(s)} \cdot y_{FD}]} \quad (1)$$

In which,

$$\begin{cases} f(s) = \omega_F + \frac{\lambda_{Ff}}{3s} \sqrt{sf_f(s)} \tanh[\sqrt{sf_f(s)}] \\ f_f(s) = \frac{3\omega_f}{\lambda_{Ff}} + \frac{\lambda_{fm}}{\lambda_{Ff}} \sqrt{\frac{3\omega_m}{\lambda_{fm}s}} \tanh \sqrt{\frac{3s\omega_m}{\lambda_{fm}}} \end{cases} \quad (2)$$



2.2. Nonlinear Desorption Equation

Material balance principle of gas reservoir engineering can be utilized to determine the average reservoir pressure in different moments:

$$\frac{\bar{p}_m}{z_g(\bar{p}_m)} = \frac{p_i}{z_g(p_i)} \left(1 - \frac{G_p}{G}\right) \quad (3)$$

In which, $\bar{p}_m$ means average matrix pressure in certain moment, MPa; p_i means initial matrix pressure, MPa; G_p and G means cumulative production and geological reserves, m^3 .

For gas viscosity and comprehensive compressibility are the functions of average reservoir pressure, pseudo-time can be introduced as follows:

$$t_a = \int_0^t \frac{\mu_{gi} c_{tmi}}{\mu_g(\bar{p}_m) c_{tm}(\bar{p}_m)} dt \quad (4)$$

Because physical parameters, such as compressibility, density and viscosity, are the function of average pressure and they should be determined before calculation. The specific calculation has been elaborated in previous theses.

Each control equation can be transformed into linear equation with pseudo-time t_a . Take control equation of inner matrix for example:

$$\frac{\partial^2 \psi_m}{\partial x^2} = \frac{\varphi_m \mu_{gi} c_{tmi}}{k_m} \frac{\partial \psi_m}{\partial t_a} \quad (5)$$

For model with slab fractures and with fracture network, two new dimensionless pseudo-time should be introduced into productivity models:

$$t_{Da} = \frac{0.0864 k_F t_a}{\mu_{gi} (\varphi_m c_{tmi} + \varphi_f c_{tff} + \varphi_F c_{tFi}) A_{cw}} \quad (6)$$

With the introduce of dimensionless pseudo-time, the model for fractured horizontal wells with slab fractures and the model for fractured horizontal wells with fracture network can be transformed into linear form, and their general solution of productivity is in the same form of linear solution. However, the calculated solution is on the condition of dimensionless pseudo-time, which means it must be transformed into real form.

Because changing real time into pseudo-time requires average pressure in different moments, and average pressure is associated with production rate as well as cumulative production which require pseudo-time for calculation, the whole calculated process of all parameters is closed and different parameters have mutual influence, requiring iterative method for solution. The process of iterative method is shown as Fig.1: a) Initialization of parameters including fundamental parameters of gas and reservoir. b) With the use of general productivity equations of slab fractures or network model, calculating dimensionless production rate with Steffest numerical inversion in every dimensionless time step. c) Assume average reservoir pressure $\bar{p}_m$ as in current time step. d) Calculate gas physical parameters under current reservoir pressure, including compressibility, density and viscosity. e) Calculate real time and real production rate and gas physical parameters. f) Calculating real cumulative production. g) Calculating new average reservoir pressure $\bar{p}_m'$. h) Repeat steps from c) to g) until the

difference of $\bar{p}_m'$ and last $\bar{p}_m$ meets requirement of accuracy. i) Calculate composition of production rate in current time step with real average reservoir pressure. j) Calculate the next time step until the whole calculating process ends.

