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Feasibility Study of "Fracture network" Fracturing Technique Applied to the Fissured Competent Sand Oil Reservoir and Field Test

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Chang 8 oil deposit, developed in Hohe oil field at the southern Yi-Shan Slop of Ordos Basin, is regarded as a kind of typical sand reservoir formation with super-low porosity, poor permeability, strong anisotropy as well as locally natural faults and fractures. Matrix reservoir has a poor permeability, but fracture reservoir has a reverse manner. In the past years, fewer researchers paid their attentions to study matrix-fracture type oil reservoir, therefore today it is still difficult to identify whether network hydraulic fracturing can be effectively exploited in low permeable matrix-fracture type reservoir. In this paper, the author tries to analyze the feasibility of network hydraulic fracturing application in Chang 8 oil deposit from following aspects: mineral component, rock brittleness index, development status of natural fractures, ground stress and net press during hydraulic fracturing. The statistical results indicate that the geological condition of research object is confirmed to meet the standard of hydraulic fracturing with medium brittleness index, high angle, developed natural fracture and horizontal layers as well as the difference of two principal horizontal stresses 5.4 MPa. The paper performed field investigation in HH6P2 well by the methods of segmental perforation, interference between multiple clusters and boosting net pressure. Then its daily output was up to 2.58 t. Finally, the paper concluded that it is an important treatment to effectively develop this type of oil reservoirs by “Fracture network” fracturing technique in horizontal wells.

1. Introduction

Hohe oil field is located at the southern Yi-Shan Slop of Ordos Basin in the northwest China, whose production layers are mainly distributed in the Chang 8 Oil Deposit of YC formation with developed natural fractures and strong anisotropy (Wang Y. et al. (2014)). The average effective porosity and mean permeability of Hohe oil field are 9.6% and $0.41\times10^{-3}\mu m^2$ respectively. These data corroborate that the Chang 8 oil deposit of YC formation is a typical competent sand reservoir with super-low porosity and permeability.

Chang 8 deposit currently has two types of reservoirs: matrix type and fracture type (Wang Y. et al. (2014)). In the earlier stage, according to the concept “making a long fracture”, the prevalent and common treatment was to build a single fracture. But there also excited some problems: the oil leak-off area was limited, the production of the single well rapidly reduced and so on. Due to these disadvantages, the new concept “network hydraulic fracture” will be induced (Chen S. et al. (2011)) in this paper. The paper attempts to prove the application feasibility of network fracturing technology in the Chang 8 oil deposit of the south of Ordos Basin. It also provides an important guidance in the process of understanding and exploiting this type of oil reservoir.

2. Mechanism

Based on the theory of rock mechanism and fracture criterion, the difference between maximum and minimum horizontal stress plays a significant role in building multiple fractures. If the difference is large enough, a couple of conjugated fissures can be created along with the direction of maximum stress. However, if it is too small, the starting-crack direction will be mainly controlled by the natural fractures of reservoir. As a result, a

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complex fracture network will be built with multiple strands extending to all directions. Under hydraulic fracturing, a single or several principle fractures can be generated, and the natural fractures keep propagating accompanied with shear slipping, which creates more branch fissures. These fissures and the principle fractures can form a fracture network system, which allows the reconstruction volume and using rate of oil reservoir to enhance.

Therefore, the natural fractures and adequate rock brittleness are assumed as the preconditions for building multiple fractures and breaking the reservoir. Furthermore, rock dynamics features, natural feature development situation, geostress as well as artificial stress are all dominant factors during network hydraulic fracturing (Blanton T.L. (1986)).

3. Feasibility study

In the previous studies, most researchers focused on the stress difference between reservoir and interlayer, Young's modulus, Poisson's ratio etc., when they were discussing the fracture morphology. Gradually, net pressure (Taleghani A D. (2009)), rock dynamics features (Rick Rickman. et al. (2010)), and properties of fracturing fluid and proppant (L.J.L. Beugelsdijket al. (2000)) started drawing their attentions because more evidence indicated that these new factors have bigger effects.

