A New Numerical Simulation technology of Multistage Fracturing in Horizontal Well

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Abstract. Horizontal multi-stage fracturing is recognized as the effective development technology of unconventional oil resources. Geological mechanics in the numerical simulation of hydraulic fracturing technology occupies very important position, compared with the conventional numerical simulation technology, because of considering the influence of geological mechanics. New numerical simulation of hydraulic fracturing can more effectively optimize the design of fracturing and evaluate the production after fracturing. This paper studies is based on the three-dimensional stress and rock physics parameters model, using the latest fluid-solid coupling numerical simulation technology to engrave the extension process of fracture and describes the change of stress field in fracturing process, finally predict the production situation.

1. Introduction
Fracturing optimization design of horizontal wells and fracturing effect evaluation is an important subject for the effective development of unconventional reservoirs. At present, the fracturing optimization design is carried out in the fracturing simulation software using the analytical calculation model, and fracturing effect evaluation is carried out by micro seismic monitoring, transient typical curve and well test interpretation.

The disadvantage of micro seismic monitoring is that the interpretation results are severely limited by the quality of the micro seismic data⁴. The limitation of the method of transient typical curve and well test interpretation is that the actual geological and geomechanical heterogeneity can’t be considered, the analytical results of these methods are often deviated⁵.

When the conventional numerical simulation technique is used to simulate the multi-stage fracturing of horizontal wells, because the traditional method can’t consider the influence of geomechanics on the hydraulic fracturing process, hence the traditional method can’t simulate the process of fracture propagation. It is not feasible to use the traditional method to optimize the fracturing design [²]. In assessing the artificial fractures of fracturing, the conventional numerical simulation technology use the differential mesh to equivalent artificial fractures, through the fracturing well production history to match the artificial fracture parameters. At the same time, there are many solutions. There are many limitations to the traditional numerical simulation methods [³].

Numerical simulation of fluid-solid coupling is the new direction of numerical simulation technology development. This study uses REVEAL numerical simulation software developed by Petroleum Experts Company. The most important feature of this simulator is that it can simulate the
propagation process of artificial fractures by considering petrophysical and geostresses, and the dynamic finite element grid is used to characterize the dynamic artificial fractures. The basic principles have been published in the relevant literature\textsuperscript{[1]}

2. Practical Application of Numerical Simulation of Fluid-solid Coupling
A representative horizontal wells in a tight gas reservoir was chosen to demonstrate the simulation method. Hydraulic fractures are simulated on the well, and then the wells are set to production to investigate the accuracy of the simulation results By contrast with monitoring data.

\textbf{Table 1.} Reservoir geology, rock mechanics, and geostress parameters

|                         |                           |
|-------------------------|---------------------------|
| **Depth**               | 3600 m                    |
| **Porosity**            | 0.08–0.1                  |
| **Permeability**        | 0.1 mD–0.5 mD             |
| **Pressure**            | 60000 KPa                 |
| **Temperature**         | 96 °C                     |
| **Young’s modulus**     | 35 GPa–50 GPa             |
| **Poisson’s ratio**     | 0.2–0.4                   |
| **The maximum horizontal principal stress** | 90 MPa–95 MPa |
| **The minimum horizontal principal stress** | 85 MPa–90 MPa |
| **The vertical stress** | 67MPa–75MPa                |

2.1 The direction and size of the simulated grid
Taking into account the need for fracturing numerical simulations, the simulation grid X and Y direction need to be consistent with the maximum and minimum horizontal principal stress direction. The direction of the maximum horizontal principal stress is near the east-west, the direction of the minimum horizontal principal stress is near the north-south.

In the three-dimensional geology and stress model, the plane grid size is 25m and the vertical grid size is 0.5m, due to the stress simulation process need to consider stress change between the fractures, the plane grid accuracy requirements are higher, the vertical grid accuracy can be appropriately relaxed. Before the simulation work, the geological modeling grid needs to be re-divided. The plane size after adjustment is 5m, the vertical grid size after adjustment is 2m–3m, and the number of X and Y direction grids after adjustment is 89 and 273, three geological layers are divided into 17 grids, and the total number of grids is 413049.

