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# Comparison of Structured Packings in $CO_2$ Absorber with Chemical Reactions

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The present study provides comprehensive performance of structured parking in $CO_2$ absorption application. The structured packings used in this study were developed in Mexican National Institute of Nuclear Research (ININ abbreviation in Spanish of Instituto Nacional de Investigaciones Nucleares), Sulzer BX and Mellapak 250Y (Sulzer Brothers Ltd.). Aqueous solution of 30 % Monoethanolamine was employed as absorption solvent. The performance of the structured packing was evaluated in terms of the pressure drop, holds up, volumetric overall mass transfer coefficient and height of a global transfer unit of gas and liquid side as a function of the process operating parameters including gas and liquid load, and three types of structured packings. The pressure drop of ININ packing was higher than Sulzer BX and Mellapak 250Y, and volumetric overall mass transfer coefficient values higher than Mellapak 250Y and Sulzer BX, although Mellapak 250Y and ININ18 packing had less height of a global transfer unit of gas side values than Sulzer BX packing. The above-mentioned are consequences of the geometric characteristics and operational behavior for each packing.

## 1. Introduction

With current technologies, $CO_2$ separation can be performed by several approaches (Aroonwilas et al., 1999) including absorption into liquid solvents (Mangalapally et al, 2009), saving energy $CO_2$ capture and sequestration processes (Rubin and Rao., 2002; Desideri and Paolucci, 1999; Stangeland, 2007), permeation through membranes (Nazarko, et al., 2008), and chemical conversion (Hsiun-Min and Meng-Hui, 2004). For removing $CO_2$ from high-volume waste gas streams, absorption into liquid solvent is the suitable process approach (Aroonwilas et al., 1999).
A key feature of amine systems is the large amount of heat required to regenerate the solvent, this heat is typically drawn from the steam cycle and significantly reduces the net efficiency of the power plant. The overall energy penalty of this process has a major impact on system performance and cost.
Since $CO_2$ absorption application, structured packings show a great potential. The column fitted with structured packings yields significantly superior performance in

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terms of the mass-transfer coefficient to the column using other type of hazardous or plate column internals. Due to the potential for using structured packings in $CO_2$ absorption application, understanding the performance behavior of the structured packing is necessary for designing columns accurately and economically.
Increasing energy efficiency and a transition to renewable energy as the major energy source can reduce $CO_2$ emissions, but such measures can only lead to significant emission reductions in the long-term. Carbon capture and storage is a promising technological option for reducing $CO_2$ emissions on a shorter time scale (Stangeland, 2007)
For the above mentioned, an alternative profit and solution consists on studying a conventional method, adapting columns with high efficiency packings and using hydrodynamic and mass transfer models in order to design columns. Therefore, the objectives of this study are: to investigate the performance behavior of structured packings affected by process operating parameters, and to compare $CO_2$ absorption performance of structured packings with others. The $CO_2$ absorption performance is represented in terms of parameters in this study are gas load, pressure drop, holdup liquid, and height mass transfer unit.

## 2. Methodology

The methodology was divided in two parts:
i) The use of hydrodynamic and mass transfer models to determine the column diameter and height, respectively
ii) The use of different packings to compare the column dimensions.

### 2.1 Design procedures

Hydrodynamic model for hazardous and structured packings by Stichlmair et al. (1989).

$$\frac{\Delta P_{irr}}{\rho_L g Z} = \frac{\Delta P_{dry}}{\rho_L g Z} xAxB \quad (1)$$

$$A = \frac{\left\{1-\varepsilon\left[1-\frac{h_o}{\varepsilon}\left[1+20\left(\frac{\Delta P}{\rho_L g Z}\right)^2\right]\right]\right\}^{\frac{2+c}{3}}}{1-\varepsilon} \quad (2)$$

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

When the pressure drop in the load zone is determined, the gas molar superficial velocity is known and when we are dividing the gas molar superficial velocity among the superficial velocity, the area traverse and the column diameter are known. Mass transfer model for structured packings by Bravo et al. (1992).

$$\left(\frac{K_G\, s}{D_G}\right) = 0.054\left[\frac{\left(U_{L,eff} + U_{G,eff}\right)\rho_G\, s}{\mu_G}\right]^{0.8}\left(\frac{\mu_G}{D_G\,\rho_G}\right)^{0.33} \quad (4)$$

$$K_L = \sqrt{\frac{D_L\, U_{L,eff}}{\pi\, sC_E}} \quad (5)$$

$$\frac{a_e}{a} = F_{SE}\left[\frac{29.12\left(We_L\, Fr_L\right)^{0.15}\, s^{0.359}}{\mathrm{Re}_L^{0.2}\,\varepsilon^{0.6}\left(1-Cos\gamma\right)\left(Sen\theta\right)^{0.3}}\right] \quad (6)$$

On the bases of conventional definitions of transfer units, the height of a gas phase transfer unit and the height of a liquid phase transfer unit respectively are:

$$HTU_G = \frac{U_G}{K_G a_e \rho_G} \quad (7) \qquad HTU_L = \frac{U_L}{K_L a_e \rho_L} \quad (8)$$

The application of the two-film model is frequently used to relationship the height of the transfer global unit ($HTU_{OG}$ or $HTU_{OL}$) with the height of the gas $HTU_G$ and liquid $HTU_L$ transfer units to the absorption (Hines and Maddox, 1985).