Brittleness Index

Taleghani A D. (2009) showed that brittle minerals of reservoir such as quartz and carbonate would contribute to a complex network in the progress of hydraulic fracturing. When the quartz content is above 30%, the brittleness dominates (Zhao J. et al. (2013)). The content ratio of quartz, feldspar and debris in Chang 8 Oil Deposit is approximately 2:1:1. The average quality fraction of quartz ranges from 39.01%-41.6%.

Brittleness index can be computed if the Elastic Modulus and Poisson's Ratio are known by Rick Rickman. et al. (2010):

$$YM\_BRIT = (YMS\_c - 1) / (8-1) \times 100\% \quad (1)$$

$$PR\_BRIT = (PR\_c - 0.4) / (0.15-0.4) \times 100\% \quad (2)$$

$$BI = (YM\_BRIT + PR\_BRIT)/2 \quad (3)$$

Where YMS_c is Young's modulus, PRC is Poisson's ratio, YM_BRIT is the homogenization Young's modulus, PR_BRIT is the homogenization Poisson's ratio, BI is rock brittleness index.

The rock brittleness indices of Chang 8 Reservoir in E South Blocks are shown in table 1.

Table 1: Rock brittleness index calculation table of the Chang 8 Reservoir in Hohe oil field

Well Number	Depth/m	Lithologic Character	Elastic Modulus/MPa	Poisson's Ratio	Shear Modulus/MPa	Brittleness Index /%
HH12	2093.3-2094.3	Medium Sandstone	24870	0.20	10540	50.62
HH21	1781.4-1783.5	Medium Sandstone	35180	0.19	14710	59.99
HH5	2142.4-2143.4	Fine Sandstone	36530	0.23	14800	52.95
HH9	2167.0-2169.3	Fine Sandstone	32280	0.19	13059	57.91
Mean	/	/	32215	0.20	13277	55.37

Table 1 represents that the average brittleness index of Hohe is respectively 54.6%. According to the relationship between brittleness index and fracture morphology, Chang 8 Oil Reservoir is suitable to use mixing hydraulic fluid (slickwater + glue solution) to build network.

4. Natural fractures

It is believed that the more natural fractures or beddings develop in reservoir, the easier network can be built by hydraulic fracturing. It is helpful to create network if the angle between principle and natural fractures ranges from 0° to 60°. However, if the angle exceeds 60°, the network will not be developed (Potluri N. et al. (2005)).

The core photo and imaging logging interpretation chart show that Chang 8 oil reservoir has developed natural fractures, whose orientation keeps a same tendency with the artificial ones with ±60% development probability. The liner density is 0.03-2.6 cracks per meter, average at 0.38 cracks per meter. These demonstrate that reservoir with developed fractures is apt to form a network system to a certain degree.

Table 2: Ability to form complex fracture contrast table of the chang 8 reservoir in Hohe oil field

Oil Field	Fracture Intensity	Angel between Principle and Natural Fractures	Variation Coefficient of Horizontal Stress	Construction Displacement/m^3.min^{-1}	Net Pressure Prediction/ MPa
Hohe	Developed	0-30°	0.152	3.0-3.5	7-9

4.1 Geostress

The dynamics of network fractures will be discussed on the base of natural fractures extension, which are shown in Fig 2 (Weng D. et al. (2011)).

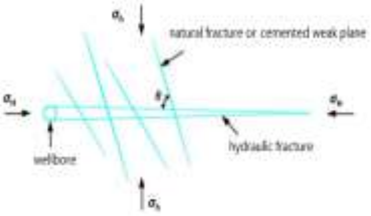


Figure 2: Schematic plot of Joint network system

Fracture morphology is influenced by the variation coefficient of horizontal stress, which is the difference between maximum and minimum of principle stress in the horizontal well.

$$K_h = \frac{\sigma_H - \sigma_h}{\sigma_h} \tag{5}$$

Where K_h is variation coefficient of horizontal stress, σ_H is the maximum horizontal stress, σ_h is the minimum horizontal stress.

