Adaptability Analysis for Sand Proppant to Conglomerate Oil Reservoir in Well-block MA 131 of Xinjiang Oil Field

Ang Chen¹, Zhao Zhang², Wei Tang¹, Lei Wang*, Huiyong Yu¹

¹CNPC Engineering Technology Research Institute of Xinjiang Oil Field, Karamay, Xinjiang, 834000, China
²College of Petroleum Engineering, China University of Petroleum, Beijing, 102249, China
*Corresponding author’s e-mail: leiwang@cup.edu.cn

Abstract. SRV (Simulated Reservoir Volume) in horizontal well is a main instrument for exploiting dense conglomerate oil reservoir in Ma Lake. The expenses of proppant are about 25% to 30% of the total SRV costs. In order to reduce costs and improve efficiency, it is inevitable to replace ceramic proppant with quartz sand, because the price of quartz sand is significantly lower than ceramic proppant. With Well-block Ma 131 as an object, this paper analyzes post-SRV production result of the existing alternative sand well; creates simple fracture and curved fracture model based on features of conglomerate oil reservoir; plots required conductivity of the target area through simulation and calculation; and analyzes adaptability of sand proppant to the target area based on conductivity data of sand proppant. The results indicate that the required conductivity of Well-block Ma 131 changes within 10 and 35 Dꞏcm; quartz sand can accommodate production demands completely when closure pressure is low; and required conductivity can be realized through improving sanding concentration when the closure stress is high.

1. Introduction

The dense conglomerate oil reservoir in Ma Lake is a large-scale monolithic conglomerate oil reservoir. It is difficult to achieve economic benefits during large-scale SRV due to bad physical properties of the oil reservoir, where expenses of proppant are about 25% to 30% of the total SRV costs. Based on the successful exploitation for unconventional oil and gas in North America [1], the precision cutting technology is used for exploitation as a whole, where 40/70-mesh and 100-mesh quartz sands are mostly used as proppants. With continuous development of precision cutting technology, reservoir is transformed through improving sand intensity on a large scale [2]. In order to reduce costs and improve the efficiency of SRV in domestic horizontal wells, quartz sand was used to replace ceramic proppant partially or completely in exploiting Changning-Weiyuan shale gas in Sichuan and achieved effective results [3]. The domestic common quartz sands mainly include Lanzhou sand, Xinjiang sand, Fuzhou sand, etc. The ceramic proppant has been replaced with quartz sand partially in SRV transformation for dense conglomerate oil reservoir in Ma Lake and shale gas reservoir in Sichuan Basin [4]. In the next 10 years, vertical depth of horizontal wells in the Ma Lake region will gradually increase to 4900m and average investment to SRV per well will be controlled to RMB 18.28 million, with the proportion of decline over 20%. Among the total costs, the proportion of materials reaches up to 40% and above and the proportion of instruments, services and operation reaches over 20%. Therefore, it is necessary to work orderly around materials, instruments and related operation and then realize maximum net present...
value for development [5]. After the 1990s, quartz sands are widely used in shallow and mid-layer oil-gas wells. However, with oil and gas exploitation in the deep layer, closure pressure of the fracture increases correspondingly, due to limitations of low intensity, fragility, and bad supporting effect, quartz sands are replaced with some artificial ceramic proppants and membrane quartz sands [6-13].

2. Analysis for production effect of alternative sand well

The reservoir at Well-block Ma 131 has porosity within 2.2% and 13.2% (with average 7.87%), permeability within 0.02 and 7.44mD (with average 1.03mD), and closure stress within 42 and 46 MPa [14-15]. In 2015, horizontal wells in Well-block Ma 131 were tested. In 2017, SRV development and productivity construction were implemented for horizontal wells in Well-block Ma 131 of Mabei Oil Field, and the solution of replacing ceramic proppant with shallow quartz sand was also implemented simultaneously. After 2018, ceramic proppant was replaced with quartz sand on a large scale in the shallow layer. Based on the relatively low closure stress in stratum and reservoir depth within 3300m in Well-block Ma 131, comparison and analysis for long-term yield and stress downtrend from related test indicate the feasibility of replacing ceramic proppant with quartz sand on a large scale.

