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Selection of Packing Material for Gas Absorption

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Abstract

Carbon dioxide (CO_2) capture is the most viable option to minimize the environmental impact by CO_2 emissions. Amine scrubbing process is the well-known technology to achieve that. There are several packing types available for gas absorption. Both random and structured packing were considered in the simulation studies. The main idea behind this study was to select the best packing material which gives lowest re-boiler duty. Complete removal model was developed for selected packing materials. Then, Re-boiler duty requirement was calculated for every single packing. The relevant parameters of packing material were taken from the literatures. The packing types BX, Sulzer packing, Flexipac 1Y and Mellapak 350Y can be recommended for coal and gas fired power plant due to lower values of re-boiler duty.

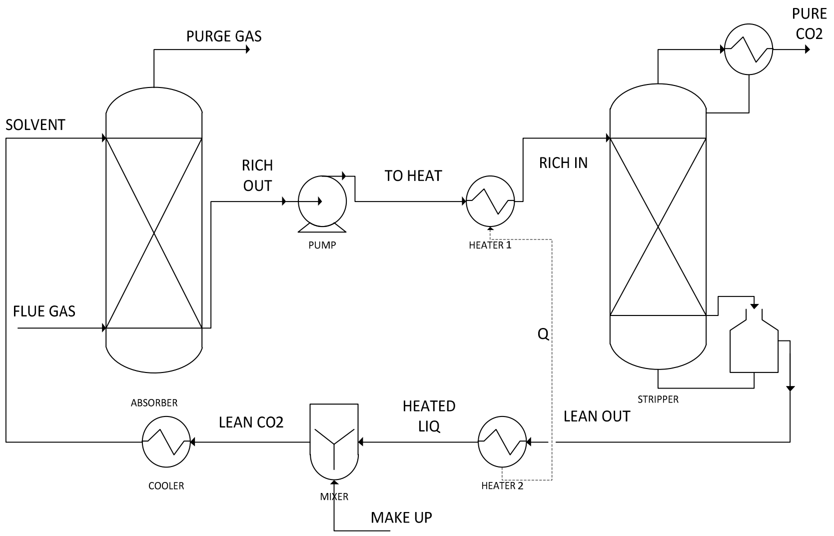
Keywords: Pollution, Carbon capture, Absorption, Packed bed, Energy, Aspen Plus

1. Introduction

1.1. Carbon Dioxide Emissions and Capture

An atmospheric emission of green house gases, carbon dioxide, is the key issue of environmental pollution and global warming. Since the beginning of industrial revolution in 18th century, the average CO_2 concentration has increased from 280ppmv to 370ppmv while the average global temperature has increased from 0.6°C to 1°C [1]. The main carbon emitting source is fossil fuel fired power plants and will contribute to half of the emissions. Effort on limitation of CO_2 emission is the priority for clean environmental management. There are several CO_2 capture technologies available. Post combustion gas scrubbing is widely concerned technology to reduce flue gas emissions from power plants. The energy requirement to operate the carbon capture process reduces the overall efficiency of the power plant and guide to increase the electricity unit cost. An energy requirement for CO_2 capture is one of the key factors for considering and will continue to be high priorities in the future gas treating processes. Flue gas from fossil fuel fired power plants is considered as one of the main environmental problems to be solved. Figure 1 shows the basic process flow diagram for post combustion carbon capture process.

