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TRANSMISSION BEHAVIOR OF MUD-PRESSURE PULSE ALONG WELL BORE*

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ABSTRACT: In oil and gas industry, mud-pulse telemetry has been widely used to obtain directional data, drilling parameters, formation evaluation data and safety data, etc. Generally, the drilling mud in most current models was considered to be a single-phase fluid through which the mud pulses travel, despite the fact that the drilling mud is composed of two or more phases. In this article, a multiphase flow formula was proposed to calculate the mud-pulse velocity as mud solids and free-gas content change, and a mathematical model was put forward to simulate the dynamic-transmission behavior of the mud-pressure pulse or waves. Compared to conventional methods, the present model provides more accurate mud-pulse attenuation, and the dynamic-transmission behavior of drilling-mud pulses along well bores can also be easily examined. The model is valuable in improving the existing mud-pulse systems and developing new drilling-mud pulse systems.

KEY WORDS: measurement-while-drilling (MWD), closed-loop drilling, multiphase flow, numerical simulation

1. INTRODUCTION

In today's drilling industry, the reliable two-way communication and data transmission between the surface and bottom of the wellbore is required, where mud-pressure pulse telemetry has been employed as one of the most popular and low-cost methods. Besides, with the increasing complexity and cost of drilling system, oil and gas industry has become more dependent on Measurement-While-Drilling (MWD) technology to monitor directional data, drilling parameters, formation evaluation sensors, and safety data. At present, the MWD technology mainly includes hardwired telemetry, electromagnetic and acoustic methods, intelligent drillstrings, fiber optics, etc.

When MWD technology is applied, the mud stream inside the drill pipes is generally used as communication medium. In fact, as early as in 1929, the concept of using mud pulses traces was put forward as an effective method for transmitting information along the wellbore. After many years' research, the first mud pulse system was developed in the 1960s and commercialized in the late 1970s [1-3].

Mud-pulse telemetry has obvious advantages in providing cost-effective data transfer and the closed-loop drilling [4-6], and how to maximize the data communication rate and transmission distance for mud-pulse telemetry has become an issue in the oil industry. On the other hand, the formation rock is almost completely destroyed during the drilling process, forming formation fragments of different sizes. Some other solids, such as barite, are also contained in the drilling mud to adjust and control

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its performance. Gas may also enter the borehole when a high-pressure zone is being penetrated. What's more, while only 0.6%-0.9% of gas in the water-base mud, large volumes of gas can be dissolved in the oil-base one. As a result, the mud-pulse velocity and attenuation is affected due to the significant influence of these solid particles and free gas on the density and compressibility of the mud. Generally, the mud-pulse velocity declines with the increase of the mud density, gas content and the mud compressibility. In many studies on the propagation velocity and attenuation of mud pulses or waves, however, the drilling mud was viewed as a single-phase fluid, despite the fact that it is composed of two or more phases[7, 8].

In the present study, a multiphase flow formula is proposed to calculate the mud-pulse velocity and a method is also put forward to examine the dynamic-transmission behavior of the mud pressure pulse or wave, with the purpose of improving the existing mud-pulse measurement and control systems. The new method is expected to determine mud-pulse velocity and attenuation more accurately than conventional ones, enhancing the understanding of mud-pulse transmission behavior.

2. MUD-PULSE VELOCITY

The mud-pulse velocity has been studied for a long time in the drilling industry, and was usually expressed as a function of the mud density and compressibility:

$$a = \sqrt{\frac{1}{\rho\left(\frac{1}{K_p} + \frac{1}{K}\right)}} \tag{1}$$

where a is the wave velocity, ρ the drilling-mud density, K the mud bulk modulus, and K_P the bulk modulus of elasticity of the drilling-pipe.

Compared with the conventional methods, the present calculating model is highlighted in the following aspects:

(1) The drilling mud is considered to be a multiphase flow system instead of a single-phase fluid.

(2) The drill pipe is considered as a thick-wall pipe.

(3) The bulk modulus of elasticity of the pipe is calculated based on a better understanding in dealing with boundary constraints.

For a differential segment of drilling mud, the relative rate of cross section is related to the elasticity and supporting condition of the pipe. To determine how the pipe is fixed, three different types of constraints are considered:

(1) The pipe anchors at the top only.

(2) No axial force acts on the pipe.

(3) The entire pipe is fixed without longitudinal strain.

Based on the above constraints and Hooke's law, the pipe bulk modulus of elasticity for thick-wall pipes is

$$K_p = \frac{\delta(1+\delta)E}{(1-0.5\lambda)+2\delta(1+\delta)(1+\lambda)}, \text{ anchored at the top} \tag{2a}$$

$$K_p = \frac{\delta(1+\delta)E}{1+2\delta(1+\delta)(1+\lambda)}, \text{ no axial force applied} \tag{2b}$$

$$K_p = \frac{\delta(1+\delta)E}{(1-\lambda^2)+2\delta(1+\delta)(1+\lambda)}, \text{ no longitudinal strain} \tag{2c}$$

where δ is the thickness-diameter ratio of drill pipe, E Young's modulus of elasticity of the drill pipe, and λ its Poisson's ratio.

In practice, Halliwell's work is frequently quoted in which the effects of pipe diameter and length on waterhammer wave velocity inside an elastic pipe were considered [9]. However, Wylie and Streeter argued that the axial force is only affected by the pipe diameter [10]. Axial stretch results in the increase of the pipe volume, which will last long enough to change the fluid density and hence reduce the wave velocity and pressure. On the other hand, the axial stretch makes the drag of fluid vary along the pipe, accelerating the process of fluid supply to the differential elements, and thus tends to increase wave velocity and pressure.

In the calculation, the bulk modulus is determined by the composition of the drilling mud, in which several phases are included, such as clay, formation cuttings, barite, and free gas mixed with water/oil. Figure 1 presents a physical model that is useful for calculating the bulk modulus of the fluid system. The container, blocked up by a piston at the right, is filled with liquid, solid particles and free

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