CHEMICAL ENGINEERING TRANSACTIONS Volume 25, 2011
Editors Jiří Jaromír Klemeš, Petar Sabev Varbanov, Hon Loong Lam
Copyright © 2011, AIDIC Servizi S.r.l., ISBN 978-88-95608-16-7 ISSN 1974-9791
DOI: 10.3303/CET1125012

Optimized Process for Post-Combustion CO_2 Capture in Thermoelectric Power Plant using structured packing

Rosa-Hilda Chavez[1*], Javier de J. Guadarrama[2]

[1]Instituto Nacional de Investigaciones Nucleares, Gerencia de Ciencias Ambientales
Carretera México Toluca S/N, La Marquesa, Ocoyoacac, 52750, México, México
[2]Departamento de Ingeniería Eléctrica y Electrónica, Instituto Tecnológico de Toluca
Av Tecnológico s/n, Metepec, 52140, México, México
rosahilda.chavez@inin.gob.mx

The purpose of this work is to simulate CO_2 capture process, using Monoethanolamine (MEA) at 30 % weight, at power plant and using Aspen Plus™ simulator. CO_2 is removed by chemical absorption processes from the flue gases of the power plant. The main challenge of the chemical absorption CO_2 capture processes is reducing the energy requirement in the stripper which has contributors from reboiler energy consumption and maximum CO_2 absorption. This work presents an enhancement the structured packing study in separation columns: ININ 18, Sulzer BX and Mellapak 250Y, and the advance of CCS technologies (CO_2 capture and sequestration). This ININ 18 material was developed by the Mexican National Institute of Nuclear Research (ININ by its acronym in Spanish). The parameters studied were: Separation absorption efficiency, flow ratio (L/G) values in order to find the load or turbulence regimen in absorption process, reboiler duty at desorption column, and column diameters at different treated flue gas flows. The results showed that Sulzer BX had the highest volumetric mass transfer coefficient values and the lowest height of mass transfer equivalent unit, with 3.76 s^{-1} and 0.317 m, respectively, with 600 t/h flue gas flow, and the paper discusses the selection of most important parameters necessary to obtain 90 % capture rate and the lowest energy consumption for CO_2 capture plants in comparison with respect to the other two packings. Sulzer BX packing shows decreased reboiler energy consumption with 8.5 MJ/kg CO_2.

Introduction

Nowadays there is great interest on researching efficient CO_2 capture, developing efficient methods to implement in the energy intensive industries (Abu-Zahra et al., 2007; Alie et al., 2004).

Absorption with aqueous alkanolamine is recognized as a proper commercial option for capturing CO_2 in dilute flows, which contain 10 % - 12 % CO_2 by volume streams gas (Thetakamol et al., 2007). The carbon dioxide capture with solution of Monoethanolamine (MEA) consists of the contact with a countercurrent gas stream with an aqueous solution of amine, which reacts with carbon dioxide to form a soluble carbonate salt, by reaction acid-base neutralization (Oyenekan and Rochelle; 2007 Leites et al., 2003).

Please cite this article as: Chavez R.H. and Guadarrama J.J., 2011, Optimized process from post-combustion co2 capture in thermoelectric power plant, using structured packing, Chemical Engineering Transactions, 25, 69-74
DOI: 10.3303/CET1125012

Figure 1 shows flow diagram of the main process. Gas flow G_1 enters at the bottom of the absorption column, while the liquid flow L_1 enters at the top. The rich liquid amine stream L_2 enters to a heat exchanger to raise its temperature and then pass to the stripper where it carries out amine regeneration. The regenerated liquid flow is mixed with MEA solution at 30 % weight L_5, in order to verify the mass balance of the whole process. Stream L_6 is re-circulated to the absorption column. The stability of the stream L_5 was clue to know the iteration number in the simulator.

