IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Study on unsteady seepage characteristics and EUR evaluation methods of tight channel sandstone gas reservoirs

To cite this article: Honglin Xiao *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **859** 012030

Study on unsteady seepage characteristics and EUR evaluation methods of tight channel sandstone gas reservoirs

Honglin Xiao*, Mingqiu Li, Benjian Zhang, Haibo Deng, Desheng Jiang, Hao Luo

PetroChina Southwest Oil & Gas Field Company, China

*Corresponding author e-mail: flcxhl@sohu.com

Abstract. Tight channel sandstone gas reservoirs have the characteristics of strong heterogeneity, low porosity and permeability, and slow formation energy supply in the later stage of mining. In the process of gas well development, the initial production deceleration rate is fast, the later production deceleration rate is slow, and the EUR prediction result is large in error. In response to the above problems, this paper starts from the perspective of seepage mechanics, establishes a EUR evaluation mathematical model, derives the staged fractured horizontal well pressure response model and productivity model, predicts future production performance based on the production instability method, and uses Topaze The production analysis software adopts the method of production instability analysis to simulate and analyze the single well controlled reserves at different production times in stages, which further confirms the change process. The research results of this paper have certain guiding significance for predicting and analyzing single-well EUR.

Keywords: Tight sandstone; Unstable seepage; Production decline; EUR.

1. The introduction

Tight sandstone gas reservoir geological condition is complex, a poor reservoir property, strong heterogeneity, has the obvious low porosity, low permeability and low production, low abundance, cause in the process of gas well drilling, the early production decline rate is fast, the late production decline rate is slow, EUR prediction result error is bigger, the decline rate of the gas reservoir is not constant, etc. [1], Therefore, the EUR evaluation of tight channel sandstone gas reservoirs is more complicated than that of conventional gas reservoirs.

The current research on the production decline rule of dense river sandstone gas reservoir has been more research methods, including traditional production decline analysis method and the modern production decline analysis method, but the traditional method of production decline and the modern production decline method cannot solve the problem of tight sandstone gas reservoir decline rate change, therefore, in this paper, starting from seepage flow mechanics theory,Combined with the scene of the geological features and production performance [2], through the establishment of the tight sandstone gas reservoir staged fracturing of horizontal seepage physical model, deduce the staged fracturing of horizontal seepage bottom hole pressure response model and the model of production, based on the unstable production method and the basis of the principle of material balance, on the basis of the history of gas well production dynamic analysis, dynamic forecast on the future production,Obtained to predict the final parameters such as gas well of the accumulative gas production, formation pressure [3-5], with the analysis of Topaze production software, by the method of production is not stable, simulation analysis and calculation of different production time in stages of single well controlled reserves, further confirms the change process of dense gas well single well controlled reserves and laws, the research results show thatThe calculated results can reach more than 80% of the final predicted recoverable reserves. This understanding of the law also provides direct guidance for the subsequent calculation of gas well EUR in tight channel sandstone gas reservoirs and has certain guiding significance for predicting and analyzing a single well EUR.

2. Block profile

In 2013, EOG company reanalyzed and demonstrated the old data, and found the gas reservoir of Shaximiao Formation in Bajiaochang gas field through the upper test Jiao 62B well, which produced $6.0\times10^4m^3/d$ of gas, $3.5m^3/d$ of oil, and $0.5m^3/d$ of water in the initial stage after the well was put into production. Given the gas potential of Shaximiao Formation, 8 Wells, including Jiao63-1, Jiao 63-2, Jiao 61-3, Jiao 61-4, Jiao 62-1, Jiao 62-1, Jiao 62-1, Jiao 72, Jiao 73, have been drilled successively, and 6 Gas Wells have been drilled, which proves that she xi Miao Formation has certain development potential.

