EXPERIMENTAL EVALUATION OF SULPHUR DIOXIDE ABSORPTION IN WATER

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A comprehensive knowledge of the relationship between a two-phase countercurrent flow and the geometry of the column and bed of the packing is essential for the design of rectification and absorption columns. A study of hydrodynamic processes was carried out in an absorption column of 0.252 metre diameter with stainless steel gauze corrugated sheet packing by means of air-water and SO_2-water systems. The experiments results include pressure drop, capacity, liquid hold-up and composition. The database has been used to evaluate the Ruhr University generalized performance model. In this work we report experimental results at loading points and compare them with model predictions. The absorption test produced a total of 48 data points. The average deviation between the measured values of pressure drop and liquid hold-up to the predicted values is $\pm 10\%$.

KEYWORDS: structured packing, SO2, absorption, hydrodynamic performance

INTRODUCTION

Atmospheric contamination in cities with a large population is a significant problem. The contamination comes from the burning of heavy oil that releases energy into the atmosphere. The burning of the heavy oil, as a primary source of energy, has high pollution effects due to the formation and expulsion of gases and particles that contaminate the atmosphere. Although new laws control atmospheric contamination, there are no solutions that adapts to each country characteristics (Chávez and Lima, 1998).

Heavy oil is used in diverse productive activities such as the electric power generation, cements, ceramics, glass and bricks for the construction industry (Chávez and Rivera, 1998).

The main purpose of this paper is the experimental evaluation of the absorption of Sulphur Dioxide in water with high efficiency packings, made in the *Mexican National Institute of Nuclear Research* (ININ) and using hydrodynamic and mass transfer models.

MATERIALS AND METHODS

The methodology was divided in two parts: The use of hydrodynamic and mass transfer models to determine the column diameter and height, respectively (Chávez and Guadarrama, 2004; Fair et al., 2000) and the use of different packings to compare the column dimensions, one made by ININ (for its acronym in Spanish) and the other by Sulzer (Olujic et al., 2000; Stichlmair et al., 1989).

HYDRODYNAMIC AND MASS TRANSFER MODELS

The bed flow is upward for the gas and downward for the liquid. Under stationary conditions, we assume that gravity and shear forces in the liquid film of the density and the dynamic viscosity are in equilibrium at a point representing any given thickness in a coaxial layer within the liquid film, and the frictional force exerted by the vapor of the density acts at the surface of the film. Operating parameters are the liquid load and the gas velocity, which also affects the liquid hold-up. As expected the differential equation solution depends upon the flow pattern.

Hydrodynamic model for hazardous and structured packings

The pressure drop per unit packed height $\Delta P/H$, the liquid hold-up $h_{L,S}$ and the model flow factor ξ_S (Billet, 1990) have been used for the packed columns prediction. The load point is described by the equations

$$h_L = 4.5803\left(\frac{\mathrm{Re}_L}{Fr}\right)^{0.3507} \tag{1}$$

$$\frac{\Delta P}{H} = \xi_L\left(\frac{a_g}{2}+\frac{2}{d_s}\right)\frac{1}{(\varepsilon-h_L)^3}u_V^2\rho_V, \tag{2}$$

$$\xi_L = 0.45W\left(\frac{64}{\mathrm{Re}_V}+\frac{3}{\mathrm{Re}_V^{0.9}}\right)\left(\frac{\varepsilon-h_L}{\varepsilon}\right)^{(3-x)}, \tag{3}$$

where Re_L and Re_V are *Reynolds* numbers for the liquid and gas phases film flow, respectively, Fr is the *Froude* number, ξ_L is the resistance coefficient, a_g is the geometric packing area (m^2/m^3); d_s is the column diameter (m), ε is the void fraction (m^3/m^3), u_V is the superficial vapor velocity (m/s), ρ_V is the gas (or vapor) density (kg/m^3), C_P and x are constants determined from experiment data and W is the wetting function.

Mass transfer model for structured packings.

The two-resistance model (Billet, 1990) is used, with the assumption of thermodynamic equilibrium at the phase interface. This makes it useful for either rate based or equilibrium stage based computational routines. The basic parameters of the model are the gas (or vapor) and liquid phases mass transfer coefficients β_V, β_L, respectively, and the effective interfacial area a_{Ph}:

$$\beta_V a_{Ph} = 1.02F_V^{3.5}u_L^{-2.15}D_V^{0.67}, \tag{4}$$

$$\beta_L a_{Ph} = \frac{u_L}{HTU_L} = C_L\left(\frac{\rho_L g}{\eta_L}\right)^{1/6}\left(\frac{D_L}{l_\tau}\right)^{1/2}a_g^{2/3}u_L^{1/3}\left(\frac{a_{Ph}}{a_g}\right), \tag{5}$$

$$\frac{a_{Ph}}{a_g} = 1.5\left(a_g d_h\right)^{-0.5}\left(\frac{u_L d_h}{\upsilon_L}\right)^{-0.2}\left(\frac{u_L^2\rho_L d_h}{\sigma_L}\right)^{0.75}\left(\frac{u_L^2}{g d_h}\right)^{-0.45} \tag{6}$$

All the constants were determined by the experiments reported in this work, using an absorption column of 0.252 metre diameter with stainless steel gauze corrugated sheet packing, named ININ18, by means of the air-water and SO2-water systems.

