Challenges and Strategies of Infill-Drilling Within Large Scale Hydraulic Fracturing Zone for Shale Gas Due to Geostress Disturbance

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Abstract: The Fuling shale gas field is planning to reduce the well spacing (600-1300 m at the early development stage) to about 300m by infill drilling works to accelerate recovery. We first summarized the drilling troubles and accidents in the early infill-drilling practices in Fuling. And we gave two representative examples to show the challenges of infill drilling works within geostress disturbance zone. One example is about gas kick and overflow, and the other is drilling fluid pollution by fracturing fluid from neighbouring well. Moreover, two practical strategies for these drilling challenges were put forward. The disturbance of the geostress caused by multistage hydraulic fracturing of neighbouring wells within a drilling units is numerically simulated to provide data for optimized design of well spacing and well path of the infill drilling in Fuling shale gas field. Recent infill-drilling practices with the aid of these effective strategies show much better performances. For example, the average rate of penetration (ROP) of an infill well (Y29-S1HF) with depth of 4245m reaches 12.02m/h, and no drilling troubles or accident occur.

1 INTRODUCTION

Shale gas becomes more and more importance worldwide. The shale gas prospecting and production was started early since 1982. The shale gas production reached $7500\times10^8 m^3$ in America at 2016, which made up more that 40% of the total natural gas production of America (Krisanne et al., 2011). Horizontal well factory and multistage hydraulic fracturing are the most important two technologies for shale gas production commercially. The well spacing within the same drilling unit is usually 200-300m in America (Hummes et al., 2012).

Aiming for more scientific design of multistage fracturing and more efficient fracturing works, researchers have done lots of studies on the induced fractures and the geostress redistribution after the hydraulic fracturing. There are two representative methods to create fracture networks: the “Commuter Frac.” method and the “Texas Two-Step” method. Roussel & Sharma (Roussel and Sharma, 2010) investigated the geostress redistribution, and developed the relation between the fracture propagation pressure and the fracture numbers. Most of these studies currently are limited to the scale of a single well. However, several horizontal boreholes (usually 4-8) within one drilling unit are drilled for the well factory, and each horizontal section was fractured stage by stage (Zhang et al., 2014). So the geostress redistribution is much more complicated than the conditions in those scientific researches.

Fuling shale gas field, the first and largest commercially developed shale gas field in China, now is aiming to reach a production capacity of 1.0×10^{10} m^3 per year in 2017. The spacing of two nearby paralleled horizontal wells is relatively large at the early development stage of Fuling, mainly 600-1300 meters (Lu, 2013; Zeng et al., 2013). For such a large spacing, infill drilling is a promising way to accelerate recovery. However, the geostress of the interested block has been greatly disturbed by the multistage hydraulic fracturing of neighboring wells, which push the infill drilling into great risk (Niu, 2014).

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2 DRILLING TROUBLES DURING INFILL-DRILLING

On one hand, the fracturing work created high productive fractures, which is an effective way for shale gas production commercially. On the other hand, it changed the geostress distribution. However, we have not found an economical and effective way to assess quantitatively the redistribution of the geostress. This leads to an embarrassing condition that we do not know the pore pressure and the stress where we will drill a new well, which severely influence the safety of the drilling work, personnel, and the investments. The drilling practice in Fuling shale gas field indicated that some well drilling works were obviously influenced by the large scale hydraulic fracturing work. Table 1 shows a simple summary of drilling troubles occurred during the infill well drilling due to the influence of hydraulic fracturing.

2.1 Case A: Gas Kick & Overflow

Hydraulic fracturing in the pay zone has a pressure elevating effect. The pore pressure will increase after the fracturing work is finished. The natural gas within the pay zone of the fracturing well would be driven to the nearby well that is under drilling. When the gas invades the wellbore under drilling, it would lead to a gas kick and overflow. If such drilling troubles are not addressed properly, they may further grow to a blowout and result in serious drilling accidents. Moreover, the formation becomes more sensitive to the drilling parameters due to the pressure disturbance by hydraulic fracture. The change of drilling work condition and the adjustment of drilling parameters also tend to cause a gas kick or overflow.

For example, the Well Y193-2HF is affected significantly by the hydraulic fracturing work in a nearby well. When the Longmaxi formation was penetrated in Well Y193-2HF, the overflow troubles totally occurred 23 times, which pushed the drilling work into great risk. And more than half of these overflow troubles were encountered after the change of drilling work condition or the adjustment of drilling parameters. One gas kick was occurred when the well was drilling to the depth of 2690m, the total hydrocarbon value reached 90%. The well was closed to exhaust the gas by burning. The height of the fire flame was more than 10 meters, and continued nearly 4 hours (as shown in Figure 1). Then the well was open to build circulation. But the total hydrocarbon value was still abnormal. It increased obviously after every circulation period, and finally reached 80% for 20-30 minutes. Trip off the drill string and change the bottom hole assembly (BHA). And then trip in the drill string to 2662m to displace the gas by circulation with the maximum total hydrocarbon value of 87%. The well was closed again to exhaust the gas by burning for nearly 2 hours. The maximum height of the fire flame was about 10 meters.

