Contents lists available at ScienceDirect

### Journal of Natural Gas Science and Engineering

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

# Novel methods predict equilibrium vapor methanol content during gas hydrate inhibition

Mohammad M. Ghiasi<sup>a,\*</sup>, Alireza Bahadori<sup>b</sup>, Sohrab Zendehboudi<sup>c</sup>, Ahmad Jamili<sup>d</sup>, Sina Rezaei-Gomari<sup>e</sup>

<sup>a</sup> Ahwaz Faculty of Petroleum Engineering, Petroleum University of Technology (PUT), Ahwaz, Iran

<sup>b</sup> School of Environment, Science and Engineering, Southern Cross University, Lismore, New South Wales, Australia

<sup>c</sup> Department of Chemical Engineering, University of Waterloo, Ontario, Canada

<sup>d</sup> Mewbourne School of Petroleum and Geological Engineering, The University of Oklahoma, OK, USA

<sup>e</sup> Petroleum Engineering Department, Teesside University, Middlesbrough, UK

#### ARTICLE INFO

Article history: Received 12 May 2013 Received in revised form 28 August 2013 Accepted 25 September 2013 Available online 15 October 2013

Keywords: Gas hydrate Inhibitor Methanol loss Correlation ANN

#### ABSTRACT

In economic and safety hazards points of view, it is crucial to avoid the formation of clathrate hydrate of gases in oil and natural gas transportation/production systems. Injection of methanol as a thermodynamic inhibitor is a common approach in industry to shift the hydrate phase boundary to higher pressures/lower temperatures. Accurate computation of methanol loss to the vapor phase within hydrate inhibition is essential to calculate the right injection rate of methanol. In this study, two procedures have been proposed for fast and precise estimating the ratio of methanol content of vapor phase to methanol liquid composition ( $R_{MeOH}$ ). In the first method, a new mathematical expression is presented. The obtained correlation is reliable for temperatures between 267.15 and 279.15 K and pressures between 1160 and 28000 kPa. The second method employs artificial neural network (ANN) approach for  $R_{MeOH}$  prediction. Both developed models results are in good agreement with reported data in literature. The ANN based model, however, is more accurate than the new correlation.

© 2013 Elsevier B.V. All rights reserved.

#### 1. Introduction

Gas hydrates, also known as clathrate hydrates, are curious type of chemical compounds that can be defined as solid solutions (Javanmardi and Moshfeghian, 2000). Combination of water molecules and gas molecules at sufficiently low temperatures and high pressures lead to formation of gas hydrate. Indeed, the water molecules form a cage like structure wherein gas molecules or guest molecules having suitable sizes are entrapped into the cavities (Sloan, 1998). Hydrates exist as three structures (I, II, and H) depending on how many water molecules incorporate the fundamental building blocks (Pellenbarg and Max, 2000) and gas molecule size (Ghiasi, 2012). Structure I is formed from small gas molecules such as methane. Larger molecules such as propane or butane form structure II. Such gases as Xe and Ar are capable of forming both I and II structures (Nasrifar and Moshfeghian, 2001; Ghiasi and Mohammadi, 2013). Formation of type H hydrate requires a small molecule in addition to the type H former such as adamantine or methylcyclopentane. In natural gas type H formers are not generally available (Caroll, 2009). More detailed description of structure H can be found elsewhere (Mehta and Sloan, 1994).

Hydrates can be used as proper approach for gas separation and purification and CO<sub>2</sub> capture (Duc et al., 2007; Kang and Lee, 2000; Kumar et al., 2006), gas transmission and storage (Javanmardi et al., 2005; Jeon et al., 2006), water sweetening (Javanmardi and Moshfeghian, 2003), and refrigeration and air conditioning systems (Fournaison et al., 2004). Stored gas in the earth as gas hydrate reservoirs can be considered as future source of energy (Chatti et al., 2005; Englezos, 1993; Milkov and Sassen, 2002). Formation of hydrates in oil and gas transmission/production systems, however, results in pipeline blockage and irreparable damages to equipment. Hence, to avoid economic risks and safety hazards it is of great importance to prevent hydrate formation. Dehydration of natural gas eliminates the possibility of condensed water formation. Consequently, the formation of gas hydrate is not probable. Albeit the gas dehydration is permanent solution to avoid hydrate formation, usually this process is not considered to be actually/ economically feasible (Bahadori and Vuthaluru, 2010). In the cases of not having bone dry gas, holding the operating conditions of pipeline out of hydrate stability zone by insulation of pipeline or by







<sup>\*</sup> Corresponding author. Tel.: +98 937 76 86 726. E-mail address: mm.ghiasi@gmail.com (M.M. Ghiasi).

<sup>1875-5100/\$-</sup> see front matter © 2013 Elsevier B.V. All rights reserved. http://dx.doi.org/10.1016/j.jngse.2013.09.006

active heating is substitute for eschewing hydrate formation. More practical option, however, is injection of hydrate inhibitors to rule out the hydrate formation. The commonly used inhibitors in the industry are alcohols, especially methanol (Bahadori and Vuthaluru, 2009; Elgibaly and Elkamel, 1999).

