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Investigation of natural gas hydrate slurry flow properties and flow patterns using a high pressure flow loop

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HIGHLIGHTS

- Hydrates aggregation is especially violent and rapid in multiphase system.
- Hydrates formation will cause gas/liquid flow rate to change in different ways.
- Three distinctions are found from flow pattern maps with/without hydrates.
- Mechanism of how hydrates affect flow pattern transition is developed.

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ABSTRACT

The formation and agglomeration of hydrates have been a major hazard to the operating safety of deep-sea oil/gas transportation pipeline. Although many studies have been conducted to investigate the hydrates formation and particle behaviors during the transportation, studies on the gas–slurry flow properties and effects of hydrates on multiphase flow patterns are still almost blank. In this work, a series of experiments were conducted in a high pressure flow loop, using the materials of a pseudo single-liquid-phase (saturated water/oil emulsion) and a gas–liquid multiphase, respectively. It was found that hydrates agglomeration was more violent and the flow property was worse in the gas–liquid multiphase system. When hydrates formed in the gas–liquid multiphase system, the liquid flow rate would decrease in all experimental conditions while the gas flow rate showed three different changing types: decreasing, increasing or keeping constant. These changes of the flow rate would further induce a transition of the gas–liquid multiphase flow pattern in the loop. Based on the experimental data, two flow pattern maps were made. One involved the effects of hydrates while the other did not. Through the comparison between the two flow pattern maps, it is confirmed that the influence of hydrates on the flow pattern is significant. The differences between the two flow pattern maps were also analyzed using a flow pattern transition model to provide an insight into the mechanism of how hydrates affect the multiphase flow pattern.

1. Introduction

With the development tendency of petroleum industry moving to deep-water, gas hydrates have been a major hazard to the flow assurance of subsea transportation system due to the high pressure and low temperature ambient (Sloan et al., 2010). Natural gas hydrates are complex clathrate crystals formed by water and natural gas molecules (Sloan and Koh, 2008). With the fluid temperature decreasing under high pressure, hydrates will form, aggregate, deposit in the pipe and eventually block the pipeline (Akhfash et al., 2013; Balakin et al., 2011; Daraboina et al., 2015; Li et al., 2015; Sohn et al., 2015), which will cause enormous economic losses. Injecting thermodynamic hydrates inhibitor (THI, e.g., methanol, ethylene glycol, ethanol) is a most common and traditional way to prevent hydrates forming by shifting the hydrates equilibrium curve to more severe conditions (Kim et al., 2015; Li et al., 2000). While this thermodynamic approach brings great costs and technical limitations especially in high water cut systems. Anti-agglomerants (AAs) are an alternative approach in the hydrate management strategy, which allows hydrates to form in flowline but prevents their agglomeration (Huo et al., 2001; Lv et al., 2014; Shi et al., 2014; Sun et al., 2015; York and Firoozabadi, 2008). The fluid with hydrates can be treated as a gas–slurry flow in the flowline. Since the complicated composition of this gas–

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slurry flow, its flow characteristics exhibit complexity and unintelligibility (Lv et al., 2014). What's more, hydrates may also have a significant effect on the gas–liquid flow pattern in the flowline, which is a key factor of flow assurance research.

Researchers have done a lot of studies about hydrates growth and slurry flow properties in water and water/oil emulsion systems (Fidel-Dufour et al., 2005; Greaves et al., 2008; Kakati et al., 2014; Shi et al., 2011; Sun and Firoozabadi, 2014; Turner et al., 2009; Webb et al., 2014). However, very few literatures involve the effects of hydrates on multiphase flow pattern and vice-versa. Zerpa et al. (2013) established a hydrodynamic slug model that considered gas–liquid–hydrates flow in gas–water system. Their results indicated that hydrates would induce a flow regime transition from stratified flow to slug flow. Hegde et al. (2015) used the model established by Zerpa et al. (2013) to predict the effects of hydrates on the slug characteristics, such as the slug length distribution, number of slugs, and slug frequency. Their results showed that the liquid–hydrates slip, hydrates volume fraction and hydrates aggregation affect the slug characteristics significantly. Joshi (2012) observed that the formation of a small quantity of hydrates might immediately lead to slug flow onset in a system near the stratified/slug flow or bubble/slug flow transition point according to their experiments. However, to the best of our knowledge, how the interaction between hydrates and multiphase flow pattern occurs and the systematic mechanism of this interaction are still not clear so far.

