EXPANDING POSSIBILITIES

Lee Ming Yang, Sulzer Chemtech, Switzerland, introduces structured packing that has been developed for post-combustion carbon capture for pressure drop optimisation, and gas sweetening for capacity improvements.

Carbon capture utilisation and storage (CCUS) has gained traction, especially in the last decade, as a key technology in managing anthropogenic CO_2 emissions. Significant focus has been placed on post-combustion carbon capture, where CO_2 is captured from flue gases produced by the combustion of fossil fuels. Compared to other approaches, post-combustion capture can be implemented with relative ease in existing industrial facilities and capture-ready power plants. Currently, there are two coal-fired power plants retrofitted with a post-combustion capture unit capable of capturing more than 1 million tpy of CO_2: the Boundary Dam Unit 3 plant in Saskatchewan, Canada, and the Petra Nova plant in Texas, US.[1]

In post-combustion carbon capture, the prevalent technology is a solvent that absorbs the CO_2 from the flue gas, using a process flow scheme involving an absorber and a regenerator, as shown in Figure 1. Typically, 85 – 95% of the CO_2 is absorbed from the flue gas. The flue gas is subsequently vented into the atmosphere, while the CO_2 gas from the regenerator is further processed for utilisation or storage. Many of the proprietary solvents on the market are amine based, where the absorption rate of CO_2 is enhanced by the chemical reaction of CO_2 with the amine in the liquid phase.

The economics of the carbon capture unit have a great bearing on the feasibility of implementing CCUS. In particular, the regenerator reboiler duty and the blower compressor duty constitute the top two spots in operating costs. Minimisation of the regenerator reboiler duty is researched thoroughly by the various process licensors and includes choosing the right solvent and optimising heat integration. Minimisation of the blower compressor duty can come from an efficient blower design, but also from the optimisation of the pressure drop in the absorber column.[2] Table 1 highlights the potential cost savings for an 800 MW coal-fired power plant producing 3 million m³/hr of flue gas. Over a 30 year lifetime operation of the power plant, the accumulated electrical costs savings can total €6.75 million.

Sulzer Chemtech has developed the patented MellapakCC™ structured packing family to address this pressure drop optimisation. By understanding the fundamentals of mass transfer and reaction kinetics in CO_2 chemisorption, the structured packing is optimised to reduce packing specific pressure drop without compromising on packing efficiency. In Figure 2, the chosen MellapakCC model is developed to mimic the CO_2 chemisorption efficiency of MellapakPlus™ 252.Y, and achieves a pressure drop reduction of 50 – 60% across a range of gas and liquid loads. The gas load is expressed as the F-factor (the gas superficial velocity multiplied by the square root of the gas density), whereas the liquid load is expressed as the specific liquid load (the liquid volumetric flow rate per column cross-sectional area). The air-water system used in Figure 2 is a good approximation of the hydraulic behaviour in the CO_2 absorber, which operates with an aqueous solvent. The overall pressure drop reduction in the column depends partly on the packing height, but the reduction of 5 mbar assumed in Table 1 is usually achieved with ease.

