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Natural Gas Sweetening Using Structured Packing

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Abstract: The present study evaluates the absorption column of the Girbotol process, in order to recover H_2S, using Methyl-Diethanol-Amine (MDA) and uses two kinds of mesh corrugated structured packing, one made in National Institute of Nuclear Research (ININ) and the other, similar than the first one, named Sulzer BX. Three different study cases were evaluated: the minimum load gas wet raw flow are 867.06, 751.16 and 718.65 m^3h^{-1} (51.5, 44.6 and 42.9 million of standard cubic feeds d^{-1}), with 1.13, 1.5 and 2% H_2S, respectively. The optimization was done applying Two Film model which is based on the number of global mass transfer units, involving the separation efficiency in terms of the height of a global transfer unit. The results show that ININ packing has higher separation efficiency but higher pressure drop than Sulzer BX. An analysis is done with respect to the pressure drop through the system for the two packings considered and a discussion is presented for each mass transfer parameter studied.

Key words: Structured packing, absorption, hydrogen sulfide

INTRODUCTION

One of the major concerns in the petroleum and natural gas industry is to achieve the best efficient operation due to the expensive installation and operation costs[1-4]. The technology based on structured packing materials, as a liquid gas contactor in a separation column, leads to increase mass transfer separation efficiency and the capacity of the separation. Structured packing, geometrically heaped in a separation column, has been achieving wider acceptance in the separation processes due to their geometric characteristics that allow them to have greater efficiency in the separation processes[5,6,12-15]. When those advantages apply to the natural gas sweetening, the process reaches high yield.

The main purpose of the present research was to study the absorption column of the Girbotol process[1] that recovers H_2S, using Methyl-Diethanol-Amine (MDA) and two kinds of mesh corrugated structured packing, one developed in the Mexican National Institute of Nuclear Research (ININ, for its acronym in Spanish) and another similar packing, named Sulzer BX. Figure 1 shows the ININ structured packing and the sketch of absorption column of Girbotol process.

MATERIALS AND METHODS

The methodology was divided in two parts: i) Models simulation, hydrodynamic and mass transfer models to determine the hydrodynamic behavior and mass transfer efficiency of the column, respectively and ii) the use of two packing with different study cases to compare the column dimensions.

Hydrodynamic model: The pressure drop model[7] describes all flow regimes: dry gas, irrigated gas flow below the load point, loading region and flooding; for any kind of packing. It has used to predict pressure drop and flooding in packed columns and the gas and liquid streams flow in countercurrent, from Eq. 1-3. The pressure drop was calculated in the loading region, near the 1025 Pa m^{-1} or up to 70 % flooding, by iteration using Eq. 1. On the basis of data analysis and for the sake of simplicity as well as to maintain positive values of effective gravity at all time, a value of 1025 Pa m^{-1} was selected for the flooding pressure drop[8].

$$\frac{\Delta P_{irr}}{\rho_L g Z} = \frac{\Delta P_{dry}}{\rho_L g Z} AB \tag{1}$$

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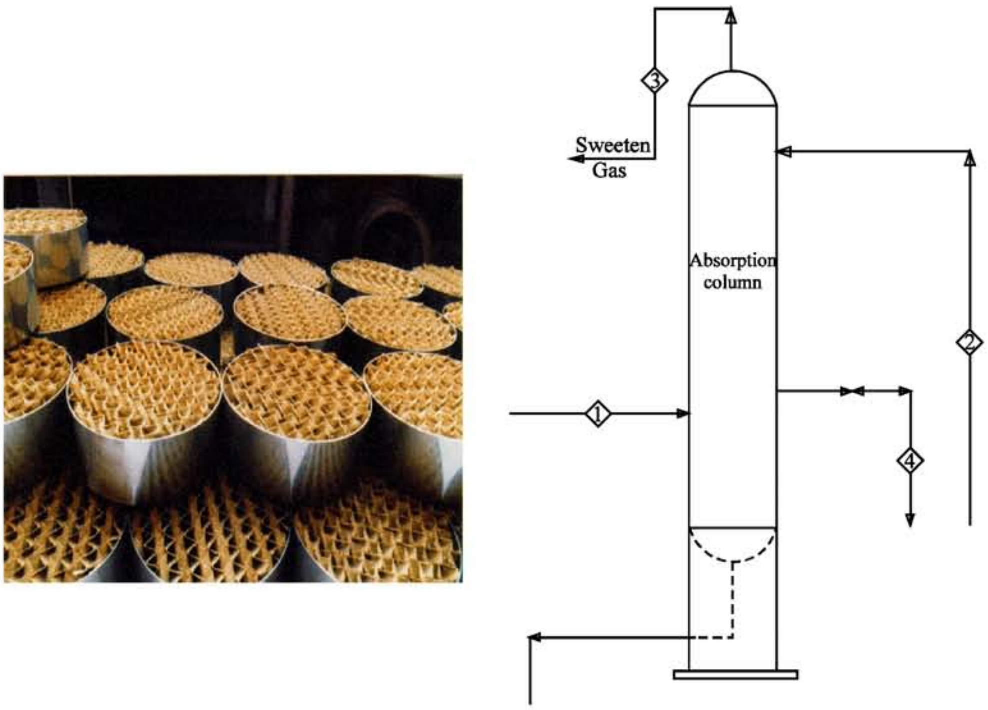