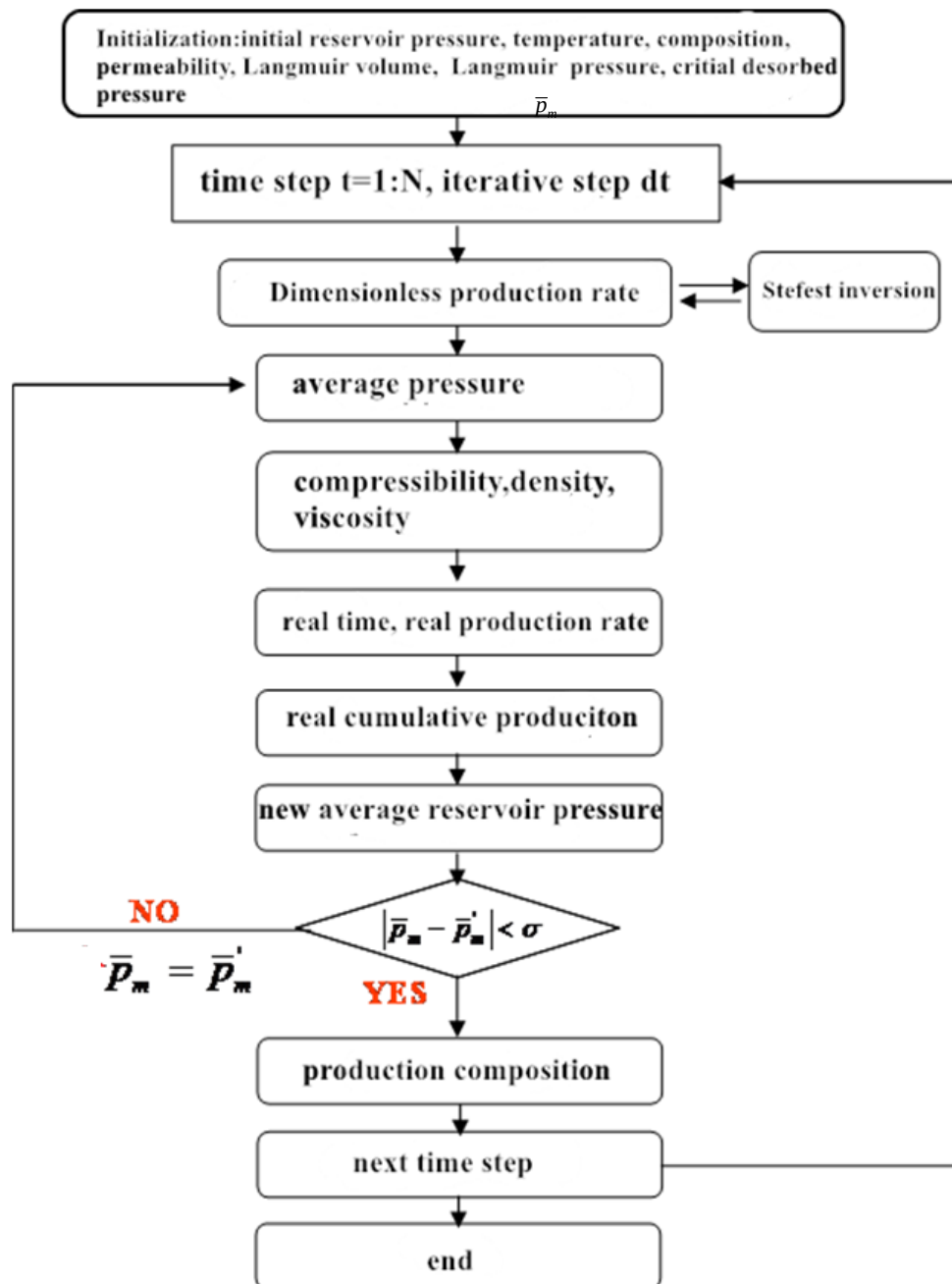


Figure 1. Flow chart of iteration for production composition model

If real average reservoir pressure is worked out, the proportion of desorbed gas can be calculated. Owing to depletion development of shale gas reservoir, the proportion of desorption compressibility equals to the proportion of desorption gas. The relationship of the total compressibility c_{tm} with average reservoir pressure can be represented as follows:

$$c_{tm}(\bar{p}_m) = c_{pm} + c_g(\bar{p}_m) + \frac{z(\bar{p}_m)p_{sc}T}{\phi_m Z_{sc} T_{sc}} \frac{V_L p_L}{\bar{p}_m (p_L + \bar{p}_m)^2} \quad (7)$$

