Study of Controlling Factors on Productivity of Keshen Gas Field: A Deep Tight Sandstone Reservoir in Kuqa Depression

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Abstract. The Keshen gas field in the Kuqa depression of the Tarim Basin with characteristics of deep buried depth, tight matrix and developed fracture, has great differences in gas well productivity within different parts of the structure, which bring difficulties to the gas field development and deployment. Based on the study of the reservoir matrix property, fracture characteristics and individual well productivity of the Keshen ultra-deep gas reservoirs, combined with reservoir geostress research, the difference between high and low efficiency wells in Keshen2 block is analysed, and the main geological factors influencing productivity are revealed. It is found that the effectiveness of reservoir fracture is a necessary condition for high production of gas well. Further study shows that there is a negative correlation between the open flow of gas well and the effective normal stress of fracture. The larger the effective normal stress of fracture is, the more difficult it is to achieve high production with reservoir reconstruction. According to study of the productivity influencing factors of the fractured tight sandstone reservoirs, some suggestions on well deployment and well perforation are given in the paper, which are beneficial to increase production and efficiency of this kind of reservoirs.

Keywords. Kuqa depression; Keshen gas field; controlling factors on productivity; fractures; efficient development.

1. Introduction
Keshen ultra-deep gas reservoirs in Kuqa depression with the depth of 6500-7500 have the characteristics of tight matrix and developed fractures [1-4]. The production shows that gas productivity of gas wells located in different structural positions is quite different. The open flow of gas wells ranges in 10-520 x 10⁴ m³/d. Some wells have high natural productivity, such as Keshen 8 and Keshen 3 wells, and the open flow is more than 230 x 10⁴ m³/d; while some wells such as Keshen 208 and Keshen 2-1-5 cannot obtain commercial gas flow even though they are undergoing volume fracturing, which brings challenges to the development and deployment of the gas field. The purpose of this study is to analyse the key factors of high productivity of gas wells through the study of reservoir quality, fracture development, fracture effectiveness, especially in close combination with reservoir geostress, so as to provide basis for well deployment and efficient development.

2. Geological Characteristics
Keshen gas field is located in the Eastern part of Kelasu thrust belt, Kuqa depression, Tarim Basin. It is composed of a series of imbricated thrust folds mainly formed in the Cenozoic Himalayan movement [5]. The target stratum of the study area is the Cretaceous Bashijiqikie formation, with thickness of about
310 m and depth of 6500-7500 m. It belongs to the braided river delta front and fan delta front deposit [6]. The sand bodies overlap and connect with each other, while the thickness of shale interlayer is generally less than 4m, and most of them pinched out between wells. The lithology of the reservoir is mainly feldspathic detritus fine sandstone and siltstone, with strong compaction and cementation [7]. The reservoir space mainly includes residual intergranular pores and intergranular dissolution pores, with small pore throat (pore radius range in 0.4-100 μm observed by thin sections, and pore throat radius range in 0.1-0.5 μm analysed by mercury injection within the samples with porosity higher than 4%). The property of matrix of the sandstone reservoirs is poor. The average porosity of core is 4.1%, and the average permeability is only 0.05md. However, fractures are generally developed within the reservoirs, and the fracture linear density identified by core is 2-10 m⁻¹ [8]. Fracture development can greatly improve the reservoir permeability [9], with limited contribution to the reservoir porosity.

3. Productivity Control Factors
As to Keshen gas reservoirs, the gas well productivity within the different part of the anticline varies due to the heterogeneity of fracture distribution [9]. Take Keshen 2 and Keshen 8 blocks for examples, the open flow generally ranges in 10-520×10⁴ m³/d (figure 1). Some wells can achieve high production without fracturing or only with simple acidizing. The productivity of some wells after reservoir fracturing increases by more than 5-10 times, and some wells cannot obtain commercial productivity after volume fracturing. According to the geological conditions, test data, reconstruction and open flow of test wells, it can be divided into three classes (table 1).

