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Numerical simulation method of ultrasonic wave propagation in gas-liquid two-phase flow of deepwater riser

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ABSTRACT

The ultrasonic transmission monitoring in risers is a promising method for the early detection of gas kick in deepwater drilling. It is difficult to obtain satisfactory results using only theoretical calculation because the ultrasonic wave propagation in the multiphase flow in risers is very complicated. In addition, the key parameters such as bubble shape and void fraction of two-phase flow are hard to be accurately controlled and measured. In view of the above-mentioned facts, this paper aims to analyze the principle and physical model of ultrasonic monitoring of gas kick in risers, and to establish a numerical simulation model based on COMSOL platform. Through an analysis of the numerical simulation results, it was found that the time domain diagram of the received signals contains longitudinal wave, transverse wave, surface wave and coda wave. The cross-correlation function was used to quantitatively analyze the waveform of the received signals under different void fraction conditions. It also suggested that the direct wave was insensitive to the void fraction while the coda wave was sensitive to the void fraction, which was verified through frequency domain analysis. By establishing the experimental system, the attenuation coefficient was used to verify the numerical simulation results. After comparing and analyzing data, this paper argued that the numerical simulation method established in the project can be used as an effective supplement to experiments, and it can be used to calculate and analyze the ultrasonic propagation and attenuation under conditions, such as different bubble sizes and densities, and bubble non-uniform distribution, which can not be accurately and quantitatively measured or controlled in the experiments.

1. Introduction

Early monitoring of gas kick is crucial to the safety of well control in deepwater drilling [1,2]. With the depth of deepwater drilling exceeding 3000 m [3], the advantages of monitoring gas kick technology in risers gradually appears [4], which has recently become a research hot spot by scholars. In 2011, Li et al. [5] studied the method of detecting gas kick by using ultrasonic Doppler in risers, and they measured the fluid velocity based on the frequency difference of the ultrasonic wave reflected by the solid particles or bubbles in the fluid. To a certain extent, it verified the feasibility of gas kick detection using ultrasonic waves in risers. In 2015, E.D. Toskey et al. [6] proposed to measure the variation of drilling fluid density in the riser

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annulus by installing a fluid density detector at the bottom of the riser to determine whether there is overflow or gas kick. This method further verified the feasibility of detecting overflow or gas kick at riser. In the same year, Guan et al. [4] proposed to detect the gas content of multi-phase fluid in riser annulus by ultrasonic transmission and set up an experimental device for the analysis of ultrasonic propagation under different gas–liquid ratio conditions. In 2016, Geng et al. [7] demonstrated the feasibility of using ultrasonic Doppler to detect gas kick at riser by means of experiments. In 2017, the authors conducted a preliminary study on the propagation of ultrasonic waves under different void fraction conditions by numerical simulation [8], and confirmed the advantages of the numerical simulation method in the research of this issue.

As discussed above, the current research on this issue is still at exploratory stage. The experimental methods are mostly used to evaluate the feasibility and effectiveness of different ultrasonic monitoring methods. However, there are few studies on the common basic problems of ultrasonic propagation in gas–liquid two-phase flow in riser annulus, and on the specific influence of different factors on the propagation law. The main reason is that the propagation of ultrasonic wave in the multiphase flow in riser is a complex process. It is difficult to obtain the satisfactory results using only the calculation of the theoretical model. At the same time, the bubble shape and void fraction and other key parameters are difficult to be accurately controlled and measured in experiments. The numerical simulation method can simulate the propagation process of ultrasonic waves by accurately controlling the simulation conditions under the premise of comprehensively considering various influencing factors, which is beneficial to reveal the propagation rules of ultrasonic waves and to analyze the influence of various factors according to the propagation rules. Therefore, it is necessary to study and establish a set of numerical simulation methods for the propagation of ultrasonic wave in gas–liquid two-phase flow in risers. It can be used to accurately analyze the propagation of ultrasonic waves in gas–liquid two-phase flow in riser annulus. Associated with experimental research, it can provide an effective means for the eventual establishment of quantitative relationship between ultrasonic parameters and gas–liquid ratio of two-phase flow under the actual conditions.

2. Materials and methods

2.1. Physical model of ultrasonic detection of gas kick in riser

Through an investigation, there are two main ways to monitor gas kick at the riser by using ultrasound: Doppler and transmission. As described in reference [4], the ultrasonic Doppler monitoring method is limited by its measurement principle. It needs to be further explored and studied in the aspects of effective monitoring range (information window), monitoring accuracy, extraction of effective signal of acoustic wave (bubble reflection signal) and simulation of annular multi-phase flow field in riser; Ultrasound transmission method is a more potential program for early monitoring of gas kick in deepwater drilling [4]. It sends the ultrasonic wave through the multi-phase fluid in the riser and utilizes the sensitivity of the ultrasonic wave to the bubbles in the multiphase flow to detect the gas, which can more fully reflect the gas void fraction of the riser annulus. Therefore, this paper takes ultrasonic transmission monitoring method as the research object, and its physical model diagram is shown in Fig. 1.

In the actual drilling process, when the advance gas bubbles reach the bottom of the riser, the flow pattern is bubbly flow, but the size and distribution of the bubbles are not uniform because of the influence of the drill pipe rotation and the well structure, at el. Experimental and numerical simulation results show that: the dimension, number and distribution of bubbles can affect the sound propagation in different ways and to different degrees, and they are also the influence factors of the gas fraction. However, the non-uniform distribution of bubbles is difficult to be quantified by quantitative indicators. In order to establish an effective method for studying the basic propagation law of ultrasound under different conditions, the bubbles were distributed evenly in the model.

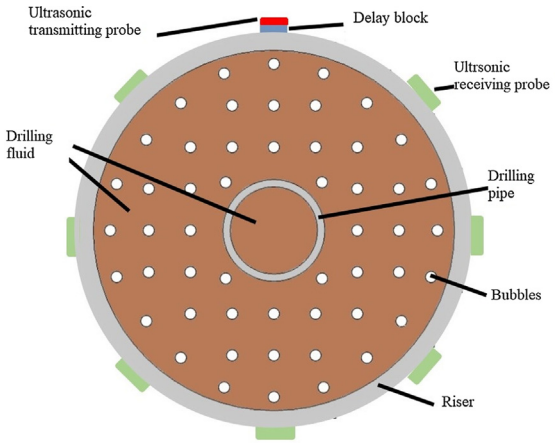

Fig. 1. Schematic diagram of physical model for ultrasonic monitoring of gas kick at riser.