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Gas–liquid flowing process in a horizontal well with premature liquid loading

Zhouhua Wang [a, *], Xin Fu [b], Ping Guo [a], Hanmin Tu [a], Hao Wang [a], Shichao Zhong [a]

[a] State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, Sichuan, 610500, China
[b] Southwest Oil and Gas Field, Chuanzhong Oil & Gas Mines, Sui Ning, Sichuan, 629000, China

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ABSTRACT

Horizontal wells are widely utilized as an important technique to improve the individual well producing rate. However, the actual production performance characteristics of a horizontal well in a reservoir demonstrate that the deliverability of several horizontal gas wells has not been developed effectively because of liquid loading. Understanding of this issue is confined to the production performance characteristics of the horizontal well because of the lack of techniques for the study of the liquid removal mechanism. To address this problem, an experimental device for the liquid removal mechanism of a visual-simulation horizontal well was established. Compared with the conventional conduit flow experimental device, the experimental device established in this study not only comprehensively considers the effect of the horizontal, bend, and vertical sections of the well but can also carry out the simulation under the conditions of different trajectories and intake locations. Through an in-depth analysis of the experimental phenomenon, two parameters, namely, water lock effect and reasonable velocity of liquid removal, were introduced to represent the liquid removal mechanism of the horizontal well under different conditions. Results indicate that the liquid lifting capability of the horizontal well is restricted by the producing energy. For a low-permeability sand reservoir with high water saturation, using a horizontal well with down-dip trajectory and opening the entire formation close to the toe are propitious for the removal of liquid in the horizontal well. These experimental results support the theory on trajectory optimization, opening the middle layer position optimization, reasonable proration, and improving the liquid removal result of the horizontal well in low-permeability sand gas reservoirs with high water saturation.

1. Introduction

The tight gas reservoir has been paid more attention. Low permeability (kg less than or equal to 0.1 mD), low porosity and higher water saturation are the main features of tight gas reservoirs (Desbois et al., 2011; Clarkson et al., 2012). With a large reservoir contact area, horizontal wells can greatly improve well productivity in lower grade reservoirs compared. Giger (1987) has established one theory method to answer that horizontal wells have played an increasing role as alternate production tools to vertical or slanted well in low permeability oil reservoir. Edgeman and Walser (2003) analyzes the detailed production data from 32 horizontal Devonian wells in the Permian Basin, and thought that horizontal wells could greatly improve the productivity of single well. Coskuner (2004), Luan et al. (2007) and Medeiros Petrobras and Ozkan (2007) all suggest that horizontal wells should be widely used in tight gas reservoir, because its stable performance and higher productivity in low permeability reservoirs.

Meanwhile, horizontal wells have been widely adapted in low-permeability gas reservoirs in China (Zou et al., 2012). In Sichuan basin, more than 100 horizontal wells have been drilled in the low-permeability sandstone gas reservoirs and sour gas reservoir. And the productivity-ratio of a horizontal well to one of a nearby vertical well is about 5–10 (Fuxun, 2002; Shukun, 2008). However, the experience of using horizontal wells in Xujiahe Gas Reservoir shows an interesting phenomenon (Wang, 2009): compared with vertical wells, the liquid loading has more significantly impact on horizontal wells with undulating wellbore trajectory or an uneven gas producing profile along the horizontal wellbore (Fig. 1). For example, Guangan A and Guangan B are respectively adjacent

* Corresponding author.
E-mail address: wangzhouhua@126.com (Z. Wang).

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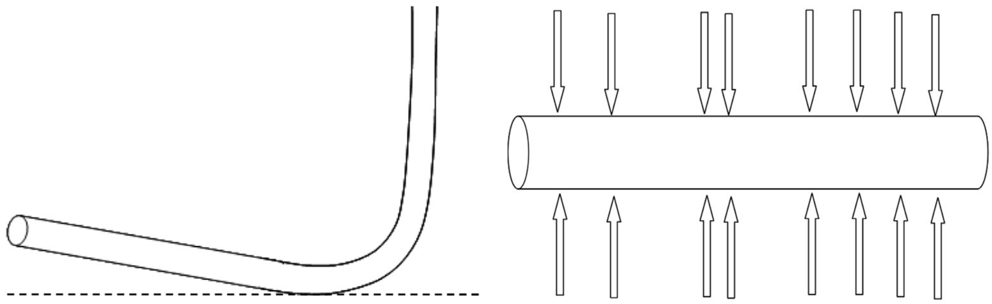


