Application Of Numerical Well Testing In Strong Anisotropic Sandstone Gas Field

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Abstract

Sulige gas field in the Ordos Basin, a typical tight sandstone gas field with great heterogeneity, has difficulties in its development because its reservoirs are featured by small-scale effective sandbodies, rapid changes, strong horizontal heterogeneity, and poor connectivity. Analytical well testing widely used in Sulige gas field has limitations. Numerical well testing, which provides a way of tuning a static model with dynamic well testing information, can more accurately estimate reservoir parameters and wellbore effects, and improve the understanding of different types of gas seepage theory.

This study compared the difference between numerical well testing and analytical well testing, and summarized the key points of numerical well testing analysis technology, formed technical ideas of numerical well testing, proposed an interpretation workflow on the typical numerical well testing, and estimated the distribution of the main parameters, such as effective permeability reservoir, fracture half-length, and fracture conductivity, and so on. The interpretation results from various vertical and horizontal wells can deepen the understanding of reservoir and provide valuable technical support for stable gas production.

Introduction

Sulige gas field in the Ordos Basin, a typical tight sandstone gas field with great heterogeneity, has difficulties in its development because its reservoirs are featured by small-scale effective sand bodies, rapid changes, strong plane heterogeneity, and poor connectivity. It plays a crucial role on stabilizing gas production. Well testing can deepen the understanding of reservoir and reduce the uncertainty of estimates.

Currently, analytical well testing widely applied in Sulige gas field has limitations, mainly manifested in three aspects: (1) analytical well testing of reservoir heterogeneity is simplified to the radial composite or linear composite, which is difficult to effectively depict gas field in a complex geological condition and the characteristic of the strong heterogeneity of the reservoir; (2) Analytical well testing is derived by solving a second order partial deferential diffusivity equation. Uncertainty is resulted from the inverse nature of the problem. In general, ideal assumptions are made in order to solve a mathematical model. This results in the limit of its practical application. Analytical solution usually can be derived when a mathematical model is ideal. Non-ideal case (real case) is analysed using solutions derived from ideal model. Engineers use analytical model and solutions (type curves) for well test analysis. The final results are verified by matching analytical solution with measured pressure data. Assumptions made are ignored while perusing "perfect match" during the analysis. Results derived by such an approach are misleading. Well testing-a very useful engineering dynamic measurement itself is flawed due to this practice (Zheng 2006).

Numerical well testing has significant advantages over analytical well testing that assume constant reservoir and fluid properties. By contrast, numerical well testing can handle multiphase flow and stress-

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dependant reservoir properties, and relative permeability functions to handle complex problems (Deng et al. 2011). Thus, numerical well testing can more accurately estimate reservoir properties and wellbore effects, and provide valuable technical support for stable gas production.

The Difference between Numerical Well Testing and Analytical Well Testing

The difference between numerical well testing and analytical well testing is that fluid seepage equation in the porous media are solved by different methods. Seepage equation of analytical well testing is solved by means of analytic expression. However, for numerical well testing, seepage equation is solved by numerical methods and various parameters are calculated in each grid node. Therefore, numerical well testing can be more widely adapted to detailed requirements of actual field applications.

In other words, numerical well testing can overcome almost all the actual problems in analytical well testing, including different permeability, porosity, formation thickness, and fluid saturation at an arbitrary point of the formation, the influence of the reservoir rock stress, the special problems of unconventional reservoirs and multiple well productions, and the effect of interference and irregular internal and external boundary problems, et al.

Numerical Well Testing Technical ideas

Interpretation of numerical well testing is a technology based on unstructured mesh technology on the complex seepage area. It applies numerical discrete methods to solve the fluid seepage equation, and then determines reservoir parameters, reservoir limits, and wellbore effects (skin and storage) by fitting the measured bottom-hole-pressure and production (Li 2000; Zhuang 2004; Liu 2008).

