Applied Research and Well Interference Test Model of Ultrahigh Pressure Gas Reservoir of Keshen Gas field

Hongfeng Wang[1], Yinglin Jia[1(✉)], Songbai Zhu[1], Xia Qiao[1,2], Shengjun Wang[1], and Yanbo Nie[1]

[1] Tarim Oilfield Company, Petrochina, Korla, China
[2] College of Petroleum Engineering, Southwest Petroleum University, Chengdu, China

Abstract. The ultra-deep gas reservoir in the Keshen gas field is characterized by complicated geological conditions, poor static data and gas reservoir description, making it a world-class challenge of exploration and development. To depict the characteristics of gas reservoir, long distance multi-well and multi-azimuth interference well testing in gas reservoir was carried out in Keshen gas field. Accurate multi-well interference data was acquired and verified by both positive and negative authentication. Approaches like extremal value analysis, investigation radius method, etc. are employed to analyze the tested data, which is also compared with numerical simulation outcomes. The results of investigation show that the interference signals in the developed area of Keshen Block 2 are strong, indicating that the reservoir is highly connected with natural fractures. Few faults or dominant fractures appear. The fracture permeability is above Darcy level; obvious interference signals have been detected between Wells in Keshen Block 5 and 11, which means that the two blocks are interconnected and proved to be the same gas reservoir. Results from numerical simulation show that connectivity in the west area is better than that in the east. This technology has made quantitative analysis of fractured gas reservoir a reality. It can serve a solid foundation of fine reservoir description, well location selection, well drilling and completion, and related development processes. An objective judgment on the contradictions of dynamic and static data can be

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achieved using this technology, which is of great significance for the effective exploration and development of ultra-depth, high pressure, and fractured tight sandstone gas reservoirs.

Keywords: Keshen gas field · Multi-well interference · Well interference test model · Numerical well test · Connectivity

1 Introduction

The study of interference well testing at home and abroad can be traced back to 1935. For a long time, the research of the interference well testing was mainly focused on homogeneous reservoirs. Obge and Brihgma established the well testing model for homogeneous reservoir and studied the influencing factors for vertical wells [1–3]. So the methods for homogeneous reservoir's well testing are quite complete. But it was not until 1980 that scholars started to study reservoirs with natural fractures, dual media, and horizontal wells [4–6]. So there still exists many difficulties when it comes to the interpretation of well testing data for complex media reservoir.

Keshen gas reservoir is located in the kuche depression of Tarim basin's Crassus tectonic belt, which is a salt faulted anticline gas reservoir under the clamping of a north thrust fault. The gas reservoir is characterized with deep depth (6500–8000 m), high formation pressure (116–136 MPa), high formation temperature (160–193 °C), and ultra-low porosity and permeability (porosity lower than 7.0%, permeability lower than 0.1 mD), which makes it a very rare ultra-deep ultrahigh pressure fractured tight sandstone gas reservoir. The main producing formation is the braided river delta front sand body of Bashijiqi Formation of Cretaceous. The sand body is vertically superimposed and located one next to another in lateral, which made it with low degree of well control and hard to describe the connectivity in between [7, 8]. Based on former research and on the premise of scientific design of the interference well testing [9–11], this article aims to use the developed Keshen Block 2 and the exploring Keshen Block 5 and 11 to study the interference well testing data together with numerical simulation, so as to know about the application of the technology in complex media reservoir and also provide suggestions for other similar fractured reservoirs.

2 Multi-well Interference Well Testing Plan Design

Keshen Block 2 is a developed gas reservoir while Keshen Block 5 and 11 are now still under exploration. However, with the further exploration and development, it occurs that the geological conditions are quite complex; the seismic data is quite poor; real drilling rate is quite low compared to the designed, and the static data is quite uncertain, making it extremely hard to describe the reservoir accurately. Meanwhile, with the multiple-stage natural fractures, and the uncertainty of the inter-well connectivity and flow conductivity, it is very hard to make solid development plans and well placement.

Based on this, we aim to design the interference well testing so as to understand the inter-well connectivity and provide support for further development.

2.1 Interference Well Testing Design of Keshen Block 2

So far there are more than 20 production wells in Keshen Block 2, all of which are vertical wells. The average depth of the producing formation is around 6500–7100 m. High precision pressure gauges were placed to the target areas with steel wire. To reduce the influence of other wells, we shut off all the producers and delicately chose observation wells at different locations and directions to place pressure gauge. In order to effectively distinguish the excited well signals, the connectivity monitoring design used non-equidistant exciting method throughout the whole exciting process (Fig. 1).