Table 1: The summary of drilling troubles in wells disturbed by fracturing

Well	Well depth (m)	Average ROP (m/h)	Drilling period (d)	Drilling troubles	Percent of non-productive time (%)
Y39-2-1	4845	8.74	65.50	Loss circulation 1 time Overflow 1 time	2.60
Y11-2-1	4155	6.86	68.13	Loss circulation 1 time Overflow 9 times	3.18
Y7-1HF	4130	7.35	58.83	Overflow 1 time	4.11
Y39-1HF	4350	7.26	64.46	Overflow 23 times	21.04
Y46-2HF	4550	9.79	49.61	Gas kick 1 time Pipe breaking 1 time Overflow 1 time	13.00
Y22-3HF	4680	8.74	112.35	Loss circulation 7 times Overflow 1 time Sticking pipe 1 time	52.82

Figure 1: The field picture of burning the gas kick in Well Y193-2HF.

2.2 Case B: Drilling Fluid Polluted By Fracturing Fluid From Neighbouring Well

When the infill-well was drilling, the infill-well would be connected to the fractures of the neighbouring well if the drilling work of the infill-well and the fracturing work of the neighbouring well were conducted at the same period of time. So the fracturing fluids of the neighbouring well would invade into the infill well under drilling, and the oil-based drilling fluid would be polluted. This will degrade the properties of the drilling fluid, such as the rheology, filter loss, and emulsion-breaking voltage, which would further affect the safety of drilling works.

For example, the Well Y39-1 is affected by the fracturing work of a neighbouring well. The performance of the oil-based drilling fluid was significantly deteriorated due to the invasion of the fracturing fluid from the neighbouring well. Measurements at the work site indicated that the density of the drilling fluid decreased by 2.2%, the viscosity increased as high as 85%, the emulsion-breaking voltage decreased by 48.5%, and the oil/water ratio (OWT) decreased by 23.5%. The properties of drilling fluid of the Well Y39-1 before and after the pollution are shown in Table 2. Figure 2 and Figure 3 are the pictures of the drilling fluid before and after the pollution taken at the work site, respectively.

Figure 2. The drilling fluid of Well Y39-1 before pollution.

Figure 3: The drilling fluid of Well Y39-1 after pollution.

Table 2: The drilling fluid properties of Well Y39-1 before and after the pollution

Properties	Density, ρ (g/cm^3)	Viscosity*, η (s)	Emulsion-breaking Voltage, U (V)	Oil/water ratio (%)
Before pollution	1.38	70	875	85/15
After pollution	1.35	130-trickle	450	65/35

*The viscosity is measured by the Marsh funnel viscosimeter at 20 ℃ according to the API standard.

3 STRATEGIES

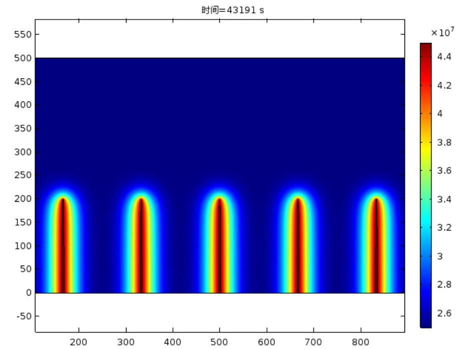
3.1 Numerical Simulation of Pore Pressure Redistribution

As the development of computers, numerical simulation has become a popular method to give predictions as important complements to experiment measurements and field monitoring. In order to further investigate how far and to what extent the pore pressure had been changed, we carried out dynamic numerical modeling of pore pressure redistribution by finite element method. The numerical modelling can be done by the ABAQUS. Parameters used in these modellings are shown in Table 3. Firstly, we build 2D geometrical model of a drilling unit with four parallel horizontal wells, and then we dynamically simulate the pore pressure change due to multistage fracturing. For such modeling, we considered the interaction between fractures and wells. We can also numerically test the effect of the well spacing, fracturing pump pressure, stage interval, and fracture length on the induced geostress change.

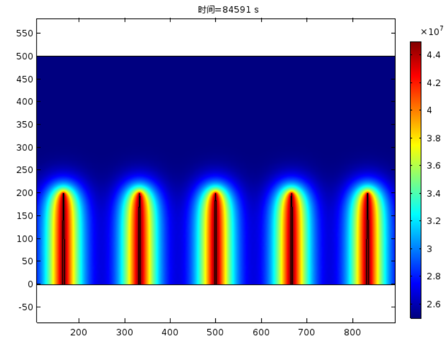
Table 3: The values of parameters used in the numerical modellings.