The relationship of desorption compressibility c_d with average reservoir pressure can be represented as follows:

$$c_d(\bar{p}_m) = \frac{z(\bar{p}_m)p_{sc}T}{\phi_m Z_{sc} T_{sc}} \frac{V_L p_L}{\bar{p}_m (p_L + \bar{p}_m)^2} \quad (8)$$

The proportion of absorbed gas production to the whole gas production can be represented as follows:

$$R_a = \frac{c_d(\bar{p}_m)}{c_{tm}(\bar{p}_m)} \times 100\% \quad (9)$$

3. Production composition of model with fracture network

The production composition can be analysed with parameters in Table 10. Fig.2 shows the effect of matrix permeability of inner zone on production composition of horizontal wells. Higher matrix permeability of inner zone can increase flowing capacity of both free gas and desorbed gas, and accelerate spread of pressure drop in inner matrix, which is helpful for the desorption of absorbed gas.

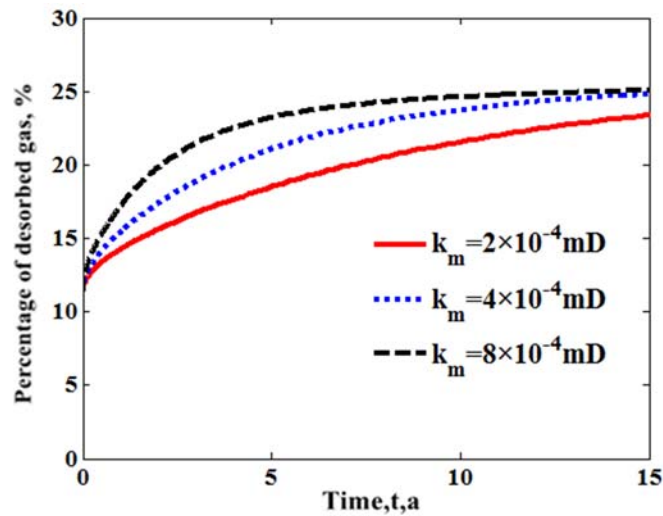


Figure 2. The effect of matrix permeability of inner zone on production composition

Fig.3 shows the effect of outer matrix permeability on production composition of horizontal wells. Higher matrix permeability of outer zone increases accelerates spread of pressure drop in inner matrix, which is helpful for the release of absorbed gas. However, the influence of matrix permeability of outer zone is less than that of inner matrix.

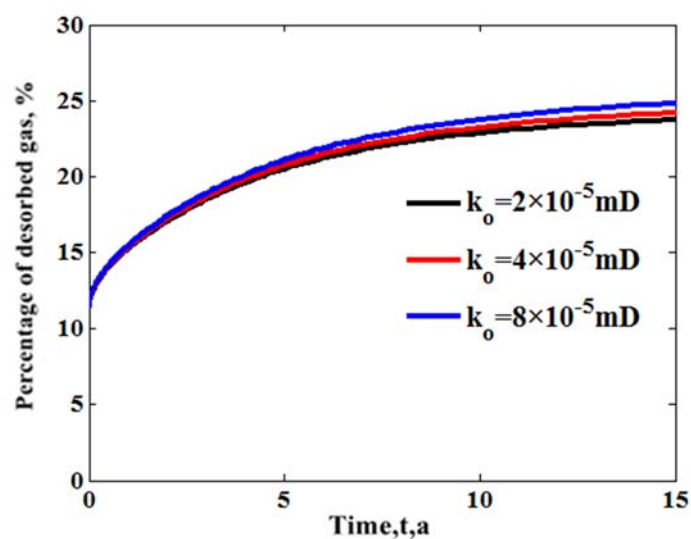


Figure 3. The effect of matrix permeability of outer zone on production composition of horizontal wells

Fig.4 shows the effect of fracture length of primary fracture on production composition of horizontal wells, on the condition of the same amount of secondary fractures. It is evident that fracture length of primary fracture exerts great influence on production composition of fractured horizontal wells. Longer primary fracture decreases spacing of secondary fractures and helps mutual interference of secondary fractures, which has the same effect of closed boundary and results in fast drop of average pressure as well as the desorption of absorbed gas.