Fig. 1: ININ structured packing (on the left) and sketch of absorption column for the separation of H_2S (on the right): Line 1 is the gas standard raw feed flow, Line 2 is the MDA liquid feed flow with low H_2S concentration, line 3 is the sweetened gas output flow and line 4 is the MDA liquid output flow with high H_2S concentration

Where, A is:

$$A = \frac{\left\{1-\varepsilon\left[1-\frac{h_0}{\varepsilon}\left[1+20\left(\frac{\Delta P_{irr}}{\rho_L g Z}\right)^2\right]\right]\right\}^{\frac{2+c}{3}}}{1-\varepsilon} \tag{2}$$

And B is:

$$B = \left[1-\frac{h_o}{\varepsilon}\left[1+20\left(\frac{\Delta P_{irr}}{\rho_L g Z}\right)^2\right]\right]^{-4.65} \tag{3}$$

Where, ΔP_{irr} is the irrigated pressure drop (Pa m^{-1}), ΔP_{dry} is the dry pressure drop (Pa m^{-1}), ρ_G ρ_L is the gas and liquid density (kg m^{-3}), respectively, g is the gravitational constant (m s^{-2}), Z is the column height (m), ε is the porosity of the packing ($m^3 m^{-3}$), h_0 is the liquid hold up in the load point ($m^3 m^{-3}$) and c is an exponent, Eq. 4. The porosity of the material was evaluated by the displacement of the liquid measured when some structured packings are introduced in liquid volume measured.

$$c = \frac{\frac{-c_1}{Re_G} - \frac{c_2}{2Re_G^{1/2}}}{f_o} \tag{4}$$

The friction factor for a single particle is:

$$f_o = \frac{c_1}{Re_G} + \frac{c_2}{Re_G^{1/2}} + c_3 \tag{5}$$

And c_1, c_2 and c_3 are the fitting parameters and Re_G is the Reynolds number of gas flow from Eq. 5.

Mass transfer model: The Two-Film model[8] is used, assuming thermodynamic equilibrium at the phases interface. This applies only to structured packings in the loading region. The basic parameters of the model are the gas (or vapor) phase mass transfer coefficient, the liquid phase coefficient and the effective interfacial area.

$$\left(\frac{K_G\, s}{D_G}\right) = 0.054\left[\frac{\left(U_{L,eff}+U_{G,eff}\right)\rho_G\, s}{\mu_G}\right]^{0.8}\left(\frac{\mu_G}{D_G\,\rho_G}\right)^{0.33} \tag{6}$$

$$K_L = \sqrt{\frac{D_L\ U_{L,eff}}{\pi\ sC_E}} \qquad (7)$$

$$\frac{a_e}{a} = F_{SE}\left[\frac{29.12\ (We_L\ Fr_L)^{0.15}\ s^{0.359}}{Re_L^{0.2}\ \varepsilon^{0.6}\ (1-Cos\gamma)\ (Sin\theta)^{0.3}}\right] \qquad (8)$$

