Available online at www.sciencedirect.com

ScienceDirect

Natural Gas Industry B 3 (2016) 571–576

www.elsevier.com/locate/ngib

Research Article

Optimization of the key geological target parameters of shale-gas horizontal wells in the Changning Block, Sichuan Basin

Yang Hongzhi [a], Zhang Xiaotao [a,*], Chen Man [a], Wu Jianfa [a], Zhang Jian [a], You Chuanqiang [b]

[a] *Exploration and Development Research Institute of PetroChina Southwest Oil & Gas Field Company, Chengdu, Sichuan 610041, China*
[b] *Capital Management Department, PetroChina Oil & Gas Field Company, Chengdu, Sichuan 610051, China*

Received 12 June 2016; accepted 25 August 2016
Available online 3 July 2017

Abstract

In recent years, great progress has been made in geologic evaluation, engineering test and development optimization of the Lower Cambrian Wufeng Fm–Lower Silurian Longmaxi Fm shale gas in the Sichuan Basin, and the main shale gas exploitation technologies have been understood preliminarily. In addition, scale productivity construction has been completed in Jiaoshiba, Changning and Weiyuan blocks. In this paper, the Wufeng Fm–Longmaxi Fm shale gas wells in Changning Block were taken as the study object to provide technical reference for the development design of similar shale-gas horizontal wells. The technology combining geology with engineering, dynamic with static, and statistical analysis with simulation prediction was applied to quantify the main factors controlling shale-gas well productivity, develop the shale-gas well production prediction model, and optimize the key technical parameters of geologic target of shale-gas horizontal wells in the block (e.g. roadway orientation, location and spacing, horizontal section length and gas well production index). In order to realize high productivity of shale gas wells, it is necessary to maximize the included angle between the horizontal section orientation and the maximum major stress and fracture development direction, deploy horizontal-well roadway in top-quality shale layers, and drill the horizontal section in type I reservoirs over 1000 m long. It is concluded that high productivity of shale gas wells is guaranteed by the horizontal-well wellbore integrity and the optimized low-viscosity slickwater and ceramsite fracturing technology for complex fracture creation. Based on the research results, the technical policies for shale gas development of Changning Block are prepared and a guidance and reference are provided for the shale gas development and productivity construction in the block and the development design of similar shale-gas horizontal wells.

Keywords: Sichuan Basin; Changning Block; Late Cambrian–Early Silurian; Shale gas; Horizontal well; Productivity evaluation; Prediction model; Technical parameter; Development design

The success in North American shale gas and oil development triggers a shale gas revolution throughout the world. In the recent decade, great progress has been made in shale gas geologic evaluation and technological improvement for the Upper Ordovician Wufeng Fm–Lower Silurian Longmaxi Fm in the Sichuan Basin, China, with a certain shale gas productivity scale constructed in the Jiaoshiba, Changning and Weiyuan blocks [1–4]. However, China still falls behind North America in shale gas development technology [5–10]. In order to provide the guidance to shale gas development design and productivity construction in the Changning Block, the Sichuan Basin, we took the Wufeng Fm–Longmaxi Fm shale gas as the study object to analyze the main factors controlling shale-gas well productivity and high-productivity model. Then, key technical parameters of geological targets of shale-gas horizontal wells were optimized. These research results may also provide a technical reference for the development design of similar shale-gas horizontal wells.

* Corresponding author.
E-mail address: zxt8206@petrochina.com.cn (Zhang XT.).
Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2017.05.007

1. Overview

Located in the southwestern Sichuan Basin, the Changning Block hosts an anticline structure named "Changning Anticline", which is less faulted at the main portion. Stratigraphic sequence in this block penetrated by wells comprises the Triassic, Permian and Silurian strata. The Longmaxi Fm can be divided into two members: S_1L_1 and S_1L_2. S_1L_1 can be further divided into two sub-members: $S_1L_1^1$ (containing $S_1L_1^1$-1, -2, -3 and -4 micro-layers) and $S_1L_1^2$. The outer shelf subfacies black siliceous carbonaceous shale and the organic-rich black carbonaceous shale in the Wufeng Fm–S_1L_1 that are steadily deposited and have high porosity, organic abundance and gas content are considered as the primary target layer. Core measured porosity ranges from 2.0% to 6.8%, and log interpreted porosity from 3.6% to 7.3%. Core measured organic abundance ranges from 3.0% to 4.2%, and log interpreted organic abundance from 2.7% to 4.5%. Core measured total gas content ranges from 2.0 to 3.5 m^3/t, and log interpreted total gas content from 2.9 to 7.4 m^3/t, averaging at 4.8 m^3/t, with maxima recorded in $S_1L_1^1$-1 and $S_1L_1^1$-3 micro-layers [11]. Laterally, cross-well correlation shows little change in physical properties and gas-bearing potential of the same layer across the block. As for rock mechanical properties, the $S_1L_1^1$-1 and $S_1L_1^1$-2 micro-layers exhibit the highest Young's modulus and brittleness index and, hence, are considered the most favorable for the implementation of volume fracturing.

