Application of Fracture Development Recognition in Fuyang Reservoir of Daqing Oilfield-Low Permeability Reservoir-A Development Zone in Integral Fracturing Completion

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Abstract. Fuyang reservoir in a development area has large geological reserves and is regarded as an important reserve potential in the development stage after the 12th Five-Year Plan. Fuyang reservoir has the characteristics of deep burial, low quality, small effective thickness, low permeability and difficult to produce without fracturing. Aiming at the disadvantageous factors of reservoir development, combined with the optimization of well pattern deployment of reservoir engineering, the overall fracturing and completion technology of development block is optimized by using the fine geological research results of fracture development recognition. The direction of in-situ stress extends, and the perforation phase is optimized. Under the permissible conditions of perforation technology, the direction of hole is as close as possible to the direction of maximum principal stress, which is conducive to reservoir communication during fracturing. At the same time, according to the understanding of fracture development, in order to improve productivity and control water cut rising speed, the half-length of fracture and fracture conductivity are optimized to control the occurrence of water immersion. Through the integration of multi-disciplinary geological research and well completion engineering, a fracturing displacement system adapted to Fuyang reservoir in the development zone has been established, and good productivity results have been achieved, which provides a reference experience for the follow-up large-scale and efficient development of Fuyang reservoir in the development zone.

Introduction

The geological reserves of Fuyang reservoir are 7676.0 x 104t, which is regarded as the important reserve reserves potential in the development stage after the 12th Five-Year Plan. The average burial depth of Fuyang reservoir is about 1700 meters, the effective thickness is 5.1 meters, the effective porosity is 12.5%, and the average permeability is 1.1 millidarcy. It has the characteristics of low quality, low permeability and difficult to use without fracturing. At the same time, the reservoir fractures are developed, the physical properties of reservoirs are poor, and the shale content is high. In view of reservoir characteristics, based on the understanding of reservoir fracture development, combined with the optimization of well pattern deployment of reservoir engineering, oil production engineering has optimized the overall fracturing and completion technology of development block, established a fracturing displacement system adapted to Fuyang reservoir in this development zone, and achieved good productivity results.

Oil Reservoir

Geological Characteristics of Experimental Area. The Fuyang reservoirs exploited in the test area are divided from top to bottom into four reservoir groups, namely, Fu I, Fu II, Fu III and Yang I. The oil-bearing area of the test area is 0.87 km^2, the geological reserves are 74.91 x 10^4t, the burial depth of the reservoir is 1500-1900m, the average effective thickness is 15.0m, the effective porosity is 12.5%, and the average air permeability is 1.1mD.

Structural Characteristics of Experimental Area. According to the structural map of the top surface of the oil reservoir, the fault of Fuyang oil reservoir in the development area is very well developed, with many faults, short extension, multi-stage development and complex cutting relationship, forming a complex structural form of horst, graben and fault terrace. There are 132 normal faults with an extension length of more than 2 km. The fault spacing is generally 20-60 m, the maximum is 150 m, the extension length is 3.5-14.0 km, the maximum is 28.5 km, and the dip angle is 40-50 degrees. The north-west direction is the main direction, followed by the North-South direction. Faults of different stages and strikes form a complex fault system in space. Six fault zones are mainly developed. The fault zones are mainly distributed in NNW direction. Controlled by fault cross fault, many local structural traps are developed.

Description and Application of Reservoir Fracture Development

Description of Reservoir Fracture Development. In order to obtain higher productivity, the completion and modification section of productivity wells should pass through as many high-angle natural fracture systems with better permeability as possible, or intersect with natural fractures through fracturing artificial fractures. However, the direction of reservoir fracturing fracture is controlled by the direction of the maximum principal stress of the formation, so it is necessary to refer to the fracture development and stress distribution of the target reservoir when considering the completion technology of productivity wells.

In order to study the fracture development of Fuyang reservoir in this area, fracture monitoring work was carried out in well XX-A. According to the test results (Table 1), the fracture in this well is well developed, mainly vertical fracture. The fracture strikes near East-West direction, and the maximum horizontal stress orientation is between 55 and 85 degrees.

