

## Support Vector Machine based modeling of an industrial natural gas sweetening plant



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### ARTICLE INFO

#### Article history:

Received 6 May 2013

Accepted 17 June 2013

Available online 11 July 2013

#### Keywords:

Gas sweetening plant

Amine regenerator column

Absorption column

Support Vector Machine

### ABSTRACT

In this study Support Vector Machine (SVM) is employed to develop a model to estimate process output variables of an industrial natural gas sweetening plant. The developed model is evaluated by process operating data of Hashemi Nejad natural gas refinery in Khorasan/Iran. A set of 13 input/output plant data each consisting of 145 data has been used to train, optimize, and test the model. Model development that consists of training, optimization and test was performed using randomly selected 80%, 10%, and 10% of available data respectively. Model estimations are compared with those obtained from an ANN based model developed using the same dataset as used for training and test of SVM based model. Test results from the SVM based model showed to be in better agreement with operating plant data compared to artificial neural networks based model. The minimum calculated squared correlation coefficient for estimated process variables is 0.99. Based on the results of this case study SVM proved that it can be a reliable accurate estimation method.

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## 1. Introduction

Natural gas is found in deep underground natural rock formations or associated with other hydrocarbon reservoirs. After natural gas passes the over-well facilities, it goes to a processing plant where impurities are removed and various components of natural gas are separated. The impurities of untreated natural gas may include acidic gases such as Hydrogen Sulfide and Carbon Dioxide which must be removed before further processing can be performed. Hydrogen sulfide is a common reduced sulfur compound found in most natural gas reservoirs. It is easily recognizable by its offensive rotten eggs odor (Maddox et al., 1987; Fouad and Berrouk, 2013). Sour gas is natural gas containing significant amounts of hydrogen sulfide (H<sub>2</sub>S). Natural gas is usually considered sour if it contains more than 5.7 mg/m<sup>3</sup> of H<sub>2</sub>S, which is equivalent to approximately 4 ppm H<sub>2</sub>S by volume. Presence of hydrogen sulfides can cause serious health risks and problems that make its removal a necessity. Hydrogen Sulfide also has undesirable effects that include reducing the commercial value of chemical products if presented as impurity (Fidler et al., 2003), causing extensive

corrosion (Buisman et al., 1991) and thus increasing operating costs (Oyarzun et al., 2003). Hydrogen sulfides removal, often called gas sweetening, is necessary to avoid its aforementioned undesirable effects (Abedini et al., 2010; Fortuny et al., 2008; Mohebi et al., 2009).

There are many treating processes available for removal of H<sub>2</sub>S from natural gas. Some processes utilize chemical, physical, and hybrid solvents while few others using physical separation by special membranes and adsorption is also used for small scale operations with low H<sub>2</sub>S concentration (Seqatoleslami et al., 2011; Shahsavand et al., 2011). Selective H<sub>2</sub>S removal can be accomplished by using a process based on the precipitation reaction of H<sub>2</sub>S with metal ions present in an aqueous solution that result in formation of solid metal sulfide (Ter Maat et al., 2005; Kuo et al., 2012). In some of these processes, regenerative processes, the active reagent that removes hydrogen sulfide from natural gas can be regenerated and used again. Some alkanolamine aqueous solutions are capable of absorbing impurities such as hydrogen sulfide and carbon dioxide from natural gas. Due to the weak bond between hydrogen sulfide and alkanolamine it is possible to regenerate used amine solution in stripping process. Alkanolamines, such as, monoethanolamine (MEA), diethanolamine (DEA), di-2-propanolamine (DIPA), and N-methyldiethanolamine (MDEA) are commonly used in natural gas sweetening absorption processes.

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MDEA has a number of distinguished properties that are (Dincer et al., 2008; Castillo and Dorao, 2010):

- High solution concentration (up 50 to 55 wt %)
- High acid gas loading
- Low corrosion
- Slow degradation rates
- Lower heats of reaction
- Low vapor pressure and solution losses

These properties have made MDEA a desirable choice among alkanolamine for industrial application. Mixtures of these amines have been called a variety of names including formulated amines and MDEA-based amines (Bullin et al., 1984). In the past few years, mixed amine solvents for the removal of acid gases have received increased attention (Polasek and Iglesias-Silva, 2006). Application of mixtures of alkanolamines, a solution of two or more amines in varying concentration, has been shown to produce absorbents with excellent absorption characteristics as well as superior stripping qualities (Chakravarty et al., 1985; Seo and Hong, 1996). Mixtures of alkanolamines combine the absorption characteristics of the constituent amines such as higher loading capacity, faster reaction rates and less energy requirements for regeneration (Libreros and Trejo, 2004). Some processing applications have been proposed in recent years for selective removal of  $H_2S$ . As an example MDEA, diisopropanolamine (DIPA) has shown a great selectivity for  $H_2S$  over  $CO_2$  than either MEA or DEA. DIPA is a constituent of the Sulfinol process and has also been used in the Adip process (Klein, 1970). Deterministic modeling of gas sweetening processes requires accurate thermodynamic property prediction of alkanolamines and acidic gases whereas statistical models require rich operating database instead.