Figure 1 illustrates the key steps of a numerical well test. First, reservoir numerical model is established by referring the effective thickness, porosity and permeability of geological information. Then, the initial value of the fitting parameters is got by analytic method for numerical well testing interpretation model. The fitting parameters and reservoir numerical parameters are adjusted by validation of production dynamic data to establish numerical well testing model.
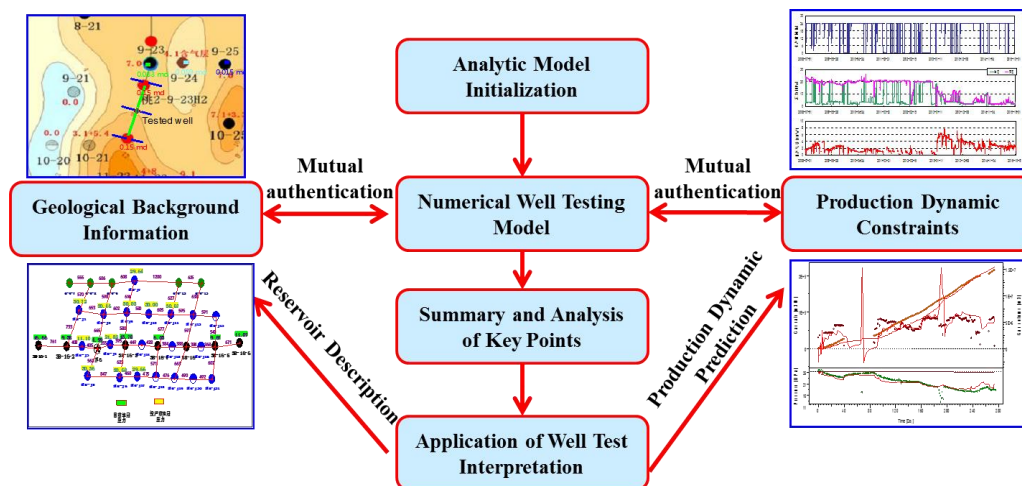

Figure 1—Numerical well testing technology.

Establishing the numerical well testing model not only can accurately characterize heterogeneity of the reservoir, including reservoir thickness, porosity, permeability, boundaries, skin factor, and wellbore storage, but also visually display pressure distribution dynamically.

Key Technical Points of Numerical Well Testing

Feature recognition of different types of well testing models is the key. Sulige gas field is a typical tight gas reservoir. It needs horizontal drilling and hydraulic fracturing to improve well performance. Thus, it is critical to establish typical curves of unsteady well test based on theoretical study on fractured vertical

wells and horizontal wells (Wang et al. 2013; Qi et al. 2007; Yang et al. 2010; Wu et al. 2010), as shown in **Figure 2** and **3**.
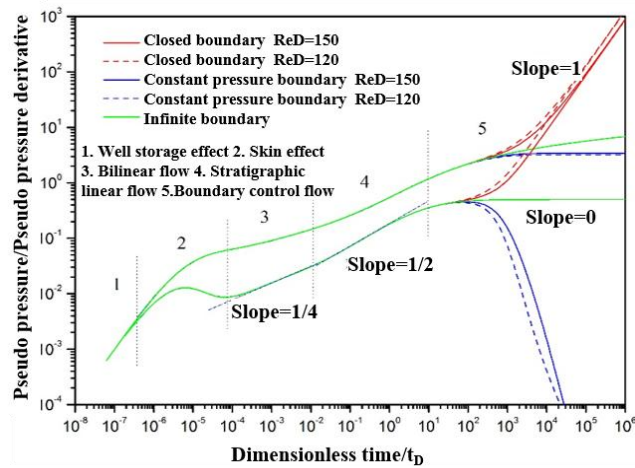

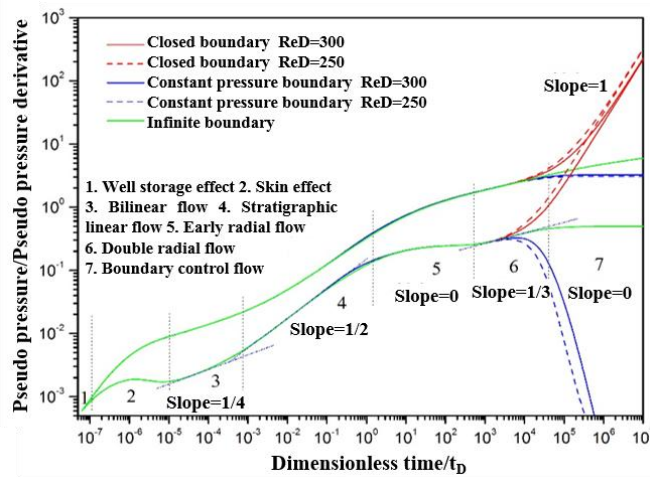**Figure 2—Typical curves of fractured vertical well.**

Figure 3—Typical curves of fractured horizontal well.