In the present work, a series of hydrates slurry flow experiments were conducted in a high pressure flow loop. Firstly, the characteristics of hydrates agglomeration and slurry flow were found quite different between multiphase (gas–liquid) system and pseudo single-liquid-phase (saturated water/oil emulsion) system. Besides, three changing types of the gas/liquid flow rates were observed when hydrates formed in the multiphase system. Furthermore, through the comparison between two flow pattern maps with/without hydrates formation, the influence of the hydrates on multiphase flow pattern transition was put forward. Finally, a detailed analysis of the influence was presented based on the mechanism of flow pattern transition.

2. Experimental

2.1. High pressure hydrate flow loop

The experiments in this work were conducted in a high pressure flow loop, which was constructed by the State Key Laboratory of Pipeline Safety in China University of Petroleum (Beijing). The loop is 30 m long and the internal diameter is 2.54 cm. The design pressure is 15 MPa and the design temperature ranges from −20 to 100 °C. The gas and liquid can be injected into the loop by a plunger compressor and a magnetic centrifugal pump, respectively, to form a gas–liquid multiphase flow. Flow parameters, such as pressure, temperature, flow rate, and pressure drop, can be collected by the sensors equipped on the loop. Besides, the loop is also equipped with a focused beam reflectance measurement (FBRM) probe and a particle video microscope (PVM) probe, which can help to study the size and behaviors of hydrate particles from a microscopic view. The Schematic diagram of the loop is shown in Fig. 1.

2.2. Materials and procedures

The materials used in the experiments include civil natural gas from Shanjing Natural Gas Pipeline in China, deionized water, −20# diesel oil and AAs. The composition of the gas and −20# diesel oil is shown in Tables 1 and 2, respectively. AAs are used for reducing the degree of hydrates agglomeration during the experiments, which are compounded by the Chemical Engineering Department in China University of Petroleum – Beijing (Chen et al., 2014).

Before the experiments proper start, the loop should be cleaned by deionized water circling and gas sweeping. For procedures of the pseudo single-liquid-phase please refer to our previous work (Lv et al., 2014), and procedures for gas–liquid multiphase system are as follows: (1) vacuum the loop to −0.1 MPa using a vacuum pump. (2) Load the deionized water and diesel oil into the flow loop. The total volume of the liquid is kept constant at 50 L and the water cut is defined as the ratio of water volume to the total liquid volume. (3) Inject the natural gas into the loop to reach the experimental

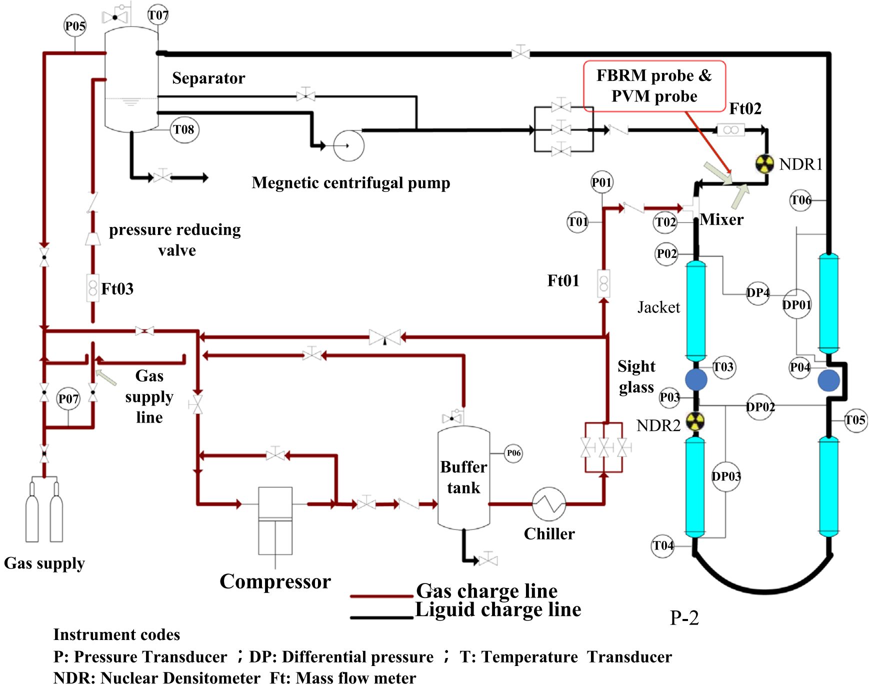

Fig. 1. Schematic diagram of the high pressure hydrate flow loop.