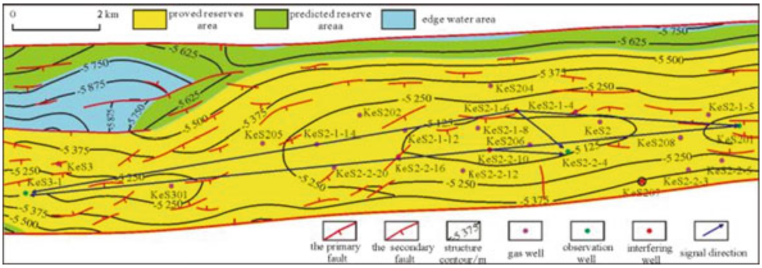


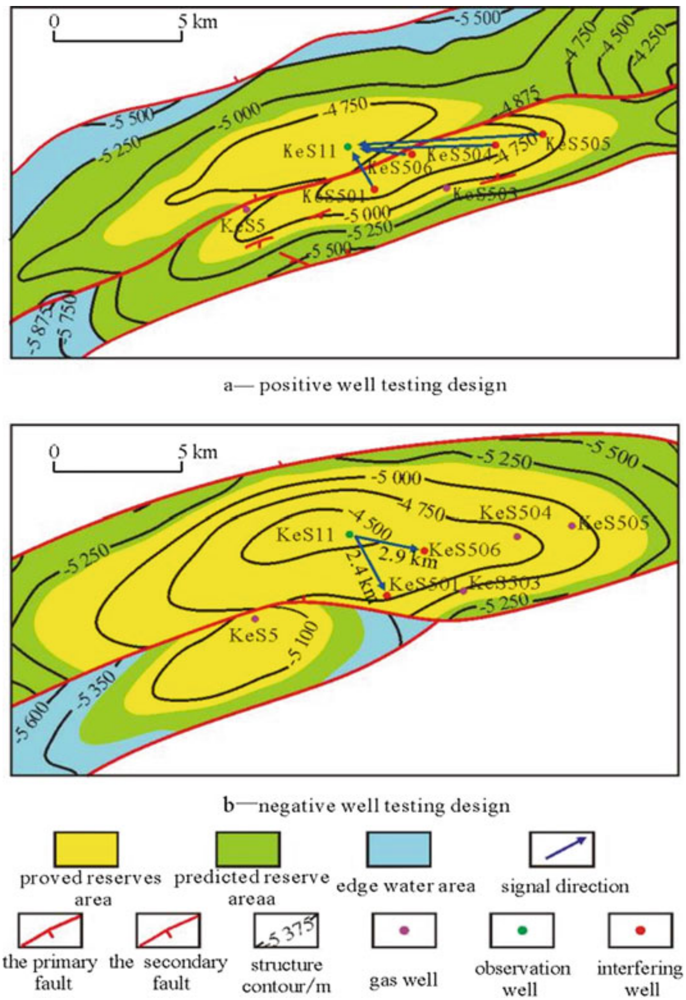
Fig. 1. Keshen Block 2's top surface structure and the interference well testing design

2.2 Interference Well Testing Design of Keshen Block 5 and 11

Keshen Block 5 and 11 are now both under exploration evaluation. Due to the uncertainty of seismic data, which leads to the unclear fault and block structure, there exists high risk for well placement and reserves clarification (Fig. 2). To figure out all these questions, we designed the test as follows: first use Keshen 11 as observation well, open 4 exciting wells in Keshen 5, and observe the pressure alteration in Keshen 11; then use the wells in Keshen 5 as observation wells, while open Keshen 11, so as to make sure of the inter-well connectivity and optimize the well testing design.