Permeability heterogeneity has strong effect on the shape of pressure drop curve and pressure derivative curve at the end of the effect of wellbore storage and skin, as shown in **Figure 4** and **5**.
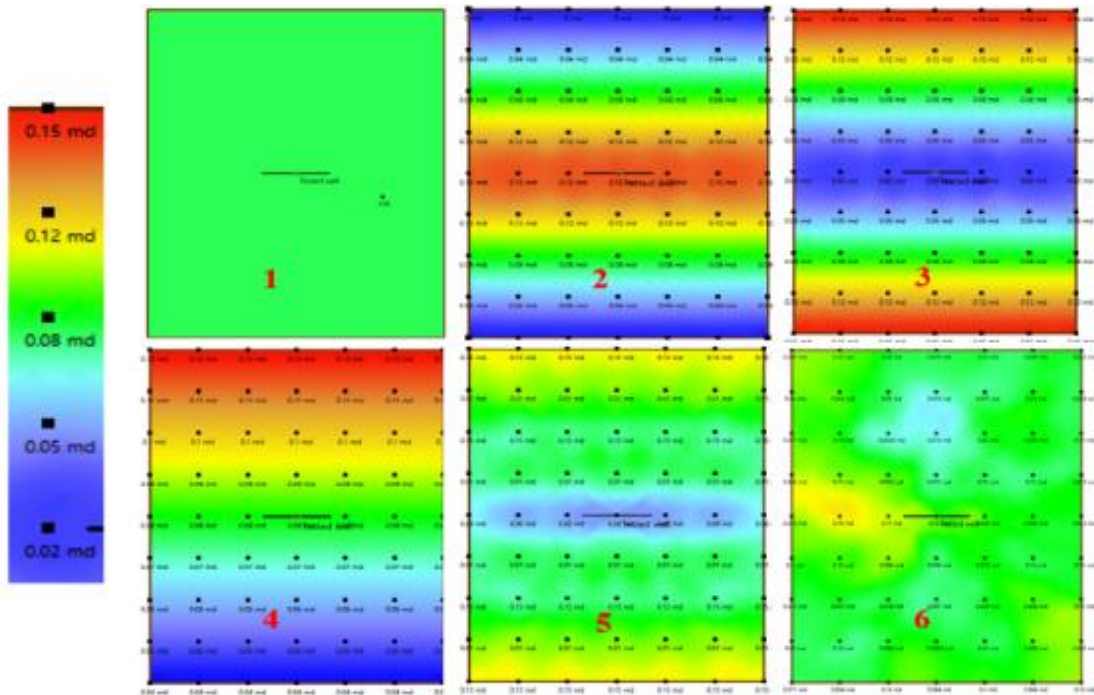
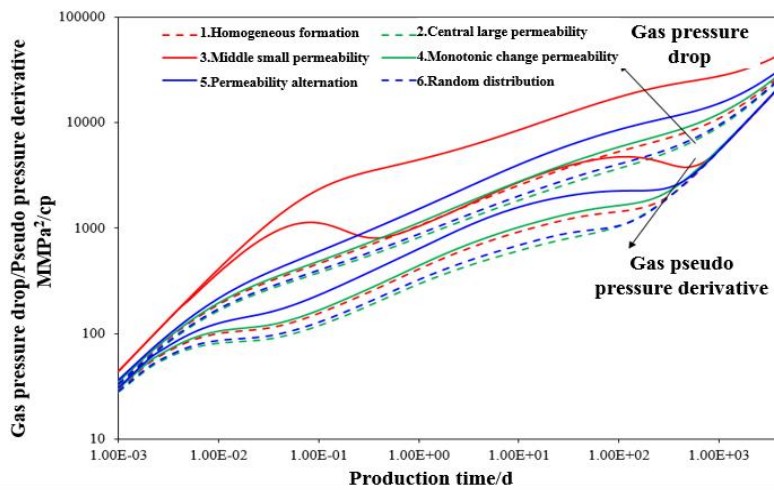**Figure 4—Reservoir permeability distribution.**

Figure 5—Influence of heterogeneity of permeability on well test curve.

Typical Wells Numerical Well Test Analysis Workflow

Take SuA-B-CH2 Well as an example. First, we obtained the average reservoir parameters with analytical well testing technique. Interpretation results are shown in **Table 1** and **Figure 6**. Then, we drew the effective sandbodies isopach map (**Figure 7**).