By the gas and liquid side, respectively:

$$HTU_{OG} = HTU_G + \lambda HTU_L \quad (9)$$

$$HTU_{OL} = HTU_L + \frac{1}{\lambda} HTU_G \quad (10)$$

The term λ is the ratio of slopes, equilibrium line to operating line and it is known as the removed factor.

**2.2 Experimental Procedure**

Figure 1 shows $CO_2$ absorption experiment system. It took place in a 0.27 m internal diameter metallic column packed with ININ18 gauze stainless steel structure packing. The height of the packing section was 3.37 m. The experiment data was necessary in order to determine the adjust parameters of both models.

Prior to the $CO_2$ absorption experiments, as absorption solvent was prepared at a given concentration. A mixture of air and $CO_2$ was initially introduced into the bottom of the absorption column. Then, the prepared solution was circulated through the absorption column counter currently to the gas stream. The circulation rate of the liquid solution was gradually increased until it reached a load regimen. At this point, the $CO_2$ absorption had already taken place in the column. However, samples from both gas and liquid phase could be taken until the absorption reached a steady state indicated by constant value of temperature and pH values at given gas sampling points up and down column.

## 3. Results and Discussion

Table 1 shows geometric characteristic of the different studies of packings. According to the values of Table 1, as a consequence of their pressure drops, ININ 18 packing reaches faster the load regimen because it has 74.58 % with respect flooding region. Later, that happens with the Sulzer BX packing, 60.93 %, and lastly with Mellapak 250Y, 37.1 % with respect the flooding region. The operated gas and liquid flows for all packings of 1.2575 m/s and 0,011 m/s, respectively. This means that the highest irrigated pressure drop value is for ININ18 packing, then Sulzer BX packing and last Mellapak 250Y.

The Figures 2 is shown the pressure drop values of three packing, and Figure 3 is liquid hold up values versus gas flow rate, respectively. Hold up values of Sulzer BX (0.2442) is 4.39 % higher that ININ18 (0.2361) and 69 % higher than Mellapak 250Y (0.0715).

Figure 4 is shown the $K_G a_e$ values for the Sulzer BX packing are the biggest one, with 42.85 $s^{-1}$, continues to ININ18 packing, with 41.87 $s^{-1}$, and then Mellapak 250Y packing, with 22.42 $s^{-1}$.

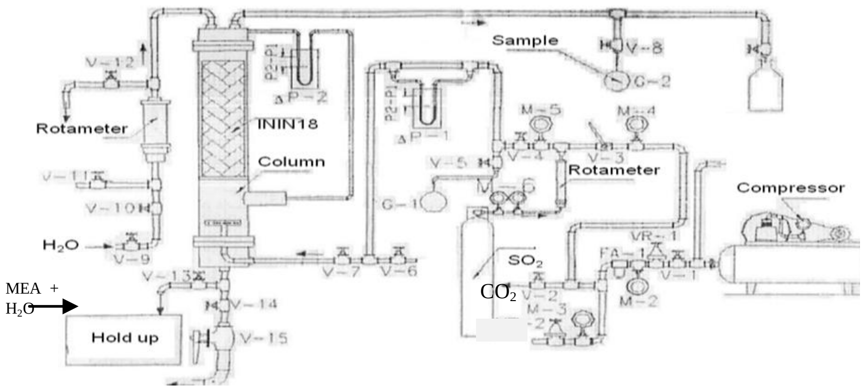



*Figure 1: Experimental system*

*Table 1: Geometric characteristics of the different studies of packings*

| Packing | $C_1$ | $C_2$ | $C_3$ | $\varepsilon(m^3m^{-3})$ | $\theta$ (º) | $a_p$ ($m^2$/ $m^3$) |
|---|---|---|---|---|---|---|
| Sulzer BX | 15 | 2 | 0.35 | 0.96 | 60 | 450 |
| ININ 18 | 2.4024 | 0.3351 | 1.071 | 0.98 | 45 | 418 |
| Mellapak 250Y | 5 | 3 | 0.45 | 0.85 | 45 | 250 |

The Sulzer BX packing was more efficient than ININ18 because the $K_Ga_e$ values of Sulzer BX packing increased bigger than ININ18 and Mellapak 250Y packing.