3 Interference Well Testing Data Analysis

The test data for Keshen Block 2 shows that three different pressure gauges in each well have the same variation trend, meaning that they reflex the real pressure change underground. The results are as follows: Well Keshen 201 only received signals from Well Keshen 2-1-11, which shows that it only connects to it. The pressure of Keshen 3-1 began to drop after Keshen 2-2-10 and 2-1-6's open, proving that these two wells have good connectivity. Keshen 2-2-4 received signals from Keshen 2-1-6 and 2-2-10, indicating that it has good connection with all these three(Fig. 3). By using the



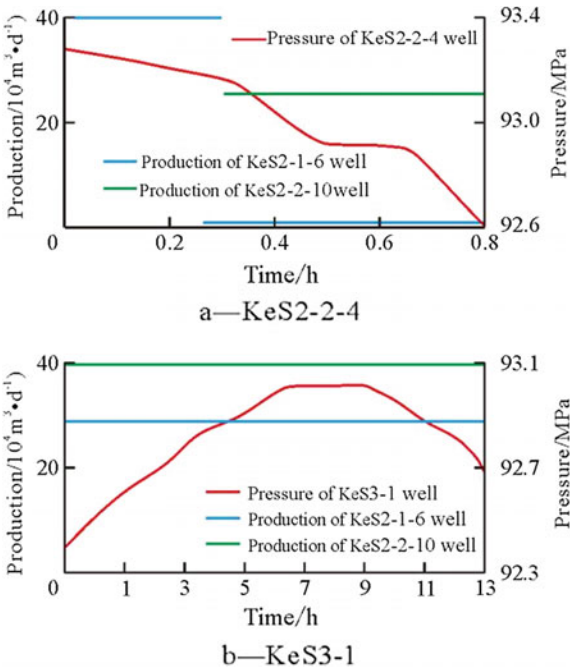
(a) Keshen 5/11 positive well testing design

(b)Keshen 5/11 negative well testing design

Fig. 2. Keshen Block 5 and 11 well testing design

multi-direction and long distance interference well testing, we obtained the multi-well interference data and know about the inner connection of the block.

According to the investigation radius method and extreme point method [12], we assume that the formation is homogeneous with infinite fractures. When the excited well is open, the observed pressure curve has an extreme value and based on the following equation we could calculate the permeability of inter-well fracture (Table 1).



(a) Pressure changes of Keshen 2-2-4
(b) Pressure changes of Keshen 3-1

Fig. 3. Pressure changes of Keshen Block 2 with interference test

Table 1. Calculation results of the inter-well connectivity and fracture permeability

Exciting well	Keshen2-1-6			Keshen2-2-10		
Observation well	Distance km	Time hr	Permeability D	Distance km	Time hr	Permeability D
Keshen3-1	11.5	7.7	/	10.8	7.3	/
Keshen201	5.8	3.6	6.6	5.2	3.7	5.8
Keshen 2-2-4	1.5	0.36	5.6	1.8	0.3	7.5

According to the investigation radius method, the relation between inter-well distance and time is:

$$R = 2\sqrt{\frac{Kt}{\varphi \mu C_t}} \tag{1}$$

The pressure transmitting coefficient between exciting well and observation well is:

$$\eta = \frac{R^2 t_p}{14.4 \times 10^{-3} t_m \left(t_m - t_p\right) \ln \frac{t_m}{t_m - t_p}} \tag{2}$$

In which: R well distance, m; K—fracture permeability, mD; t—travel time between wells, h;

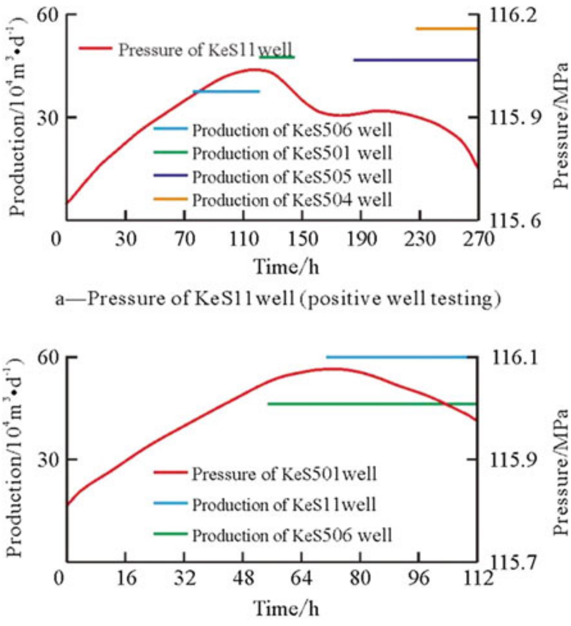
t_p—producing time, h; t_m—time when extreme point shows up, h; μ—gas viscosity, mPa·s;

η—pressure transmitting coefficient, mD·MPa/(mPa·s);

φ—porosity, %; C_t—rock compressibility, MPa-1.