Where, K_G, K_L are the mass transfer coefficient of the gas and liquid phase (m s^{-1}), respectively; a is the geometric packing area per volume packed unit (m^2m^{-3}), calculated by exposure area of all wire mesh; a_e, is the effective interfacial area per volume unit (m^2m^{-3}), evaluated by Eq. 8; the product of K_Ga_e, K_La_e are the mass transfer volumetric coefficient of the gas and liquid phase, respectively, per unit of time (h^{-1}), evaluated by Eq. 6-8; s is the corrugated side of the structured packings (m); D_L, D_G are the solute diffusivities of liquid and gas phase, respectively (m^2s^{-1})[9], μ_L, μ_G, are the viscosities of the liquid and gas, respectively ($kg(ms)^{-1}$)[9]; $U_{G,eff}$, $U_{L,eff}$ are the effective velocities of gas and liquid, respectively (m s^{-1}); C_E is the correction factor for surface renewal equal to 0.9; F_{SE} is a factor for surface enhancement equal to 0.259; Fr_L is the Froude number for the liquid flow; Re_L is the Reynolds number for the liquid flow; We_L is the Weber number for the liquid flow; γ is the contact angle between solid and liquid film; θ is the corrugated angle of the structured packing; ε is the porosity of the structured packing.

On the basis of conventional definitions of transfer units, the height of a gas phase transfer unit is Eq. 9:

$$HTU_G = \frac{U_G}{K_G a_e} \qquad (9)$$

And the height of a liquid phase transfer unit is Eq. 10:

$$HTU_L = \frac{U_L}{K_L a_e} \qquad (10)$$

Where, U_G and U_L are the velocities of gas and liquid, respectively (m s^{-1}).

The application of the Two-Film model is frequently used to relate the height of the mass transfer global unit HTU_{OG}, HTU_{OL} with the height of the gas HTU_G and liquid HTU_L mass transfer units to the absorption[10]. The height of the mass transfer global units was determined in the present paper.

On the gas-side:

$$HTU_{OG} = HTU_G + \lambda HTU_L \qquad (11)$$

And on the liquid-side:

$$HTU_{OL} = HTU_L + \frac{1}{\lambda}HTU_G \qquad (12)$$

The Two Film model is based on the number of mass transfer global units, NTU_{OG} and NTU_{OL}, of both gas and liquid resistance and they involve the efficiency in terms of the height of a mass transfer global unit HTU_{OG}, HTU_{OL}[10].

On the gas phase side:

$$Z = HTU_{OG} * NTU_{OG} \qquad (13)$$

And on the liquid phase side:

$$Z = HTU_{OL} * NTU_{OL} \qquad (14)$$

The term λ is the ratio of the equilibrium line slope to the operating line slope and λ is known as the removal factor. The inverse of λ is known as the absorption factor, m is the slope of the equilibrium curve[11]:

$$\lambda = m\frac{U_G}{U_L} \qquad (15)$$

Use a structured packing and three different study cases: Different study cases were evaluated having a minimum load gas wet raw flow of 867.06, 751.16 and 718.65 m^3h^{-1}, with 1.13, 1.5 and 2.0% H_2S, respectively.

Figure 1 shows the gas standard raw flow fed at the bottom of the column, named stream <1>; the sweetened gas output at the top of the column, named stream <3>; the liquid flow fed at the top of the column, named stream <2> and the liquid output at the bottom of the column, named stream <4>.

RESULTS AND DISCUSSION

The simulation results of the absorption column were obtained using hydrodynamic and mass transfer models. Table 1 and 2 show the process data and hydrodynamic and mass transfer results, respectively.

Table 2 shows the comparison between the pressures drop of ININ packing with respect to Sulzer BX packing. The pressures drop, ΔP(N m^{-2} m^{-1}), has a dependency to the gas volumetric flow. The ININ packing presents bigger pressure drop than Sulzer BX. It is because ININ packing has more the double of the geometric packing area per volume packed unit (1033 versus 492 m^2m^{-3})

Table 1: Process data results

	Study case 1	Study case 2	Study case 3
Gas standard feed flow (feet^3 d^{-1}), stream <1>	51.5×10^6	44.6×10^6	42.9×10^6
Gas feed flow (kmol m^{-2} s^{-1}), stream <1>	0.6467	0.5600	0.5387
Gas standard feed flow (m^3 h^{-1}), stream <1>	867.06	751.16	718.65
Liquid feed flow (kmolm^{-2} s^{-1}), stream <2>	0.3165	0.3165	0.3165
Gas feed flow composition % H_2S, stream <1>	1.4	1.5	2.0
Gas flow composition % H_2S, stream <2>	0.35	0.35	0.35
H_2S mol per MDA mol	0.002	0.0033	0.0043
Pressure (kg cm^{-2})	69.0	69.8	69.8
Equilibrium line slop	0.4897	0.4897	0.4897