The contrast well is selected from the view of geology and engineering. The geological parameters include vertical depth of about 3300m, which can ensure similar formation pressure and drilling on the same stratum instead of the same section due to a smaller number of wells. The engineering parameters are similar, including horizontal section length within 1601m and 1678m (with average 1623m) and drilling ratio within 85.7% and 98.5% (with average 91.5%). With respect to the number of sections and clusters, it is 42 clusters/well in average for ceramic well, which is lower than 59 clusters/well for sand well. The main difference is that the number of fractures on each fracturing section increases with the optimization of the fracturing process. The sand intensity is about 1.0. Table 1 shows basic parameters.

| Well No. | Vertical depth (m) | Section length (m) | Number of sections | Number of clusters | Proppant | Sand volume(m³) | Sand intensity (m³/m) |
|----------|--------------------|--------------------|--------------------|-------------------|----------|----------------|---------------------|
| Ma1      | 3227               | 1615               | 25                 | 49                | Ceramic proppant | 1852             | 1.15                |
| Ma2      | 3220               | 1604               | 23                 | 45                | Ceramic proppant | 1542             | 0.96                |
| Ma3      | 3195               | 1604               | 22                 | 42                | Ceramic proppant | 1597             | 1.00                |
| Ma4      | 3353               | 1605               | 26                 | 51                | Ceramic proppant | 1750             | 1.09                |
| Ma5      | 3209               | 1605               | 21                 | 41                | Sand proppant   | 1815             | 1.13                |
| Ma6      | 3219               | 1601               | 22                 | 63                | Sand proppant   | 1635             | 1.02                |
| Ma7      | 3399               | 1670               | 24                 | 70                | Ceramic proppant | 1550             | 0.93                |
| Ma8      | 3321               | 1678               | 23                 | 65                | Ceramic proppant | 1695             | 1.01                |

Figure 1 Production curve of sand well and ceramic well in Well-block Ma 131
The 400-day production data is used for comparison. The yields of 8 wells are overlapped respectively to plot the comparison curve in daily oil output and cumulative oil output. As shown in Figure 1, the daily yield of ceramic well has a slight change and maintains at 80-100t/day, because ceramic wells operated in 2017 have large well spacings. They are not adjusted for the production system on a large scale in a short term and not interfered basically. But alternative sand well indicates large fluctuation, of which production capacity is greatly improved due to drilling at over 200 days. The ceramic wells were drilled and filled at over 350 days. As a whole, the cumulative oil output of sand wells is slightly lower than ceramic wells as a whole. According to the comparison of yield for 400 days, the difference in cumulative oil output is about 1300t and oil output difference in a single well is 325t. From the view of difference in oil output, production capacity of alternative wells with 1.0 times of quartz sands is slightly lower than ceramic wells. However, in consideration of fracturing costs, sand proppant can accommodate large-scale development of oil field to a certain extent.

This study analyzes wellhead pressure of the above two types of wells respectively based on output statistics and analysis in Well-block Ma 131, selects the existing 42 wells (including ceramic wells and alternative wells) with normal operation, and plots their changing curve of wellhead pressure for 350 days, as shown in Figure 2. At the early stage of production (i.e. from 50 to 150 days), the wellhead pressure of sand well is slightly higher than ceramic well, mainly because the number of clusters at each section increases. The increased number of clusters means more fractures under the same well pressure, enhanced communication among strataums, and increased capacity of flow feeding to well shaft. After production for 150 days, both wells have seen decrease to a different extent. The stratum pressure decreases, and inter-fracture pressure waves are gradually transmitted to the boundary. In the process of production, the decreased daily oil output is offset through extending oil nozzle, resulting in a rapid decrease of wellhead pressure. For sand wells, wellhead pressure decreases significantly 150 days later, and difference in wellhead pressure with ceramic well is close to 1MPa at 200 days and final difference maintains at about 0.5MPa. For ceramic well, the wellhead pressure can be kept for a longer time. It begins to decline 200 days later. Therefore, ceramic wells are superior after production for 150 days.