Based on the above two methods, we could calculate the inter-well fracture's permeability according to equation (1) and (2):

Providing that all the wells were shut in Keshen Block 5 and 11, the observation wells in Keshen 11 initially received signals from Keshen 506 (2.9 km away) and Keshen 501 (2.5 km away) and their pressure began to decrease in their build-up processes. Then with the shut-off of Keshen 501 and Keshen 506, the pressure of Keshen 11 started to build up after 13 h. Keshen 505, Keshen 501 and Keshen 504's pressure began to drop as well, which shows that Keshen Block 5 and Block 11 are



a—Pressure of KeS11well (positive well testing)

b—Pressure of KeS501well(negative well testing)

(a) underground pressure change of Keshen 11 (positive);
(b) underground pressure change of Keshen501(negative)

Fig. 4. Underground pressure changes of Keshen Block 5 and 11 with positive and negative interference well testing

connected. Then use Keshen 11 as exciting well, Keshen 501 as observation wells. Keshen 501's pressure starts to drop 16 h after Keshen 11's open while Keshen 506's pressure starts to drop 20 h after. In conclusion, after positive and negative interference testing, it shows that Keshen Block 5 and 11 are connected, which means that they are in fact one gas reservoir. Based on the calculation results of Eqs. (1) and (2), the fracture permeability between Keshen 11 and Keshen 501 is 410 mD, and that between Keshen 11 and Keshen 506 is 560 mD, which are all quite high (Fig. 4).

4 Numerical Simulation of the Interference Well testing

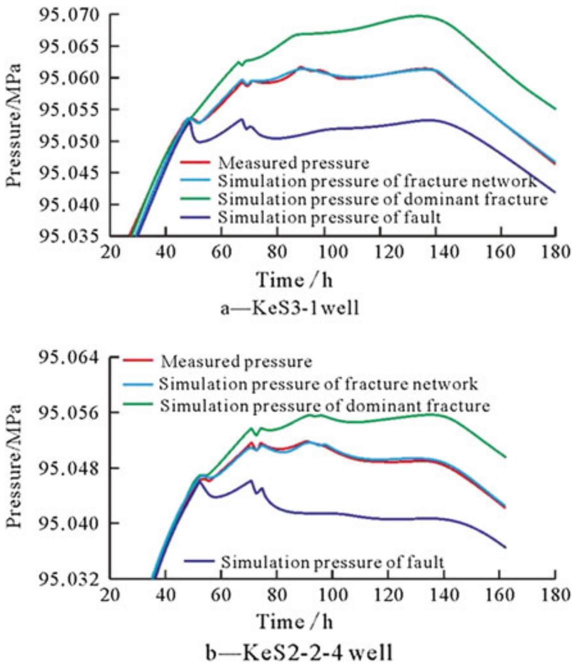
Keshen gas field is an abnormal high-pressure reservoir with wellhead pressure as high as 100 MPa. This gives rise to a series of problems while monitoring underground pressure: high risk of well control, high downhole temperature, and huge damage of tubing while opening and shutting in processes. On the basis of flow mechanisms, delicate numerical simulation is conducted based on the obtained geological description and tested pressure data. Voronoi grid is employed to discretize the grids: fine grids around the well and coarse grids for area far away [13–15]. Then the numerical simulated pressure data is compared with the tested interference data, and the signal travel model is established under different connection conditions. At last, the inter-well connectivity and natural fracture network are figured out.

4.1 Numerical Simulation of Keshen Block 2 Interference Well Testing

With the static data, structure, fault, well placement, porosity, effective depth and permeability of Keshen Block 2, a gas reservoir model is established. Then history match is conducted with the actual well testing scheme (Fig. 5). Finally, the pressure travel model is built up by giving a certain flow paths between observation wells and exciting wells. Results show that it is hard to match the tested pressure with the simulated one, which is due to the fact that the gas reservoir is a homogeneous network connection and there is no obvious fault or dominate fractures.