In 2018 (during THE EOG operation), the proved reserves of Sha2 gas reservoir (EOG38 sand body) of Bajiaochang Gas field passed the evaluation of the State Reserve Commission, with a newly calculated area of $10.32km^2$, proved reserves of natural gas of $18.8\times10^8m^3$, and proved reserves of condensate of 5.93×10^4t.

As of December 2019, 40 Wells (25 in Xu4 gas reservoir and 15 in Shaximiao Formation gas reservoir) and 20 Wells (5 in Xu4 gas reservoir and 15 in Shaximiao Formation gas reservoir) have been put into production in the Bajiaochang gas field, with a daily output of $119.9\times10^4m^3/d$ of gas, $16.35m^3/d$ of oil and $3.5m^3/d$ of water. Accumulated gas production is $26.11\times10^8m^3$, accumulated oil production is $5.81\times10^4m^3$, accumulated water production is $1.38\times10^4m^3$. The main developed strata are Shaximiao Formation.

3. EUR evaluation mathematical model

Figure 1 describes the physical seepage model of a multi-stage fractured horizontal well in a tight sandstone gas reservoir. The top and bottom of tight sandstone gas reservoir are closed boundaries, and the distance of the closed outer boundary is Re; the height of tight sandstone gas reservoir is H; the length of the horizontal well is 2L; the distance between horizontal well and floor is Zw; the horizontal well is fractured according to N stages, and the single-stage length is Li.

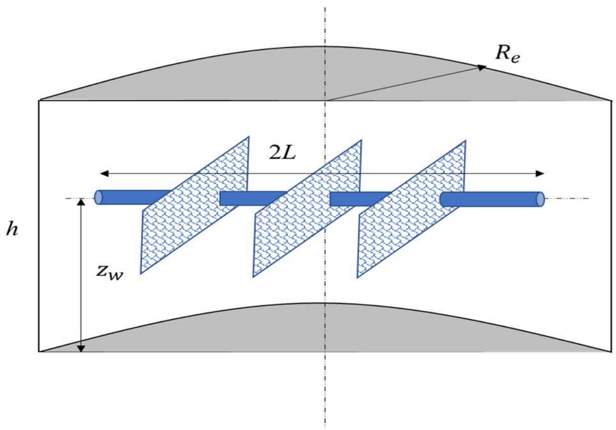

Figure 1. Schematic diagram of staged fracturing for tight sandstone gas reservoirs

The basic instantaneous point source solution of tight sandstone gas reservoir is:

$$\bar{\gamma} = \frac{1}{2\pi Z_{eD}}\left[K_O(R_D\sqrt{u}) + 2\sum_{n=1}^{n=\infty} K_0\left(R_D\sqrt{u+\frac{n^2\pi^2}{Z_{eD}{}^2}}\right) cos\left(n\pi\frac{Z_D}{Z_{eD}}\right) cos\left(n\pi\frac{Z_D{}'}{Z_{eD}}\right)\right] \tag{1}$$

Firstly, the wellbore pressure response can be obtained by integrating along the wellbore square:

$$\overline{\psi_D}(x_D, y_D) = \frac{1}{2u}\int_{-1}^{1} K_o\left[\sqrt{u}\sqrt{(x_D-\alpha)^2+y^2{}_D}\right]d\alpha \tag{2}$$

The seepage mathematical model of tight sandstone gas reservoir with an asymmetrical two-wing fracture is as follows:

$$\bar{\psi}_D(x_D, y_D) = \frac{1}{2u}\int_{-1}^{1} K_o\left[\sqrt{u}\sqrt{(x_D-\alpha)^2+y^2{}_D}\right]d\alpha \tag{3}$$