The quantity a_g is the geometric packing area (m^2/m^3); $\beta_V a_{Ph}$ and $\beta_L a_{Ph}$ the gas and liquid phase (1/h) volumetric mass transfer coefficient, respectively; u_L the liquid load, (m^3/m^2s); d_h the hydraulic diameter of the packing (m); η_L the dynamic viscosity (kg/ms); σ_L the surface tension; g the gravitational constant, 9.8 m/s^2; υ_L the cinematic viscosity (m^2/s); D_L the liquid phase, (m^2/s) solute difusivity; C_L a constant determined from experiment data and l_τ is the characteristic length of the path of contact (Olujic, Z, 1999; Spiegel L. and Knoche M., 1999; Xu, Z.P. et al., 2000).

The two-film model is based on the number of gas and liquid resistance transfer global units, (*NTU*) that are related to the efficiency in terms of the height of a transfer global unit (*HTU*) (Henley and Seader, 1981; Hines and Maddox, 1985; Welty and Wicks, 1991).

The column total packed height Z for the gas and liquid are:

$$Z_G = HTU_{OG} * NTU_{OG}, \tag{7}$$

$$Z_L = HTU_{OL} * NTU_{OL}. \tag{8}$$

The application of the two-film model is frequently used to relate 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:

$$HTU_{OG} = HTU_G + \lambda HTU_L, \tag{9}$$

$$HTU_{OL} = HTU_L + \frac{1}{\lambda} HTU_G. \tag{10}$$

The height of the transfer global units HTU_{OG} is determined through the expression

$$HTU_{OV} = HTU_V + \lambda NTU_L = \frac{u_V}{\beta_V a_{Ph}} + \left(\frac{m}{L/V}\right) \frac{u_L}{\beta_V a_{Ph}} \tag{11}$$

The equality λ is given by

$$\lambda = m \frac{V}{L}, \tag{12}$$

where m is the ratio of the slope of the equilibrium line to the operation line, and (L/V) is known as the removed factor. The absorption factor is the inverse of λ.

If the gas is highly soluble in the liquid, Henry's constant is small. In this case the liquid-side resistance is negligible. If the gas is relatively insoluble (large Henry's constant), the gas-side resistance becomes negligible in comparison with the liquid-side resistance. The relative magnitude of the individual resistance evidently depends on gas

Table 1. Geometric characteristic of different structured packings

Packing	ININ18	Sulzer BX	Units
Material	Stainless Steel	Stainless Steel	
α	35	30	
n_t	36	60	
B	0.0165	0.012	m
S	0.012	0.009	m
θ	45	45	°
ρ_p	317.1	187.52	kg/m^3
ε	0.9633	0.90	
a_g	418	498	m^2/m^3

solubility. This explains the common statements that "the liquid side resistance is controlling" in the absorption of a relatively insoluble gas, and the "gas-side resistance is controlling" when a relatively soluble gas is absorbed (or stripped) (Sherwood et al., 1975).

USE OF DIFFERENT PACKINGS

Table 1 shows the geometric characteristics of the two structured packings, where α is the corrugated angle with respect to vertical axis of the column, n_t is the gauze threads number per squared foot, B is the long of the channel flow, S is the side corrugated wide, θ is the corrugated angle, ρ_p is the packing density, ε is the void fraction and a_g the geometric area of the packing.

RESULTS

The mass transfer results are presented in Table 2, where y_{in} and y_{out} are the inlet and outlet mol fraction concentration, respectively, and %Rec is the recuperation percentage

Table 2. Experiment mass transfer results

$u_L\left[\frac{m^3}{m^2\cdot s}\right]$	$u_V\left[\frac{m^3}{m^2\cdot s}\right]$	$F_V\left[\frac{kg^{1/2}}{m^{1/2}\cdot s}\right]$	$y_{in}10^{-2}$	$y_{out}\ 10^{-2}$	NTU_{OV}	$HTU_{OV}[m]$	$\beta_V \cdot a_{Ph}$	%Rec
0.013611	0.62192513	0.5595491	0.86862	2.62799	3.9048	0.64536	0.98022	97
	0.81362200	0.7320198	0.86862	2.62799	6.5625	0.38399	2.15061	97
	1.00531887	0.9044904	0.86862	9.62922	12.976	0.19421	5.26522	89
0.018325	0.62192513	0.5595491	1.13497	3.44282	3.4196	0.7369	0.85840	97
	0.80912912	0.7279775	1.13497	3.44282	4.3123	0.58438	1.40874	97
	0.99633310	0.8964059	1.13497	3.44282	6.026	0.4182	2.42334	97
0.023477	0.62192513	0.5595491	1.20347	1.21798	3.378	0.7459	0.84808	99
	0.81811490	0.7360621	1.20347	1.21798	3.933	0.64075	1.29907	99
	1.01430466	0.9125750	1.20347	1.21798	4.823	0.5225	1.94126	99