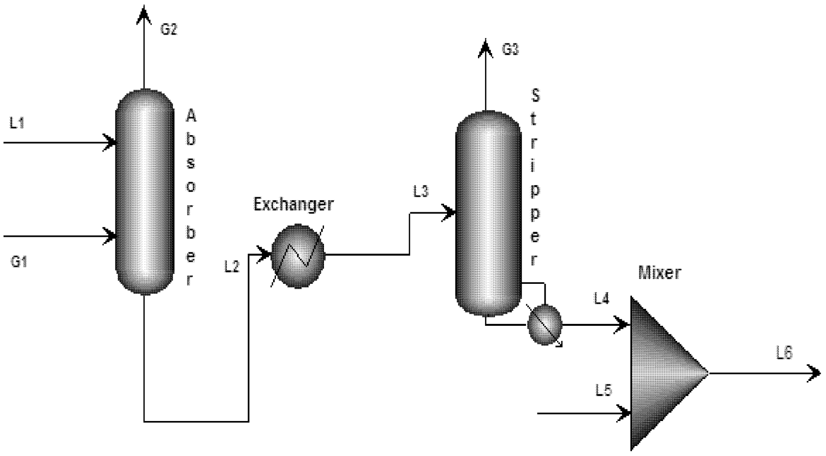

Figure 1:. Flow diagram of the main process.

Methodology

The main element of separation columns is gas-liquid internals or packing. In this material is where mass transfer operation is taken. Table 1 shows the geometric differences of the three structure packing studied.

To evaluate energy requirements and to choose the best packing structured, CO_2 capture process efficiency and CO_2 absorption efficiency were define as follows:

$$Abs.Eff. = \frac{x_{G1} - x_{G2}}{x_{G1}}(100) \quad (1)$$

$$Cap.Eff. = \frac{x_{G3} - x_{G1}}{x_{G3}}(100) \quad (2)$$

Table 1: Geometric properties of structured packings

Structured packing	Material	a (m^2/m^3)	ε (m^3 empty space /m^3 packed bed)	θ (°)
Sulzer BX	Ac Inox.	498	0.9	45
ININ 18	Ac. Inox.	418	0.9633	45
Mellapak 250Y	Ac. Inox.	350	0.86	45

Absorber and stripper are modelled with the RateFrac™ unit operation model in Aspen Plus™ that performs rigorous rating and design for single and multiple columns. RateFrac™ is a rate-based non-equilibrium model for simulating all types of multistage vapour-liquid fractionation operations by simulating packed columns, rather than idealized representation of equilibrium stages. RateFrac™ explicitly accounts for the underlying inter-phase mass and heat transfer processes to determine the degree of separation. It does not use empirical factors such as efficiencies and the height of mass transfer unit (HTU). The use of RateFrac™ completely avoids the need for efficiencies in tray columns or HETPs in packed columns.

RateFrac™ directly includes mass and heat transfer rate processes in the system of equations representing the operation of separation process units. It has far greater predictive capabilities than the conventional equilibrium model.

There is no condenser and reboiler in the absorption column or absorber. A significant amount of CO_2 is recycled through the process and the most important factor is the amount of flue gas and solvent that flows through the column.

The purpose of modelling the stripper is to minimize the reboiler heat duty. Thermal degradation of the MEA solvent due to high reboiler temperature is one of the major limitations in the desorber column. Another important operating parameter for the desorber is its CO_2 recovery. A low CO_2 recovery causes a huge amount of CO_2 recirculation throughout the columns and subsequently increases the equipment size and the reboiler duty due to a large amount of material to heat. On the other hand, with a high CO_2 recovery much less material is recirculated, but the reboiler duty increases to achieve high CO_2 separation. There is therefore an optimized CO_2 recovery in the stripper that would minimize the reboiler duty.

Absorber and stripper need to be specified on the basis of column configurations, column type, internal geometry, and column pressure.

The flue gas enters at the bottom of the column and the lean-MEA enters at the top of the column. The lean-MEA flows back from the stripping column after the amine regeneration process. The stripper is composed of partial vapour condenser and a kettle reboiler. The feed enters the column above the mass transfer region. Inside the stripper, two design specifications are specified. The first one is to achieve the desired mass flow of CO_2 in the distillate by varying the bottoms to feed ratio at the bottom of the stripper.