Table 1 Data table for anisotropic analysis of Fuyang reservoir in well XX-A

Serial number	Well section (m)	Anisotropy (%)	Anisotropic orientation (deg)	Influence of in-situ stress	Borehole influence	Crack influence	Maximum horizontal crustal stress (MPa)	Minimum horizontal crustal stress (MPa)	Maximum and minimum horizontal stress difference (MPa)
1	1630.0-1637.0	2.4	85	√	√		32.5	29.0	3.5
2	1638.4-1648.0	2.1	85	√	√		31.5	28.4	3.1
3	1648.4-1659.6	2.6	55	√	√		32.1	28.2	3.9
4	1660.4-1673.4	2.3	85	√	√		34.1	30.6	3.5
5	1674.0-1681.4	2.8	80	√	√	√	35.5	31.3	4.2
6	1684.6-1699.4	3.3	75	√	√		34.1	29.2	4.9
7	1700.4-1704.0	3.6	50	√	√		40.1	34.7	5.4
8	1704.6-1742.4	3.0	80	√	√	√	33.5	29.0	4.5
9	1744.0-1755.0	3.8	55	√	√	√	40.5	34.9	5.6
10	1755.0-1768.6	2.0	55	√		√	33.5	30.5	3
11	1782.4-1817.2	2.0	55	√			35.8	32.8	3
12	1818.6-1871.6	1.8	50	√		√	35.4	32.7	2.7

In addition, 16 layers of 6 wells were selected to carry out microseismic artificial fracture monitoring. The monitoring results are shown in Table 2. The orientation of artificial fracture is mainly in NE direction. There are 5 wells, 12 layers in NE direction and 50.4-89.1 layers in NE direction. There are 2 wells in the NW direction, 4 in the north and 77.5 to 88 in the North West.

Reservoir engineering analysis shows that the direction of fracture system in the test area is 50.4-89.1 condyle in the northeast. When fracture direction is adopted in well pattern direction, the greater sweep coefficient of system area and displacement efficiency are, the direction of well row should be parallel to fracture direction. In order to match well pattern with artificial fracture, the maximum principal stress direction is adopted in the direction of well row and 70_direction in the north-east.

Optimization Technology for Integral Fracturing of Rectangular Well Pattern in Fuyang Reservoir. Completion is a measure to form an effective passage between production zones and wellbore. Completion technology has a direct impact on oil well productivity and later investment measures. The selection of completion mode is directly related to the whole process of production in the future. In order to ensure the realization of the productivity index of oilfield development, on the basis of fine geological research results and optimized well pattern deployment of reservoir engineering, the oil production engineering tries hard to construct an effective displacement system of Fuyang reservoir suitable for this development block and improve the reservoir utilization process by carrying out integral fracturing optimization test of rectangular well pattern of Fuyang reservoir. Degree.

Table 2 Monitoring data of microseismic artificial fractures in Fuyang oil reservoir

Well	Well section (m)	Artificial fracture azimuth (°)	Intake crack length (m)	Intake crack height (m)	Dip angle (°)	Inclination
XX-A	1654.2-1647.6	north-east 60.1	208.0	12.0	1	Northwest
	1763.4-1758.0	north-east 58.4	208.0	14.7	3	Southeast
XX-B	1937.2-1932.4	north-east 66.4	205.3	17.3	3	Northwest
	1908.8-1905.2	north-east 50.4	205.3	17.3	4	Southeast
	1807.8-1803.2	north-east 52.0	208.0	16.0	0	
	2023.0-2017.6	north-east 68.9	208.0	14.7	9	Northwest
XX-C	1859.2-1844.0	north-east 60.2	173.3	22.7	0	
	1725.0-1713.4	North-west 84.8	165.3	24.0	0	
	1625.8-1604.4	north-east 50.7	170.7	20.0	1	Southeast
XX-D	1753.6-1749.2	north-east 80.5	162.7	21.3	6	Northwest
	1660.6-1656.8	north-east 63.5	234.7	17.3	2	Southeast
	1630.6-1628.0	north-east 89.1	202.7	22.7	8	Southeast
XX-E	1691.0-1686.0	north-east 65.2	168.0	21.3	5	Northwest
XX-F	1600.8-1598.0	North-west 80.0	152.0	20.0	1	Northeast
	1570.0-1559.0	North-west 88.0	213.3	22.7	3	Northeast
	1496.0-1489.0	North-west 77.5	213.3	22.7	1	Northeast