2.2 Grid attribute assignment
The grid parameters are extracted directly from the geological model. In addition to the parameters required for conventional numerical simulation, the depth of the grid, porosity, permeability, net to gross ratio, saturation, pore pressure and other parameters, also extracted the stress and rock physics parameters, which include the maximum horizontal principal stress, minimum horizontal principal stress, vertical stress, Pore pressure, Young’s modulus, Poisson's ratio and other parameters, these parameters are shown in Figure 1–Figure 4.
2.3 The fracturing string structure
The horizontal wells was used in this work with a horizontal length of 900m, 12 fracture stages were used with several potential fractures at each stage, there are a total of 23 fractures. The different fracture stages are isolated with packers in the well. In the process of fracturing simulation, the complex well model provided by the REVEAL software is used to describe the fracturing string structure. And the software uses the ICV device to control the process of stepwise fracturing.

2.4 Fracturing operation parameters
From the actual fracturing process, it can be seen that the total amount of single-stage total fluid is about 700m$^3$~1200m$^3$, the surface pump injection rate is 4m$^3$/min~10m$^3$/min, the surface injection pressure is about 50MPa ~ 85MPa, the software fracturing simulation the process of injecting in the simulation exactly in accordance with the actual pumping procedure is shown in Table 2 below.

Well is controlled with fixed THP, the VLP curve was used to calculate the relationship between injecting pressure and rate.
Table 2. Fracturing operation data tables

| Stage | Segment Length m | Total injection volume m³ | Sand volume m³ | Injection rate m³/min | Injection pressure MPa |
|-------|------------------|----------------------------|----------------|-----------------------|------------------------|
| 1     | 142              | 1236.2                     | 70             | 3.0-8.5               | 56-84                  |
| 2     | 65               | 1034.1                     | 80             | 8.4-9.9               | 58-82                  |
| 3     | 70               | 1176.5                     | 85.6           | 7.9-10.1              | 57-83                  |
| 4     | 70               | 1075.4                     | 50             | 7.9                   | 54-58                  |
| 5     | 74               | 1235.9                     | 70             | 8-10.2                | 53-78                  |
| 6     | 43               | 749.8                      | 40             | 5.2-10                | 45-82                  |
| 7     | 66               | 1474.1                     | 85.5           | 2.4-7.5               | 55-82                  |
| 8     | 82               | 1082.2                     | 75             | 5.0-5.6               | 58-80                  |
| 9     | 63               | 1046.4                     | 75             | 5-6.3                 | 53-80                  |
| 10    | 75               | 1182.4                     | 80             | 4.7-5.5               | 55-84                  |
| 11    | 43               | 658.5                      | 40             | 5.5-6.0               | 50-81                  |
| 12    | 104              | 1139.5                     | 85             | 5.3-7.1               | 47-80                  |

2.5 Analysis of Simulation Results

Fig. 5 shows the final result of the simulation of hydraulic fracturing. The fractures are stimulated stage-by-stage, with each stage containing 1~3 fractures, it can be seen that due to the heterogeneity physical properties of reservoirs, The length of the fractures is quite different, the half-length of dynamic fractures of the horizontal wells are 100m ~ 160m.

![Figure 5](image-url)

Figure 5 the final result of the simulation of hydraulic fracturing

Fig. 6 shows the horizontal minimum principal stress profile of the second stage perforation center along the horizontal maximum principal stress direction, it can be seen from the figure that, due to the heterogeneity of the stress, during the fracturing process, the fractures are always extended in the direction of relatively small stress.
after each stage of fracturing, due to the loss of fracturing fluid, poro-elastic stress changes caused by successive sequential stimulation. Fig. 7 shows a snapshot at various times during the simulation of hydraulic fracturing. The minimum horizontal stress shows a significant change, and the increase in the minimum horizontal stress between the fractures is about 2MPa ~ 4MPa.

2.6 Simulation results validation
Base on the results of the simulation of artificial fracture, predicting early production after fracturing, well is controlled with fixed oilrate in the prediction, the calculated results of flowing pressure was coincident with monitoring data, the result shows that the artificial fracture simulation is reliable.
3. Conclusion

(1) The high-precision three-dimensional reservoir geology, stress and petrophysical model are the basis of numerical simulation of multi-stage fracturing of horizontal wells.

(2) The hydraulic fracturing numerical simulation technique used in this paper overcomes the shortcomings of conventional simulation technology. The new method can accurately simulate the dynamic expansion of artificial fractures in the multi-stage fracturing process of horizontal wells, and quantitatively describe the changes of stress field.

References

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