Properties	Value
The effective coefficient of compressibility of the shale, C (Pa^{-1})	0.05×10^{-9}
Porosity, ϕ (%)	2%
The density of the shale, ρ (g/cm^3)	2.48
The Poisson's ratio, ν	0.234
The viscosity of the fracturing fluid, η_f (Pa.s)	0.001
Pressure of the gas reservoir, P_p (MPa)	25
Differential pressure for production, ΔP (MPa)	20

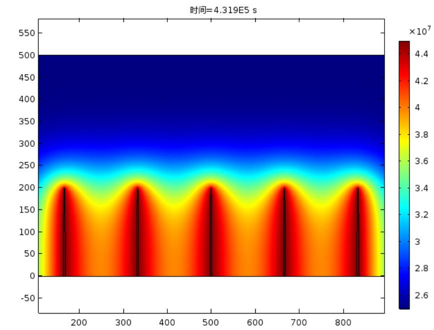
Figure 4 gives the modelling results of pore pressure redistribution after a five-stage fracturing in horizontal section. It shows that the influence zone of pore pressure is gradually extended with the duration time of fracturing and well shut-off. For this example, the pore pressure disturbance reached as far as 91m in x direction, and 75m in y direction after 24 hours since the hydraulic fracturing work has been finished.



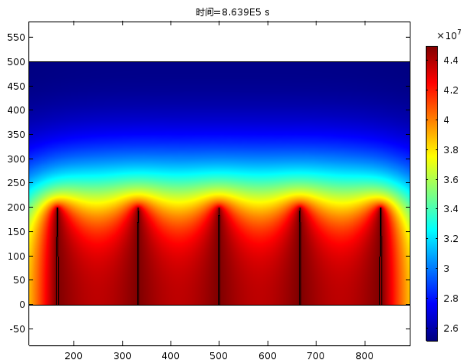
(a) t=12h



(b) t=24h



(c) t=120h



d) t=240h

Figure 4. Pore pressure (unit: Pa) redistribution at different times after a five-stage fracturing in horizontal section.

3.2 Optimization of Well Spacing and Well Path

For infill well drilling, it is important to optimize the well spacing. We need an appropriate well spacing to enhance the recovery with an economical number of wells. But assuring the safety of infill well drilling work should be the first priority. Based on results of the numerical modelling of pore pressure redistribution of the neighbouring well, we divided the geostress disturbance area into three parts according to the disturbance level. These results are used for optimized design of well spacing and well path. Usually, we should check the following questions when we make the design:

Would the infill well go through the geostress disturbance zone?

If yes, is it possible to avoid? If this can not be avoided, how to minimize the length of the affected section?

If not, which well spacing should be the best?

After optimization, we need appropriate bottom hole assembly (BHA) and monitoring techniques to ensure that the drill bit is go along the predesigned well path as well as possible.

Recent drilling practices of infill well within the Fuling shale gas field demonstrated that these two strategies are effective to reduce the drilling troubles and improve the drilling efficiency. For example, after the application of these strategies, the average ROP of an infill well (Y29-S1HF) with depth of 4245m reaches 12.02m/h, and no drilling troubles or accidents occur.

4 CONCLUSIONS

We first summarized the drilling troubles and accidents in the early infill-drilling practices in Fuling shale gas field, and gave two representative examples. Then two practical strategies for these drilling challenges were put forward. And the strategies were proven to be effective by current infill drilling practices. Based on this study, we can conclude that:

Wide application of hydraulic fracturing in Fuling shale gas field have changed the geostress significantly. Such kind of geostress disturbance currently still can not be assessed quantitatively with its economic and effectiveness, which push the infill drilling into great risk.

Gas kick, overflows, loss circulation, pipe sticking and breaking are the main drilling troubles due to geostress disturbance. And sometimes, the drilling fluid can be polluted by the fracturing fluid.

The numerical modeling of pore pressure redistribution after fracturing helps us to better understand the current geostress distribution.

Optimized design of well spacing and well path with the aid of numerical simulation of pore pressure redistribution is an effective way for the infill drilling.

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REFERENCES

Hummes O, Bond P R, Symons W and Jones A, et al. 2012 Using advanced drilling technology to enable well factory concept in the Marcellus shale. IADC/SPE Drilling Conference and Exhibition, 6-8 March, San Diego, California, USA, SPE 151466

Krisanne K L, Weissert S, Jackson J B and Marcotte D 2011 Marcellus shale hydraulic fracturing and optimal well spacing to maximize recovery and control costs. SPE Hydraulic Fracturing Technology Conference, 24-26 January, The Woodlands, Texas, USA, SPE 140463

Lu Baoping 2013 Sinopec engineering technical advances and its developing tendency in shale gas *Petroleum Drilling Techniques* **41** 1

Niu Xinming 2014 Drilling technology challenges and resolutions in Fuling shale gas field *Petroleum Drilling Techniques* **42** 1

Roussel N P and Sharma M M 2010 Role of stress reorientation in the success of refracture treatments in tight gas sands *SPE Production & Operations* **27** 346

Zeng Fanhui, Guo Jianchun, Liu Heng and Xiao Yong 2013 Experience of efficient fracturingof shale gas in North America and enlightenment to China *Journal of Southwest Petroleum University (Science & Technology Edition)* **35** 90

Zhang Jincheng, Sun Lianzhong, Wang Jiachang and Zang Yanbin 2014 Application of multi-well pad in unconventional oil and gas development in China *Petroleum Drilling Techniques* **42** 20