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Probabilistic estimation of hydrate formation

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ABSTRACT

Hydrate formation is one of the major challenges for offshore oil and gas production and the transportation industry. The blockage of subsea pipelines and equipment due to hydrate formation imposes a potential safety hazard. To ensure continuous functionality of the production system and minimize production losses, many approaches are currently being adopted by the industry where probabilistic estimation of hydrate formation can be considered as a critical step of safety evaluation. In this work, a novel approach is proposed to predict hydrate formation probability in a subsea production and transportation system for a given composition and operating conditions. The proposed approach considers the Shortest Path of Hydrate Formation (SPHF) in predicting the probability of hydrate formation.

1. Introduction

With the ever-rising demand for energy, offshore drilling continues to be pushed to new depths, increasing the exploration for oil and gas resources in deeper and farther offshore sites. The continuous drilling in deepsea with depths over 5000 feet poses higher risks due to catastrophic accidents, spills and fires. This requires rigorous risk assessment related to hydrate formation ensuring safer design and equipment integrity. Formation of hydrates is considered to be one of the many challenges faced in deepsea operations where hydrate formation may result in blockage of subsea pipelines and equipment (Sloan, 1998). Hydrate plugging is the prime problem in offshore flow assurance compared to other flow assurance challenges, such as solids asphaltenes or waxes (Davies et al., 2008). Pipelines carrying natural gas are more susceptible to burst and explosion as a result of hydrate plugging. During dissociation of hydrates in a pipeline, any pressure gradient across a plug will result in hydrates traveling at very high velocities and compress downstream gas which causes blowouts (Sloan, 2003). To restrain the formation of hydrates in subsea equipment, the oil and gas industry spends up to 8% of their total estimated operating cost. Hydrate inhibition costs are estimated at 220 million dollars annually (Sloan, 2003).

In order to mitigate economic risks in the offshore oil and gas industry, a significant amount of money (Lederhos et al., 1996) is spent annually on research to study the phenomena of hydrate formation and prevention. Among the various methods available for preventing hydrate formation in pipelines (insulation, heating and inhibition), the use of kinematic inhibitors is widely adopted. Understanding of hydrate formation and prevention methods are under constant research (Seo and Kang, 2012; Urdahl et al., 2004; Wu et al., 2007). Research related to hydrates has been carried out extensively during the past two decades to better understand and hinder this undesirable phenomena. Several conceptual models are available which have been developed to describe the nucleation of hydrates. Colorado School of Mines Hydrate Kinetics (CSMHyK) model is a gas hydrate model specifically designed for oil-dominated systems based on the conceptual model which assumes that hydrates form at the interface of water droplets and continuous oil phase (Zerpa et al., 2012). Several methods are available to predict hydrate forming pressure and temperature, out of which the K-factor (Carson and Katz, 1942) method is most frequently referred to in literature. There are other correlations developed by researchers to estimate hydrate forming conditions based on gas gravity such as Elgibaly and Elkamel (1998), Mokhatab and Towler (2005), Motiee (1991) and so on. Most of the commercially available process simulation software (PVTsim, PIPESIM, Hysys etc.) has the capability of predicting hydrate forming conditions. However, there are other tools dedicated to hydrate calculations such as *CSMHYD* (Sloan, 1998). Though general phase equilibrium calculations are performed using fugacities, hydrate calculations are based on chemical potentials where the hydrate formation process is modeled in two steps (with a hypothetical state for the ease of calculations). Carroll (2009) explains both hand calculation methods as well as computer methods in detail. Induction time in gas hydrate crystallization plays a vital role in hydrate research due to its association with kinetic inhibitors, where both induction time and growth/agglomeration of hydrate

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Nomenclature

T_{SP}	temperature at safe point, °F
P_{SP}	pressure at safe point, psi
T_i	temperature at intersecting point, °F
P_i	pressure at intersecting point, psi
T_{OP}	temperature at operating point, °F
P_{OP}	pressure at operating point, psi
T_{md}	mean difference between safe temperature and average temperature on hydrate equilibrium curve, °F
P_{md}	mean difference between safe pressure and average pressure on hydrate equilibrium curve, psi
ΔT	temperature depression due to inhibition, °F
x_{MeOH}	mole fraction of inhibitor in liquid phase, wt%

crystals are affected by kinetic inhibitors (Kashchiev and Firoozabadi, 2003). Different models for calculating induction time can be found in literature (Kashchiev, 2000).