Table 1—Analytical well test interpretation results of SuA-B-CH2 well.

Parameters	Value
Well model	5 stage fractured horizontal well
Reservoir model	Homogeneous reservoir + Infinite boundary
C (cm^3/MPa)	5.39
S	-7.11
Kh(md.m)	3.8
K (md)	0.38
Pi (MPa)	23.25
H$_w$ (m)	331
X$_f$ (m)	30.5
F$_C$ (md.m)	274
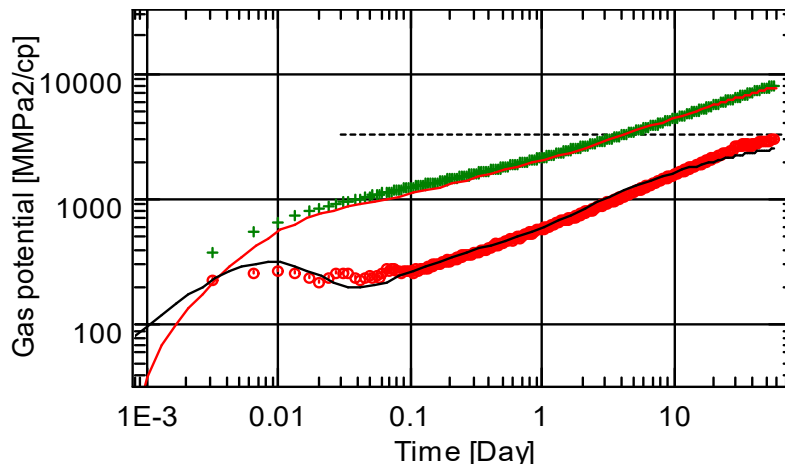
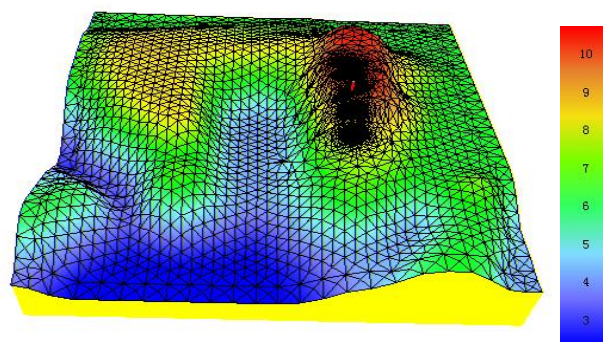**Figure 6—Log-log curves of analytical well test of SuA-B-CH2 well.**

Figure 7—Distribution of effective thickness around SuA-B-CH2 well.

Next, porosity logging data from adjacent wells was used to determine the porosity distribution around SuA-B-CH2 well which is shown in **Table 2** and **Figure 8**.

Table 2—Porosity statistics of SuA-B-CH2 adjacent wells.

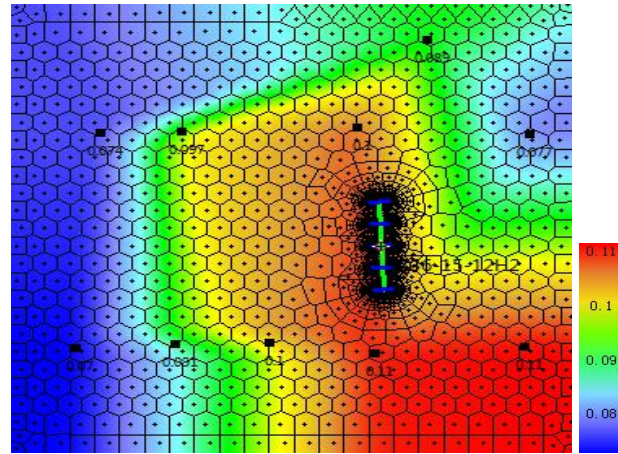| Well Name	Porosity (%)	Well Name	Porosity (%)
SUA-B-13a	7.2	SUA-D-9	6.6
SUA-C-9	6.9	SUA-D-10	9.0
SUA-C-10	9.5	SUA-D-10H1	8.4
SUA-C-12	9.3	SUA-D-11	9.3
SUA-C-13	7.1	SUA-D-12	10.8
SUA-D-13	10.9		

Figure 8—Porosity distribution of SuA-B-CH2 wells.

