Optimization of Hydraulic Fracture Parameters for Low-Permeability Condensate Reservoir

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Abstract—In order to develop a low-permeability condensate gas reservoir named X in Jilin Oilfield efficiently, it is significant to study and optimize the hydraulic fracture parameters of development wells. This paper builds a compositional model by utilizing the PVTi module of Eclipse software considering the PVT experimental result in this regard. On this basis, the effect of hydraulic fracture parameters on productivity is analyzed by establishing the numerical model in the view of theoretical analysis. Finally, the optimal hydraulic fracture of target area are obtained with the established geology model. The following conclusions can be drawn from this study:(1) Hydraulic fracturing can enhance the productivity of condensate gas reservoir; (2) Fracture length plays a more critical role in increasing productivity than fracture conductivity; (3) For the low-permeability condensate gas reservoir named X in Jilin Oilfield, the optimal parameters of fractures are half length=280m, conductivity= 22 $\mu m^2\cdot$cm.

Index Terms—condensate gas reservoir, low-permeability, hydraulic fracturing, composition model, Parameters optimization

I. INTRODUCTION

At the beginning of the condensate gas reservoir development, the formation pressure is higher than the dew point pressure, while the bottom-hole pressure is lower than it compared with the conventional gas reservoir, which leads to the two-phase region in the vicinity of the well. The condensate accumulation causes the changes in the interfacial tension, saturation, gas phase relative permeability, and the production declines. Numerous studies have been undertaken on the condensate gas reservoir performance [1]-[12]. It is proved that hydraulic fracturing is an efficient way to greatly reduce the damage to the gas production caused by retrograde condensation. Antonin Settari et al. conducted a systematical research on the effect of retrograde condensation on the production index of an offshore hydraulically fractured condensate gas well and showed that hydraulic fracture is beneficial to restore the productivity damage caused by retrograde condensation and the effectiveness relies on the fracture length, reservoir heterogeneity and fracture conductivity [13]. A. M. Aly et al. integrated the reservoir model with hydraulic fracture model and researched on the performance of three types of wells: vertical wells, vertical wells with multiple fractures, and horizontal wells [14]. Wu et al. conducted fracture optimization design based on reservoir simulation methods and investigated the fracture parameters that affect post fracturing well performance in both homogeneous and heterogeneous formations [15].

This paper studies the well performance of hydraulically fractured condensate gas wells for Jilin oilfield with sophisticated reservoir simulation models. Optimization of hydraulic fractures has been made for this oilfield and this paper provides some practical insights for real field operation.

II. PRE-NUMERICAL SIMULATION WORK

A. Experimental Analysis

According to the oil and gas industry standards of PRC SY/T 6434-2000 (Analysis for Natural Gas Reservoir Fluids Physical Properties), PVT experimental studies have been conducted for the low-permeability condensate gas reservoir in Jilin oilfields, which includes compositional analysis, the Constant Constituent Expansion experiment (CCE) and Constant Volume Depletion (CVD) test. The experimental results can be seen in Section B.

B. Build Compositional Simulation Model

In order to analyze the phase change principle in the recovery of the low-permeability condensate reservoir, the compositional model of ECLIPSE 300 is utilized to build a 3D and two phase model. PVT phase match is conducted using the ECLIPSE software module PVTi to obtain the specific parameters in the equation of state based on the experimental results, which confirmed the applicability of the simulator for the following reservoir simulation.

According to the experimental results, the original fluid constituents in the original well are divided into 16 kinds. The specific composition and mole percentage is shown in Table I. As can be seen from the table, the gas
reservoir falls into the category of condensate gas reservoir. During the PVT experiments, analysis of added components is very limited and the condensate is particularly sensitive to the added components and properties. Therefore, it is necessary to split the added components into several pseudo-components to better match the PVT phase behavior. In this simulation, for the added components: $\rho_{C_{11+}} = 0.8400 \text{ g/cm}^3$, $M_{C_{11+}} = 307.17 \text{ g/mol}$. Multi-Feed method is used to split the added components into two pseudo-component $FRC1$ and $FRC2$.

With an aim to reduce the compositional simulation time but with adequate accuracy, components need to be merged in PVT phase match. In this simulation, 17 split components will be merged into nine pseudo-components.