Although several models have been developed regarding nucleation of hydrates, the assessment of hydrate formation probability and their associated risks are still in their infancy. Therefore, it is of great importance to evaluate and predict the probability of hydrate formation for any given operating condition, which enables any blockages or other associated incidents/accidents due to hydrate formation to be prevented. Deng et al. (2014) calculated the probability of hydrate formation using the combined probability method by establishing a "probability limit state equation" from the difference of hydrate formation temperature and operating temperature. They were able to calculate the probability of hydrate formation by adopting simulation methods for a temperature and pressure distribution obtained from an experimental flow loop. This method entails the logging of temperature and pressure data for the generation of distributions and it is not capable of predicting the probability for a specific operating condition, which are considered as key limitations. Therefore, a better and rigorous method of predicting hydrate formation probability is required which assists in preventing hydrate blockage and subsequent equipment failure or catastrophic accidents.

This study mainly focuses on developing a novel methodology to assess the probability of hydrate formation for a given operating condition and composition. The present work is only focused on the right-hand side of the hydrate forming curve (hydrate-free zone) and develops a methodology to quantify the likelihood of reaching hydrate-stable zone in probabilistic terms. The proposed method considers all achievable pathways for any given operating point (temperature and pressure) to reach hydrate forming conditions. Due to the simplicity of proposed method, it does not require extensive logging of temperature and pressure data. Hence, the probability of hydrate formation of any natural gas pipeline with known composition and operating conditions can be easily predicted, expediting the decision making process around hydrate remediation. Furthermore, the present work can be considered as the first step towards the risk assessment of hydrate formation. To demonstrate the applicability of the proposed method, two case studies are considered. Also two different scenarios with different compositions (99%-CH_4, 1%-C_2H_6 and 99%-CH_4, 1%-C_2H_6, MeOH 10 wt%) are compared to validate the accuracy of the proposed methodology. Based on the findings, a novel correlation between the respective probability curves is presented.

2. Hydrate formation probability estimation method

The proposed methodology can be summarized in four key steps as shown in Fig. 1. The four key steps are explained in detail in the following sections.

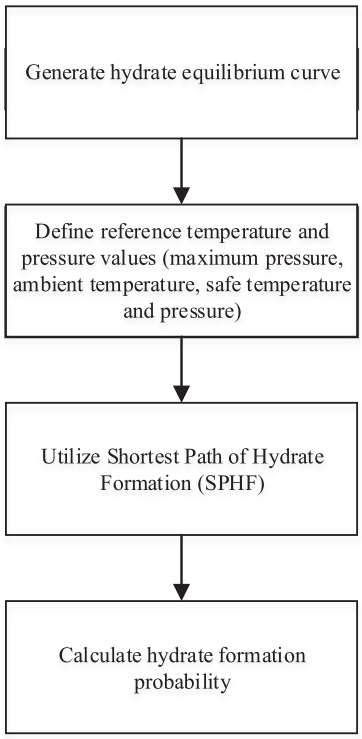

Fig. 1. Methodology.

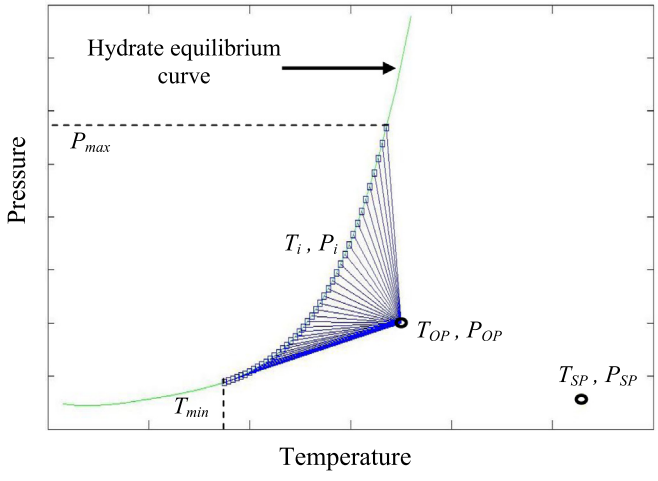

Fig. 2. Possible shortest pathways.

2.1. Calculation of hydrate forming conditions

Hydrate forming curves are used to define the temperature and pressure conditions at which hydrates tend to form (Fig. 2). In order to avoid the possibility of hydrate formation, the hydrocarbon system must operate outside the temperature and pressure