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Estimation of the water content of natural gas dried by solid calcium chloride dehydrator units

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HIGHLIGHTS

- Multilayer perceptron (MLP) neural network is used to model calcium chloride dehydration system.
- A simple correlation is developed to estimate water content of natural gas dried by $CaCl_2$.
- The model has been developed and tested using 200 series of the data.
- Statistical and graphical error analyses are presented to show accuracy of the model.

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ABSTRACT

Natural gas is an important source of energy. It is efficient, versatile and abundantly available. Calcium chloride ($CaCl_2$) dehydrator is the most common non-regenerative adsorption system in natural gas industry. As the need for natural gas increases, calcium chloride dehydration can help to make some gas wells more profitable to operate gas from remote or offshore wellheads, gas of a low flow rate, or gas which is high in sulphur content may benefit from this dehydration.

In this article two mathematical-based models are developed to estimate approximate water content of natural gas dried by calcium chloride dehydrator units for both freshly recharged and just prior to recharging conditions as a function of temperature and pressure. Firstly, a simple empirical correlation is presented to estimate water content of natural gas dried by solid calcium chloride dehydrator, Secondly, a multilayer perceptron (MLP) neural network is developed for the same calculations. The results of both presented models are found to be in excellent agreement with reported data in the literature. The tools developed in this study can be of immense practical value for engineers to have a quick check on water content of natural gas dried by calcium chloride dehydrator units as a function of dehydrator temperature and pressure at various conditions without opting for any experimental trials. In particular, engineers would find the approaches to be user-friendly with transparent calculations involving no complex expressions.

1. Introduction

Calcium chloride ($CaCl_2$) can be used as a consumable desiccant to dehydrate natural gas [1]. Solid calcium chloride combines with water to form a brine solution. Fig. 1 shows a typical Calcium chloride ($CaCl_2$) dehydration column. Large liquid $CaCl_2$ dehydrators are usually operated in a series that can be reversed with a moisture monitor located between the beds. In that way when the lead sacrificial bed is exhausted, no wet product is produced. The exhausted $CaCl_2$ bed is then recharged and the vessels reversed in service [2].

Solid anhydrous $CaCl_2$ combines with water to form various $CaCl_2$ hydrates. As water absorption continues, $CaCl_2$ is converted to successively higher states of hydration, eventually forming a $CaCl_2$ brine solution [2,3].

Calcium chloride ($CaCl_2$) dehydrator is simple, no moving parts and no heat required, it does not react with H_2S or CO_2 and it can dehydrate hydrocarbon liquids [4]. As the need for natural gas increases, calcium chloride dehydration can help make some gas wells more profitable to operate gas from remote or offshore wellheads, gas of a low flow rate, or gas which is high in sulphur

Abbreviations: BP, back-propagation; FFNN, feed-forward neural networks; LM, Levenberg–Marquardt; MLP, multilayer perceptron; MSE, mean squared error; RBFN, radial basis function networks; RNN, recurrent neural networks.

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Nomenclature

A	tuned parameter	o	predicted value
$a_{\max}$	maximum of the original data	P	dehydrator pressure, kPa (abs)
$a_{\min}$	minimum of the original data	r_m	linear combiner output
a_{norm}	the normalized data which transformed	t	target value
B	tuned parameter	T	temperature, K
b_m	bias term	w_{mn}	synaptic weight
C	tuned parameter	x	data point
D	tuned parameter	x_n	input signal of neuron
e	cost function	y	data point
i	index	y_m	neuron's output
j	index	ψ	natural gas water content, g/(std. cubic meter)

content may benefit from this dehydration [5]. Calcium chloride is an excellent desiccant which, as it passes from a solid to a liquid state, can absorb more than 3.5 times its weight in water [6]. Even in its liquid state as brine, the chemical continues to absorb water at significant rates. The four advantages of calcium chloride dehydrators are [6]:

(1) Energy efficient: no energy consuming equipment is part of the basic design of a calcium chloride dehydrator. In locations of extreme cold, it may be necessary to incorporate a heating unit to maintain system temperature. But a calcium chloride unit consumes a fraction of the energy required by glycol units.
(2) Low labour costs: other than the recharging of the dry desiccant beds, calcium chloride dehydrators require little or no attention. They can function up to six months unattended.
(3) Reduced fire hazard: calcium chloride is not flammable, and the dehydration system requires no open flame.
(4) Competitive equipment costs: calcium chloride dehydrators usually cost a fraction of comparatively sized glycol and molecular sieve dehydrator units.