Results and Discussion

Table 2 shows the mass transfer parameters obtained for the three structured packings at the same flow ratio, L/G=3, at turbulence or loading regimen. Sulzer BX is the lowest height of mass transfer unit, 0.3167 m, 25.39 % less than ININ18 and 26.29 % less than Mellapak 250Y, and the highest effective area, 1.19 times greater than ININ18 and 1.31 greater than Mellapak 250Y. Those values were depended on the geometric characteristics per each packing. Also, Sulzer BX packing shows the highest value on the volumetric mass transfer coefficients, $k_G a_e$=3.76 s^{-1}, ININ18 of 2.80 s^{-1} and Mellapak 250Y of 2.7732s^{-1}. The diameter of the absorption and desorption columns with any of the three structured packings is 1.1 m.

Table 2: Mass transfer parameters results

Flows (kg/h)		G	L	G	L	G	L
		115.00	345.00	115.00	345.00	115.00	345.00
		Sulzer BX		ININ 18		Mellapak 250Y	
k_G	m/s	4.8142E-02		4.2815E-02		4.6539E-02	
k_L	m/s	7.0635E-02		6.3445E-02		6.7171E-02	
a_e	m^2/m^3	78.16		65.55		59.59	
HTU_G	m	0.3157		0.4233		0.4284	
HTU_L	m	0.0014		0.0019		0.0020	
HTU_{OG}	m	0.3167		0.4245		0.4297	
HTU_{OL}	m	0.4777		0.6405		0.6483	
$k_G a_e$	s^{-1}	3.7630		2.8066		2.7730	
$k_L a_e$	s^{-1}	5.5211		4.1590		4.0024	

Table 3 shows flows values, from Figure 1, per each packing. The pressure of whole process was 1 bar. L_1 and G_1 streams were considered the same values for the three packing and compare them under the same conditions. Sulzer BX packing requires less recovery solution L_5=50.52 t/h, releases less CO_2 into the atmosphere CO_2 % at G_2 of 1.06 % and provides higher CO_2 concentration at G_3 stream CO_2 % at G_3 of 28.39 %. ININ packing requires recovery solution of L_5=53.939 t/h and 6.33 % greater than Sulzer BX, releases CO_2 into the atmosphere CO_2 % at G_2 of 1.91 % and 44.5 % greater than Sulzer BX, and provides CO_2 concentration at G_3 stream CO_2 % at G_3 of 26.06 % and 8.2 % less than Sulzer BX. Mellapak 250Y packing requires recovery solution of L_5=56.236 t/h and 10.16 % greater than Sulzer BX, releases CO_2 into the atmosphere CO_2 % at G_2 of 2.63 % and 59 % greater than Sulzer BX, and provides CO_2 concentration at G_3 stream CO_2 % at G_3 of 24.12 % and 15 % less than Sulzer BX.

Figure 2 shows different of duty reboiler energy required in the desorption column. Simulations were made at different reboiler energies and it was evaluated absorption column efficiency with respect to CO_2 concentration at gas streams. The three packing had the same graphical tendency; however Sulzer BX packing presented the highest values in all cases. The required duty energy in reboiler is linked to power plant generation. It was considered duty energy requirement of 120 MW in order to determine percentage absorption efficiency per each packing due to the capture efficiency versus reboiler energy was deep changed slope from each line.

Table 3: Flows and mass concentration of CO_2 per each stream

	Sulzer BX	ININ18	Mellapak 250Y
G_1 (t/h)	600.00	600.00	600.00
CO_2 % at G_1	9.80	9.80	9.80
G_2 (t/h)	471.15	475.038	477.888
CO_2 % at G_2	1.06	1.91	2.63
G_3 (t/h)	179.37	178.902	178.349
CO_2 % at G_3	28.39	26.06	24.12
L_1(t/h)	1800.00	1800.00	1800.00
L_2(t/h)	1928.85	1924.962	1922.113
L_3(t/h)	1928.85	1924.962	1922.113
L_4(t/h)	1749.48	1746.061	1743.764
L_5(t/h)	50.52	53.939	56.236
L_6(t/h)	1800.00	1800.00	1800.00