Clear the Overall Fracturing Technology of Rectangular Well Pattern. In order to establish effective drive between rows of oil and water wells and improve completion effect, the overall fracturing design idea is adopted under the condition that the current well pattern and maximum principal stress orientation are fixed. That is to say, two artificial fractures parallel to the well pattern are formed at both ends of oil and water wells by corresponding fracturing modification at both ends of oil and water wells. At the same time, in close connection with the actual situation of single well sand body development, oil and water wells corresponding layer fracturing transformation is carried out, effective communication between oil and water wells is established, and a fracturing displacement system suitable for Fuyang reservoir in Wuchang area is formed.

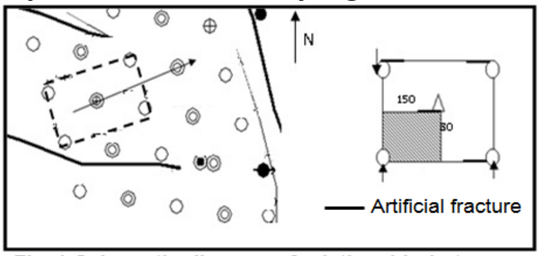

Fig.1 Schematic diagram of relationship between artifical fracture and well pattern layout and ground strees

Optimize the Whole Fracturing Process Parameters of Rectangular Well Pattern. Fracture system has significant effect on improving the development effect of low permeability reservoir, but also has a significant impact on oil and water wells. Therefore, in order to control the rising rate of water cut and ensure that two parallel fractures with reasonable fracture lengths are reformed, parameters such as perforation phase, half-length of fracture and conductivity are optimized and deployed, so as to delay the negative impact of fracture on production wells while increasing productivity.

Perforation Phase Optimization Design in Experimental Area. From rock mechanics, we know that fracturing fractures extend along the maximum horizontal stress direction. When the direction of perforation channel is consistent with the direction of maximum horizontal in-situ stress, the wellbore stability is high; when the direction of perforation hole is not consistent with the direction of maximum horizontal in-situ stress, the fracture will extend from the perforation channel around casing and cement ring to the bottom or tip, resulting in cracks around the wellbore, which will cause fracture pressure and liquid friction resistance during fracturing process. Increase. Therefore, perforation angle should be chosen as the maximum principal stress direction. The 135° phase perforation has the highest phase angle and the lowest productivity at 0° angle. The maximum horizontal Geostress in the test area is 50.4-89.1° in the North East. From Fig.2, it can be seen that after perforation in several circumferential ranges, the hole direction is more similar to the direction of the maximum principal stress, and the perforation direction is more spatially distributed, which is conducive to reservoir communication during fracturing. The designed oil well uses 135° phase angle perforation.

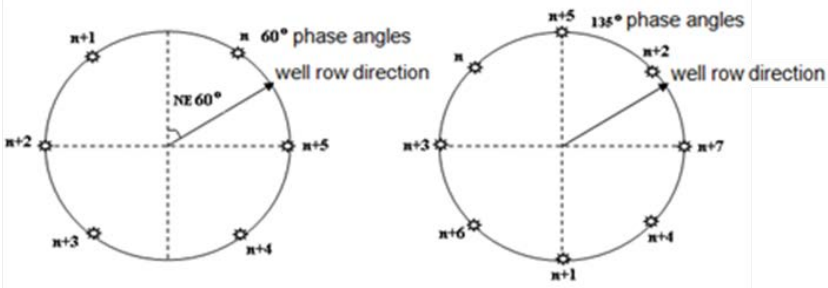

Fig.2 The phase distribution of the 60° and 135° phase angles in the circular projection

Optimization Design of Water Injection Well Length in Test Area. In the test area, a 300*80m rectangular well pattern is adopted to optimize the fracture length under different penetration ratios (Table 3).