Only if the variation coefficient ranges from 0 to 0.125, hydrofracture will form complex cracks with braches near the borehole, which has more small fissures extending along with the dominant direction at the same time. If the coefficient is 0.125-0.25, the braches will propagate near the borehole and eventually form a network under pressure of net stress. If the coefficient exceeds 0.25, hydrofracture will mainly build a single fracture rather than a network. According to the above theory, the horizontal stress variation coefficient of Hohe oil field is 0.156, which are shown in Table 3, thus being able to build complex network fractures.

Table 3: Horizontal stress difference coefficient of the Chang 8 reservoir in Hohe oil field

Well Number	Lithologic Character	Depth /m	Vertical Geostress /MPa	Maximum Geostress /MPa	Minimum Geostress /MPa	Variation Coefficient
HH12	Medium Sandstone	2093.3-2093.8	51.3	41.3	35.9	0.150
HH21	Medium Sandstone	1781.4-1783.5	42.6	35.2	29.9	0.177
HH5	Fine Sandstone	2143.4-2143.8	52.7	42.4	36.8	0.152
HH9	Fine Sandstone	2267.0-2268.5	56.1	44.8	39.2	0.143
Mean	/	/	50.68	40.93	35.45	0.156

4.2 Net stress

Net stress is the differential between the pressure inside the cracks and the minimum stress of layers. It is relative to formation Young's modulus, reservoir depth, viscosity of hydraulic fluid, construction discharge and fracture length.

$$p_{net} \propto \frac{E}{h}\left[\mu Q^{1/2}L\right]^{1/3} \tag{6}$$

Where P_{net} is net stress, E is formation Young's modulus, h is the reservoir depth, μ is viscosity of hydraulic fluid, Q is construction discharge, L is fracture length.

Based upon the minimal energy principle, if net pressure becomes greater than the difference between maximum and minimum stress, the energy will be released along with the orientation of the shortest distance, altering fractures direction, finally form a network. The data obtained from 60 vertical wells of Chang 8 oil deposit in the Hohe oil field show that there is a liner correlation between net pressure and construction discharge. The construction discharge is 1.8-2.5 m^3/min, and the net pressure is 2.0-5.0 MPa, lower than the difference 5.6 MPa, thus building a single fracture. If construction discharge is 2.5-3.0 m^3/min, there are more than 70% wells, whose net pressure is above 5.6 MPa, building complex fractures. If the construction discharge exceeds 3.0 m^3/min, and the net pressure is above 7 MPa, exceeding the difference, a relatively complex network will be created.

The data collected from staged fracturing of HH1 well in the Hohe oil field is analyzed by the method of net pressure matching, in order to confirm the effects of net pressure toward fracture morphology.

Table 4: Net pressure fitting data tables of well HH1

No.	Construction discharge $m^3.min^{-1}$	Injection volume /m^3	Fitted net pressure/MPa	Fitted fracture length/m	Fitted fracture height/m	Difference between maximum and minimum stress/MPa	Morphology of net pressure curve	Transmit the natural fractures
1	4.0	221	9.6	94	45	5.6	falling	Yes
2	4.0	262	9.3	96	47		falling	Yes
3	4.0	262	8.8	95	46		falling	Yes
4	3.4	225	11.7	85	37		flat	No
5	3.6	187	6.5	108.2	32.1		flat	No

Table 4 shows that under the cementing condition, the construction discharge is 3.4-4.0m^3/min, the fitting net pressure surpasses the principle stresses difference between maximum and minimum, and the fractures tend to be complicated. G function analysis also proves that there is an obvious transmission between the natural fractures, and it has an apparent trend to grow multiple fissures.

Based on the above analysis, the results can be obtained: the net pressure in the hydraulic fracture of Chang 8 oil reservoir is greater than the planar difference of maximum and minimum stress, and the stress deviations between reservoir and interlayer should be influenced by their behaviors. If the condition is allowed, the fracture height is limited, and it tends to grow into network fractures. But if the deviation is too small, the fractures prefer to expand in vertical direction, that is: (1) net pressure>planar difference>deviation between reservoir and interlayer, the network fractures prevail; (2) net pressure> deviation between reservoir and interlayer > planar difference, the fracture height would lose control.