Figure 1: Process flow diagram for CO_2 recovery

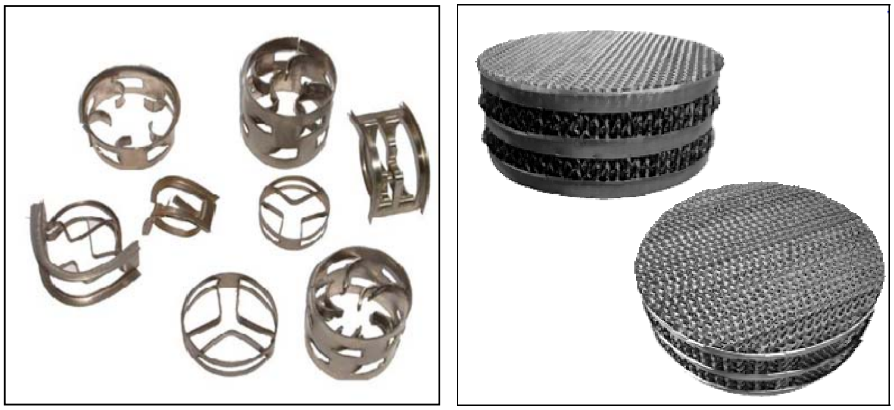


The energy requirement in stripper section is the main energy penalty in the capture process. Absorption process can be either tray or packed column. However, packed column is considered as the preferred option for CO_2 capture. Packed columns are being broadly used in various chemical industries and gas separation (absorption and desorption) technologies. With reference to tray towers, lower residence time and the lower bottom temperature provide an advantage for separation of heat sensitive mixtures in packed columns [2]. Packing material use in the gas absorption process can be either random packing or structured packing. There are several packing types available in the Aspen Plus process simulation tool. Both random and structured packing are considered in the simulation studies. The purpose of this study is to assess the characteristics of packing types on the absorption process for CO_2 capture.

1.2. Packing Materials

Packing section in the absorption process plays important role providing surface area for the gas and liquid phases to contact upon. Mainly, two different types of packing materials are available for gas absorption; Random packing (Pall ring, IMTP, Raschig rings) and Structured packing (Flexipac, Mellapak, Gempak, BX). The overall mass transfer coefficient is high in structured packing compared to the random packing [3]. This is due to large contacting area by structured packing for flow distribution in gas-liquid contacting. Figure 2 shows the examples for random and structured packing.

Figure 2: Random (left) and Structured (right) packing [4]



The characteristics of random and structured packing are given in table 1.

Table 1: Comparison of Random and Structured Packing [5]

Random Packing	Structured Packing
Flow channels do not have a fixed shape.	It is manufactured in modular form to permit stacking in an ordered array.
It can have a nominal size from 1/2” to 4” and is normally dumped randomly into a column.	The height of each module can be varied from 6 to 12 inches.
Made of ceramic, metal or plastic.	Having higher surface area than random packing.
Easy transport and storage.	Provides better performance and are costly.
Cheaper than structured packing	Transportation is difficult without damaging the shape.

Aspen Plus can handle a wide variety of packing types, including different sizes and materials from various vendors. Aspen Plus stores packing factors for the various sizes, materials, and vendors in databanks. The main objective of any packing is to maximize the efficiency for a given capacity, at a reasonable cost. To achieve this, packing materials are designed to get the following characteristics [6]:

- Maximize the specific surface area - This maximizes vapour-liquid contact area, and, therefore, efficiency.
- Spread the surface area uniformly - This improves vapour-liquid contact, and, therefore, efficiency.
- Maximize the void space per unit column volume - This minimizes resistance to gas up flow, thereby enhancing packing capacity.
- Minimize friction - This helps an open shape that has good aerodynamic characteristics
- Minimize cost.

The most important two factors for selecting packing material are surface area and void fraction. Aspen Plus performs liquid holdup calculations for both random and structured packing for gas absorption. However, for Raschig and Sulzer packing, it uses the vendor procedure for hold up calculation while performing the simulations. If the user does not provide these parameters, Aspen Plus will retrieve data from the built-in databank. For other packing types, Aspen Plus uses the Stichlmair correlation [7]. The Stichlmair correlation requires packing void fraction and surface area as well as three Stichlmair correlation constants to perform the calculations. The parameters in the Stichlmair correlation, C_1, C_2, C_3, are constants and vary with the type of packing. According to the type of packing, information is tabulated for simulations and given later. Onda et al. [8] give the correlation for mass transfer coefficients in the gas absorption process for random packing. The Bravo et al. [9] correlation, predicts mass transfer coefficients and interfacial area for structured packing. However, the Billet and Schultes [3] correlation predicts mass transfer coefficients and interfacial area for all kinds of packing. Stichlmair correlation [7] is used for pressure drop calculations in both types of packing. The comprehensive flow sheet is developed in Aspen Plus with relevant mass and heat transfer correlations as well as liquid holdup and pressure drop model.