Since 2014, the productivity construction in the Changning Block has focused on Well Ning 201 area. A combination of evaluation, test and optimization enables 300×10^4 m^3 per day of shale gas to be producible from over 30 shale-gas horizontal wells that were put into production successively.

2. Main factors controlling shale-gas well productivity

With geologic characteristics and rock mechanical parameters of the Wufeng Fm–Longmaxi Fm shales in the Changning Block, systematic tests were carried out in batches to determine the influences of horizontal section length, orientation, target location, roadway spacing, stimulation process and scale over gas well productivity. The first batch of horizontal wells were designed to evaluate the influences of horizontal-well target location and orientation over gas well productivity and yielded an average of 10.8×10^4 m^3 gas per day in stability test (during the flowback by stepwise increasing the choke sizes, a 5%/d or below change in tested gas production rate and a 0.5 MPa/d change in wellhead pressure were sustained for at least 15 days). As a result of optimization, the horizontal roadway of the second- and third-batch wells are placed in top-quality shale layers to evaluate the influences of stimulation processes and parameters over gas well productivity. They yielded an average of 17.0×10^4 m^3 and 22.9×10^4 m^3 gas per day in stability tests, respectively. The pilot production result from the whole well area indicates that, with an increasing degree of geologic understanding and engineering technology, the increase in test production of shale-gas horizontal wells can be achieved batch by batch.

Existing test wells were taken as our sample points, and the statistical product and service solution (SPSS) software was used for optimizing the multiple linear regression variables and parameters, by taking into account the geologic, engineering and technological parameters, a prediction model was built (Eq. (1)) for the stability test production (Q) of fractured shale-gas horizontal wells.

$$Q = 0.051\,658N + 0.001\,214L + 1.209\,95T + 5.608\,7\,TOC + 1.186\varphi - 21.898 \quad (1)$$

where N is the number of the fracturing stages, dimensionless; L is the length of the effective horizontal section, m; T is the gas content, m^3/t; TOC is the total organic carbon content; and φ is the porosity.

Accordingly, a correlation analysis was carried out on a total of 17 parameters including shale reservoir porosity, gas content, brittleness, TOC, thermal evolution maturity (R_o), horizontal section length, orientation, roadway location, roadway spacing, Type I reservoir encountering rate, borehole integrity degree, fracturing stage spacing, fracturing fluid type, fracturing fluid volume, proppant type, proppant dosage and pump injection displacement. Since it is clearly noted by the test that the horizontal-well wellbore integrity, the optimized low-viscosity slickwater and ceramsite fracturing technology, and the usage of large volume of sand fluids are favorable for complex fracture creation, engineering parameters for test are valued in a relatively concentrated range and, as a result, the comprehensive analysis is less sensitive. Parametric variables including effective horizontal section length, number of fracturing stages, porosity, TOC and gas content are deemed to be highly credible, since their significance, standard deviation, and sum of squares for residuals meet the requirement of multiple regression model and accord with the geological and engineering rules for the prediction of shale gas horizontal well production, and the predicted single-well shale gas production matches well with the field test production (Fig. 1).

The correlative analysis of geologic and engineering conditions for test wells indicates that, shale reservoir quality, wellbore integrity, and the combination mode of fracturing

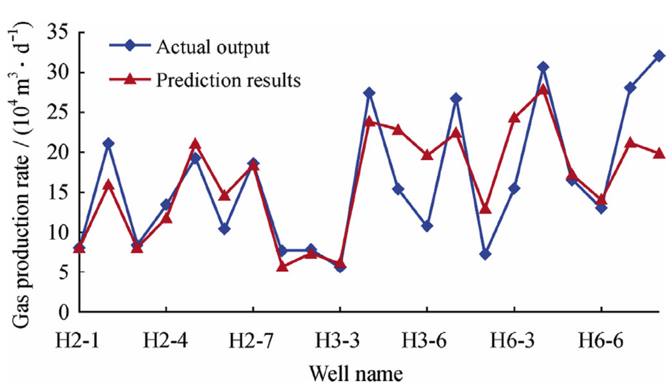

Fig. 1. Correlation of actual gas production rate and prediction results from multiple linear regression models for test shale gas wells in the Changning Block.