Influence of Liquid-Gas Physical Parameters on Severe Slugging in a Pipeline-Riser System

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ABSTRACT

A CFD method is proposed to simulate the gas-liquid severe slugging in a pipeline-riser system in the present paper. Based on the consistence principle of the severe slugging formation condition, the 3D flow in a pipeline-riser system is simplified into a 2D flow. The severe slug flow in a pipeline-riser system with a given pipeline declination angle is simulated numerically. The effects of gas-liquid physical parameters on slug flow characteristics are studied and analyzed when the liquids are water, crude oil and kerosene, and the gas are methane and air, respectively. Numerical results show that physical properties of the liquid, including viscosity, density and surface tension, have remarkable influence on the characteristics of severe slugging, including the flow pattern, the period and the pressure fluctuation, whereas the influence of the gas physical properties on the characteristics of the severe slugging is not significant.

KEY WORDS: Severe slugging; pipeline-riser system; CFD method; liquid-gas physical parameters.

INTRODUCTION

The pipeline-riser system, including a downward inclined pipeline and a vertical riser, is needed to transport oil (with water) and associated gas from subsea wellheads up to offshore platform systems in the exploitation of offshore oil and gas (Sertã, 2004). At low flow rates of gas and liquid, one important problem experienced in such a pipeline-riser system is a severe slugging phenomenon that is defined as the buildup of liquid slug that equals to or exceeds the riser’s height (Schmidt, 1985; Fabre, 1990). This phenomenon, also called terrain-induced slugging, is a considerably harmful flow pattern in offshore petroleum production systems because of its high potential in causing sudden fluctuations of pressure and flow mass in the pipeline and overflow or interruption of the terminal gas-liquid separator (Sarica, 2000). Such a severe slug flow can thus damage the production equipment and greatly reduce the production capability.

The gas-liquid severe slugging in a pipeline-riser system has been studied experimentally in several flow laboratories. These experiments mainly focused on the formation mechanism and flow characteristics, as well as the elimination method (e.g., Linga, 1987; Taitel, 1990; Wang, 2005 and 2008; Mokhatab, 2007; Luo, 2009). Some simplified numerical models were also proposed to study the severe slugging in a pipeline-riser system (e.g., Schmidt, 1980; Sarica, 1991; Baliko, 2010; Mokhatab, 2010). These models can be divided into two categories. One of them is called the two-fluid model, where one uses partial differential equations (PDE’s) for the conservation of mass and momentum in each phase. The other is the drift flux model, where one has PDE’s for conservation of mass in each phase, and a combined momentum conservation equation. However, phase behaviors are not ideally incorporated due to inherent limitations of these simplified models.

In order to study the influence of gas-liquid physical parameters on severe slugging systematically, a CFD model is developed to simulate the gas-liquid severe slugging in a pipeline-riser system. Based on the consistence principle during the severe slugging formation, the 3D flow in a pipeline-riser system is simplified into a 2D flow. The gas-liquid severe slug flow in a pipeline-riser system with a given pipeline declination angle is simulated numerically, in which water, crude oil and kerosene are selected as the liquid, while methane and air as the gas, and all cases have the same flow conditions. The effects of gas-liquid physical parameters on slug flow characteristics are studied and analyzed. Specifically, the effects of viscosity, density and surface tension of the liquid on the characteristics of severe slugging, including formation mechanism, flow pattern and its period, pressure fluctuation are analyzed by comparing the results obtained from the CFD simulation. The present research is helpful to the damage evaluation of the oil-gas severe slugging in different undersea oil fields, which can provide a useful reference for the design of pipeline-riser systems.

NUMERICAL MODEL AND VALIDATION

The definition sketch of the pipeline-riser system is shown in Fig. 1, which consists of a downward-inclined pipeline and a vertical riser. The diameter of the pipeline considered in this study is 0.051m, and the declined pipe is 10.8m-long with an inclination angle of $\beta = -4^\circ$, and the length of the vertical pipe is 4.1m. Since its geometric model is not