Optimization of Hydraulic Fracture Parameters for Low-Permeability Condensate Reservoir

Lin Hun, Zhang Shicheng, Wang Fei, and Yu Baihui
China University of Petroleum, Beijing, China
Email: linhun016@aliyun.com, {zhangsc, wangfei}@cup.edu.cn, 15210878135@163.com

Liu Hongchang
CNOOC Enertech-Drilling &Production Co.
Email: liuhch3@cnooc.com.cn

***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= 22μm^2 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

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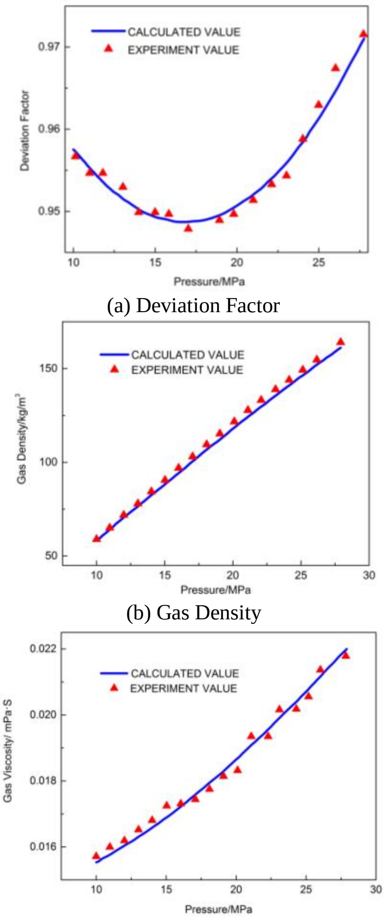
reservoir falls into the category of condensate gas reservoir.

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: ρ_{C11+} =0.8400 g/cm^3, M_{C11+} =307.17 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℃ in CCE and CVD experiments. The experimentally measured dew point pressure is 33.13 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.



(a) Deviation Factor

(b) Gas Density

(c) Gas Viscosity

Figure 1. Comparisons between the model values and experimental data

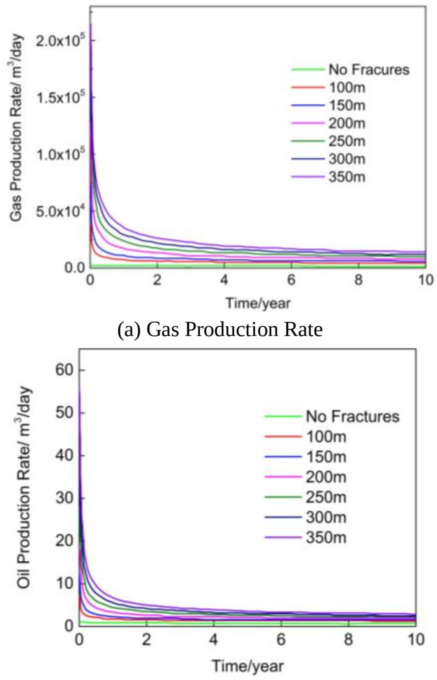
TABLE I. COMPOSITION ANALYSIS DATA

Component	Mole Percent	Component	Mole Percent
H_2S	0.22	iC_5	0.63
CO_2	0.54	nC_5	0.72
N_2	2.89	C_6	1.06
C_1	76.74	C_7	1.21
C_2	6.35	C_8	1.00
C_3	4.19	C_9	0.70
iC_4	0.80	C_{10}	0.50
nC_4	1.55	C_{11+}	0.90

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 20μm^2·cm, and the production pressure drop is 25 MPa. Fig. 2 show the effect of varied fracture half-length on gas flow rate and oil flow rate respectively.



(a) Gas Production Rate

(b) Oil Production Rate

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.

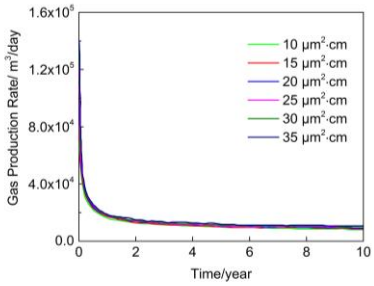
At varied fracture half length, the gas flow rate and the condensate oil production is higher in the early production time but with a high decline rate. As production continues, the production tends to be stable and the production gap between varied fracture half-length decreases. It is due to the fact 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 flow rate, such impact on oil and gas relative permeability reaches a steady state, leading to a steady oil and gas production.

Hydraulic fracturing has a much stronger impact on the condensate gas production than that of condensate oil. Take the case of Lf = 300 m by the end of 4th year for instance. The gas production rate is eight times larger than that before the hydraulic fracturing treatment, while 4.4 times for the condensate oil production.