The well group at t1b3 layer on fault of Well-block Ma 131 operated in 2017 was selected for single-well comparison. This group of contrast wells is featured with relatively low burial depth and almost similar reservoir pressure, length of horizontal section, number of clusters, and volume of SRV liquid. The sand intensity of alternative sand well is 1.2 times higher than ceramic well. The sand volume at single-cluster fractures of Ma16 and Ma17 is 44.2 m³ and 38.0m³ respectively, and well spacing is 300m. There are few interference factors due to earlier operation and production.
Table 2 Basic parameters of contrast wells

| Well No. | Ma17       | Ma16       |
|----------|------------|------------|
| Vertical depth m | 3103       | 3106       |
| Length of effective section m | 1692       | 1612       |
| Reservoir pressure MPa | 42.6       | 42.1       |
| Number of sections/clusters | 22/42       | 21/41       |
| Type of proppant | Ceramic proppant | Sand proppant |
| Volume of proppant m³ | 1597       | 1814       |
| Sand intensity m³/m | 0.95       | 1.13       |
| Volume of SRV liquid m³ | 24578       | 25785       |
| Production date | 2017.06  | 2017.07 |
| Cumulative oil output for 1200 days t | 23072 | 22937 |

From the view of production system, there are slight differences in the size of oil nozzle. The sand well Ma16 uses 4mm oil nozzle for production and ceramic well Ma17 uses 3.5mm oil nozzle for production. Although the production system is different, wellhead pressure is kept well. This indicates that quartz sands in fracture can provide good communication and accommodate long-term stable production.

Figure 3 Change of contrast wells in wellhead pressure

Figure 4 Change of contrast wells in production
In addition to the uncertainty difference due to geological conditions, the engineering factor of contrast wells is that difference in sand intensity is 1.2 times. It can be seen from overall effect that there is not significant difference in production result at flush stage if ceramic proppants are replaced with 1.2 times of quartz sands. From the curve of daily oil output, both wells indicate an especially similar production trend and undertake fracturing interference from infill wells on different layers after production for 600 days. Although they are interfered by three new wells, the new well and target well are located on different layers, which has a small influence on subsequent stable production. After production for 1200 days, the difference in oil output is 135t only and production of alternative well with 1.2 times of sands is basically consistent with ceramic well.

3. Required reservoir conductivity
The required fracture conductivity is different for reservoir with different physical features. Therefore, it is necessary to explore the matching relationship between fracture conductivity and effective reservoir permeability. It is difficult to accommodate production requirement if fracture conductivity is low, otherwise, it is impossible to reach economic permission or technical conditions. Hence, a production calculation model is created for the target block to fit historical production and explore the optimal conductivity.

This paper uses a typical well as the basis of numerical simulation, implements 21-section and 41-cluster fracturing solution for the horizontal section with length 1200m, and sets sand intensity to 1.12m$^3$/m and single-cluster sand volume to 32.9 m$^3$. The detailed petrel-based geological model is combined with reservoir description and meshing model in CMG to create a numerical model for oil reservoir. Based on historical production data and dynamic parameters, basic parameters of the model are fit and corrected to simulate cumulative production under different reservoir conditions and process parameters, and finally obtain the optimal conductivity under different reservoir conditions.

Considering changes in fracture type, cluster space, reservoir permeability, and conductivity, the simulation divides fractures into simple and symmetric double-wing fracture and curved fracture (as shown in Figure 5) and analyzes required conductivity of reservoir with different types of fracture.

| Table 3 Simulated parameters of required conductivity |
|---------------------------------|----------------|
| Variables                      | Parameters    |
| Conductivity /D·cm             | 1, 5, 10, 15, 20, 30, 50 |
| Cluster space/m                | 20, 30, 40     |
| Permeability /mD               | 0.01, 0.1, 0.5, 1, 2, 5, 10 |

Figure 5 Simple fracture and curved fracture model
With the three-year cumulative oil output as reference value, this paper obtains over 100 groups of data about production capacity through simulation under limited production and certain pressure, then selects the optimal conductivity under each changed parameter, and finally combines the optimal conductivity with cluster space to get required conductivity of a typical reservoir with different types of fracture in Well-block Ma 131, as shown in Figure 6 & 7.

