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Correlating the additional amine sweetening cost to acid gases load in natural gas using Aspen Hysys

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ABSTRACT

Natural gas with high acid gas contents represents a challenge in process engineering and energy industry. Exploring the alternative solutions requires correlating additional costs accompanying the process scale-up to treat high acid-gas contents. This work estimates this relation and validates it against various conditions in amine sweetening plants. An amine sweetening process was simulated using Aspen Hysys to treat a natural gas (25 MMSCFD, 1.7 mol% H_2S and 4.13 mol% CO_2). Amine circulation rate, lean amine temperature, re-boiler temperature and amine concentration were chosen as the main input variables to optimize the process total cost using the central composite experimental design model. The process was scaled-up to handle a sour gas up to (25 mol% CO_2 and 3 mol% H_2S) by scaling up the amine circulation rate. The capital and operating costs showed a linear relationship with the increase of CO_2 percentage in natural gas. Moreover the utility requirements, regenerator column diameter and the surface area of the re-boiler, the lean-rich amine heat exchanger and the lean amine cooler showed a strong linear increase correlation. There was no statistical difference using either Li–Mather or Kent–Eisenberg thermodynamic models. Low feed gas pressure yielded a similar linear relationship irrespective of the costs for purchasing and operating the inlet compressor and air cooler. No statistical difference found between cost regressions lines of different tray efficiency of the distillation tower. For various partial pressures of CO_2 and H_2S, assuming no other sulphur compounds, the economics scaled up as a second order polynomial.

1. Introduction

The growing needs of the world for natural gas imply improving the existing processes for production, treatment, energy harvesting and pollution control. One of the most serious problems facing natural gas processing technology is the presence of high contents of acid gases such as CO_2 and H_2S. Acid gases are known to contaminate about 40% of the known gas reserves (van Kemenade et al., 2013). About 13.46% of the world's natural or associated gas reserves have H_2S over 10% and about 26.9% have more than 10% CO_2 (Lallemand et al., 2011). Several methods have been developed to reduce the content of acid gases in natural gas streams including absorption by physical and chemical solvents, adsorption, cryogenic or low-temperature separation and membrane separation (Berstad et al., 2012; Olajire, Jun. 2010). Manning and Thompson reported charts to aid the designer select the appropriate sweetening process based on the partial pressure of acid gases in the feed and product stream (Manning and Thompson, 1995). These charts show that amines, potassium carbonate and physical solvents are generally suitable till a maximum of about 8% acid gas concentration in the feed gas to meet the pipeline specification (2% CO_2 and 4 ppm H_2S). To handle sour gases with more contamination only physical solvents and membranes are more suitable. One drawback of these guidelines is that they are approximate and general because many other factors should be considered including operating conditions, the gas sales contract and detailed gas analysis (Manning and Thompson, 1995; Kidnay and Parrish, 2006). In order to compare different alternatives the design engineer needs to perform an economic analysis for the additional costs per unit increase in the acid gas contents. The capital cost increase due to the scale up of the processing equipment has to be analysed and correlated to the acid gas content in the feed gas. Also the need for purchasing and installing new equipment e.g. compressors to recompress the feed gas to the high pressures required by the physical absorbent processes or the membrane module has to be

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included in the capital cost analysis. Additional operating costs due to the additional energy requirements for solvent regeneration, lean solvent pumping and acid gas separation has to be also evaluated. This paper focuses on correlating additional fixed capital and operating costs with acid gas increase for amine sweetening processes. The current work is divided into four parts. The first part focuses on simulating an amine sweetening process to treat acid gases (1.7 mol% H_2S and 4.13 mol% CO_2) in a sour natural gas feed. The second part is concerned with identifying the key variable(s) and the effect of their interactions on the estimated total cost of the process. This is done by extending the concept of experimental design models for laboratory setups to the numerical output of the simulation. The third part deals with scaling up the process to treat higher content-sour gas (up to 3% H_2S and 25% CO_2). The key variable(s) and the total cost are then correlated to the percentage of acid gases in the feed. Finally, the obtained relation is tested against different operating conditions to assure the validity of the results for a wide range of conditions that reflect situations in typical industrial amine sweetening plants.