Through multi-fracture superposition, the equations of the seepage mathematical model of multi-stage fractured horizontal well in tight sandstone gas reservoir can be obtained:

$$\begin{cases} \tilde{q}_1\bar{\psi}_{D1}(X_{WD}, Y_{WD}, u) + \tilde{q}_2\bar{\psi}_{D2}(X_{12D}, Y_{12D}, u) + \ldots + \tilde{q}_n\bar{\psi}_{D3}(X_{1nD}, Y_{1nD}, u) = \tilde{P}_{wf} \\ \tilde{q}_1\bar{\psi}_{D1}(X_{21D}, Y_{21D}, u) + \tilde{q}_2\bar{\psi}_{D2}(X_{WD}, Y_{WD}, u) + \ldots + \tilde{q}_n\bar{\psi}_{D3}(X_{2nD}, Y_{2nD}, u) = \tilde{P}_{wf} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \tilde{q}_1\bar{\psi}_{D1}(X_{n1D}, Y_{n1D}, u) + \tilde{q}_2\bar{\psi}_{D2}(X_{n2D}, Y_{n2D}, u) + \ldots + \tilde{q}_n\bar{\psi}_{D3}(X_{WD}, Y_{WD}, u) = \tilde{P}_{wf} \\ \tilde{q}_1 + \tilde{q}_2 + \ldots + \tilde{q}_n = 1 \end{cases} \tag{4}$$

After the production term distribution of different stages is calculated, the seepage bottom hole pressure response model and production model of multi-stage fractured horizontal Wells can be obtained.

$$\overline{\psi_{wf}} = \overline{q_1}\overline{\psi_D}(x_{WD}, y_{WD}, 0) + \overline{q_2}\overline{\psi_D}(x_{12D}, y_{12D}, 0) + \ldots + \overline{q_n}\overline{\psi_D}(x_{1nD}, y_{1nD}, 0) \tag{5}$$

4. Single well EUR evaluation method

The production instability method is based on the theoretical basis of Blasingame et al. and applies the material balance principle to predict the future production performance based on analyzing the historical production performance of gas Wells [3-6]. It is mainly applicable to single well. According to the basic static parameters of the single well, the geological model of the single well is established, and then by fitting the production history data of the gas well, whether the established model is in line with the actual geological situation of the gas well is tested. After obtaining reliable fitting, parameters such as dynamic reserves, reservoir permeability, skin coefficient, and discharge area controlled by gas Wells are obtained. According to the established geological model, the future production model is set up, the production performance of the gas well under the set production mode is predicted, and the cumulative gas production, formation pressure, and other parameters of the gas well at the end of the forecast are obtained.

The reservoir properties, actual production history, and typical curve analysis considered in this method can be calculated for different production stages, and the method has good adaptability. Typical well: For Jiao 61-3 well, production data processing, theoretical characteristic curve analysis, single well model and fitting analysis, formation physical property calculation, and single well-controlled reserves prediction were carried out, and the single well-controlled reserves were calculated to be 1.22 $\times 10^8 m^3$.

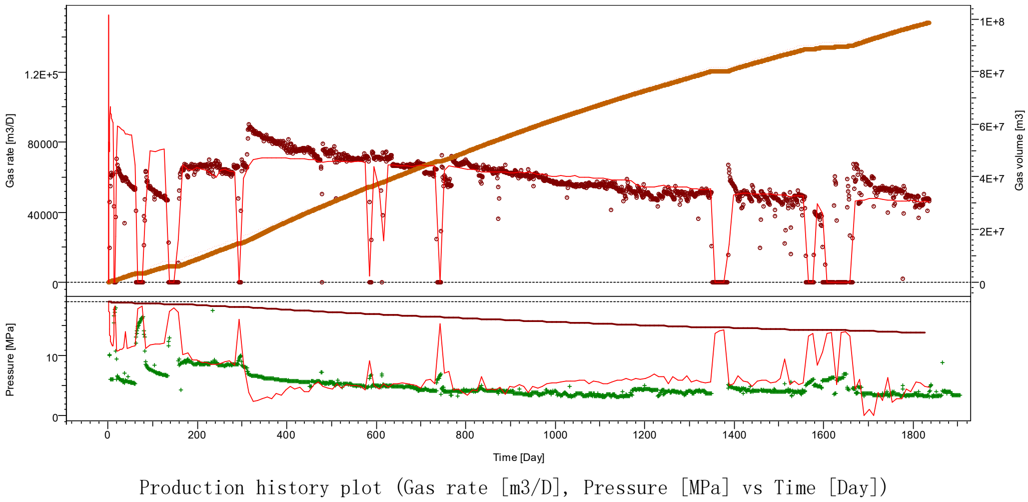

Figure 2. Production history fitting analysis curve of Well Jiao 63-1 in Shaximiao Formation gas reservoir of Bajiaochang