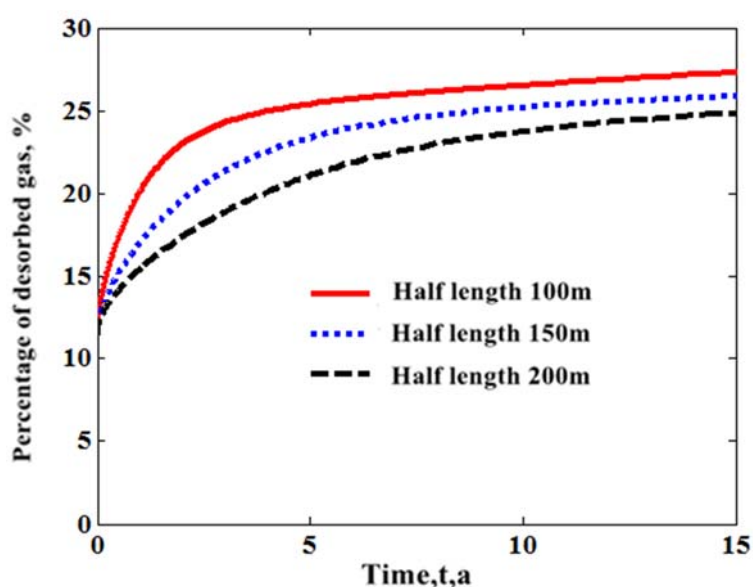


Figure 4. The effect of half-length of primary fracture on production composition of horizontal wells

Fig.5 shows the effect of induced fracture spacing on production composition of horizontal wells on the condition of the same half-length of primary fracture. Smaller induced fracture spacing helps mutual interference of secondary fractures and facilitates the desorption of absorbed gas.

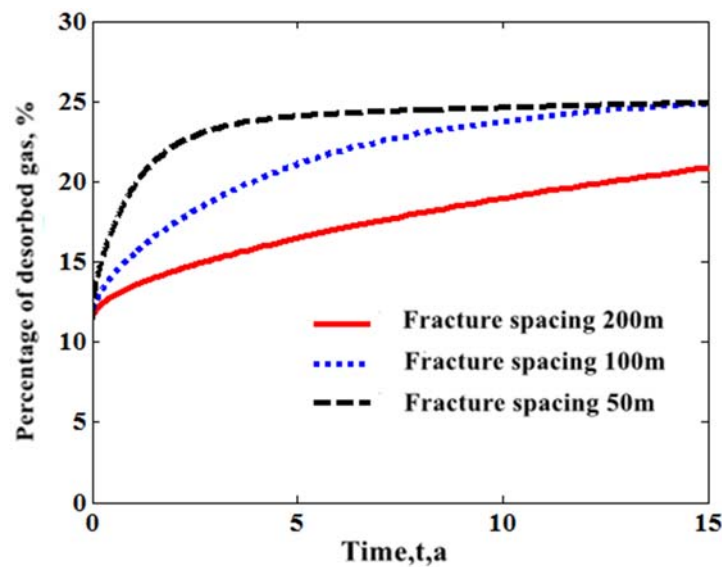


Figure 5. The effect of induced fracture spacing on production composition of horizontal wells with fracture

4. Conclusion

With the introduction of nonlinear desorption into matrix control equations, production composition of fractured horizontal shale gas wells in different moments is deeply analysed with material balance principle and iterative method. The production composition of fracture network model is majorly influenced by matrix permeability of inner zone and spacing of secondary fractures.

Acknowledgments

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