Journal of Natural Gas Science and Engineering 21 (2014) 540–555

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

A new approach for modeling of gas-condensate flow through pipelines under industrial operating conditions

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ARTICLE INFO

Article history:
Received 1 February 2014
Received in revised form
9 September 2014
Accepted 12 September 2014
Available online

Keywords:
Mathematical modeling
Multiphase flow
Natural gas
Pipeline
Pressure drop
Liquid holdup

ABSTRACT

The main objective of this study is to achieve a comprehensive integrated two-phase/single-phase hydrodynamic model for gas-condensate flows through transmission pipelines under industrial operating conditions, i.e. large pipe size and elevated pressure. The model developed in the present work covers single-phase gas, mist flows, and also all flow patterns occurring in transition from stratified to annular having liquid volume fraction from 0.005 to 0.3. Flanigan's correlation was corrected in the way that it was applicable for mist two-phase flow under industrial operating conditions. For liquid film holdup, Grolman and Fortuin model and Taitel and Duckler approaches were employed for uphill and downhill two-phase flows respectively. Grolman and Fortuin and BJA methods were applied to find pressure drop through upward and downward pipelines respectively. Two new relations for predicting liquid–gas and liquid–wall friction factors, which were obtained based on fitting to the field data, were used in Grolman and Fortuin model. 200 field pressure data were collected by conducting a field experiment on an industrial gas-condensate pipeline. 160 of these field data were applied to make the required corrections to the model including the development of two new correlations for both liquid–gas and liquid–wall friction factors. The rest of the data points were utilized to verify the model. The comparison of the present model results with the field data revealed that the proposed model is capable of predicting pressure drop accurately in gas-condensate pipelines.

1. Introduction

Two-phase flow phenomena can be observed in different parts of petroleum industries. The transmission of extracted natural gas from wells to refineries using pipelines is one of the important cases in which two-phase flow can be formed. Although natural gas is normally dried by passing through wellhead equipment, the variations of pressure and temperature through transmission pipelines may eventually result in the formation of liquid phase due to retrograde condensation behavior. Gas-condensate flows usually fall into the category of low liquid loading in two-phase flow science. Many attempts have been made to propose a model for predicting pressure drop and liquid holdup in two-phase flow pipe with low liquid loading. However, apparent discrepancies emerge among the predictions of these different models while being applied for undulating gas-condensate pipelines. The first reason is that these models are usually adjusted based on the experimental data which is obtained under laboratory conditions, i.e. small pipes and low pressures, being too far from industrial operating conditions. The second reason can be explained by the fact that nearly all two-phase flow models were tuned for a particular limited range of liquid holdups. Nonetheless, in gas-condensate pipelines the liquid holdup varies greatly from low values (less than 0.005) to high values (0.3) depending on the pipeline inclination. In other words, gas transmission

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http://dx.doi.org/10.1016/j.jngse.2014.09.016
1875-5100/

pipelines are usually characterized by undulating topography. Consequently, various liquid holdups are formed in different sections of the pipeline regarding their inclinations. That is why the available models of gas-condensate flow suffer from poor prediction of pressure drop while applying for an undulating pipeline. According to the aforementioned characteristic of gas-condensate flows with low liquid loading, it is necessary to find a reliable comprehensive model which is able to predict pressure drop and liquid holdup in a wide range of liquid holdup under industrial operating conditions accurately. Having large pipe diameter, being at high pressure and considering mass transfer between gas and liquid phases are meant by industrial operating conditions. Such a model should satisfy the following criteria:

1. The model should predict pressure drop for both two-phase and single-phase gas flow cohesively.
2. The model should be so comprehensive that it covers flow patterns in a wide range of liquid holdups including single-phase gas, mist, stratified and annular flows up to slug flow.
3. Gas–wall, liquid–wall and gas–liquid friction factors must be calculated accurately for high pressure and large diameter pipelines.