Based on the analytical solution and geological information constraints, permeability distribution of formation was obtained by fitting the well test data (**Figure 9**).
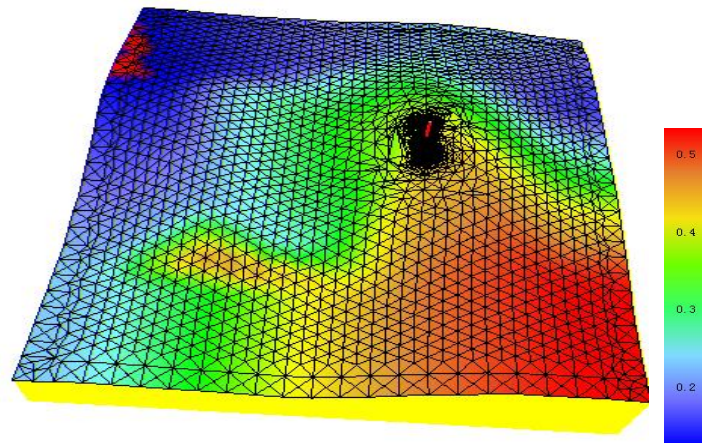

Figure 9—Numerical model of permeability distribution of SuA-B-CH2 well.

Interpretation and fitting results by numerical well test are shown in **Table 3** and **Figure 10**, respectively.

Table 3—Numerical well test interpretation results of SuA-B-CH2 well.

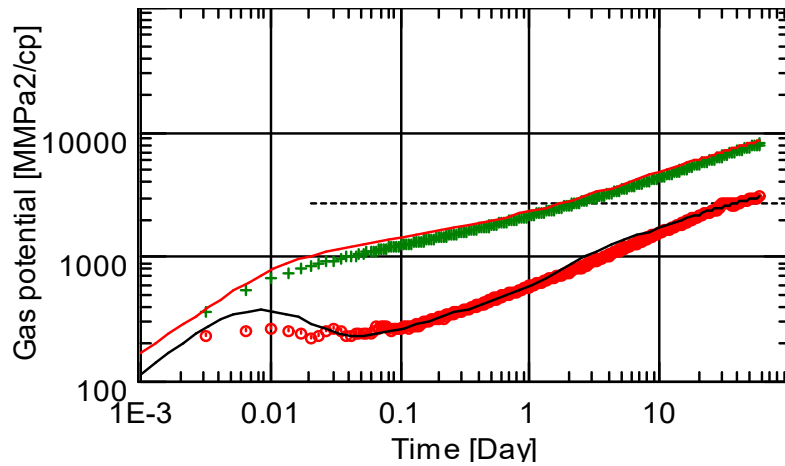| Parameters	Value
Well model	Numerical model
C (cm³/MPa)	4.39
S	0.11
K (md)	0.511
P_i (MPa)	24.5
H_w (m)	331
X_f (m)	30.5

Figure 10—Log-log curves of numerical well test of SuA-B-CH2 well.

The Results of Numerical Well Test Interpretation

Interpretation Results of Statistics Vertical Numerical Well Testing. Statistics of parameters estimates from 19 vertical wells are shown in **Figure 11** through **13**. Effective permeability of reservoir is 0.03-0.74 md, with a mean of 0.22 md. Fracture half-length is between 11.6 m and 228.4 m, with a mean of 71.1 m. Fracture conductivity is from 101 to 301 md·m, mean is 167 md·m.
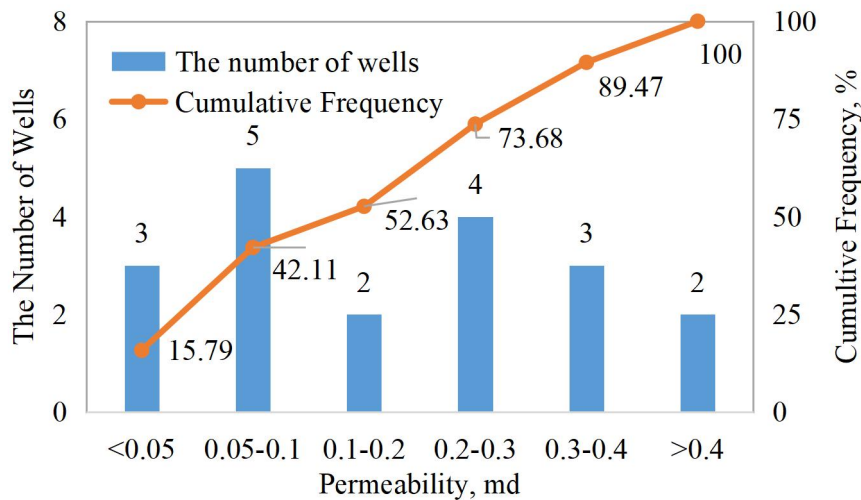