5. Different production time EUR calibration plate

Due to the influence of low permeability in tight sandstone gas reservoirs, fluid seepage and pressure conduction information are relatively slow, which directly proves that pressure recovery in shut-in is difficult to achieve stability in a long time. Therefore, the control range of the gas well is relatively small in the early stage of production, and the calculated control reserves of the single well are small. With the increase of production time, the control of the single well keeps expanding, and the total is close to the final recoverable reserves of the single well.

With the help of Topaze production analysis software, the method of production instability analysis was used to simulate and calculate the single-well controlled reserves of different production times by stages, which further verified the changing process and rules of the single-well controlled reserves of tight gas Wells. See Figure 3 to Figure 4.

Typical well: Jiao 61-3, the single-well controlled reserves of 1 year, 2 years, 3 years, and 5 years after production were calculated respectively. According to the change curve, the increase of single-well controlled reserves slowed down in the later period and approached the final single-well recoverable reserves. This rule has a certain guiding significance for predicting and analyzing single-well EUR.

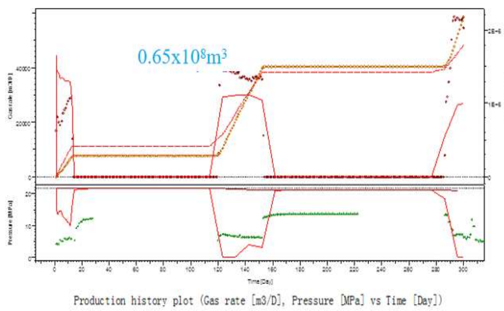

Figure 3. Fitting analysis curve of Jiao 61-3 well production history (1 year)

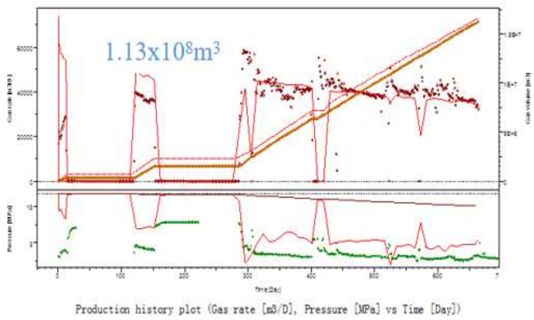

Figure 4. Fitting analysis curve of Jiao 61-3 well production history (2 years)

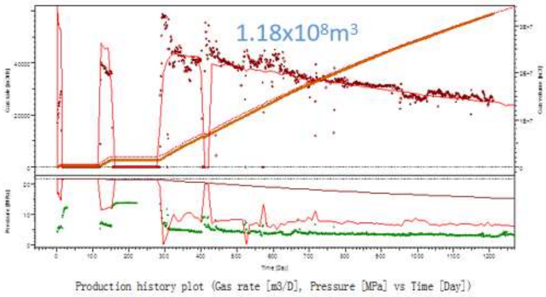

Figure 5. Fitting analysis curve of Jiao 61-3 well production history (3 years)

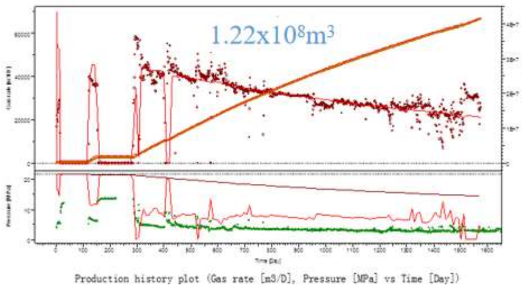

Figure 6 Fitting analysis curve of Jiao 61-3 well production history (5 years)