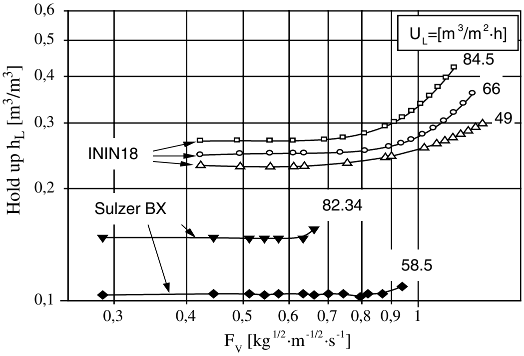

Figure 1. Liquid Hold-up, versus the gas capacity factor

like SO_2 absorbed or removed in the water. Figure 1 shows the liquid hold-up with respect to the gas capacity factor F_V. If the gas velocity is higher than $u_V = u_{V,S}$, the liquid hold-up increases rapidly above the value at the loading point, i.e. $h_L \rangle h_{L,S}$ until the flood point is reached, i.e. $h_L = h_{L,Fl}$. At this point, all the liquid is forced upwards by the stream of gas in the bed. The liquid hold-up of ININ18 is greater than that of Sulzer BX by 44 to 63%, depending upon the values of α, B, S, ε and a_g. The percentage variation depends on the operation regimen. Figure 2 shows the pressure drop per unit packed height with

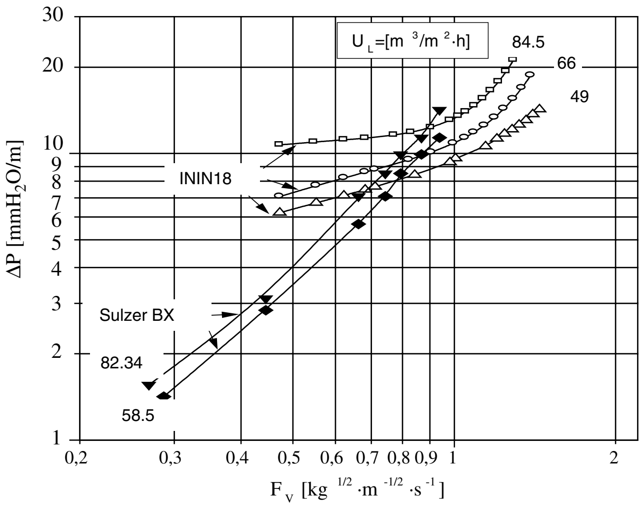

Figure 2. Pressure drop, versus the gas capacity factor

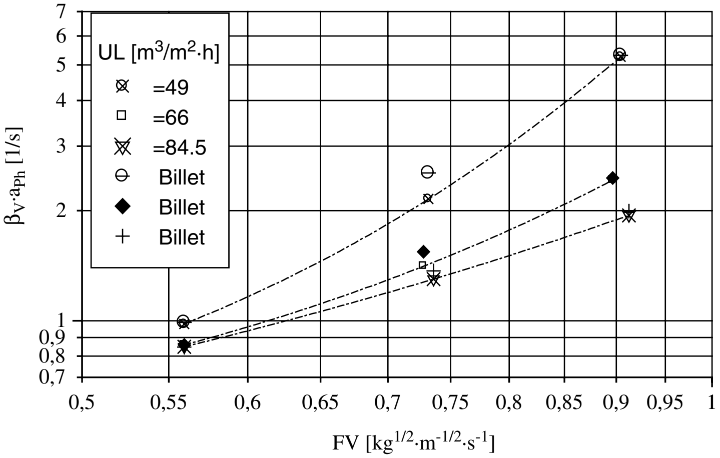

Figure 3. Global mass transfer coefficient, versus the gas capacity factor

respect to the gas capacity factor, from 49 to 84.5 m^3/m^2h. The Sulzer BX pressure drop per unit packed height is less than for ININ 18 packing. This result is a consequence of their geometry parameters of the packing. The performance column with Sulzer packing has 0.07 m of column diameter and with ININ18 has 0.252 m, this different of the column do not let to do a good comparison. Figure 3 shows the volumetric mass transfer coefficient with respect to the gas capacity factor and in Figure 4 we present the global