Table 3 Fracture half length table of well pattern with different penetration rates

well pattern	Penetration ratio					
	0.3	0.5	0.6	0.7	0.8	0.9
300×80m	45 m	75 m	90 m	105 m	120 m	135 m

By calculating the relationship between water cut and injection volume and time in different fracture lengths of injection wells (Figs. 3 and 4), the larger the penetration ratio, the earlier the water breakthrough time of connected oil wells and the higher the water cut at the same production time. Therefore, considering the control of water cut and the improvement of water drive effect, the fracture penetration ratio of injection wells is determined to be 0.7-0.9. The half well length of 300*80m well pattern is 105 ~ 135m.

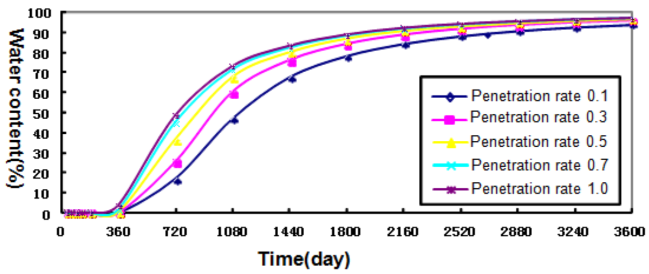

Fig.3 Curves of water cut rate of oil well with time under different length of water injection well

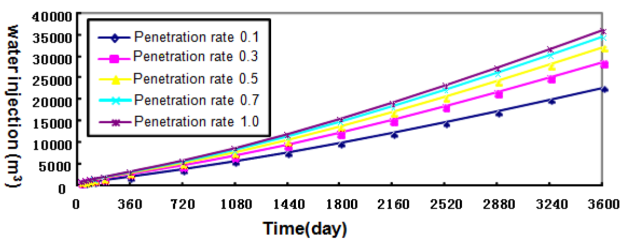

Fig.4 Curves of cumulative water injection volume varying with time under different length of water injection wells

Optimization Design of Production Well Length in Experimental Area. The optimization design software is used to optimize the fracturing scale of the production well in the test area. The average cumulative production of a single well varies with the change of fracture length (Fig. 5). The cumulative oil production increases relatively fast when the fracture penetration ratio is between 0.3 and 0.7. When the penetration ratio exceeds 0.7, the cumulative oil production increases slowly, and the penetration ratio of 0.6 to 0.7 is the best half-length of the fracture. Therefore, the optimum fracture penetration ratio is 0.6-0.7, which is 90-105 m in the half-length of 300*80m well pattern.

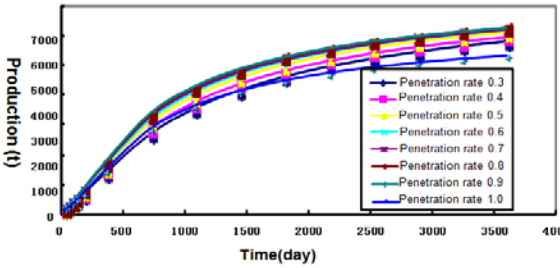

Fig.5 The curve of average cumulative yield of single well with fracture length

Optimization of Fracture Conductivity. The average cumulative production of a single well varies with the change of fracture conductivity (Fig. 6). When the fracturing scale is fixed, the conductivity is optimized. With the increase of the conductivity, the production increases and the water breakthrough time accelerates correspondingly. When the conductivity increases from 25μm^2·cm to 40μm^2·cm, the productivity increases with the increase of the conductivity. The increase has slowed down. Under the conductivity of 25μm^2·cm, the average initial productivity and the average stable productivity of a single well can meet the needs of the development plan for productivity. The conductivity of a fractured well is designed to be 25μm^2·cm. In order to reduce the water injection pressure drop and conductivity of a fractured well, the conductivity of a fractured well should be increased accordingly, and the conductivity of a fractured well designed for test is 35μm^2·cm.