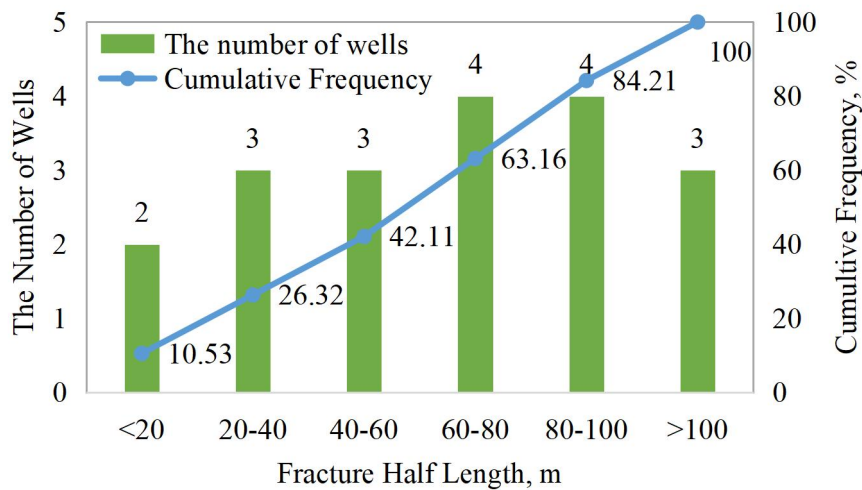**Figure 11—Cumulative frequency distribution of vertical wells permeability.**

Figure 12—Cumulative frequency distribution of fracture half-length of vertical well.
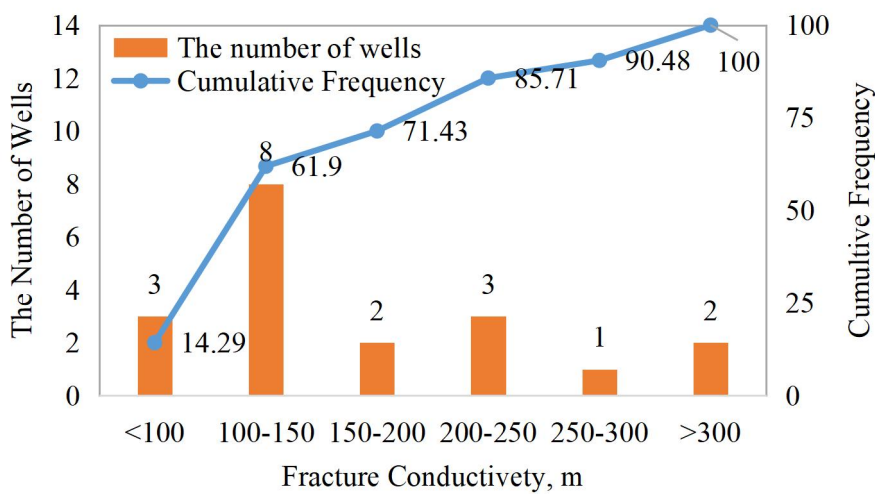

Figure 13—Cumulative frequency distribution of fracture conductivity of vertical wells.