It is concluded that different construction parameters and network hydraulic fracturing techniques should be applied to Chang 8 oil reservoirs with various features in the south of Ordos Basin. A certain degree of complex fractures can be formed by increasing the net pressure through large displacement construction, changing the fracturing fluid performance or adding temporary plugging agent. When the horizontal stress difference is less than 6 MPa, the net pressure can be increased by large displacement construction until it exceeds the difference between two minimum planar stresses. If the propagation of principle fracture is arrested, the net pressure will start to increase. Until the pressure is up to great enough, the fracture changes its propagation direction and produces shear fraction in order to link the distal end of natural fracture, eventually build a fracture network.

5. Field test and results

5.1 Field test

Multi-section hydraulic fracturing with drillable bridge plug was applied to test the reservoir of HH6P2 well (brittleness index 45.7%, variation coefficient between maximum stress and minimum stress 0.139) in Hohe oil field. There were 12 sections with 23 clusters in horizontal segment, where mixing hydraulic fracturing fluid system (① 0.15%HPG + 1%BRD-S10 anti-water blocking agent + 1.0%KCL + 0.08% bactericide; ②0.35%HPG + 0.5%BRD-S10 anti-water blocking agent + 0.3%CX-307 cleanup additive + 1.0%KCL + 0.15%

bactericide + 0.3% low-temperature activator) and multiple-group proppant system (40/70 mesh silt was used to support micro-fracture in the early stage; the bending friction was decreased through abrasion of crack surface with 20/40 mesh silica sand during the middle stage in order to reduce the risk of construction; 20/40 mesh silica sand was applied to improve the flow conductivity of propped fractures in the late stage) are used. Section 2-12 adopted two-cluster perforation method, and the perforation level of horizontal section was enhanced through optimization of perforation parameters and length, limited entry fracturing principle. We performed various density patterns perforation to balance the stress difference between sections and achieve equilibrium assignment. The horizontal geostress is calculated by its analysis software (e.g. section 8 and 9), then the other data of geostress profile are acquired. Combined with the analysis of geology and logging materials, it is believed that section 8-9 is able to perform cluster perforation. Table 5 shows that four perforation sections are selected to be the perforated intervals, which have similar two-cluster property, and the difference between maximum and minimum in-situ stress is less than 1 MPa.

Table 5: Cluster type perforation condition analysis of the data table of section No.8 and No.9 in HH6P2 well

Fracturing section	Perforation section/m	GR /API	Interval transit time/μs.m^{-1}	Porosity /%	Permeability /mD	Minimum geostress /MPa
No.9	1837-1839	80.2	230.5	10.3	0.69	26.0-26.4
	1817-1819	84.0	233.8	10.8	0.75	26.3-26.7
No.8	1894-1896	76.5	228.1	9.7	0.63	26.8-27.2
	1874-1876					27.0-27.8

There are 12 hydraulic fracturing segments applied with drillable bridge plug (section 2-12 applied with multi-cluster perforation), the total liquid amount is 5441.8 m^3, adding sand 497.2 m^3. Segmented clusters fracturing construction graph of in No.8 section is shown in Fig 3.