2. Model Development

2.1. Flue Gas and Solvent Properties

Information related to the inlet flue gas and solvent condition are taken from literatures. The 85% removal process model is developed for simulations with monoethanolamine (MEA) as a solvent. Aspen Plus Electrolyte NRTL property method is used for model development. Flue gas compositions are taken from 500MW coal and gas fired power plants (table 2). The compositions of the solvent streams are given in table 3.

Table 2: Flue gas stream conditions [10, 11]

Parameter	Coal fired flue gas	Gas fired flue gas
Flow rate [kg/s]	673.4	793.9
Temperature [K]	313	313
Pressure [bar]	1.1	1.1
Major Composition	Mol%	Mol%
H_2O	8.18	8.00
N_2	72.86	76.00
CO_2	13.58	4.00
O_2	3.54	12.00
H_2S	0.05	0.00

Table 3: Solvent stream conditions [12]

Specification	Coal fired flue gas	Gas fired flue gas
MEA concentration [w/w%]	40	40
Lean CO_2 loading [mole CO_2/mole MEA]	0.27	0.30
Temperature [K]	313	313
Pressure [bar]	1	1

The 85% removal model is developed with selected solvent condition, which is given optimum results. The chemical reactions [13] and relevant parameters associated with those reactions are taken from the literatures [14]. Open loop removal process model is used for the simulations. The similar value of solvent and flue gas conditions are used for all the simulations. Only packing material and relevant packing factors according to the packing type is changed.

2.2. Packing Material Information

The relevant values for packing materials are given below (table 4). The packing information is extracted from literature, and both random and structured packing types are considered in the simulations.

Table 4: Packing material information used for simulations

Packing type	Size (mm or #)	Area (m^2/m^3)	Voids - ε (%)	C_1	C_2	C_3	Vendor	Reference
Random Packing								
Pall rings	16	341	93	0.05	1	3	Generic	[7]
Pall rings	25	205	94	0.05	1	3	Generic	[7]
Pall rings	38	130	95	0.1	0.1	2.1	Generic	[7]
IMTP	25	207	97	0.815	-0.106	1.499	Koch	[6]
Raschig rings	25	185	86	40	1	6	Generic	[6]
Structured Packing								
Flexipac	1Y	420	98	-1.58	0.629	0.846	Koch	[6]
Flexipac	250Y	250	99	0.866	-0.088	0.698	Koch	[6]
Mellapak	250Y	250	98	1	1	0.32	Sulzer	[6]
Mellapak	350Y	350	98	1	1	0.32	Sulzer	[6]
BX	-	450	86	15	2	0.35	Sulzer	[7]
Gempak	2A	220	93	0.83	-0.071	0.681	Koch	[15]

3. Complete CO_2 Removal Model

The CO_2 capture process model is developed in Aspen Plus for different packing materials which are given in the table 4. Packing material and relevant specifications such as surface area, void fraction, and constant values are indicated for different packing types. However, packing height and diameter is maintained as a constant for all the simulations.

The simulation studies are performed to understand the effect of random and structured packing on the carbon capture process. There are five different types of random packing, and six different structured packing materials select for this study. The Pall-16, Pall-25, Pall-38, IMTP-25 and Raschig rings are selected for the random packing category and Flexipac-1Y, Flexipac-250Y, Mellapak-250Y and 350Y, BX and Gempak are chosen for the structured packing. Complete removal process model is developed in Aspen Plus to check the re-boiler energy requirement in every single case. Temperature of liquid and vapor phases and CO_2 loading profiles in the absorber are analyzed for all cases. However, temperature profiles and CO_2 loading profiles are shown only for coal fired flue gas treating because of similar observations are also obtained for gas fired systems. Figure 3 and 4 show liquid phase temperature profiles in the absorber for random and structured packing for coal fired system, respectively.

Figure 3: Liquid phase temperature profiles in absorber for random packing (coal fired flue gas); symbols refer to Δ, Pall-16; ♦, IMTP-25; ∗, Pall-25; ●, Raschig; ▲, Pall-38