Table 1. Classification and characteristics of gas wells within Keshen2 and Keshen8 blocks.

| Gas well classification | State of results of fracturing | Open flow (10⁴m³/d) | Geological characteristics | Typical well |
|------------------------|--------------------------------|---------------------|---------------------------|--------------|
| I                      | High production without fracturing or only with simple acidizing | >200                | Fracture development, strong effectiveness, and low reservoir pollution | Ks8, Ks3     |
| II                     | High production after reservoir fracturing | >100                | The fractures are generally developed, highly active, relatively low geostress | Ks203, Ks3-1 |
| (1)                    | Commercial production after reservoir fracturing | >50                 | The fracture is underdeveloped or general, with poor activity and relatively low geo stress | Ks2-1-1, Ks2-2-1 |
| III                    | No commercial production after reservoir fracturing | <50                 | Poor fracture development, poor activity, relatively high geostress | Ks208, Ks2-1-5 |

Figure 1. Map showing the distribution of single well productivity in Keshen 2 and keshen 8 blocks (before and after reconstruction).
3.1. Effect of Fracture Development on Gas Well Productivity

The porosity of fractures in Keshen 2 block is generally less than 0.5% [4, 8], which has small contribution to reservoir space. The individual well permeability interpreted by well testing ranges from 1 to 10 mD, which is hundreds of times of that of reservoir matrix interpreted by logging and core analysis [9]. Therefore, fractures are not only the main seepage channel of the reservoir, but also determine the high production of gas wells in Keshen 2 block. It is found that the average open flow of gas well in Keshen 2 block is only 4-5×10^4 m^3/d by matrix seepage. After comprehensive evaluation, the contribution rate of fracture to gas well productivity in Keshen 2 block is 60-99% (figure 2). The more fracture develops, the higher contribution rate. Deliverability of gas wells is generally related to the linear density and aperture of natural fractures [9]. For example, well Kes2-2-8, with the fracture line density of 5.62 m^-1 [8] and aperture of aperture exceeding 0.105mm, obtained open flow of 280×10^4 m^3/d; while well Kes205, with the density of 2.1 m^-1 [8], obtained open flow of 150×10^4 m^3/d (figure 2).

![Figure 2. Gas well productivity and fracture contribution rate in Keshen2 block.](image)

3.2. Effect of Normal Stress on Productivity after Fracturing

When fractures are developed in rock, triaxle geostress can be divided into normal stress (σ_n) and shear stress (τ) on the fracture surface. The former is perpendicular to the fracture surface and the latter is parallel to the surface. Effective normal stress (σ_n') can be expressed by formula σ_n' = σ_n - P_p (P_p stand for pore fluid pressure in formation) on the fracture surface. When the horizontal principal stress difference is large, σ_n' is mainly controlled by the angle θ between the fracture surface and the horizontal maximum principal stress. The larger the θ is, the greater the principal stress on the fracture surface is (figure 3).

It is found that there is a significant negative correlation between the open flow of gas well and the effective normal stress of fracture after the reconstruction of Keshen 2 block. The larger the effective positive stress of fracture is, the more difficult it is to achieve high productivity in reservoir reconstruction (figure 4). When the effective normal stress of reservoir fracture is more than 30MPa, it is difficult to achieve high productivity with reservoir reconstruction. For example, the production of Kes2-2-1 well is only 6.3×10^4 m^3/d after sand fracturing with SRV due to the average normal stress is 33 MPa with the θ ≈ 40°; while that of Kes206 well achieve 72.1×10^4 m^3/d after sand fracturing with SRV due to the average normal stress is 16 MPa with the θ ≈ 5°.
4. Suggestions on Well Deployment and Well Perforation

