CHEMICAL ENGINEERING RESEARCH AND DESIGN 93 (2015) 148–162

Contents lists available at ScienceDirect

Chemical Engineering Research and Design

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

Analytical methods to calculate water content in natural gas

Lin Zhu[a,*], Luling Li[a], Jia Zhu[a,b], Li Qin[c], Junming Fan[a]

[a] Key Laboratory of Gas Process Engineering, School of Chemistry and Chemical Engineering, Southwest Petroleum University, Chengdu 610500, PR China
[b] Suining Field of Sichuan Oil and Gas Mine, Petro-China Southwest Oil & Gas Field Company, Suining 629000, PR China
[c] Carbon Black Plant of Luzhou, Petro-China Southwest Oil & Gas Field Company, Luzhou 646000, PR China

ABSTRACT

This work presents a review on the main analytical methods for estimating water content in natural gas samples of different types and with different contents. The analytical methods for sweet natural gas are mainly developed for gas under conditions of temperatures of 223.15–510.93 K and pressures of 0.1–100 MPa. The calculation of water content in sour natural gas should be calculated in a temperature range from 288.15 to 444.26 K and a pressure range from 0.5 to 69 MPa. By combining correction methods with analytical methods for sweet natural gas randomly and comparing the results with the experimental value published in the literature, it was found that the simplified thermodynamic mode & Bahadori correction method, the simplified thermodynamic mode & Mohammadi correction method, the Sloan & Bukacek–Maddox correction method and the Bahadori & Khaled correction method could reproduce with the least AAD%. Additionally, by comparing the results of these analytical methods with the experimental data in literatures, this work presented the optimum analytical methods for sweet natural gas and sour natural gas, respectively, at different temperatures and at different pressures.

Keywords: Water content; Sweet natural gas; Sour natural gas; Analytical method; Evaluate; Combination mode

1. Introduction

In the initial design of the facilities of production, transmission, and processing of natural gas (NG), the dissolved water in the gas phase of NG is an essential factor to be considered. The main forms that the dissolved water exists in are liquid water, gas hydrates and ice. The formation of a liquid phase may cause corrosion or/and two-phase flow problems. Additionally, a decrease in the temperature (or an increase in the pressure) will make the problems caused by the gas hydrates or ice more worse. The acid gases contained in NG may generate acid liquor, which would integrate with free water, resulting in the corrosion of pipeline, instruments, valves etc. Consequently, to prevent corrosion and to avoid the formation of ice or gas hydrate, it is necessary to remove saturated water from the acid gas concentration by dehydration facilities before transmitting and processing. For engineers, accurate prediction of water content is the foundation of calculating the consumption of dehydrate agents and for predicting the aqueous dew points.

NG can be divided into two categories: sweet natural gas (gas whose acid concentration is less than 5% of the gas mixture) and sour natural gas (gas whose acid concentration is more than 5% of the gas mixture) (Zhu, 2008). Many related approaches have been conducted for the estimation of water content in NG. To sum up, the methods for sweet natural gas are composed of three main types: charts plotted with limited experimental data, thermodynamic models based on phase equilibrium, and empirical or semi-empirical correlations developed with limited application. Because an increase in the amount of liquefied H_2S or CO_2 significantly enhances the solubility of water, presence of acid gases (i.e. hydrogen sulfide and carbon dioxide) makes the water content increase obviously (Carroll, 2002; William et al., 2012). Therefore, some corrections including charts and correlations should be applied, when it comes to analyzing water content in sour natural gas.

* *Corresponding author at*: No.8 Xindu Avenue, Xindu District, Chengdu City, 610500, PR China. Tel.: +86 15884505696.
E-mail address: zhulinswpi65@gmail.com (L. Zhu).

Available online 2 June 2014
http://dx.doi.org/10.1016/j.cherd.2014.05.021
0263-8762/

Nomenclature

W	water content in mg/Sm^3 (288.15 K, 0.101 MPa)
T	absolute temperature (K)
P	total pressure (MPa)
C	parameter in Eq. (1)
a	parameter in Eqs. (2), (4), (5), (6), (9), (23), (24), (32) and (35)
b	parameter in Eqs. (4), (6), (29), (30), (31) and (35)
A	parameter in Eqs. (7) and (8)
B	parameter in Eqs. (18) and (19)
τ	parameter in Eqs. (20) and (21)
S	the mole fraction of brine in water
d	the average relative molecular mass
F	the correction factor between sweet natural gas and sour natural gas
V	the average molar volume over the pressure interval P to P_{sw} or P to P_0
V	the molar volume
M	molecular mass
y	the mole fraction in the gas phase
K	the standard equilibrium constant
x	the mole fraction in liquid phase
R	the universal gas constant
AAD	the average absolute deviation
AD	the absolute deviation
a	equation of state parameter
b	equation of state parameter
Z	the compressibility factor
NG	natural gas
MIM	modified ideal model
STM	simplified thermodynamic model
MTM	modified thermodynamic model