Table 2: Hydrodynamic and Mass Transfer Results of the Three Study Cases

	Study Case1 ININ	Study Case1 Sulzer BX	Study Case2 ININ	Study Case2 Sulzer BX	Study Case3 ININ	Study Case3 Sulzer BX
$G_{<1>}$ (m^3 h^{-1})	867.06	867.06	751.16	751.16	718.65	718.65
% $H_2S_{<1>}$	1.13	1.13	1.5	1.5	2.0	2.0
ΔP(N/m^2 m^{-1})	888.42	449.17	829.07	339.18	739.18	311.83
K_Ga_e(h^{-1})	162000.00	726.00	4670.00	574.00	2240.00	540.00
K_La_e(h^{-1})	8.76	4.55	7.77	4.30	6.85	4.24
HTU_{OG}(m)	2.34	5.52	2.42	5.25	2.75	5.15
NTU_{OG}	6.36	6.36	6.25	6.25	6.61	6.61
Ht_{OG}(m)	14.95	35.21	15.18	32.89	18.25	34.09

Where, $G_{<1>}$ is the gas standard feed flow (m^{3}h^{-1}) in stream <1>; % $H_2S_{<1>}$ is H_2S concentration in stream<1>; ΔP is the pressure drop (N/m^2 m^{-1} packing height), K_Ga_e and K_La_e are the volumetric mass transfer coefficient (h^{-1}) on gas and liquid side, respectively, HTU_{OG} is the height mass transfer unit (m), NTU_{OG} is the number of the mass transfer unit and Ht_{OG} is the total height of the absorption column, (m)

less corrugated angle (45° versus 60°), less corrugated side of the structured packing (0.005 versus 0.009 m) and less porosity (0.966 versus 0.98 m^{3}m^{-3}) than Sulzer BX.

Table 2 also reports a comparison of the gas volumetric mass transfer coefficient, K_Ga_e (h^{-1}) and K_La_e (h^{-1}), with the same packings and with all study cases. The gas volumetric mass transfer coefficient has an increase dependency with respect to the gas volumetric flow and the liquid volumetric mass transfer coefficient has a decrease light dependency with respect to the gas volumetric flow. In all study cases the ININ packing has bigger values than Sulzer BX packing: 99.55% on the first study case, 87.7% on the second study and 75.89% on the third study case in the gas side and 47.99% on the first study case, 44.67% on the second study and 38.06% on the third study case in the liquid side. It is due to their differences of geometric characteristics. K_Ga_e (h^{-1}) and K_La_e (h^{-1}) are essentially dependent on the packing surface area.

In the same Table 2, it is also shown the values of the height of the mass transfer units on the liquid and the gas side of the ININ and Sulzer BX packings, respectively. The ININ packing has smaller height than Sulzer BX because the first packing has bigger geometric packing area per volume packed unit and pressures drop than the second one: 57.54% on the first study case, 53.84% on the second study case and 46.46% on the third study case.

As a consequence of the hydrodynamic and mass transfer behavior, the first study case was evaluated having a minimum load gas wet raw flow of 867.06 m^{3}h^{-1} with 1.13% of H_2S in the gas sour wet flow. The calculated total height of the column was 14.95 m using ININ packing and 35.21 m using Sulzer BX. The second study case was evaluated having a minimum load gas wet raw flow of 751.16 m^{3}h^{-1} with 1.5% of H_2S in the gas sour wet flow. The calculated total height of the column was 15.18 m using ININ packing and 32.89 m using Sulzer BX. The third study case was evaluated having a minimum load gas wet raw flow of 718.65 m^{3}h^{-1} with 2.0% of H_2S in the gas sour wet flow. The calculated total height of the column was 18.25 m using ININ packing and 34.09 m using Sulzer BX. In all study cases, the ININ packing showed to be more efficient than Sulzer BX, due to its less height of a mass transfer global unit.

CONCLUSIONS

Based on the results of this analysis, the ININ packing proved to be better than the commercial packing to do the sweetening of the raw gas stream. It was more efficient in the mass transfer because it presents the lowest value of the column height, even when it had the higher value of pressure drop of the Sulzer BX. This fact is a consequence of their geometric characteristics: higher porosity and higher geometric area than Sulzer type.

This methodology also enables the finding of the best operating condition of the column, as well as the sizes required to achieve the best response without being in the flooding zone. In other words, this method allows evaluating the sensibility of each hydrodynamic and mass transfer parameters and each structured packing used.

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