4.2 Numerical Simulation of Keshen Block 5 and 11 Interference Signal

Due to the poor quality of seismic data in Keshen Block 5 and 11, it is very hard to describe the fault slip and orientation. Based on the obtained dynamic and static data, the numerical models for the two blocks are established. Three scenarios are set: assuming the western part of the fault is connected, or the eastern part is connected, or both parts connected (Fig. 6). The simulated results are matched with the measured pressure curves of Keshen 11, which indicates that the latter two assumptions can't match with the measured pressure drop. This proves that the connection must be in the western part. When taking Keshen 11 as observation well, Keshen 5's interference signal traveled through the western part of the fault to Keshen 11 (Fig. 7). Further proof is that the measured pressure value for Keshen 11 and Keshen Block 5 are all 126 MPa, and the wellhead pressure of Keshen 11 started to drop gradually after Keshen 5 is under production.



(a) history match of curve for Keshen 3-1 interference signal
(b) history match of curves for Keshen 2-2-4 interference signal

Fig. 5. The numerical simulated pressure and tested pressure for Keshen 2

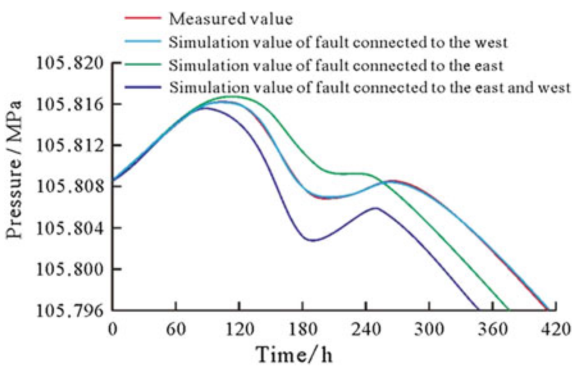


Fig. 6. Comparison between the simulated pressure and measured pressure for Keshen 11

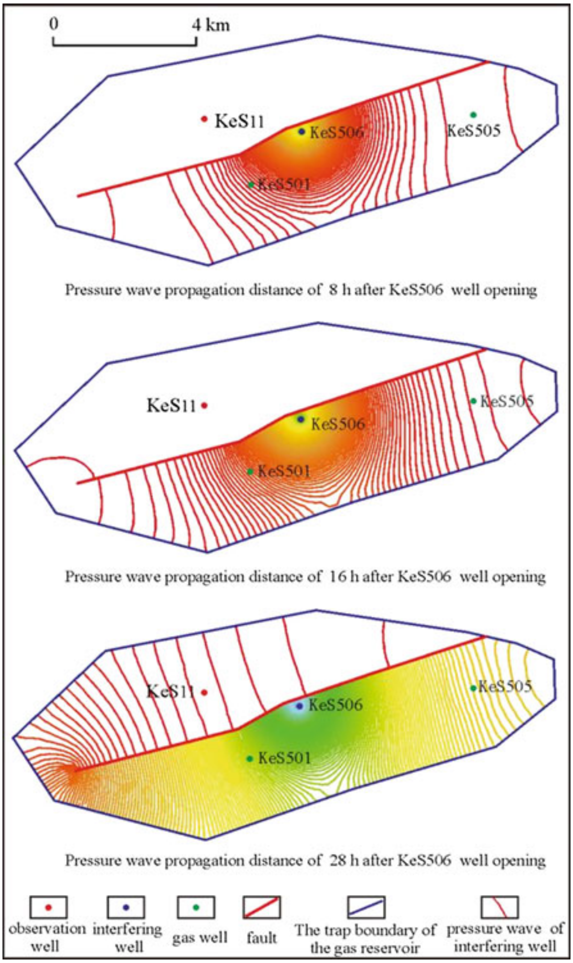


Fig. 7. Simulated pressure wave travel diagram for Keshen 5 and Keshen11

5 Conclusions

1. Keshen gas field has complex geological conditions which is hard to describe. By using multi-well and multi-azimuth, long distance and mutual authentication well testing technology, solid interference data is obtained for multi-wells.
2. Interference signals within Keshen Block 2 is strong, indicating that this reservoir is highly connected with natural fractures, whose permeability is in the level of Darcys. The outcomes of numerical simulation reveal that no faults or dominate fractures develop in Keshen 2. Fractures are common while there exists a non-permeable zone separating the west and east parts of the block. Keshen 5 and Keshen 11 are connected. The numerical simulation also proves that there is good

connectivity in the western part, which proves that the two reservoirs are actually one connected reservoir.
3. An objective judgment on contradictions of dynamic and static data can be achieved with this technology, which is of great significance for the high efficiency exploration and development of ultra-depth, high pressure, and fractured tight sandstone gas reservoir.

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