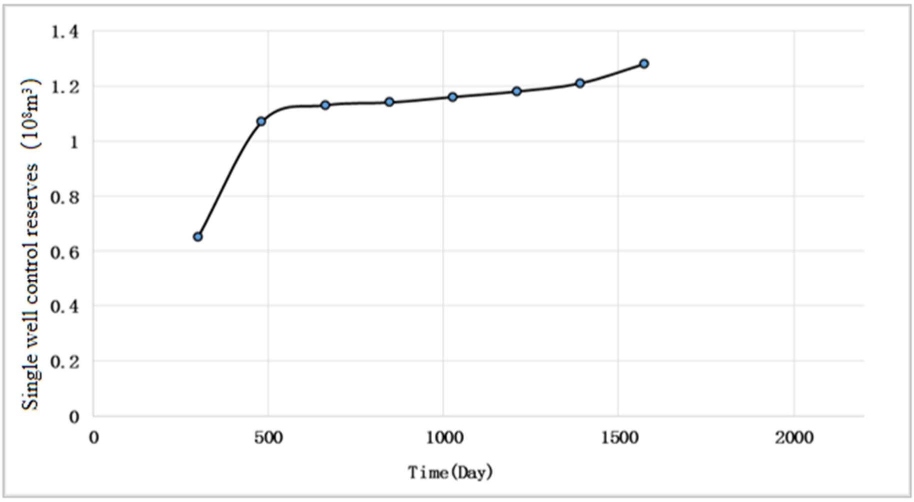

Figure 7. The single-well controlled reserves of Jiao 61-3 vary with time

Further, according to the unstable production analysis method, the controlled reserves of the 8 Wells with long production time in organize fields at different stages were calculated respectively, and the relationship between the controlled reserves of the single well and the production time was analyzed (FIG. 8-9).

By changing curve can be seen that as the extension of production time, gas well control increases gradually, increase the single well-controlled reserves, different production stages dynamic reserves predicted results vary, but when the gas well production more than 2 years in a row, the calculation results more reliable, can reach the final settlement results to predict recoverable reserves by more than 80%. The understanding of this rule also provides direct guidance for the subsequent EUR calculation of tight gas Wells in Qiulin and Jinhua blocks.