It is found that the fractures in Keshen 2 block can be divided vertically into three layers: (1) The East-West tension fractures are mainly developed above the fold neutral plane, with small fracture density and large aperture. (2) The fractures are relatively undeveloped on the fold neutral plane. (3) Under the middle surface, there are mainly north-south shear fractures and network fractures with large fracture density but relatively small aperture. At present, the maximum horizontal principal stress direction of Keshen 2 block is mainly in the near NS direction, and the stress field will change in some parts due to structural overturning and fault development. Due to the strong heterogeneity of fracture development and local deflection of main stress direction, the fracture effective normal stress profile of Keshen 2 block is complex and diverse, which can be divided into three types: (1) The whole well section is relatively small, such as well kes2-2-4. (2) The whole well section is relatively large, such as well Keshen 208. (3) The upper large and lower small, such as well kes2-2-1. Therefore when the well location is deployed in Keshen gas field, it is necessary to select the well location in the area where fracture effective stress is relatively small. When the drilling depth is designed, the thickness of high fracture effective normal stress zone should be fully considered, and the low fracture normal stress zone should be opened as much as possible to ensure high production of gas wells. It is considered that the design of well perforation in Keshen 2 block can open at least 60-70 m of low fracture normal stress zone with the drilled reservoir thickness of 160-220 m.

5. Conclusion

The research results of main control factors of productivity show that for the fractured tight sandstone reservoir in Keshen 2 block, the favourable geological conditions such as the fracture development degree, fracture effectiveness, geological and mechanical characteristics of the reservoir, are the necessary conditions for high production of gas wells. In addition, whether the high production can be truly realized is also related to the well location, the perforation section and reservoir reconstruction measures (acidizing, acid fracturing or SRV fracturing). In order to improve the development quality and efficiency of Kuqa ultra deep gas reservoirs, it is necessary to do a good job of optimization of well location before drilling, optimization of drilling depth during drilling, optimization of perforation section.

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References

[1] Neng Y, Xie H, Sun T, et al. 2013 Structural characteristics of Keshen segmentation in Kelasu structural belt and its petroleum geological significance China Petroleum Exploration (2) 1-6.

[2] Zhao L, Shi S and Xiao X 2012 Geologic modeling of fractured and porous sandstone reservoirs in the Keshen 2 gas field of the Kuqa Depression, Tarim Basin Natural Gas Industry 32 (10) 10-13.

[3] Jiang T and Sun X 2018 Development of Keshen ultra-deep and ultra-high pressure gas reservoirs in the Kuqa foreland basin, Tarim Basin: Understanding points and technical countermeasures Natural Gas Industry 38 (6) 1-7.

[4] Wang K, Zhang H, Zhang R, et al. 2015 Comprehensive assessment of reservoir structural fracture with multiple methods in Keshen-2 gas field, Tarim Basin Acta Petrolei Sinica, 36 (6) 673-685.

[5] Tian Z and Song J 1999 Tertiary structure characteristics and evolution of Kuqa foreland basin Acta Petrolei Sinica 20 (4) 7-13.

[6] Zhang R, Yang H, Wang J, et al. 2014 The formation mechanism and exploration significance of ultra-deep, low porosity and tight sandstone reservoirs in Kuqa depression, Tarim Basin Acta Petrolei Sinica 35 (6) 1057-1069.

[7] Zhang R, Wang J, Ma Y, et al. 2015 The sedimentary microfacies, palaeo-geomorphology and their controls on gas accumulation of deep-buried cretaceous in Kuqa Depression. Tarim Basin, China Natural Gas Geoscience 26 (4) 667-678.

[8] Wang J, Zhang R, Zhao J, et al. 2014 Characteristics and evaluation of fractures in ultra-deep tight sandstone reservoir: Taking Keshen gas field in Tarim Basin, NW China Natural Gas Geoscience 25 (11) 1735-1745.

[9] Luo R and Zhang Y 2018 Geological characteristics and production performance of ultra-deep naturally fractured tight sandstone gas reservoirs IFEDC 2018 pp 959-972.