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Multi-branched horizontal wells for coalbed methane production: Field performance and well structure analysis

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ABSTRACT

Horizontal wells, such as multi-lateral and multi-branched horizontal wells (MBHWs) have been effectively used in the development of coalbed methane (CBM) fields, especially for coal beds with very low permeability and low compressive strength, in which the performance of conventional fracture-stimulated vertical wells is ineffective. In this study, the performance of MBHWs in the Liulin block of the Ordos Basin in central North China is analyzed and compared to that of hydraulically fractured vertical wells. The field pilot data show that the gas production rate of most fractured vertical wells decreased rapidly after a short period of time, far below expectation, while the performance of MBHWs is satisfactory and relatively stable during 3 years of production. A numerical simulation model was established based on the coal reservoir characteristics. The productivities of different well types are predicted and compared to the field data. The poor performance of the fractured vertical wells is thought to be caused by the early closure of the fractures and proppant embedded in the coal matrix or by a poor proppant delivery inside the fractures. The high and stable productivity of the MBHWs is attributed to their large drainage volume and to the stability of the wellbores. Simulation results show that the parameters of a MBHW, such as the branch angle, length, and spacing, can be optimized to maximize its productivity. Though the drilling cost of a MBHW is relatively high in comparison to vertical wells, its high and stable productivity can compensate for the drilling cost. Therefore, MBHWs are thought to be more appropriate than vertical wells for the successful exploitation of the CBM resource potential in the Liulin Block and surrounding area.

1. Introduction

The geological features of coalbed methane (CBM) reservoirs are complicated. They are considered as self-sourcing gas reservoirs, in which the coal seams act both as source and reservoir rocks for natural gases (mainly methane) (Clarkson and McGovern, 2005; Gash et al., 1992; Pan and Connell, 2012). Most coalbed methane can be considered as adsorbed gas, with the remainder existing as free gas in pore spaces and fractures. Coal has a large specific area, with 1 cm^3 of coal rock sample containing approximately 3 m^2 of pore surface area. This has made it possible for a large quantity of gases to adsorb on the surface area (Mares et al., 2009; Radlinski et al., 2004). In terms of petrophysical characterization, coal is composed of a dual porosity system, namely in the matrix and in natural micro fractures. Coal matrix makes a relatively large contribution to its porosity but has very little impact on its permeability. On the other hand, micro fractures have a relatively high permeability but make much less contribution to total porosity. Permeability in coal is controlled by the cleat system, the face cleats and butt cleats (Gentzis, 2000; Karacan and Okandan, 2000; Laubach et al., 1998; Law, 1993). While the gas content of coal seams is determined by porosity, pressure, and methane adsorption capacity, the gas flow or production rate is dominated by permeability. Permeability in the coal matrix is very small (less than 0.001 mD) but cleat permeability can be relatively high (0.01 mD up to many mD) depending on coal quality and in-situ stress. This results in permeability anisotropy being very high in most coal seams (Paul and Chatterjee, 2011). During gas production, desorbed methane enters fractures via a diffusion process that is controlled by a concentration gradient and observes Fick's Law, and then flows through the fracture network into the wellbore by Darcy Law. The two types of flow may interact with each other (Levine, 1996; Wang, 2006; Wang and Ward, 2009). Though a coal seam may be rich in methane, stimulation treatment of production wells such as conventional hydraulic fracturing is required to produce gas at economic rates, particularly from vertical wells.

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Horizontal and multi-branched horizontal wells increase the exposure of a wellbore to the micro fracture systems of a coal bed, subsequently improving the flow conductivity and enhancing well production and recovery factor. By drilling a horizontal wellbore, a drainage volume gain is realized (Fig. 1). Irrespective of the drainage radius, if the length of the lateral (L) is equal to the drainage radius (r), then the horizontal well is in contact with 64% more coal bed volume than a vertical well that intersects a single coal bed thickness. Fig. 2 shows the total surface area contacted by a vertical fracture-stimulated coal bed versus a horizontal well. For a single coal bed having a thickness of 4.5 m, a 7.5 cm-thick horizontal lateral needs to be 409 m long in order to be equivalent to a 7.5 cm-thick vertical hole with an effective fracture length of 22.8 m (i.e., fracture reaching top to bottom in a coal bed and extending 22.8 m in both directions). However, with multiple coal seams more laterals would be needed to negate the net coal bed thickness effect; otherwise the increase in thickness of vertical wells over the single zone lateral completion is significant and forces either multiple laterals to be drilled or L has to be several times longer than r in order for horizontal wells to be more effective than vertical fracture-stimulated wells.

If coal bed thicknesses are the same and $L = r$, then a horizontal wellbore will be in contact with 64% more rock volume. If $L = 2r$, then it will be in contact with 128% more volume. π is a mathematical constant and refers to the ratio of a circle's circumference to its diameter, equal to 3.14159.