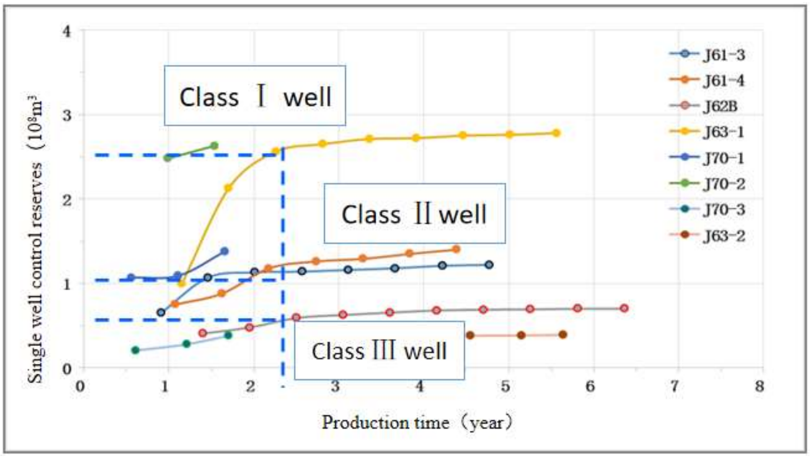

Figure 8. Change curves of controlled reserves in different production stages

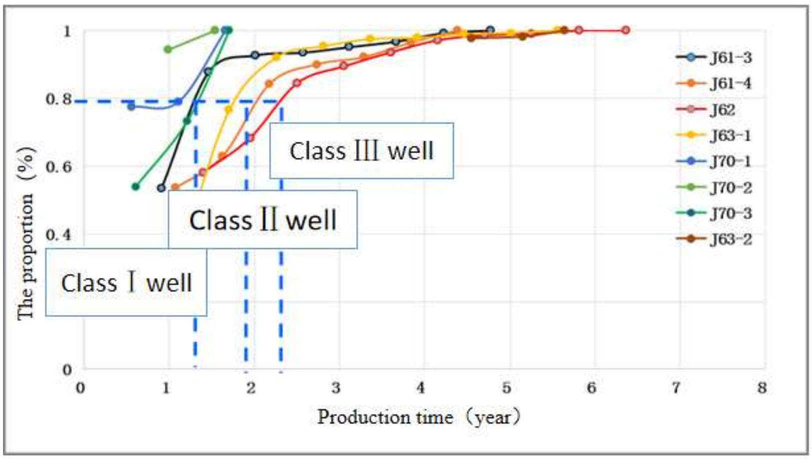

Figure 9. Ratio curves of single well-controlled reserves to final recoverable reserves at different production stages

The material balance method is widely used in the middle and late stages of gas field development, and the calculation results are more accurate than the volume method [7]. The material balance method requires more accurate reservoir pressure measurements, which require both the original formation pressure and the average formation pressure over different periods of production, as well as the volume of oil and gas produced during these periods. Based on material balance, the implicit relationship between average formation pressure and gas production is analyzed, and the material balance equation suitable for the gas reservoirs is established. By drawing P/Z and Gp diagrams, the total volume is finally calculated.

6. Conclusion

(1)Based on the production instability method and the material balance principle, the future production performance is predicted based on the analysis of the historical production performance of gas Wells. Through the prediction of single well-controlled reserves for the field well Jiao 61-3, it is proved that the research method in this paper has good adaptability.

(2) with the aid of Topaze production analysis software, by the method of production is not stable, simulation analysis to calculate the octagon field in stages of 8 production Wells in the different production time of single well-controlled reserves, the results show that the longer the production time,

the greater the gas well control, increases the single well-controlled reserves, different production stages dynamic reserves prediction results vary, The more reliable the calculated results are, the calculated results can reach more than 80% of the final predicted recoverable reserves.

References

[1] Qiao X, Jing L I, Feng D, et al. Pressure and production decline laws of low-permeability gas wells and their influential factors[J]. Oil Drilling & Production Technology, 2017.
[2] Li Xiaoxue, Huang Xiaoliang, Chen Haiyong, et al.Characteristics of sublevel decline law of tight sandstone gas reservoir [J].Natural Gas Exploration and Development, 2019, 42(002):89-94.
[3] Jia Lianchao, Liu Pengfei, Xu Sen, et al.Summary of calculation methods for dynamic reserves of gas reservoirs [C].// Proceedings of the 15th Ningxia Young Scientists Forum on Petrochemical.2019:327-329.
[4] Ren Dong, Dong Jiaxing, Wang Zhiping, et al.Production performance law and prediction method of a gas well in volcanic gas reservoirs [J].Natural gas geoscience,2016,27(11):2037-2042,2053.
[5] Lin Long. Single well dynamic reserves evaluation and variation characteristics analysis of Jingbian Gas Field [D]. Xi 'a Shiyou University,2014.
[6] Zhang Qi, ZHANG Zhenghang, Wang Xu, et al.The dynamic reserves and stable production period of horizontal Wells were obtained by using production instability analysis software Application of Petroleum And Chemical Industry,2012(06):46-48.
[7] WANG Ying. Study on calculation method of gas well dynamic reserves in Su S block, Sulige Gas Field [J].China petroleum and chemical standards and quality, 2019,491(09):107-108.