![Figure 6 Required conductivity of simple fracture in Well-block Ma 131](image)

![Figure 7 Required conductivity of curved fracture in Well-block Ma 131](image)

The conductivity is selected based on changes in production capacity and conductivity. The required conductivity is 10-30D·cm for simple fracture and 15-35D·cm for curved fracture. The optimization of required conductivity of the target well block with different types of fracture is combined with reservoir
permeability and cluster space to plot conductivity under multiple factors, as shown in Figure 8 & 9. They can provide important references for on-site construction and design.

4. Adaptability analysis for sand proppant
The simulation indicates relatively small difference in required conductivity of the target block, which mainly reflects in reservoir permeability and transformation of cluster space. In 2019, the main framework of Ma Lake was designed with 3 clusters with 20m cluster space. The cluster space now in many large-section and multi-cluster tests at Ma Lake are controlled to about 10m. The decreased cluster space indicates a smaller radius of displacement of reservoir oil, which can decrease reservoir conductivity to a certain extent. The closure stress of fracture also determines the feasibility of replacing
ceramic proppant with sand proppant to a large extent, of which development orientation reflects in the concept of “collective support from liquid and sand” and required reservoir conductivity.

The concept of “collective support from liquid and sand” is created based on the condition that effective stress of proppant is mainly affected by closure stress of fracture and BHFP change. If the formation pressure coefficient is high, then effective stress applied to proppant at early stage will be small. At Well-block Ma 131, the formation pressure coefficient changes within 1.11 and 1.18, average closure stress is 47.5MPa, and vertical depth is 3259m. Based on the wellhead pressure 0.5MPa, effective stress applied to proppant at the early stage of production is lower than 25MPa, and sand proppant can accommodate supporting requirement of fracture. After flush stage, bottom hole pressure can be further decreased due to pumping, resulting in increase of stress applied to proppant. Based on the 2000m working fluid level, effective closure stress applied to proppant after pumping is about 30MPa, which basically reaches the anti-pressure limit of sand proppant.

As shown in Figure 10 & 11, increasing concentration of sand proppant can improve conductivity, but sand scale in fracture is limited. The proppant cannot be added infinitely during SRV process and increased scale of proppants will undoubtedly increase investment costs. From the view of fracturing...
process and economic efficiency, adaptability of sand under different oil reservoirs of the target block shall be determined by oil reservoir and economic investment solution together.

It can be seen from oil output analysis and sand scale that the effect of 1.0 times of sand proppants is lower than ceramic proppants, but there is not significant difference. The effect will be better if the scale of sands is increased to 1.2 times and above.

The solution of replacing ceramic proppant with sand proppant is also challenged, where the most important problem is low anti-pressure ability. The quartz sands with anti-pressure level 28 MPa and 35MPa are mostly used on site. The results of lab experiment indicate that conductivity will drop dramatically when closure stress changes within 35 Mpa and 40Mpa, mainly because proppants may break in a large area with increase of closure stress, and yield of sand well is basically consistent with ceramic well at the early stage of replacement. However, as production goes on, effective closure pressure increases, sand conductivity declines and cannot provide long-term support [16]. In this case, adaptability of sand proppant can be improved through increasing sand scale in the allowable range of construction conditions and economic ability.

5. Conclusions
1. According to production result of existing alternative well in Well-block Ma 131, oil output of alternative sand well is close to ceramic well at the early stage of production; subsequent oil output of alternative well is slightly lower than ceramic well; oil output of alternative well is basically consistent with ceramic well if sand intensity of alternative well is 1.2 times higher than ceramic well.

2. Through creating prediction model for production capacity of horizontal wells under different types of fractures on reservoir, this paper obtains the required conductivity of simple fracture (10-30 Dꞏcm) and curved fracture (15-35Dꞏcm) and plots required conductivity under different permeability and cluster space, which can provide references for rapidly optimizing on-site construction parameters.