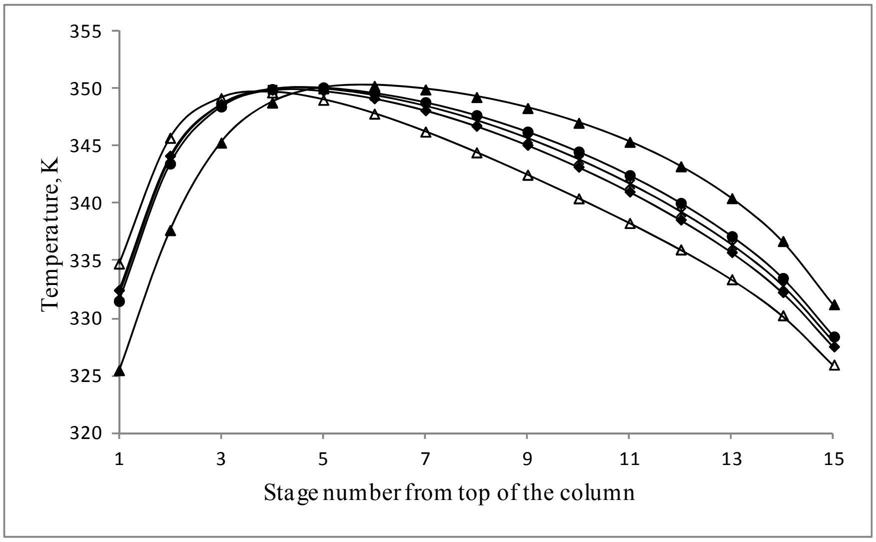
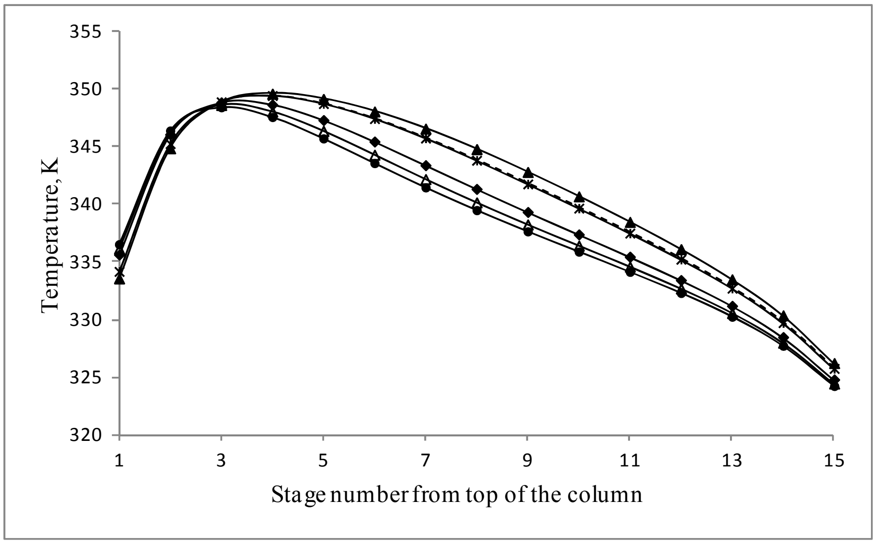


Figure 4: Liquid phase temperature profiles in absorber for structured packing (coal fired flue gas); symbols refer to ●, BX; Δ, Flexipac-1Y; ♦, Mellapak-350Y; ----, Mellapak-250Y; ∗, Flexipac-250Y; ▲, Gempak



When the surface area of the packing material is decreasing, temperature profile along the column are increasing. The lowest temperature profile in random packing is given for Pall-16, which has highest surface area among all the random packing mentioned in table 4. Similar to that, lowest temperature profile for structured packing is represented by BX packing type, which has highest surface area. Reason for this is, with the higher surface area in packing section, rich CO_2 loading is increased and the high amount of CO_2 can be absorbed using fewer amount of solvent. Therefore, the total amount of solvent moving inside the absorber column is reduced and temperature inside the column is less. The maximum temperature is reached to around 350 K in liquid phase. In both cases, similar patterns are obtained in temperature profiles for all packing types.

Figure 5 and 6 show vapor phase temperature profiles in absorber for random and structured packing, respectively.