Reliable accurate models of gas sweetening processes allows one to optimize operating conditions thus minimizing operational costs. This is a necessity due to inherent seasonal variations in feed stream and temperature. Attempts to develop such models include those that are based basic principles and those that are data-based using input/output plant data (Ding et al., 2012). Models based on detailed mass and energy balance equations proved to be very complicated and hard to solve especially when coupled with optimization computer routines (Mehdizadeh and Movagharnejad, 2011; Haghbakhsh et al., 2013). Available commercial simulation softwares that are not open-source can be used to perform accurate simulations, however coupling them with optimization procedures is a difficult task to manage. Moreover, the proprietary nature of these softwares is another discouragement to their industrial

application. Operating plant data is an invaluable information source that is readily available through programmable logic control systems that most plants are already equipped with. Therefore, in recent years application of modeling methods such as Artificial Neural Networks (ANN) and Support Vector Machine (SVM) which just dealing with input and output variables, receives increase attention. The ANN model which was developed by Koolivand Salooki et al. (2011) is an example that focused on simulation of amine regenerator column of a natural gas sweetening plant.

In this work a SVM based model is developed to determine the output variables of the Hashemi Nejad natural gas sweetening plant. Section 2 of this paper is dedicated to process description of the natural gas sweetening plant under study. In the third section, the principle and the equations of the Support Vector Machine have been discussed in detail. Section 4 presents preprocessing and normalization of operating plant data. Input/output operating plant data, model parameters and model validation are included in Section 5 that is followed by conclusions in the sixth section.

## 2. Process description of natural gas sweetening plant

As mentioned there are many chemical processes for natural gas sweetening, however, the amine process (also known as the Girdler process), is the most widely used method for  $H_2S$  removal at present. The process description in full detail is available (Campbell, 1976) and a brief version is presented here to ease further discussions. Although many designs of natural gas sweetening plants are in operation, Fig. 1 shows the basic unit operations of Hashemi Nejad natural gas refinery schematically, in which  $H_2S$  is mainly removed from Sarakhs natural gas reservoir located in north east of Iran. The reversible gas sweetening reaction of interest in this gas refinery is:



where  $R$  is mono, di, or tri-ethanol in which the forward reaction is exothermic and reverse reaction is endothermic and can be promoted by heating up the used amine solution. As can be seen in Fig. 1, sour gas stream enters bottom of the absorber and comes into contact with cooled lean amine solution counter-currently that enters from top of the absorption column. During the contact time in absorber, hydrogen sulfide transfers from gas phase to liquid phase according to the reaction of Eq. (1). The amine solution that has absorbed hydrogen sulfide and exits from the bottom of absorber is referred to as rich amine. The sour natural gas that is treated in absorber and its hydrogen sulfide content decreased

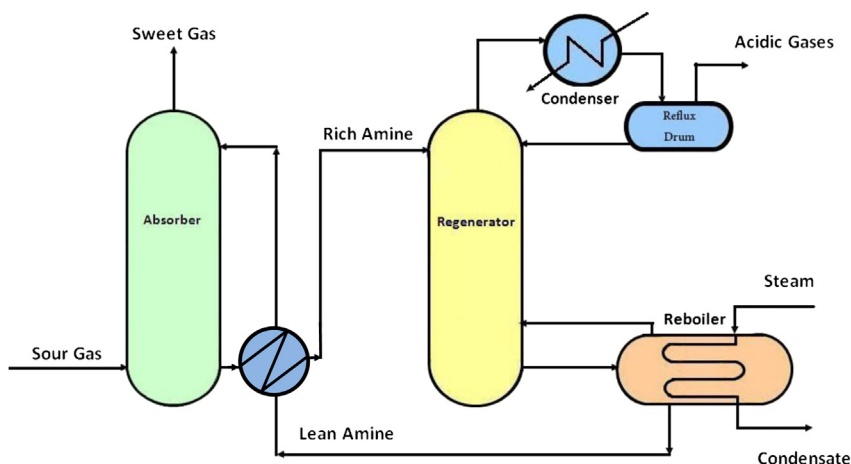


Fig. 1. Schematic diagram of basic unit operations of Hashemi Nejad natural gas refinery.

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