3. According to conductivity of sand proppant under different closure stresses, quartz sand can accommodate reservoir conductivity completely under low closure stress. The concept of “keeping quality by quantity” can enhance the adaptability of sand proppant when the closure stress is high. The required reservoir conductivity is accommodated through increasing sand concentration.

References
[1] Weijers, L., Wright, C., Mayerhofer, M., et al. Trends in the North American Frac Industry: Invention through the Shale Revolution. Society of Petroleum Engineers, 2019, 194345-MS.
[2] Olmen, B. D., Anschutz, D. A., Brannon, H. D., et al. Evolving Proppant Supply and Demand: The Implications on the Hydraulic Fracturing Industry. Society of Petroleum Engineers, 2018, 191591-MS.
[3] Yang Lifeng, Tian Zuhong, Zhu Zhongyi, et al. Economic adaptability of quartz sand for shale gas reservoir fracturing[J]. Natural Gas Industry, 2018,38(05):71-76.
[4] Li Xiaogang, Liao Zijia, Yang Zhaozhong, et al., Application and Development of Fracturing Proppant[J]. Bulletin of the Chinese Ceramic Society, 2018,37(06):1920-1923.
[5] Mack, M. G. and Coker, C. E., 2013b. Proppant Selection for Shale Reservoirs: Optimizing Conductivity, Proppant Transport and Cost. Paper SPE 167221 presented at the Unconventional Resources Conference-Canada held in Calgary, Alberta, Canada, 5-7 November.
[6] Lee D S, Elsworth D, Yasuhara H, et al. Experiment and modeling to evaluate the effects of proppant-pack diagenesis on fracture treatment[J]. Journal of petroleum science and engineering, 2010, 74:67-76.
[7] Zhu Wen, Zhu Huayin. Permeability discrepancy of proppant fracture its effect on economic net present value after fracturing[J]. Oil drilling and production technology,199618(4):5-89.
[8] Zhao Yanrong, Wu Bolinn, Wu Tingling. The development of high-alumina ceramic proppants[J]. China Ceramics,2010,42(2):46-49.
[9] Wen Q Z, Zhang S, Wang L, et al. The effect of proppant embedment upon the long term conductivity
of fractures[J]. Journal of petroleum science and engineering, 2007, 55:221-227
[10] Rickands A R, Brannon H D, Wood W D, et al., High Strength, Ultra-light weight proppant lends new dimensions to hydraulic fracturing Applications[J], Society of Petroleum Engineer, 2003:1-4.
[11] Wang Jinjuai, Zhao Youyi, Gong Hongyu, et al. Advance of ceramic proppant for oil hydraulic fracture[J]. Bulletin of the Chinese ceramic society, 2010, 29(3):633-636.
[12] Ma Xue, Yao Xiao, Hua Sudong, et al. Effects of MnO₂ and Fe₂O₃ on microstructure and crush resistance of alumina matrix fracturing proppant[J]. Journal of the Chinese ceramic society, 2009, 37(2):280-2
[13] Liang, F., Sayed, M., Al-Muntasheri, G., et al. Overview of Existing Proppant Technologies and Challenges. Society of Petroleum Engineers. 2015, 172763-MS.
[14] Xiao Meng, Yuan Xuanjun, Wu Songtao, et al. Conlomerate reservoir characteristics of and main controlling factors for the Baikouquan Formation, Mahu sag, Junggar Basin[J]. Earth Science Frontiers, 2019, 26(1):212-224.
[15] Tang Yong, Guo Wenjian, Wang Xiatian, et al. A New Breakthrough in Exploration of Large Conglomerate Oil Province in Mahu Sag and Its Implications[J]. Xinjiang Petroleum Geology, 2019, 40(02): 127-137.
[16] Wang Hongbo, Zhang Zhen. Experimental research on long-term conductivity of different supports[J]. Petrochemical Industry Application, 2019, 38(10):70-72.