The Horizontal Well Numerical Well Test Interpretation Results of Statistics. Statistics of parameters estimates from 18 horizontal wells are shown in **Figure 14** through **16**. Effective permeability reservoir is 0.02-0.94 md, with a mean of 0.295 md. Fracture half-length ranges from 22 to 197 m, with a mean of 65.8 m. Fracture diverting capacity is 26.5-498 md, with a mean of 179 md.
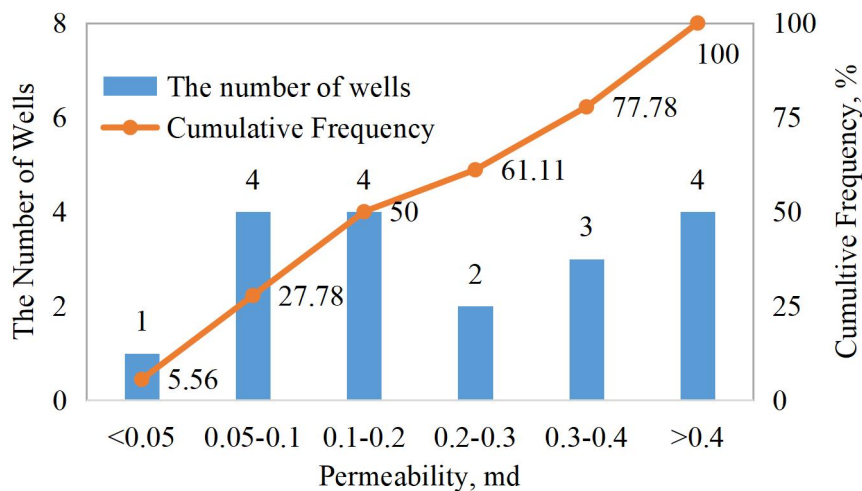

Figure 14—Cumulative frequency distribution of horizontal wells permeability.
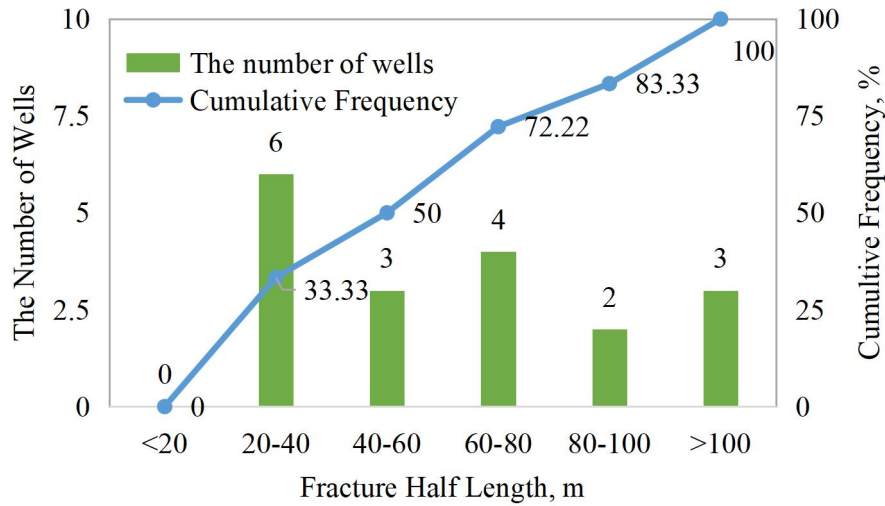
Figure 15—Cumulative frequency distribution of horizontal well fracture half length.
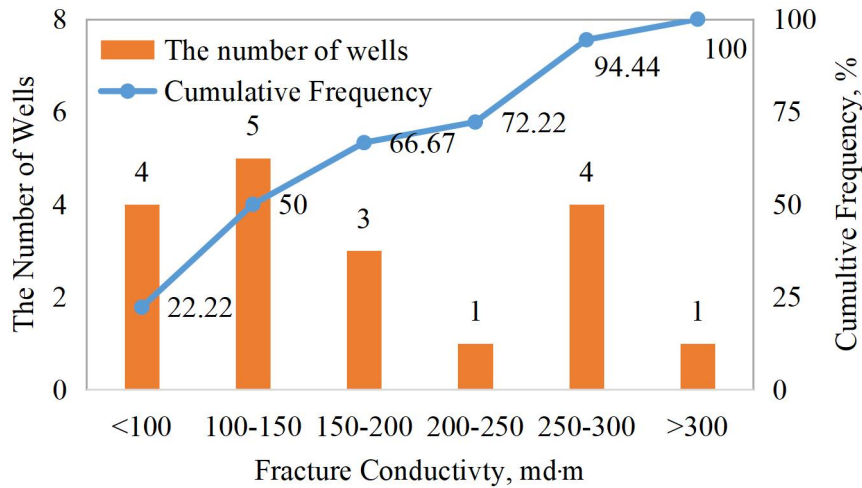

Figure 16—Cumulative frequency distribution of horizontal well fracture conductivity range.

Conclusions

Compared with the analytical well test, the numerical well test can obtain the reservoir and wellbore information more accurately, and the application effect of the numerical well test is better in the tight and strong heterogeneous sandstone gas field.

Conflicts of Interest

The author(s) declare that they have no conflicting interests.

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