Methanol or methyl alcohol is an aliphatic alcohol and known as a highly polar molecule. This small molecule interacts strongly with other fluids in an H-bonded network (Simonson et al., 1987). Hence, mixtures having methanol as one of the components show some anomaly (Bands et al., 1982; Marcus, 1999; Staib, 1998). Methanol is one of the most frequently used chemical compounds in various industries. It can be used as a basic feedstock for plastic manufacture (Mokhatab et al., 2006) and also can be employed as an alternative fuel for gasoline cars (Matar, 2000). Since methanol has high reactivity, it could be used for production of many chemicals (Chang, 1984). Industrial usages of methanol have been described elsewhere (Machado and Streett, 1983). As a thermodynamic inhibitor, methanol shifts hydrate formation conditions to lower temperatures/higher pressures by reducing water activity. Hammerschmidt (Caroll, 2009) proposed the following equation to estimate the effect of methanol on hydrate formation temperature:

$$\Delta T = \frac{1297W}{M(100 - W)}$$
(1)

where  $\Delta T$  is the temperature depression in K; *M* is molecular weight of methanol in g/mol; and *W* is methanol concentration in liquid water in wt%.

In 2005, Østergaard et al. (2005) developed another equation for calculation of various salts and alcohols effect on hydrate formation temperature. Correlation of Østergaard et al. (2005) is as follows:

$$\Delta T = (c_1 W + c_2 W^2 + c_3 W^3)(c_4 \ln(P) + c_5)(c_6 (P_0 - 1000) + 1)$$
(2)

where  $c_i$  are constants; P is pressure in kPa; and  $P_0$  is Dissociation pressure of hydrocarbon fluid in the presence of distilled water at 273.15 K in kPa.

In addition to the available empirical and semi-empirical correlations, thermodynamic models are also presented by some authors such as Nasrifar and Moshfeghian (2001), Nasrifar and Moshfeghian (2001), Tavasoli et al. (2011) and Tavasoli et al. (2011) to compute the hydrate formation temperature in the presence of alcohols. The calculated amount of methanol by these models for injection in pipelines, however, is only sufficient to prevent freezing of the inhibitor water phase. Indeed, the injection rate of methanol must be adequate so that it provides the methanol vapor loss, methanol loss to the hydrocarbon liquid phase, and required methanol concentration in liquid water. It should be noted that methanol is only fruitful in liquid water phase; hence, the dissolved methanol in vapor and liquid hydrocarbon phases is considered as losses (Bruinsma et al., 2004). The injected methanol as hydrate inhibitor, however, causes many problems for glycol dehydration plants (Gue and Ghalambor, 2005). From environmental point of view, the vented methanol vapor from regeneration system to the atmosphere is hazardous and should be recovered (Gue and Ghalambor, 2005). In addition, the operating expense related with the lost methanol cost will be decreased by regeneration of methanol. So, calculation of methanol vapor loss is crucial for both hydrate calculations and methanol regeneration system design.

In order to compute the equilibrium methanol vapor content within gas hydrate inhibition, a proper equation of state (EoS) could be used. It should be noted that finding a convenient EoS for the system of interest is a true challenge (Orbey and Sandler, 1998; Poling et al., 2004). It is believed that cubic equations of state like PR EoS (Peng and Robinson, 1976) and SRK EoS (Soave, 1972) give good results for non-polar mixtures and slightly polar systems (Asselineau et al., 1978; Graboski and Daubert, 1978; Huron et al., 1977). Nevertheless, in the case of polar system, the estimations are poor. Types of equations of state presented by Chapman et al. (Chapman et al., 1989, 1990, 1988) and Huang and Radosz (1990) based on Wertheim's theory, i.e. statistical associating fluid theory (SAFT) equations of state, is precise for pure fluids and mixtures consisting associating fluids. SAFT EoS suffers from complexity (Haghighi, 2009). To avoid sophisticate calculations, combination of the association term from SAFT with a cubic EoS has been proposed in the literature (Haghighi, 2009). These models are known as CPA which indicates cubic plus association.

The main objective of this work is to present novel methods for accurate and fast prediction of methanol vapor loss within hydrate inhibition. First, a new analytical expression will be developed for  $R_{MeOH}$  prediction. Next amongst available artificial neural networks (ANNs) the proper network and the best topology for selected network will be found for the application of interest. Using this type of computational intelligences has been proven to give excellent results in the case of natural gas hydrate modeling (Elgibaly and Elkamel, 1998; Ghiasi and Ghayyem, in press; Zahedi et al., 2009). Applying ANN for  $R_{MeOH}$  prediction is new based on our literature survey. The final section presents comparison of developed ANN model and the obtained correlation results based on average absolute deviation percent (AAD %).

#### 2. Proposed methods

#### 2.1. Development of statistical model

With the aim of developing a simple to use correlation capable to predict the methanol loss in vapor phase within hydrate inhibition accurately, first, 326 data points have been collected from reliable source (GPSA, 2004). Next, the ratio of methanol content of vapor phase to methanol liquid composition, as defined by Equation (3), is assumed to be function of temperature and pressure.

$$R_{\text{MeOH}} = \frac{\frac{\text{kg MeOH}}{\text{MSm}^3 \text{ Natural Gas}}}{\text{Wt\% MeOH in Water Phase}}$$
(3)

The final step is finding a proper approximate function for the application of interest. The approximant does not need to pass through all the points. It is necessary, however, that this function mark out the data points as a whole with the smallest error (Yang et al., 2005). Amongst most commonly used approximants include trigonometric functions, exponential functions, and polynomials (Hoffman, 2001), the last one is widely used for treating with functions on finite domains. Weierstrass approximation theorem (Burkill, 1959; Hoffman, 2001) could be defined as a suitable reason for usage advantageous of polynomials. In this study, a bivariate polynomial of the form of Equation (4) is selected to represent the dependent and independent variables.

$$z = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 y^2 + a_5 x y + a_6 x^3 + a_7 y^3 + a_8 x^2 y + a_9 x y^2$$
(4)

The final correlation for estimation of methanol vapor loss found to be as follows:

Download English Version:

## https://daneshyari.com/en/article/1758081

Download Persian Version:

https://daneshyari.com/article/1758081

Daneshyari.com