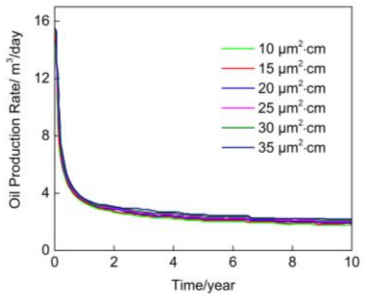
In conclusion, the production increases as the fracture half-length grows. However, in light of real field operation, the larger fracture length can result in higher operation costs. Thus, it is necessary to optimize the fracture half-length considering the constraints in economy and technology.

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 10μm^2 cm, 15μm^2 cm, 20μm^2 cm, 25μm^2 cm, 30μm^2 cm, 35μm^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.



(a) Gas production rate



(b) Oil production rate

Figure 3. Oil and gas production rate Vs time with different conductivity

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 to20μm^2 cm, and the production pressure drop is 10 MPa.

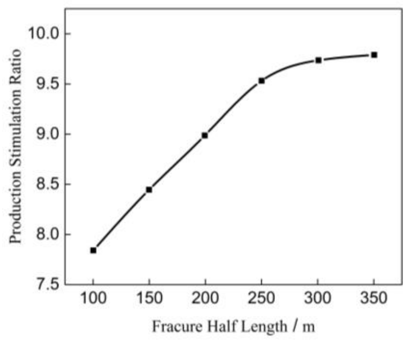


Figure 4. X well gas total production stimulation ratio with different fracture length

As the fracture half-length increases from 100m to 350m, the cumulative condensate gas production and condensate oil production keep the increasing trend. The simulation ratio is defined as the ratio of the production pre-fracturing and post fracturing. Fig. 4 shows that the increment of cumulative production is the largest when fracture length increases from 100m to 250m. Thus, the fracture length has an optimal value in light of the fracture treatment costs. For the target area in Jilin oilfield, the optimal fracture length is 250m.

Fracture conductivity is optimized at 10μm^2 cm, 15μm^2 cm, 20μm^2 cm, 25μm^2 cm, 30μm^2 cm, 35μm^2 cm. The fracture half-length is set to 250m, and the production pressure drop is10MPa.

Fig. 5 illustrates that the cumulative condensate gas production and condensate oil production keep the increasing trend as the fracture conductivity ranges from 10μm^2 cm to 35μm^2 cm. The largest increment is achieved when the conductivity increases from 10μm^2 cm to 25μm^2 cm, while the increasing rate tends to decline from 25μm^2 cm to 35μm^2 cm. Hence, the best optimal fracture conductivity is 25μm^2 cm for the target area considering the operation costs.

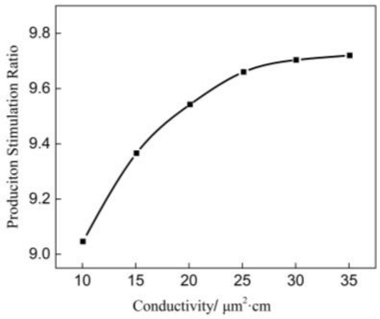


Figure 5. X well gas total production stimulation ratio with different fracture conductivity

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 22μm^2 cm, 25μm^2 cm, 28μm^2 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 22μm^2 cm and the bottom hole pressure is 12 MPa.

TABLE II. RESULTS OF ORTHOGONAL TEST METHOD

Case Number	Half Length (m)	Conductivity (μm^2 cm)	Bottom Hole Pressure （MPa）	Production Stimulation Ratio
1	220	22	8	6.01
2	220	25	10	7.65
3	220	28	12	9.83
4	250	22	10	11.95
5	250	25	12	7.29
6	250	28	8	7.41
7	280	22	12	13.68
8	280	25	8	12.76
9	280	28	10	9.22

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 22μm^2 cm.

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Lin Hun is a Phd candidate in the College of Petroleum Engineering, China University of Petroleum, Beijing. He holds a BS degree and MS degree in oil-gas field development engineering from China University of Petroleum, Beijing. His major field of study is in numerical simulation and unconventional reservoirs development.

Zhang Shicheng is a professor in the College of Petroleum Engineering, China University of Petroleum, Beijing. Zhang holds a BS degree in oil production engineering from East China Petroleum Institute, MS and PhD degrees in oil-gas field development engineering from China University of Petroleum, Beijing. He has served on the editorial committees of several journals and has authored or coauthored more than 80 technical papers.

Wang Fei is a lecturer in the College of Petroleum Engineering, China University of Petroleum, Beijing. Wang holds a BS degree from China University of Petroleum, Beijing and a PhD degree from Heriot-Watt University, both in petroleum engineering. She has published over 20 academic articles in academic periodicals home and abroad.

Yu Baihui is a graduate student in the College of Petroleum Engineering, China University of Petroleum, Beijing. Her research mainly centers around unconventional oil and gas well stimulation techniques and reservoirs simulation studies.

Liu Hongchang is a BS degree graduate from China University of Petroleum, Beijing. His major field of study is well stimulation technology and downhole tools.