2. Materials and methods

Aspen Hysys v8.0 was used to model the process flow sheet. This software was chosen for two reasons. First, the software offers a powerful thermodynamic package called the “Amine package” which is a special package designed for modelling amine sweetening units. This package includes experimental solubility and reaction kinetics data over wide range of conditions (A. HYSYS, 2004). Incorporating this package in the simulation, generally, reduce errors arising from using general thermodynamic equations of state or activity models. The second reason is the powerful cost analysis tool integrated in the software which was used to estimate the fixed and operating costs of the process under different conditions. This tool saves the time and effort needed through the tedious paper-and-pencil calculations to size and estimate the cost of various equipment. It provides can provide summarized and highly detailed estimated information depending on the user's requirements.

Since the program provides numerical results as an output after modifying the tested non-modifiable variable(s), the optimization procedure and the statistical analysis was done using Statistica v7.0 software. Statistica provides powerful industrial experimental models to relate a numerical output from an experiment to inputs through experimental design techniques. This procedure reveals the relative effect of the variables being studied and their interaction on the output. The program provides experimental models for multi-input experiments which is more relevant to analyse and optimize an industrial process.

3. Results and discussion

The typical amine sweetening plant consists of an absorber column where the sour gas feed is contacted with amine solution in a counter-current fashion where trays or packing are used to enhance mass transfer. Acid gases are absorbed into the solvent that is then regenerated in a regeneration distillation tower to recover the amine solution which is cooled and recycled back to the absorber tower.

As a starting point, inputs and equipment parameters data from an available tutorial file accompanying the software documentation (2004 version) were used to simulate the main case. Such data was important as a starting point to set the software solvers computational parameters like the solution algorithm for equipment like the distillation tower and the heat exchangers with the optimum solver

Table 1
Composition of sour natural gas fed to the DEA amine sweetening simulated case (temp. = 25 °C and pressure = 1000 psia).

Component	Mol fraction	Component	Mol fraction	Component	Mol fraction
N_2	0.0016	i-C4	0.0026	C2	0.0393
H_2S	0.0172	n-C4	0.0029	C3	0.0093
CO_2	0.0413	i-C5	0.0014	i-C4	0.0026
C1	0.8692	n-C5	0.0012	C6	0.0018
H_2O	0.0122	DEAmine	0		

parameters. This data also saves time required to converge the towers and the recycle operation. For this simulation case Kent–Eisenberg along with the non-ideal vapour model were selected based on the guidelines in the package manual (A. HYSYS, 2004). The sour gas (25 MMSCFD, composition shown in Table 1) initially enters a Knock-out drum to separate any free water carried with the gas.

The gas is then sent to the contactor (absorber) fed with 28wt% DEAmine solution (@ 35 °C and 995 psia) flowing at a standard ideal liquid volumetric flow rate of 43 m^3/h. Operating conditions and temperature profile estimates of the absorber column are summarized in Table 2.

Rich DEA amine is directed to a control valve to reduce its pressure to 620 KPa (close to the regenerator operating pressure). After pressure reduction the exit stream is directed to a flash separator to flash off gases from the stream. The stream that exits the flash tank enters a shell and tube heat exchanger (tube side) to be heated to 95 °C before being sent to the regenerator. The bottom product from the regenerator (lean regenerated amine) is the shell side stream that will be further processed to be recycled back to the absorber. Pressure drop for both tube and shell sides was set to 70 KPa. The simple weighted design was chosen as design basis for the software to calculate the heat exchanger size and duty.

The regenerator (distillation column) consists of 18 stages (trays). It should be noted that Aspen Hysys considers the re-boiler automatically as the nineteenth stage. The details used to simulate the regenerator are summarized in Table 3.

After being cooled in the heat exchanger the lean amine solution is mixed with pure make-up water (temp. = 25 °C). The mixer parameters were set to equalize all pressures and the combined stream was assigned a standard ideal liquid volumetric flow rate of 43 m^3/h. A cooler is further needed (pressure drop = 35 KPa) to further cool the lean amine solution which is then pumped through a centrifugal pump to be recycled to the tower. The exit stream from the pump was assigned a temperature of 35 °C and a set operation was used adjust its pressure with respect to the Gas to contactor stream pressure with a multiplier of 1 and an offset of −35 KPa (i.e. pressure of lean amine is always less than the entering gas pressure by 35 KPa). This stream is recycled through a recycle operation to the tower.

The simulated flow sheet is shown in Fig. 1.

Table 2
Operating conditions and temperature profile estimates used to simulate the amine-sour gas absorber column.

Item	Value	Item	Value
Number of stages	20	Bottom stage pressure	6900 KPa
DEA to contactor stream fed at	Top stage	Estimates for top stage temperature	40 °C
Sour gas feed	Bottom stage	Estimates for bottom stage temperature	70 °C
Top stage pressure	6850 KPa		