Figure 5: Vapor phase temperature profiles in absorber for random packing (coal fired flue gas); symbols refer to Δ, Pall-16; ♦, IMTP-25; ∗, Pall-25; ●, Raschig; ▲, Pall-38

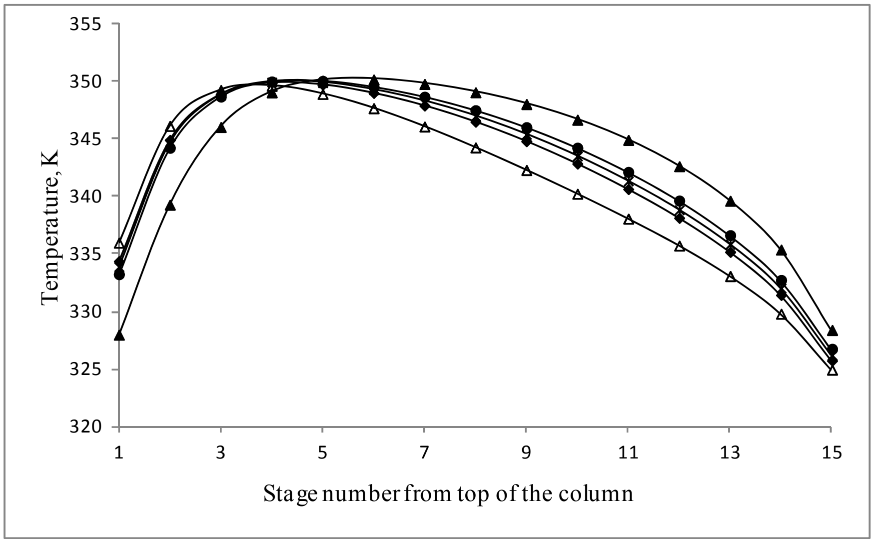
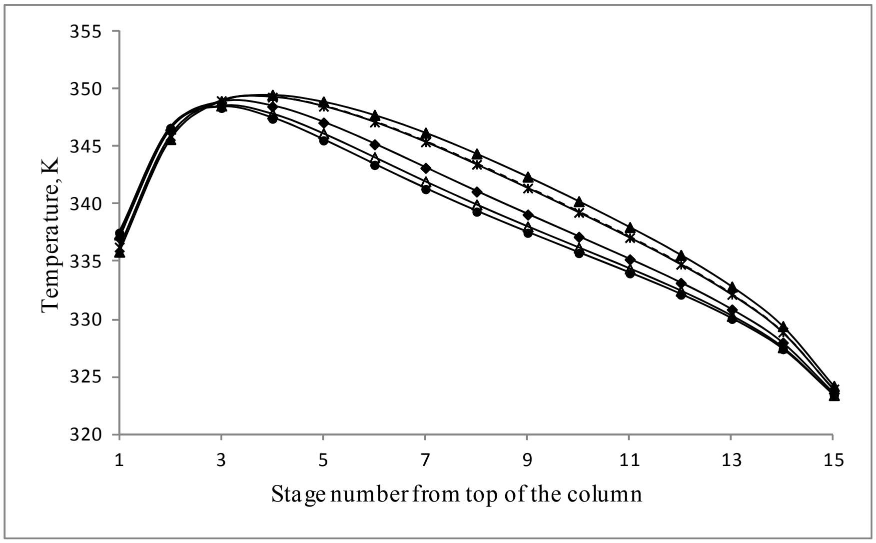


Figure 6: Vapor phase temperature profiles in absorber for structured packing (coal fired flue gas); symbols refer to ●, BX; Δ, Flexipac-1Y; ♦, Mellapak-350Y; ----, Mellapak-250Y; ∗, Flexipac-250Y; ▲, Gempak



Similar observations are achieved with the temperature profiles in vapor phase. In both random and structured packing, lowest temperature profiles are given for highest surface area material. However, shapes of the profiles are almost similar and maximum temperature reach to 350K for both random and structured packing. Structured packing show the lower temperature profiles compared to random packing for both liquid and vapor phase. Reason for that is, highest surface area of structured packing materials for gas absorption process.

Figure 7 and 8 are presenting the CO_2 loading profiles for both random and structured packing along the absorber column.