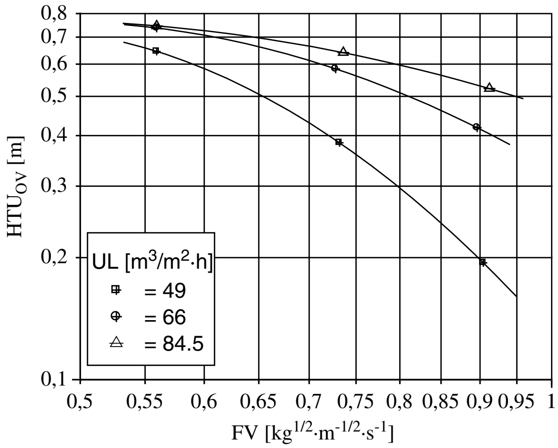

Figure 4. Global height mass transfer unit, versus the gas capacity factor

height mass transfer unit with respect to the gas capacity factor. Both graphics shows the experiment data and predicted data from Billet model. The average deviation between the measured and predicted values is $\pm12\%$.

CONCLUSIONS

Despite the fact that our packing has the higher pressure drop value of the studied structured packing types, the lower column height of our packing makes it to have the highest mass transfer rate. This is a consequence of their geometric characteristics.

The fluid dynamics and mass transfer description takes into account the great diversity in the geometry, structure and materials for packings in industrial columns, which normally entails differences in the fluid dynamics under operation conditions and thus in the packing performance.

The model correlations were checked against the results of comprehensive and systematic experimental studies. The average deviation between the measured and predicted values is $\pm12\%$. Considering the results presented in this work, we recommend the ININ packing for SO_2 recovery.

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REFERENCES

Chávez, T.R.H. and Lima, R.F., (1998) "Influence of the reflux ratio in a distillation column in the unsaturated polyester resins process", Int. J. Environment and Pollution, Vol. 9, No. 4, pp. 432–438.

Chávez R.H. y Guadarrama J.J., (2004) "Caracterización experimental de un empaque estructurado de gasa de latón de alta eficiencia", Información Tecnológica – Revista Internacional, La Serena – Chile, v15, n1, pp. 17–22.

Chávez R.H. y Guadarrama J.J., (2004) "Ajuste de un Modelo Hidrodinámico para una Columna con Empaques Estructurados usando Valores Experimentales", Información Tecnológica - Revista Internacional – La Serena –Chile, v15, n2, pp. 19–24.

Chávez, T.R.H. y Rivera, D.D., (1998) "Especificaciones del horno tabiquero de prueba, en el Municipio de San Bartolomé Tlaltelulco, Metepec, Estado de México", IT,CA-DEA-9817, ININ.

Fair, J.R., Seibert, A.F., Behrens, M., Saraber, P.P. and Olujic, Z., (2000) "Structured packing performance-Experimental evaluation of two predictive models", Ind. Eng. Chem. Res., Vol. 39, pp. 1788–1796.

Henley, E.J. and Seader, J.D., (1981) "Equilibrium-Stage Separation Operation in Chemical Engineering", John Wiley & Sons, USA.

Hines, A. and Maddox, R., (1985) "Mass transfer", Prentice Hall.

Olausson, S., Wallin, M., Bjerle, I., (1993) "A model for the absorption of sulfur dioxide into a limestone slurry", Chemical Engineering Journal, Vol. 51, pp. 99–108.

Olujic, Z, 1999, "Effect of column diameter on pressure drop of a corrugated sheet structured parking", Trans IChemE, Vol. 77, Part A, September, pp. 505–510.

Olujic, Z., Seibert, A.F. and Fair, J.R., (2000) "Influence of corrugation geometry on the performance of structured packings: an experimental study", Chemical Engineering and Processing, Vol. 39, pp. 335–342.

Sherwood, T.K., Pigford, R.L. and Wilke C.R., (1975) "Mass transfer", International Student Edition, Japan.

Spiegel L. and Knoche M., 1999, "Influence of hydraulic conditions on separation efficiency of optiflow", Trans IChemE, Vol. 77, Part A, October, pp. 609–612.

Stichlmair, J.J., Bravo, J.L., Fair, J.R., (1989) "General model for prediction of pressure drop and capacity of counter current gas/liquid packed columns", Gas Separation & Purification, Vol. 3, March, pp. 19–28.

Welty, R.J. and Wicks, C.E., (1991) "Fundamentos de transferencia de momento, calor y masa", Limusa, México.

Xu, Z.P., Afacan A. and Chuang K.T., 2000, "Predicting mass transfer in packed columns containing structured packings", Trans IChemE, Vol. 78, Part A. January, pp. 91–98.