In view of the above mentioned issues, it is necessary to develop accurate and simple methods which are easier than existing approaches, less complicated and with fewer computations to estimate water content of natural gas dried by calcium chloride dehydrator units as a function of temperature and pressure. This paper discusses the formulation of such predictive tools in a systematic manner to show the simplicity of the models and usefulness of such models. The first proposed method is exponential function which leads to well-behaved (i.e. smooth and non-oscillatory) equations enabling more accurate and non-oscillatory predictions and this is the distinct advantage of the proposed method. The next model is based on well-proven standard BP neural network. To the best of authors' knowledge, no work has been published on the subject of predicting the water content of dehydrated natural gas by calcium chloride using MLP neural network. Sections 2 and 3 demonstrate the computational procedures for developing the aforementioned models for the application of interest. In Section 4, performance of the presented models in calculating water content of natural gas dried by calcium chloride dehydrator units will be evaluated by employing some statistical parameters. The last part concludes this communication.

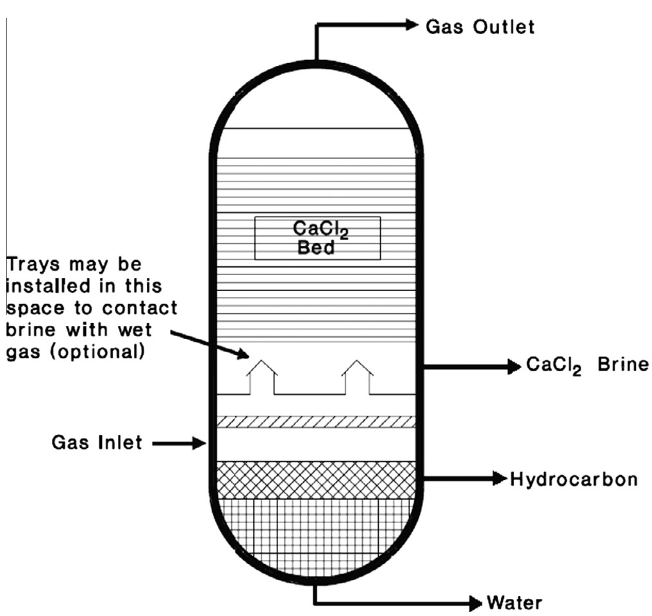

Fig. 1. A schematic of calcium chloride gas dehydration system.

2. Methodology for the development of novel predictive tool

The primary purpose of this section is to accurately correlate the water content of natural gas dried by calcium chloride dehydrator units as a function of temperature and pressure. The required data to develop this correlation includes the reported water content data of natural gas dried by calcium chloride dehydrator units as a function of temperature and pressure. The following methodology [7–12] has been applied using Matlab [13] to develop this correlation. Firstly water content data are correlated as a function of temperature for different pressure values, and then the calculated coefficients for these equations are correlated as a function of pressure. The derived equations are applied to calculate new coefficients for Eq. (1) to predict water content data on natural gas dried by calcium chloride dehydrator units as a function of temperature and pressure. In brief, the following steps are repeated to tune the correlation's coefficients using Matlab [13]:

(1) Correlate water content data on natural gas dried by calcium chloride dehydrator units as a function of temperature for a given pressure value.
(2) Repeat step 1 for other pressure data.
(3) Correlate corresponding polynomial coefficients, which were obtained for pressure data versus pressure, $a = f(P)$, $b = f(P)$, $c = f(P)$, $d = f(P)$ (Eqs. (2)–(5)).

Eq. (1) represents the proposed governing equation in which four coefficients are used to correlate the water content of natural gas dried by calcium chloride dehydrator units as a function of