Multi-branched horizontal coal bed wells (MBHW) have been used in the past 15 years to increase gas production rates considerably (Xian et al., 2005a). CDX Gas, LLC applied a multi-lateral horizontal drilling and completions technology called Z-pinnate™ in the central Appalachia Basin, West Virginia, USA, as part of a mine degasification program. A Z-pinnate well pattern drilled underbalanced in a low-permeability but high gas content coal seam can deplete 1200 acres from a single small well site (i.e., has a very small footprint) and typically recover 85 to 90% of the original gas-in-place (OGIP) within 30 months (Wight, 2004). By contrast, one vertical CBM well usually reaches only 80 acres. The Z-Pinnate system combines a dual-well system — a vertical well with a 1.8 m-wide cavity and a horizontal well that intersects the cavity — with a multi-lateral leaf-shaped drainage network. The CDX Gas Pinnacle Project in Wyoming County, West Virginia, was a successful degasification of a substantial mining area. A Z-pinnate pattern allows CBM wells to reach maximum production rates in a matter of days or weeks by minimizing the dewatering period. Variations of horizontal well patterns (e.g., overbalanced drilling, use of a perforated liner, and the application of certain drilling additives that are non-damaging to the cleat system but provide stability to the main wellbore in high in-situ stress areas) have been drilled and produced — with success — in coal beds in western Canada (Alberta Basin, Mannville Formation; Gentzis, 2011a,b), in the USA (San Juan Basin, Fruitland Formation; Gentzis, 2011c) (Arkoma Basin, Hartshorne Coal Seam; Cardott, 2009) and in Australia (Queensland and in the Bowen and Sydney/Gunnendah basins) (Gilbert et al., 2013; Moore, 2012; Thomson and MacDonald, 2003).

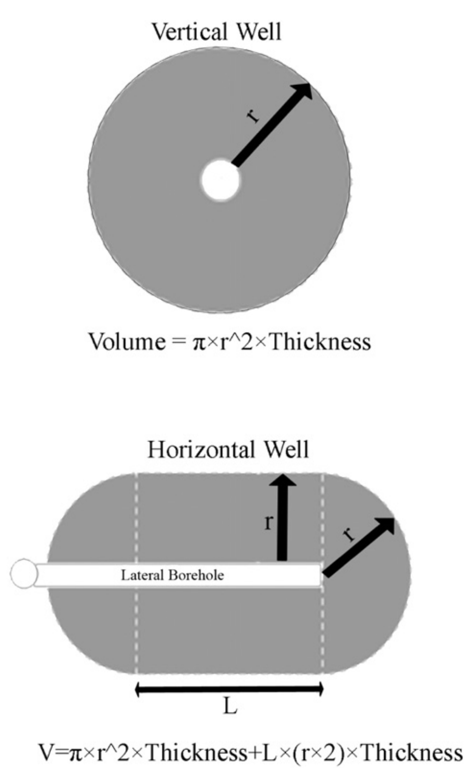

Fig. 1. Volume of rock that is contacted by a vertical vs. a horizontal well.

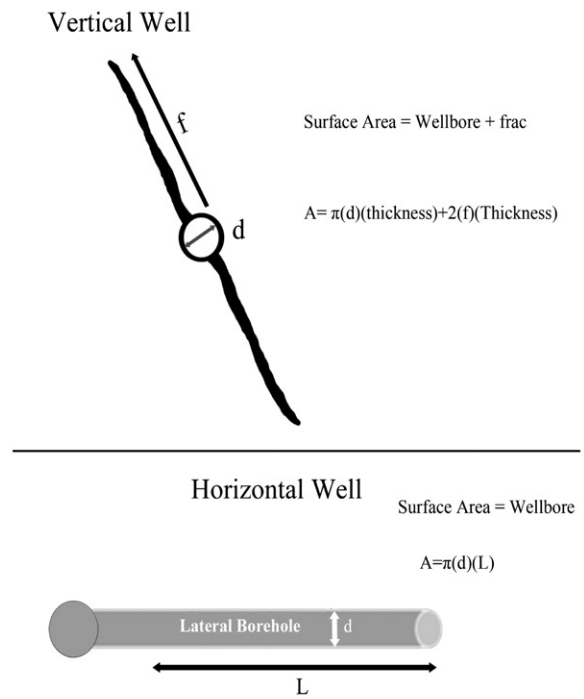

Fig. 2. Total surface area covered by a vertical well with fracture vs. a horizontal well. A single 4.5 m thick coal completed and fracture stimulated in a 3.5 in. hole (d denotes hole diameter) has the same surface area (A) as a 408 m long (L denotes length), 3-inch. wide (d denoted width) lateral wellbore. The letter f denotes the effective fracture distance, which is 22.8 m.

In many coal regions, particularly in China, where the production performance of vertical wells is poor due to low quality and inability of fracturing treatments to enhance production, the MBHW technique can play an important role in the development of coal bed methane fields, by maintaining relatively higher gas production rates and reducing the comprehensive cost in comparison with the conventional vertical wells.

In this study, the field performance of gas production of vertical and horizontal coalbed methane wells in the Liulin block of Ordos Basin, North China, is reported. The mechanisms of multi-branched horizontal wells and their advantages in the above region are analyzed based on the geological characteristics of the coal seams, reservoir properties and well configuration. The pros and cons of both vertical and horizontal wells are described and compared. Field production data from fractured vertical wells in the Liulin block have been much below the expectation, while the field performance of MBHWs has been considerably higher in line with the model prediction, and it is also stable during the last two years of the field pilot. Furthermore, a reservoir simulation model for coalbed methane production is established based on the