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New development of theories in gas drilling

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Abstract: Theories established from engineering fundamentals have been of great value in supporting the design and execution of drilling operations in gas drilling where gas is used as a drilling fluid. This work presents an overview of new theories developed in recent years for special gas drilling operations including horizontal wells. These new theories are found in the areas of gas-mixture flow hydraulics in deviated and horizontal boreholes, hole cleaning of solids accumulation, hole cleaning of formation water, flow diverging for washout control, bit orifice optimization, and depression of formation water influx. This paper provides drilling engineers with updated mathematical models and methods for optimizing design to improve gas drilling performance.

Key words: Air drilling, gas drilling, nitrogen drilling, design optimization, theory development

1 Introduction

Oil and natural gas wells were drilled utilizing portable air compressors as early as the 1920s (Singer, 1958). Popular use of air as a drilling fluid began in the early 1950s (Martin, 1952). The technology became mature in the late 1950s. The types of fluids used in gas drilling have evolved from air, through natural gas, to nitrogen gas. Many operators relied on the readily available air or pipeline gas for their gas drilling requirements in gas drilling operations prior to the 1980s. Both of these techniques of gas drilling are inherently expensive and dangerous. In an effort to lower drilling cost and improve operational safety on gas-drilled directional wells, Meridian Oil assisted the first time in the development of a nitrogen drilling system (Allan, 1994). The nitrogen drilling system provided a safe and economical means of gas drilling in hydrocarbon producing formations. Air was first used to drill Devonian shale gas formations up to 72 degrees of inclination angle in the late 1980s. Since then the types of wells drilled with gas have been expanded from vertical wells, through directional wells, to horizontal wells in various types of formation rocks (Yost et al, 1990). From the very beginning of gas drilling practice, theories established from engineering fundamentals have been of great value in supporting the design and execution of gas drilling operations. Updated theories have been documented several times in the past, including GRI (1997), Lyons et al (2001), and Lyons et al (2009). However, these documents do not reflect the theoretical advances developed in the past 5 years for gas-drilling horizontal wells under complicated geological conditions. This work is aimed to help fill this gap.

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2 Evolution of theories

This section outlines the evolution and development of theories used in gas drilling. These theories are found in the areas of multi-phase flow hydraulics in deviated and horizontal boreholes, hole cleaning of solids accumulation, hole cleaning of formation water, flow diverging for washout control, bit orifice optimization, and depression of formation water. These theories provide drilling engineers useful tools for optimizing their gas drilling design. Illustrations in this section are provided only for demonstrations of typical cases and are not explained in detail due to limited space. More detailed information is available from the authors upon request.

2.1 Multiphase flow hydraulics in horizontal wells

The major component of fluid in gas drilling is the gas phase, which can be air, natural gas, carbon dioxide, or nitrogen. Other components include drill cuttings, injected (misting) water, and fluid (water or oil) from rock formations. Angel (1957) was the first investigator who developed a gas-solid 2-phase flow model to simulate gas drilling hydraulics. Guo et al (1994) were the pioneering researchers who extended Angel's analytical model of gas-solid 2-phase flow model from vertical wells to deviated and horizontal wells. They considered volumes and weights of the injected gas and drill cuttings. Guo and Ghalambor (2002) modified Guo et al.'s (1994) analytical model for gas-solid 2-phase flow to form an analytical model for gas-water-solid 3-phase flow. This model considers volumes and weights of the injected gas, injected water, and drill cuttings. Guo and Liu (2011) made Guo and Ghalambor's model more general to a 4-phase flow. It considers the volumes and weights of the injected gas, injected water, produced fluid (water or oil) and drill cuttings. This analytical model is summarized as follows.