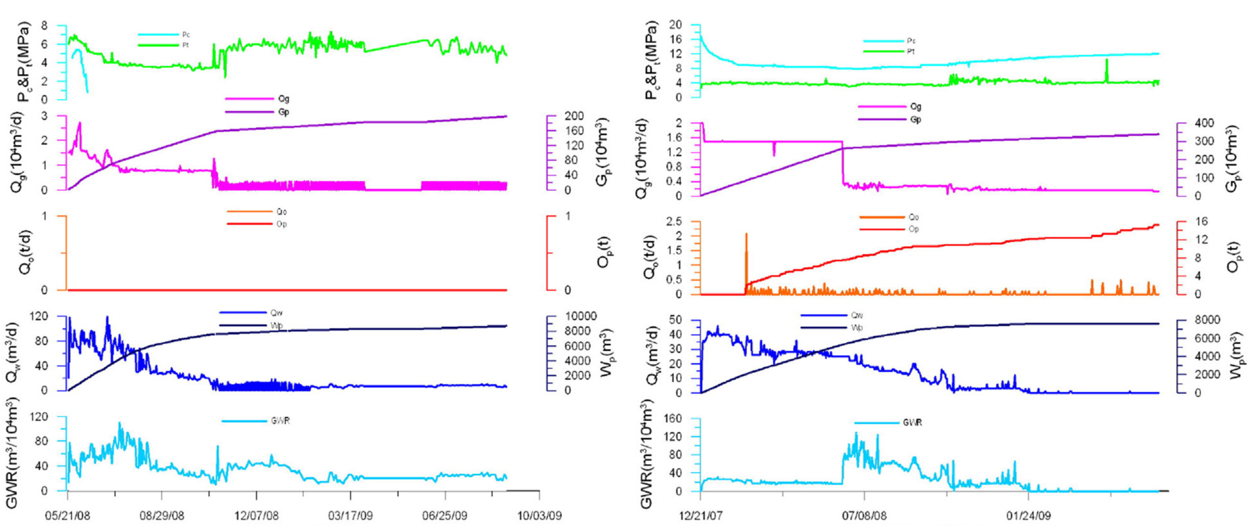
(a. Up-dip well trajectory) (b. Inhomogeneous gas supply well trajectory)

Fig. 1. Well trajectory chart of a low-permeability gas reservoir with horizontal wells.

horizontal well and vertical well in Xujiahe Gas Reservoir. The gas production curves (Fig. 2) showed that both wells could produce liquid smoothly at the early period with higher formation pressure, but with the pressure reducing, the water–gas ratio and the water-yielding capacity of Guangan A well both gradually decreased, and finally Guangan A produced gas intermittently; while, Guangan B well produced continuously with a lower production. The difference of gas–liquid flowing mechanism between horizontal and vertical wells probably is the main factors.

For gas–liquid flowing in pipes, extensive studies have been carried out numerically and experimentally by lots of investigators. The flow patterns in horizontal pipes experimentally include stratified flow, annular flow, dispersed bubble flow and slug flow (Zhao and Rezkallah, 1993; Rezkallah, 1995). Liu et al. (2012) numerically investigated the influence of gravity on gas–liquid two-phase flow in horizontal pipes, and indicated that the gravity had more affect on the flow pattern. Zhao et al. (2013) performed a series of experiments to show the effects of high viscosity oil on characteristics of oil and gas flow in horizontal pipes. Ayati et al. (2014) experimentally showed two stratified flow (smooth case, wave case) in horizontal pipes, and characterized by their interface flow pattern (smooth interface and small amplitude 2D waves). Bottin et al. (2014) and Lee et al. (2013) also respectively studied the two-phase bubbly flow and hydrodynamics model for gas–liquid stratified flow in horizontal pipes. Najmi et al. (2015) conducted an experimental study to confirm the critical flow rates (resulting in stratified wavy flow) of gas and liquid necessary to keep particles moving in a horizontal flow line. Osgouei et al. (2015) proposed a new model to estimate the frictional pressure losses for liquid–gas multiphase flow in horizontal eccentric annulus. Also mechanism and model of stratified flow in inclined pipes are investigated by Li et al. (2004), Lips and Meyer (2012), Xia and Lei (2012) and Xing et al. (2013). And the flow patterns in inclined conditions are similar to those in horizontal pipes. Wang et al. (2003, 2004, 2005, 2008) studied the two-phase flow pattern in horizontal return bend and vertical return bend; the flow reversal and freezing slug phenomena are seen in vertical return bend (D > 3 mm), and are hardly observed in horizontal pipes, they reduced the liquid loading ability in bends. de Oliveira et al. (2014) also studied the nature of the developing flow upstream and downstream of a vertical 180° tube bend (curvature ratio of 8.7) by means of gas holdup and pressure drop measurements.

All above studies almost focus on pressure drop, flow pattern and transition in horizontal pipes, inclined pipes and bends respectively. Those are different from the gas–liquid flow process in a horizontal well. The primary focus of this article is on experimentally investigating the gas–liquid flowing process and the critical conditions of liquid entrainment in the horizontal wells.



(a. Horizontal well) (b. Vertical well)

Fig. 2. The gas production curves of horizontal and vertical wells.