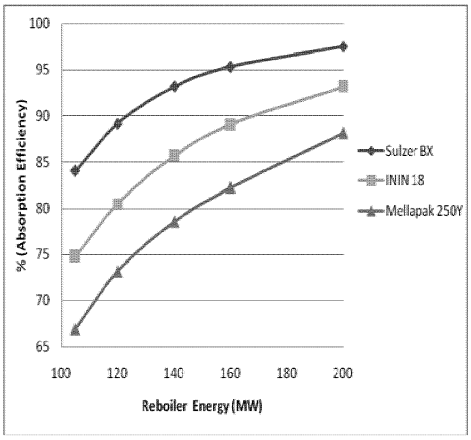

Figure 2: Absorption efficiency percentage versus reboiler energy using three structured packings material

Table 4 shows the simulations results for three packings under the same conditions. It is observed that the Sulzer BX packing required more steps in the absorption and desorption column, this mean lower height in both columns. This packing has the highest CO_2 absorption efficiency and CO_2 capture efficiency. Sulzer BX packing shows decreased reboiler energy consumption with 8.5 MJ/kg CO_2. Sulzer BX packing was more mass transfer efficiecy than ININ18 and Mellapak 250Y packings due to its higher geometric area and operational behavior, showing this efficiency at its lowest value HTU_{OG} of 0.3167 m.

Table 4. Results of the simulation in Aspen Plus™

Packing	FT (t/h)	L (t/h)	G (t/h)	D (m)	ER (MW)	E	CA	CD	Cap.Eff. %	Abs.Eff. %
Sulzer BX	2400	1800	600	1.1	120	8	0.395	0.277	65.48	89.17
ININ 18	2400	1800	600	1.1	120	7	0.389	0.282	62.40	80.47
Mellapak 250Y	2400	1800	600	1.1	120	7	0.381	0.283	59.36	73.17

Conclusions

Sulzer BX packing was the most efficient in capture CO_2 in whole process. It showed greater efficiency in the absorption column, although it required more mass transfer stages, despite this, it become the more efficient for the capture of CO_2 process with MEA.

Nomenclature

a, a_e	Geometric and effective area of structured packing [m^2/m^3]
Abs.Eff, Cap.Eff	CO_2 absorption column and CO_2 capture process efficiency [%]
CA	Enriched load in the absorber [moles of CO_2/moles of MEA]
CD	Lowed load in the desorber [moles of CO_2/moles of MEA]
D	Diameter of the two columns (absorber and desorber) [m]
E	Number of stages in the absorber and desorber
ER	Energy in the reboiler [MW]
G, L, FT	Gas flow, Liquid flow and Total flow [kg/h] or [t/h]
HTU, HTU_O	Height of total and global mass transfer unit [m]
k, $k_G a_e$	Mass and volumetric transfer coefficient [m/s], [s^{-1}], respectively
x	CO_2 fraction mol in liquid flow.
θ	Corrugated angle of the structured packing [°]
ε	Porosity [m^3/m^3], m^3 empty space / m^3 packed bed

Acknowledgments

Partial financial support of this work was provided by Consejo Nacional de Ciencia y Tecnología (CONACyT), project: CB-2007-01-82987, EDOMEX-2009-C02-135728 and Chemical Faculty of State of Mexico University in order to use Aspen Plus^{MT}.

References

Abu-Zahra M.R.M., Schneiders L.H.J, Niederer J.P.M., Feron P.H.M. and Versteeg, G.F., 2007, CO_2 capture from power plants. Part I. A parametric study of the technical performance based on monoethalonamine, International Journal of Greenhouse Gas Control 1, 37–46.

Alie C., Backham L., Croiset E. and Douglas P., 2005, Simulation of CO_2 capture using MEA scrubbing: a flowsheet decomposition method, Energy Conversion and Management, 46, 475-487.

Aspen Plus^{TM}, 2003, Aspen Plus User Guide. Aspen Technology Limited, Cambridge, Massachusetts, United States.

Leites I. L., Sama D. A. and Lior N., 2003, The theory and practice of energy saving in the chemical industry: some methods for reducing thermodynamic irreversibilities in chemical technology processes, Energy 28, 55-97.

Oyenekan B. A. and Rochelle G.T., 2007, Alternative stripper configurations for CO_2 capture by aqueous amines, AIChE Journal 53 (12), 3144-3154.

Thitakamol B., Veawab A., and Aroonwilas A., 2007 Environmental impacts of absorption based CO2 capture unit for post-combustion treatment of flue gas from coal fired power plant, International Journal of Greenhouse Gas Control, 318-342.