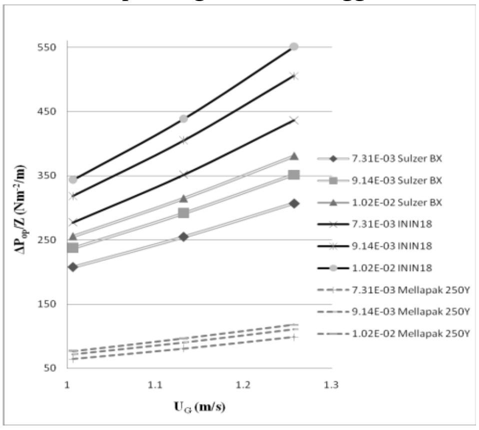



*Figure 2. $\Delta$ P/Z data versus gas flow to Sulzer BX, ININ18 and Mellapak 250Y*

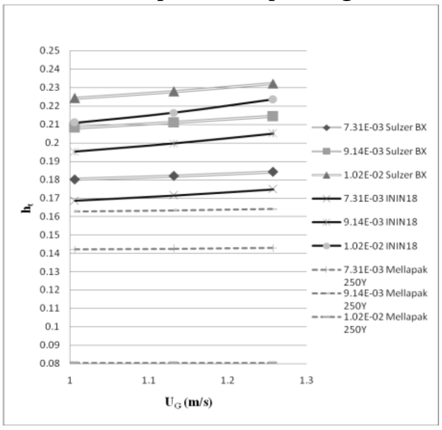
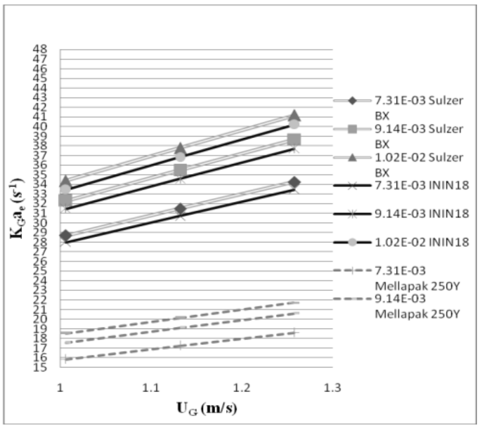



*Figure 3. $h_t$ data versus gas flow to Sulzer BX, ININ18 and Mellapak 250Y*



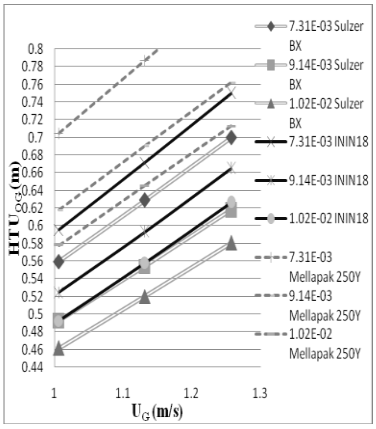




*Figure 4. $K_Ga_e$ data versus gas flow to Sulzer BX, ININ18 and Mellapak 250Y*

*Figure 5. $HTU_{OG}$ versus gas flow, Sulzer BX, ININ18 and Mellapak 250Y*

The $K_Ga_e$ values increase as the gas load increases. An increase in the gas load allows more $CO_2$ molecules to travel from gas bulk to the gas – liquid interface, which would result in higher mass transfer performance. However, the rate of gas absorption is not exclusively dependent upon the mass transfer phenomenon in the gas phase. At this point, diffusion of solvent molecules within the liquid phase is restricted in comparison with that of $CO_2$ from the gas phase to the gas – liquid interface, thus causing a constant amount of $CO_2$ absorbed regardless of the gas load values (Aroonwilas et al., 1999).
Figure 5 is shown the above mentioned will generate smaller height for mass transfer unit for the Sulzer BX with 0.5594 m, later on for the ININ18 packing with 0.6050 m, and lastly for the Mellapal 250Y with 0.6844 m.
In this study, the mass transfer performance of the gauze and sheet structured packing for the $CO_2$ absorption application is compared. From Figure 4, the $K_Ga_e$ values of Sulzer BX and ININ18 are generally comparable and better than sheet metalic structured packing as Mellapak 250Y.

## 4. Conclusions

The use of the Sulzer BX and ININ18 packings are recommended in order to capture $CO_2$. It was the most efficient in the mass trasnsfer because it presents the lowest value of the column height and the biggest $K_Ga_e$ values, respectively, even though ININ 18 packing was the biggest value of irrigated pressure drop of the studied structured packing types. This was the consequence of their geometric characteristics: bigger porosity and bigger geometric area than Mellapak types.

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