Peng and Robinson EOS correlation is used in the PVT modeling. The phase match of fluid behavior made by PVTi modeling and experimental results can be used to obtain certain parameters in the PR correlation. The formation temperature is set to $61.8 \degree C$ in CCE and CVD experiments. The experimentally measured dew point pressure is $33.13 \text{ MPa}$. As for the condensate gas reservoir, the retrograde condensation quantity is crucial in CVD tests, great emphasis is put in this parameter by increasing the weighting factor. The match result can be seen in Fig. 1, in which the blue line represents the calculation result while the red dots represent the experimental results.

III. THEORETICAL ANALYSIS

A. Effect of Fracture Half-Length on Well Performance of Fractured Condensate Wells

The impact of fracture length on well performance is examined at varied fracture half-length at 100 m, 150 m, 200 m, 250 m, 300 m, 350 m. The fracture conductivity is set to $20 \mu \text{m}^2 \cdot \text{cm}$, and the production pressure drop is $25 \text{ MPa}$. Fig. 2 show the effect of varied fracture half-length on gas flow rate and oil flow rate respectively.

As illustrated in the above results, the production rate of the hydraulically fractured well is higher than that of non-fractured one, which proves the effectiveness of hydraulic fracturing on condensate reservoir stimulation. Fracture half-length is one of the most sensitive parameters to the condensate gas wells. As the fracture half-length increases, the gas flow rate and condensate oil production rate increases substantially.

At varied fracture half length, the gas flow rate and the condensate oil production is higher in the early

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole Percent</th>
<th>Component</th>
<th>Mole Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$S</td>
<td>0.22</td>
<td>iC$_5$</td>
<td>0.63</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>0.54</td>
<td>nC$_5$</td>
<td>0.72</td>
</tr>
<tr>
<td>N$_2$</td>
<td>2.89</td>
<td>C$_6$</td>
<td>1.06</td>
</tr>
<tr>
<td>C$_1$</td>
<td>76.74</td>
<td>C$_7$</td>
<td>1.21</td>
</tr>
<tr>
<td>C$_2$</td>
<td>6.35</td>
<td>C$_8$</td>
<td>1.00</td>
</tr>
<tr>
<td>C$_3$</td>
<td>4.19</td>
<td>C$_9$</td>
<td>0.70</td>
</tr>
<tr>
<td>iC$_4$</td>
<td>0.80</td>
<td>C$_{10}$</td>
<td>0.50</td>
</tr>
<tr>
<td>nC$_4$</td>
<td>1.55</td>
<td>C$_{11+}$</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Figure 1. Comparisons between the model values and experimental data

Figure 2. Oil and gas production rate Vs time with different fracture half length

As illustrated in the above results, the production rate of the hydraulically fractured well is higher than that of non-fractured one, which proves the effectiveness of hydraulic fracturing on condensate reservoir stimulation. Fracture half-length is one of the most sensitive parameters to the condensate gas wells. As the fracture half-length increases, the gas flow rate and condensate oil production rate increases substantially.

At varied fracture half length, the gas flow rate and the condensate oil production is higher in the early
production time but with a high decline rate. As production continues, the production tends to be stable and the production gap between varied fracture half-length decreases. It is due to the fact that single phase flow dominates the early period of production when there is sufficient formation energy and the condensate dropout only occurs in the vicinity of the well. However, as production continues, a significant drop in well productivity occurs when the flowing bottom-hole pressure goes below the dew point, when a large amount of condensate dropout occurs and the two phase flow increases the flow resistance. When the equilibrium reaches between the condensate dropout velocity and the production gap between varied fracture half-length grows. However, in light of real field operation, the larger fracture length can result in higher operation costs. Thus, it is necessary to optimize the fracture half-length considering the constraints in economy and technology.

B. Effect of Fracture Conductivity on Well Performance of Fractured Condensate Wells

The impact of fracture conductivity on well performance is examined at varied fracture conductivity at 10$\mu$m$^2$-cm, 15$\mu$m$^2$-cm, 20$\mu$m$^2$-cm, 25$\mu$m$^2$-cm, 30$\mu$m$^2$-cm, 35$\mu$m$^2$-cm. The fracture half-length is set to 250m, and the production pressure drop is 25 MPa. Fig. 3 show the effect of varied fracture conductivity on gas flow rate and oil flow rate respectively.