Figure 7: CO_2 loading profiles in absorber for 85% removal efficiency for random packing (coal fired flue gas); symbols refer to ▲, Pall-38; ●, Raschig; ∗, Pall-25; ♦, IMTP-25; Δ, Pall-16

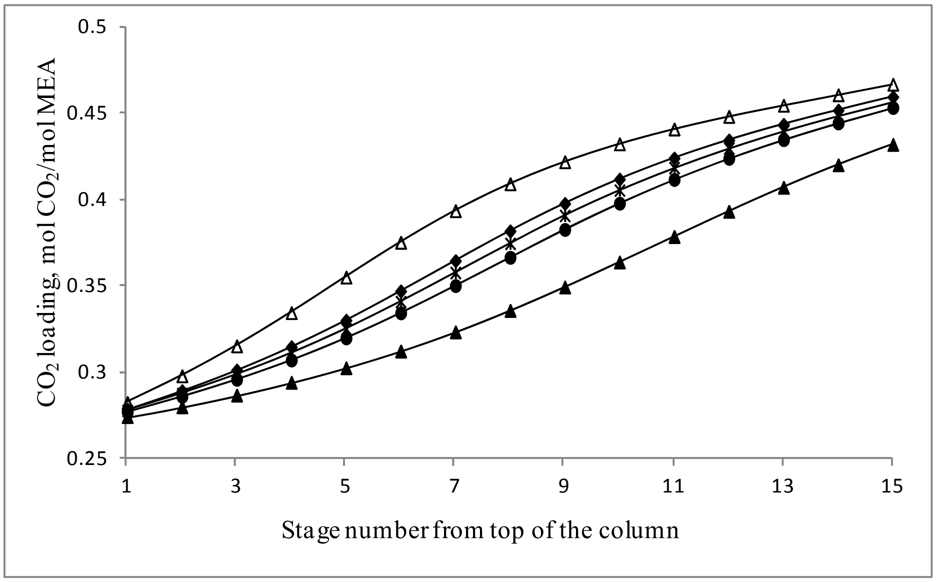
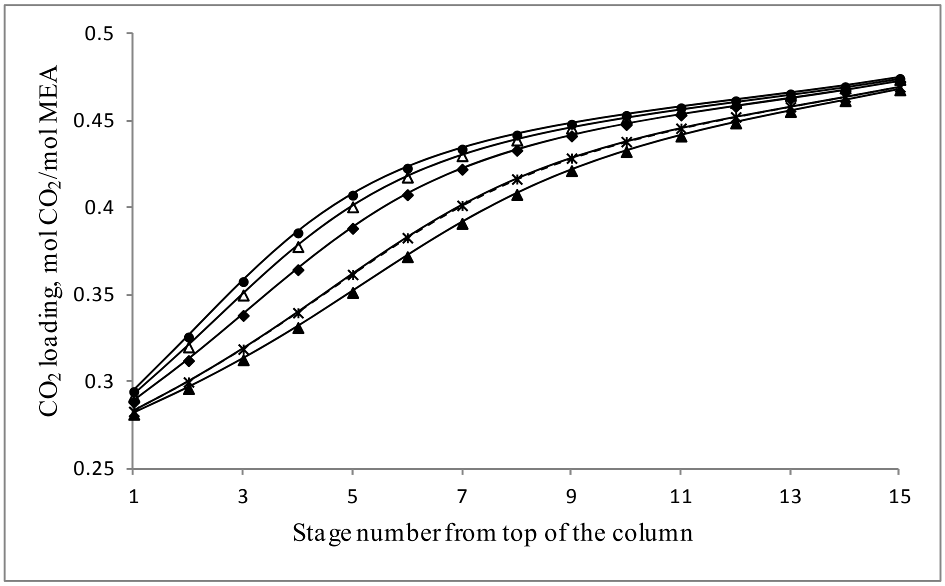


Figure 8: CO_2 loading profiles in absorber for 85% removal efficiency for structured packing (coal fired flue gas); symbols refer to ▲, Gempak; ----, Mellapak-250Y; ∗, Flexipac-250Y; ♦, Mellapak-350Y; Δ, Flexipac-1Y; ●, BX