Greek symbols

μ	the chemical potential
φ	fugacity coefficient

Superscripts

o	the standard situation
equi	the equivalent situation
l	the liquid phase

Subscripts

H_2O	water
H_2S	hydrogen sulfide
CO_2	carbon dioxide
CH_4	methane
NHC	the non-hydrocarbon gases such as H_2S, CO_2
HC	the hydrocarbon gases
sweet	sweet natural gas
sour	sour natural gas
sw	the water in saturation state
c	the critical situation
0	the reference situation
i	the component i
mix	the mixture gas
r	the reduce situation

In order to describe the water content of gas in equilibrium with hydrocarbon, several charts have been presented, some of these being: the McKetta–Wehe chart (GPSA, 1998), the Campbell chart (Campbell, 1991), the Katz chart (Khaled, 2007) etc. Of the available candidates, the McKetta–Wehe chart is the most popular, with surprising accuracy for sweet natural gas containing over 0.7 (mole fraction) of methane (GPSA, 1998). Furthermore, some correction charts, i.e. the Wichert chart (Wichert and Wichert, 1993), the Campbell chart (Campbell, 1991), and the Robinson chart (Robinson et al., 1978), have been developed for estimating water content of sour natural gas. However, because of the difficulty in obtaining accurate data and the need for interpolations, charts cannot be widely used.

Based on the phase equilibrium, several thermodynamic models are available for the estimation of water content in sweet natural gas. Some models utilize the equality in the activity coefficient of water in different phases, and others refer to the equation of state. Additionally, with the different models applied in liquid–vapor, hydrate–vapor, ice–vapor and liquid–hydrate–vapor regions, thermodynamic models always have high accuracy. However, these models are too complicated to be performed by simple tools (Mohammadi et al., 2004a; Mohammadi and Richon, 2007).

By matching the existing data to the equations, researchers have obtained some empirical or semi-empirical correlations that are simple, convenient and operated with high degree of accuracy. Consequently, these correlations remain popular among engineers. Increasing numbers of correlations such as the Bahadori method (Bahadori et al., 2009) and the Behr method (Behr, 1983) have been reported. Nonetheless, the presence of large amounts of heavy hydrocarbon may make the correlations, based on methane, (i.e., not a heavy hydrocarbon), such as the Behr method (Behr, 1983) and the Sharma–Campbell method (Sharma and Campbell, 1969), have lower accuracy. In general, most of the correlations are used for the sweet natural gas containing few heavy hydrocarbons at the applicable conditions. Unfortunately, due to the shortage of consistent experimental values, these correlations also need further verification for low temperature conditions.

Summarily, with the difficulty of reading accurately, the need for interpolation of charts as well as the complexity of thermodynamic models, the brief and non-robust analytical methods are always popular because of their high accuracy, speediness, convenience, and their programmable nature. Analytical methods generally include empirical correlations and semi-empirical correlations, as well as some simplified thermodynamic models. With the limitation of application, analytical methods are not available for every case, and a comprehensive report about the optimal methods at given conditions is still absent. As the analytical methods for sour natural gas are modified versions of the analytical method for sweet natural gas, the choice of which sweet natural gas analytical method should be used, together with the correction method to estimate water content in sour natural gas remains a controversial problem at all time.

The main aim of this work is summarizing the main analytical methods of estimating water content in natural gas by category and choosing the optimal analytical method of sweet natural gas for every correction method to accurately predict the water content in sour natural gas. Then, taking the results and the applicable range of each analytical method into consideration, the optimum analytical method for sweet or sour natural gas at specific temperature and pressure is focused on.

2. Analytical methods for sweet natural gas

The analytical methods for estimating water content in sweet natural gas mainly consist of three catalogs, namely correlations originally regressed from chart data, correlations originally regressed from experimental data, and equations referring to the calculation of the phase equilibrium in water–hydrocarbon systems. In this work, a review of the analytical methods for estimating water content in sweet natural gas is presented and is detailed in the following sections.