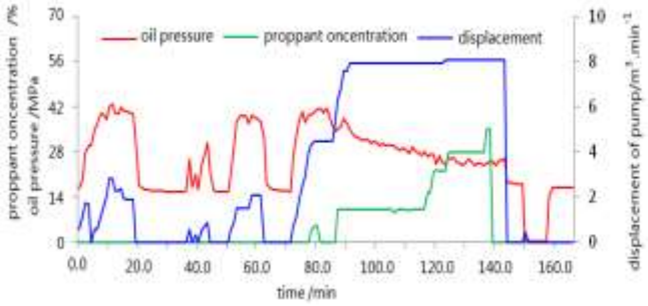
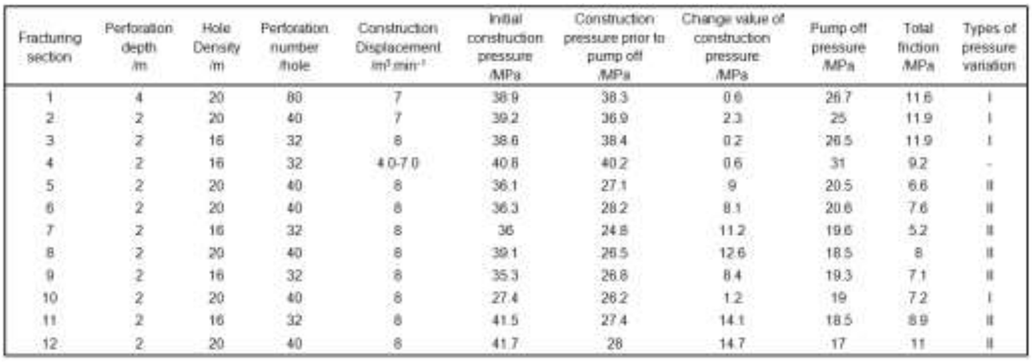


Figure 3: Segmented clusters fracturing construction graph of in No.8 section

Table 6 shows that the results can be obtained by analyzing the hydraulic construction pressure, pump off pressure as well as perforation friction of section 12 of HH6P2 well: under the similar stratum condition, if the minimum differential stress has no obvious change (within 1 MPa), the pump off pressure can reflect the net pressure, and the high displacement will lead to a low net pressure. From section 1 to 12, pump off pressure of section 12 is the least one, varying from 1.5 to 9.7 MPa, construction displacement 8.0 m^3/min, net pressure approximately 8.6 MPa, the minimum differential stress less than 1 MPa, coefficient of flow distribution 4.8. The casing performance requires large displacement, balanced flow distribution. The lower differential stress of two break-off points is, the more balanced flow distribution is, and then the subsection multiple clusters are more likely to grow into the multiple fractures. From what discussed above, it can be deduced that section 8 and 9 propagate two fractures (or complex fractures), which causes changing of flow distribution and decreases the single fracture flow and net pressure.

Table 6: Different fracturing construction pressure change table of well HH6P2



Fracturing section	Perforation depth /m	Hole Density /m	Perforation number /hole	Construction Displacement /m³·min⁻¹	Initial construction pressure /MPa	Construction pressure prior to pump off /MPa	Change value of construction pressure /MPa	Pump off pressure /MPa	Total friction /MPa	Types of pressure variation
1	4	20	80	7	38.9	38.3	0.6	26.7	11.6	I
2	2	20	40	7	39.2	36.9	2.3	25	11.9	I
3	2	16	32	8	38.6	38.4	0.2	26.5	11.9	I
4	2	16	32	4.0-7.0	40.8	40.2	0.6	31	9.2	-
5	2	20	40	8	36.1	27.1	9	20.5	6.6	II
6	2	20	40	8	36.3	28.2	8.1	20.6	7.6	II
7	2	16	32	8	36	24.8	11.2	19.6	5.2	II
8	2	20	40	8	39.1	26.5	12.6	18.5	8	II
9	2	16	32	8	35.3	26.8	8.4	19.3	7.1	II
10	2	20	40	8	27.4	26.2	1.2	19	7.2	I
11	2	16	32	8	41.5	27.4	14.1	18.5	8.9	II
12	2	20	40	8	41.7	28	14.7	17	11	II

5.2 Result

It takes 4 days to discharge fluid after hydraulic fracturing of HH6P2, then the oil sprays. The current daily production is 2.58 t, daily fluid output reaches 15.03 m^3, and flow back rate is up to 46.9%.

6. Conclusions

The brittleness index of Chang 8 reservoir in the south of Ordos Basin is within a middle-high scale. The natural fractures and horizontal beddings are commonly developed, so its geology and stress condition are suitable for network hydraulic fracturing to enhance the oil production. Chang 8 oil reservoir of HH6P2 well has been built complex fractures by means of subsection multiple clusters technique. Its sound effect proves that network hydraulic fracturing is feasible to be performed at this kind of reservoirs.

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