As can be seen from figure 7 and 8, highest CO_2 loading profiles are given by Pall-16 and BX which have highest surface area for random and structured packing, respectively. When the surface area is high, area available for reaction medium is high. Therefore, a large amount of CO_2 can be absorbed by the solvent stream. Hence, rich CO_2 loading is higher with high surface area material. Highest rich CO_2 loading value is reached to 0.47 and average value is around 0.45. Flexipac-250Y and Mellapak-250Y have exactly the same surface area, which is 250 (m^2/m^3). Because of that, liquid and vapour temperature profiles as well as CO_2 loading profiles are overlapped for both materials. Hence, surface area is the most important factor for temperature variation alone the absorber column and variation for CO_2 loading. Because of that, while selecting the packing, material with higher surface area is necessary, to improve the carbon capture process with low solvent requirement. Even though, same surface area gives exactly similar temperature and CO_2 loading profiles, the conclusion valid only inside one type of packing material (either both are random or both are structured packing). As an example, Pall rings 16 has an area of 341 (m^2/m^3) and Flexipac 250Y has an area 250 (m^2/m^3). However, Flexipac 250Y shows higher CO_2 loading compared to Pall rings 16 which has higher surface area. Main reason behind that may be better solvent distribution inside the column with structured packing. As a result, required re-boiler duty is higher in Pall 16 compared to Flexipac 250Y. Therefore, selection of structured packing is important to get better efficiency and minimum re-boiler duty.

4. Discussion

Temperature and CO_2 loading profiles follow the similar pattern in all cases and maximum temperature reached around 350K. According to rich CO_2 loading, BX packing proves to have a higher packing capacity than others. Rich loading is decreasing from structured packing to random packing. Furthermore, complete removal model is developed for all those packing types. The, re-boiler duty requirement is calculated for every packing type. Table 5 presents a comparison of the different packing for the required re-boiler duty achieved for coal fired flue gas simulation. When rich loading increases and the required solvent flow rate decreases, the re-boiler duty requirement is reduced. Packing height and diameter is kept constant for each simulation to understand the effect of packing type.

Table 5: Re-boiler duty comparison with different packing materials for coal fired flue gas capture

Packing type	Size(mm or #)	Re-boiler duty (kJ/kg CO_2)	Solvent flow rate (tonne/hr)	Rich CO_2 loading (mole CO_2/mole MEA)
Random Packing				
Pall rings	16	3620	8103	0.466
Pall rings	25	3809	8535	0.456
Pall rings	38	4369	9850	0.431
IMTP	25	3757	8415	0.458
Raschig rings	25	3881	8700	0.452
Structured Packing				
Flexipac	1Y	3488	7800	0.473
Flexipac	250Y	3561	7966	0.469
Mellapak	250Y	3566	7976	0.469
Mellapak	350Y	3508	7846	0.472
BX	-	3481	7786	0.474
Gempak	2A	3592	8035	0.467

Lowest re-boiler duty is given by BX structured packing material as 3481 (kJ/kg CO_2) for 85% removal model. Followed by that, Flexipac-1Y and Mellapak-350 Y give low re-boiler duties. However, re-boiler duty values are close for all structured packing material. Reason for low re-boiler duty is high contact surface area available with structured packing. Because of that, rich CO_2 loading is high in absorber and required solvent circulating less. Therefore, the amount of the solvent process in stripper is reduced. Hence, the amount of energy needed to heat up the solvent is decreased. Lowest re-boiler duty in random packing is given by Pall-16, which has highest surface area for reacting system.

Similar to this, gas fired flue gas capture process was performed for similar packing materials listed in table 4. Re-boiler duty is decreased with the increased of contact area in packing material. Minimum re-boiler duty is achieved for BX structured packing material as 3598 (kJ/kg CO_2) for 85% removal model. Following that, Flexipac-1Y and Mellapak-350Y give low re-boiler duties for CO_2 removal process in the gas fired system. Random packing materials give high re-boiler duties compared to structured packing due to lower rich CO_2 loading. Temperature and CO_2 loading profiles have an almost similar trend as coal fired systems.

The selection of the packing depends on the trade-off between cost of packing and re-boiler duty energy requirement.

5. Conclusions

The lowest re-boiler duty is given by the structured packing, BX, Flexipac-1Y followed by Mellapak-350Y. The most important two factors for selecting packing material are surface area and void fraction. The higher surface area gives lower solvent requirement and will lead to lower re-boiler duty. Therefore, BX, Flexipac-1Y or Mellapak-350Y can be recommended for coal and gas fired power plant flue gas treating. The required both solvent and re-boiler energy demand are play the major role for operating cost. Therefore, selection of structured packing instead of random packing gives lowest re-boiler duty with minimum solvent flow rate.

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