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Revamping of an acid gas absorption unit: An industrial case study

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ABSTRACT

This work evaluates the efficiency of the aqueous mixture of Methyl Diethanolamine (MDEA) and Diethanolamine (DEA) at various mass concentrations to remove CO_2 and H_2S from natural gas in an industrial sweetening unit in Fajr Jam Gas Refining Company located in the south of Iran and gives recommendations for modifying the process. The sweetening unit includes absorber and desorption towers, flash drum, lean and rich amine exchanger, kettle type reboiler and a reflux drum. The considered process is simulated by Promax simulator (version 3.2) taking into account operational constraints and sustainability of the environment. The validity of simulation has been evaluated by comparison between simulation results and the plant data. The main objective of this work is the modification of natural gas sweetening unit to achieve lower energy consumption. Thus, the effect of amine circulating rate and MDEA to DEA ratio on steam consumption in the regeneration tower, CO_2 and H_2S concentration in the treated gas, and the acid gas loadings have been investigated. Therefore, substitution of DEA solvent in the unit with the aqueous mixture of DEA and MDEA is proposed. In the examined cases, the mass concentration of MDEA and DEA lies between 15 and 45 wt% and 0–30 wt%, respectively, with the reference cases having MDEA 0 wt% and DEA 31.6 wt%. The results show that in the proposed cases of alternative mixtures including cases 1 (MDEA15 wt% and DEA 30 wt%), 2 (MDEA 20 wt % and DEA 25 wt%), and 3 (MDEA 25 wt% and DEA 20 wt%) the amount of reduction in amine circulation rate are between 11.1%v/v and 19.4%v/v compared to the original amine circulation rate. Likewise, steam consumption decreases between 24.4 %wt/wt and 27 %wt/wt. Influence of anti-foam injection for the different cases were also studied and it was found that anti-foam with the concentration of 5000 ppmv is more suitable for the optimum operation and is a more cost effective.

1. Introduction

Removing impurities such as H_2S, CO_2 and other sulfuric components like the RSH (mercaptans) from natural gas is necessary from environmental and safety viewpoints (Kohl and Nielsen, 1997). CO_2 decreases heating value of gas and consequently its price. To avoid human health threatening and corrosion issues in transport pipelines and refining facilities, many restrictions have been imposed in which, the largest allowable molar concentration of CO_2, and H_2S in the gas stream should not be exceeded than 2 vol% and 4 ppmv, respectively (Kohl and Nielsen, 1997).

Despite the progressive improvement in technologies related to the separation of impurities in gaseous stream, the absorption by Alkanoamine solvents is the most widely commercialized processes in many industries (Mokhatab et al., 2015). These chemicals provide necessary water solubility and alkalinity for absorbing acid gases impurities by their Hydroxyl and Amino groups, respectively (Kohl and Nielsen, 1997). Although primary and secondary amines have more alkalinity and reactivity compared to tertiary amines (Ghanbarabadi and Khoshandam, 2015), in terms of energy saving, stability and solvent losses, tertiary amines are more desirable (Penders-van Elk et al., 2013). Tertiary amines like MDEA are able to selectively absorb H_2S and do not directly react with CO2 (Kohl and Nielsen, 1997). There are many limiting factors such as the specification of sweet gas, required energy for reclaiming the solvent, circulation rate and concentration of the solvent along with its ability to absorb the acid gases which should be taken into account for selecting optimum operating conditions in which the process works qualitatively (Mokhatab et al., 2015; Abdulrahman and Sebastine, 2013; Muhammad and GadelHak, 2014). Many approaches introduced to modify the amine-based absorption-desorption process and decrease the operational cost of that process. Galindo et al. (2012) investigated the performance of the aqueous

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mixture of DEA and MEA to absorb CO_2 in an amine-based post-combustion process (Galindo et al., 2012). The results showed that DEA offers the possibility to operate the stripping column at a lower temperature level, hence the more energy saving. Qiu et al. (2014) investigated effects of the number of trays and operating pressure of the absorber in a natural gas sweetening process. They used a modified based MDEA absorbent and their results showed that improving absorption pressure and tray number would reduce the circulation rate, energy and operational cost (Qiu et al., 2014). Sohbi et al. (2007) focused on the change in the amine concentration and the circulation rate in a natural gas sweetening plant by using a mixture of amines (DEA and MDEA). Their results revealed that 40 wt% MDEA with 10 wt% DEA is the best option in terms of water losses (Sohbi et al., 2007). Younas and Banat (2014) investigated the change in amine concentration and circulating flow rate in a natural gas sweetening process by Promax software. They determined that MDEA 45 wt% with the flow of 360 (m^3/h) is the optimum conditions for their processes (Younas and Banat, 2014).

Røkke et al. (2014) proposed different CO_2 absorption unit (Røkke et al., 2014). The Aspen-Hysys simulator was used to design the proposed processes as well as cost estimation and optimization. The results showed that the vapours recompression configuration gives both the lowest energy consumption and the best net present value. Al-Lagtah et al. (2015) analyzed Lekhwair gas sweetening process by Aspen-Hysys simulator to increase profitability and sustainability (Al-Lagtah et al., 2015). The results showed that conventional split-loop by carrying out side draw from stripper to the absorber and optimizing the flow rate of this side draw, the intermediate side draw in the stripper, and the feed stage in the absorber could decrease operating cost up to 50% compared to the conventional process. Fouad and Berrouk (2013) investigated the use of amine solvents that consist of two tertiary amines namely MDEA and TEA (Fouad and Berrouk, 2013). Their results showed that the mixture containing 40 wt% MDEA and 5 wt% TEA reduces operating cost up to 3% considering the sweet gas specifications in terms of H_2S and CO_2 concentrations.