All of the models having been proposed so far for gas-condensate flow with low liquid loading are designed for a limited range, and they have not considered as a comprehensive model. Also, in the recent decades, several efforts have been made to developed phenomenological models which have been based on physical facts of gas–liquid flow phenomenon. Johannessen (1972) has indicated that Lockhart and Martinelli method had a physical base for the case of stratified two-phase flow. As a result, Lockhart and Martinelli model could be recognized as one of the phenomenological ones. Although several phenomenological models have been developed within the two recent decades, only few of them are appropriate for gas-condensate system. Taitel and Duckler (1976, 1977) conducted pioneering work which has been the base of many further phenomenological models. Oliemans (1976) put forward a theory to predict pressure drop for gas-condensate pipelines. He suggested the hypothesis that liquid is approximately stationary around the inner side of the pipe wall. This fact has two impacts on two-phase flow, i.e. reducing effective pipe diameter and modifying pipe roughness. These effects both cause an increase in friction factor. Oliemans (1987) has also obtained new relations for predicting pressure drop and effective pipe diameter. He has not proposed any method to evaluate liquid holdup. Based on the experimental data from pipe diameters 17 and 20 inches, he has come to this conclusion that Lockhart and Martinelli method predict liquid holdup well. It should be noticed that Oliemans model was used only for horizontal pipes. Baker et al. (1988) have developed a new model based on Oliemans theory to predict both pressure drop and liquid holdup. Similar to Oliemans model, liquid leads to a decrease in effective pipe diameter but an increase in friction factor. Baker et al. have employed a homogenous model to predict pressure drop, whereas they utilized Taitel and Duckler phenomenological model to evaluate liquid holdup. Taitel and Duckler have made the assumption that gas–liquid interface was flat, as shown in Fig. 1. Baker et al. model which sometimes is called BJA model could also be used for inclined pipes. Hamersma and Hart (1986) have further developed Oliemans theory. They suggested that liquid wetted a fraction of pipe wall perimeter as a thin liquid film with constant thickness, as indicated in Fig. 2. It causes a decrease in effective cross sectional area but a significant increase in apparent roughness. In the end, the friction factor increases as a result of the extra roughness created due to the wave on the surface of the liquid film. Hamersma and Hart have introduced the relations to find wetted wall fraction, θ, and apparent roughness. Hart et al. (1989) have created a new model called Apparent Rough Surface (ARS) by further developing their own previous model. The application of this model was restricted to horizontal pipelines.

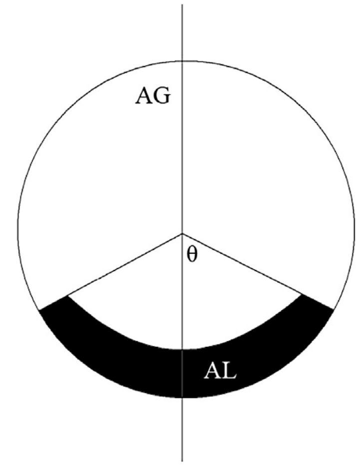

Fig. 2. The thin-layer liquid film configuration.

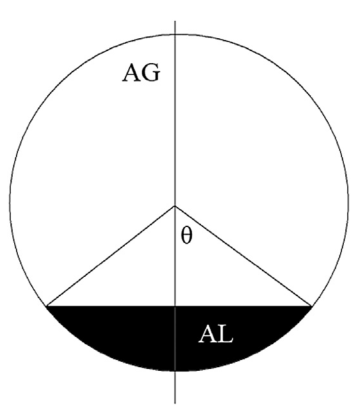

Fig. 1. The flat liquid surface configuration.

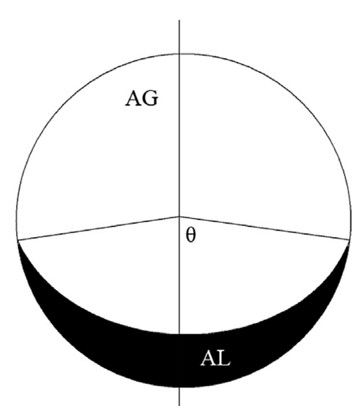

Fig. 3. The curved-interface configuration.