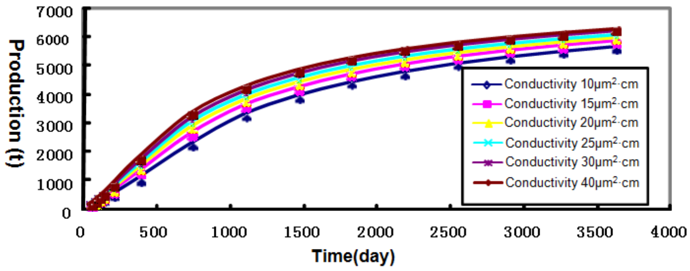

Fig.6 Curve of average cumulative productivity of single well with fracture conductivity

Overall Fracturing Optimization Results and Initial Operation Results. Through the above optimization calculation, it is determined that the fracture half-length is 90-105m when the conductivity of production wells in the test area is 25μm^2·cm, and 105-135m when the conductivity of water wells is 35μm^2·cm. The optimization results are shown in Table 4.

Table 4 Optimization results of fracturing scale for oil and water wells

Well farewell	Oil well	Injection well
Scale (m)	90～105	105～135
Diversion capacity (μm^2·cm)	25	35

All 32 oil and water wells in the test area are completed by integral fracturing technology with well pattern. Individualized integral fracturing design and corresponding fracturing horizon construction of oil and water wells are implemented in completion design. Parallel fractures are opened in oil and water wells. Good test results have been achieved in this area. The productivity wells in Fuyang reservoir after fracturing have better fluid productivity. In the initial stage of production, the average daily fluid production per well is 5.4 tons, the daily oil production is 2.6 tons, the water cut is 51.9%, and the oil production intensity is 0.26t/d.m. In view of the characteristics of low porosity and ultra-low permeability in Fuyang oil reservoir, combined with fine geological research, the whole well pattern fracturing technology is implemented to make the fracture direction parallel to the well pattern, and the fracturing technology adapted to Fuyang oil reservoir is effectively established. The displacement system and rectangular well pattern integral fracturing technology are suitable for the scale development of Fuyang reservoir, which provides a good experience for the follow-up development of Fuyang reservoir as a replacement potential.

The Overall Application Effect. ***The Production Capacity Reaches the Standard in the Initial Stage of Operation, and the Adaptability of Well Completion Technology is better***. The pilot area completed production and injection in 2012, and produced 2.6 tons of oil per day in the initial stage of production. The oil production intensity was 0.26t/d.m higher than the design target by 8 percentage points, and the injection well completion rate was 100%. Based on the fine geological research results, the "personalized" integral fracturing design of rectangular well pattern is adopted to match the direction of fracture and well row, which better meets the need of tapping potential of Fuyang reservoir.

Achieving Long-term and Stable Production. The test area has been put into development since 2012. Through fracturing modification and advanced water injection, long-term continuous and stable production has been achieved. Over the past six years, comprehensive water cut has been kept below 70%, average single well fluid production has been maintained above 3 tons, oil production has been maintained at about 1.5 tons, and the development effect is good.

Development Efficiency is better. Since the pilot area was put into development, the development effect has been good, and the long-term stable production has been achieved for six years. At present, the comprehensive water content has increased from 51.9% to 64.7%, only 24%, and the development potential is great. At present, 21 oil wells have accumulated 49,900 tons of oil, calculated at 2,396 yuan per ton of oil price. The stage output benefit is 120 million yuan, and the economic benefit is remarkable.

Conclusion and Understanding. The understanding of fracture development in Fuyang reservoir developed in this development zone provides an important basis for rational well pattern and optimal deployment of overall fracturing technology, and is the basis for better development effect of this low permeability complex reservoir.

According to the characteristics of Fuyang reservoir such as ultra-low permeability, under the premise of well pattern and formation stress, reasonable and effective optimization of perforation phase, fracture half-length, fracture conductivity and corresponding well selection provides technical conditions for improving development effect under current reservoir development conditions.

Through the research of integral fracturing technology of rectangular well pattern in Fuyang reservoir and the implementation of integral fracturing process design, a fracturing displacement system adapted to Fuyang reservoir is established, which provides a basis for large-scale development of Fuyang reservoir.

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