As can be observed in the above figures, at given fracture length and pressure drop, as the fracture conductivity increases, the gas flow rate and oil production rate improve, but with slight amount. This phenomenon is due to the fact that the connectivity between the fracture and the formation is limited in the low permeability condensate reservoir, which renders the high conductivity of the fracture ineffective. Thus, increasing the fracture conductivity can have certain effect on increasing the condensate gas productivity, but not the sensitive one.

IV. CASE STUDY

The X condensate well area in Jilin oilfield has the characteristic of high temperature, low permeability and low porosity. Well stimulation treatment is of great need owing to the low productivity. Geological model is established using the real field reservoir data. The PVT parameters are obtained based on the compositional model. And then hydraulic fracture parameter is optimized.

The fractured condensate gas well productivity is analyzed at varied fracture length of 100m, 150m, 200m, 250m, 300m, 350m. The fracture conductivity is set to 20$\mu$m$^2$-cm, and the production pressure drop is 10 MPa.

As can be observed in the above figures, at given fracture length and pressure drop, as the fracture conductivity increases, the gas flow rate and oil production rate improve, but with slight amount. This phenomenon is due to the fact that the connectivity between the fracture and the formation is limited in the low permeability condensate reservoir, which renders the high conductivity of the fracture ineffective. Thus, increasing the fracture conductivity can have certain effect on increasing the condensate gas productivity, but not the sensitive one.
fracture conductivity is $25 \mu m^2 \cdot cm$ for the target area considering the operation costs.

Due to the sensitivity analysis of each single factor is assuming that other factors are fixed, the single factor sensitivity analysis has its limitations. In order to conduct more scientific and reasonable analysis of the multiple factors’ impact on the fracturing gas well productivity, orthogonal method is applied for multi-factor analysis. Based on the result of the single sensitivity analysis, the three largest sensitivity factors are selected, namely having the largest impact on fracturing gas well productivity. In this orthogonal scheme, the fracture half-length is 220 m, 250 m, 280 m; fracture conductivity is $22 \mu m^2 \cdot cm$, $25 \mu m^2 \cdot cm$, $28 \mu m^2 \cdot cm$; and the bottom hole pressure is 8MPa, 10MPa to 12MPa. The orthogonal scheme and calculation results can be seen in Table II.

As illustrated from Table II, case 7 reaches the optimum, at which the fracture half-length is 280m, fracture conductivity is $22 \mu m^2 \cdot cm$ and the bottom hole pressure is 12 MPa.

**TABLE II. RESULTS OF ORTHOGONAL TEST METHOD**

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Half Length (m)</th>
<th>Conductivity ($\mu m^2 \cdot cm$)</th>
<th>Bottom Hole Pressure (MPa)</th>
<th>Production Stimulation Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>220</td>
<td>22</td>
<td>8</td>
<td>6.01</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>10</td>
<td>12</td>
<td>7.65</td>
</tr>
<tr>
<td>3</td>
<td>220</td>
<td>28</td>
<td>12</td>
<td>9.83</td>
</tr>
<tr>
<td>4</td>
<td>250</td>
<td>22</td>
<td>10</td>
<td>11.95</td>
</tr>
<tr>
<td>5</td>
<td>250</td>
<td>25</td>
<td>12</td>
<td>7.29</td>
</tr>
<tr>
<td>6</td>
<td>250</td>
<td>28</td>
<td>8</td>
<td>7.41</td>
</tr>
<tr>
<td>7</td>
<td>280</td>
<td>22</td>
<td>12</td>
<td>13.68</td>
</tr>
<tr>
<td>8</td>
<td>250</td>
<td>25</td>
<td>8</td>
<td>12.76</td>
</tr>
<tr>
<td>9</td>
<td>280</td>
<td>28</td>
<td>10</td>
<td>9.22</td>
</tr>
</tbody>
</table>

V. CONCLUSION

This paper performed a productivity analysis of low permeability fractured condensate reservoirs. The following conclusions can be obtained:

1. For low permeability condensate gas reservoir, as the formation pressure decreases below the dew point pressure, retrograde condensation will take place, resulting in decreasing the gas well productivity to a large extent. Hydraulic fracturing can significantly increase the productivity by lowering the amount of the condensate oil dropout and improving the permeability.
2. In the view of theoretical analysis, compared with increasing fracture conductivity, increasing the fracture length proves to be more effective in enhancing the well production.
3. Through numerical simulation study, the optimal fracture design is obtained with the fracture length of 280m and fracture conductivity of $22 \mu m^2 \cdot cm$.

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