Since the required energy to regenerate rich amine is directly related to the type and rate of circulation solvent, applying the optimal rate and solvent composition are two critical factors to reduce operational cost and increase product quality. Thus, the objective of this work is the modification of natural gas sweetening unit in Jam Gas Refining Company to achieve lower energy consumption. The main idea is the substitution of DEA solvent in the unit with an aqueous mixture of DEA and MDEA. To compare the efficiency of the aqueous solution of DEA and mixture of MDEA and DEA to capture CO_2 and H_2S, the process is simulated by Promax simulator (version 3.2) developed by Bryan Research & Engineering considering operational constraints including product specification, corrosion prevention resulted from increasing acid gases loading, degradation of solvent by increasing regeneration tower temperature and energy saving. The validity of simulation is evaluated by comparison between simulation results and plant data. Then, the effects of amine circulating rate and MDEA to DEA ratio on the performance of sweetening process are determined. Besides, due to unexpected foaming and excess consumption of antifoam to prevent foaming which is currently a critical problem in the refinery, a foaming test has been done to evaluate proposed mixture in terms of their tendency for formation of the foam.

2. Process description

The plant includes eight parallel sweetening trains that is worked separately, albeit they are similar except for their amine solvents. Table 1 shows the feed composition which supplies from three sources i.e. South Pars, Nar and Kangan gas reservoirs. Fig. 1 shows the schematic flow diagram of the process. These sweetening units include absorber (T-4101) and desorption towers (T-4102), flash drum (S-4102), lean and rich amine exchanger (E-4101), kettle type reboiler (E-4102) and a reflux drum (S-4103). In the conventional sweetening process, sour gas is fed to a drum to separate water and heavy hydrocarbon liquid from the natural gas stream (S-4105). The stabilized sour gas is fed to the bottom of the absorber and in counter-current contact with the solvent; CO_2 and H_2S are removed from the gas stream. The rich amine solution leaves the absorber at the bottom and feeds to a flash drum equipped with a throttling valve that expands the high-pressure absorber rich amine by decreasing the pressure of the gas before entering the flash drum. The purpose of the drum is to remove the most dissolved hydrocarbon gas and some acid gases. This horizontal flash drum is worked as a hydrocarbon recovery unit and could prevent foaming. A lean/rich heat exchanger serves as a preheater to heat the cold rich amine stream from the flash drum by the exchange of heat from the hot lean amine stream which exits from the regenerator. After that, the preheated rich solution flows into the regenerator column where rich solution is stripped at low pressure and high temperature. The regenerated lean amine stream is pumped via P-4101 back into the top of the absorption column after passing through the air cooler (E-4104). The air cooler is used to ensure that the lean stream is sufficiently cooled before recirculate to the amine cycle. The regenerator tower is equipped with the kettle type reboiler, a number of stainless steel condenser tubes that utilize to cool down the acid gas stream before entering to the reflux drum. At the bottom of the tower, the reboiler supplies the necessary heat to heat up the semi-rich amine to its boiling point and at the top of the tower, the reflux stream provides the condensing condition so that acid gas stripping is done and the solvent is regenerated. A pump (P-4103) is used to recycled back the condensed mixture of amine and water collected in the reflux drum to the regenerator tower. The outlet gas stream from the top of reflux drum that mainly consists of H_2S and CO_2 is fed to an incinerator and the exhausted steam that used to boiling the solution accumulated in a drum, sending to the utility unit to reproduce steam. However, there is a plan to install Sulfur Recovery Unit in near future to abide with the environmental regulations.

Table 1
Feed gas flow rate, composition and condition of the considered plant.

Component mole fraction	Nar	Kangan	Sout Pars
C_1	0.8821	0.8551	0.8706
C_2	0.0349	0.0402	0.0524
C_3	0.011	0.0128	0.0122
iC_4	0.0023	0.0028	0.0013
nC_4	0.003	0.0034	0.0012
iC_5	0.0013	0.0014	0.0004
nC_5	0.001	0.001	0.0002
nC_6	0.0016	0.0017	0.0001
C_7^+	0.0016	0.0022	0.0004
N_2	0.0457	0.0598	0.0358
CO_2	0.0155	0.0196	0.0217
H_2S (mg scm^{-1})	120	650	5800
RSH(mg scm^{-1})	10	55	15
Temperature (°C)	53	49	30
Pressure ($kPa(g)$)	8001.32	8001.32	8001.32
Molar flow $\left(\frac{kmol}{hr}\right)$	53643.3	105528	35175.9

3. Process simulator

Process simulation is a model-based representation of chemical processes and unit operations. Simulation software describes a process in flow diagrams where unit operations are connected together with the mass and energy streams. Based on the simulated process and inputs, the software solves the mass and energy balance equations to find the operating point. The main goal of a process simulation is to find the optimal condition of the simulated process. Promax which has been developed by Bryan Research and Engineering Company (TX, USA), introduced as a popular process simulator software for designing,