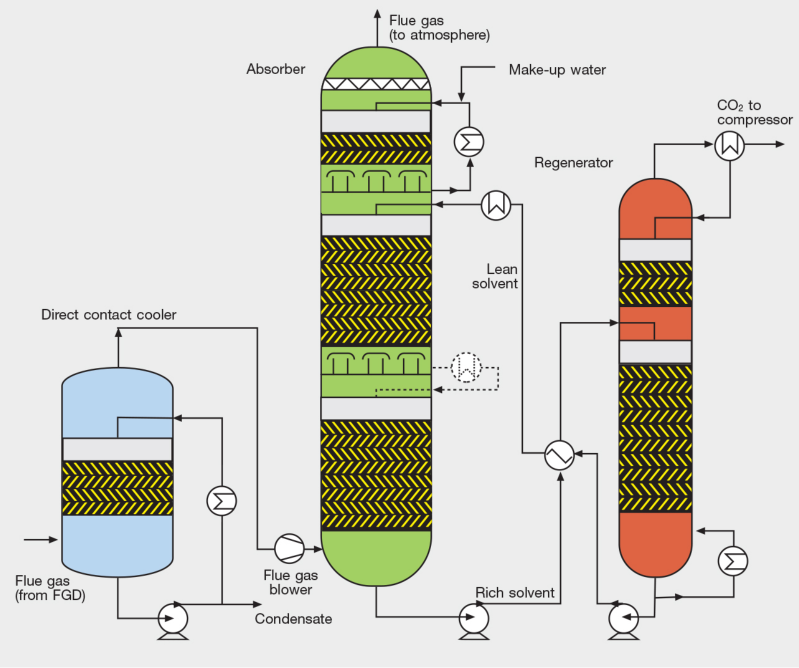

Figure 1. Process flow scheme for a post-combustion carbon capture unit.

Table 1. Yearly electrical cost savings for a carbon capture unit in a 800 MW coal power station, considering a reduction of 5 mbar in pressure drop. The electrical cost is based on a December 2016 report by IEA Clean Coal Centre[3]

Process parameter	Value
Flue gas rate	3 million m³/hr
Pressure drop reduction (Δp)	5 mbar
Fan efficiency	0.75
Operating time	8100 hr/yr
Electrical cost	€0.05/kWh
Annual energy savings	4.5×10^6 kWh/yr
Annual electrical cost savings	€225 000/yr

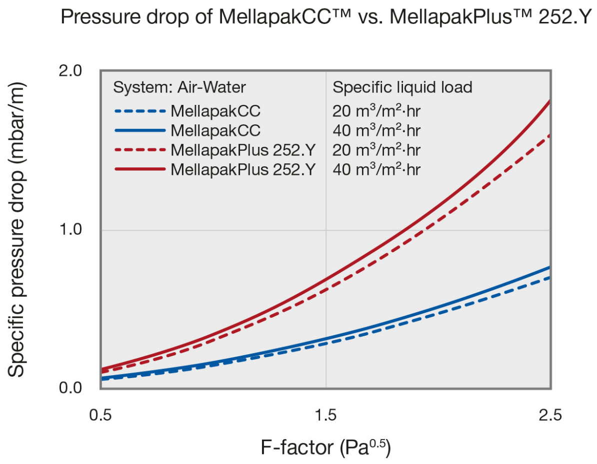

Figure 2. Comparison of the specific pressure drop trends of MellapakCC and MellapakPlus 252.Y, at two specific liquid loads.

Extending the application to high-pressure CO_2 removal

Depending on the source of the flue gas, the flowrates of the gas and liquid streams in the column can be quite different. Regardless, the flows are usually moderate, e.g. in a coal-fired power plant generally, the F-factor is less than 2.5 Pa$^{0.5}$ and the specific liquid load is less than 50 m³/(m²·hr). The situation can be significantly different for CO_2 removal in high-pressure gas sweetening applications, such as in LNG, ammonia, and ethylene oxide plants. For these CO_2 absorbers, pressure drop is not a significant concern, and columns are often pushed to capacity limits with high gas and/or liquid loads. The specific liquid loads can exceed 100 $m^3/m^2 \cdot hr$.

As mentioned, the key features of MellapakCC were optimised for carbon capture, particularly to minimise pressure drop. Subsequently, it was discovered that this new packing family can handle such high column loadings as well, hence it can be utilised in high-pressure CO_2 absorbers to provide significant improvements in both absorption efficiency and hydraulic capacity. Two case studies are presented here to illustrate these improvements. The first is a hypothetical process study for a new CO_2 absorber in an LNG plant, and the second is a revamp of an existing CO_2 absorber in a fertilizer plant.

Case study 1: design of a new CO_2 absorber in an LNG plant

The CO_2 concentration in a natural gas stream must be reduced to below 50 ppm (vol.) in the CO_2 absorber to avoid problems in the subsequent liquefaction process. However, the initial CO_2 concentration can vary significantly, from < 1 mol% to > 10 mol%. This characteristic, together with differing concentrations of components detrimental to absorber performance (e.g. heavy hydrocarbons) requires custom designs for every CO_2 absorber in LNG plants.

In this case study, the 3700 m^3/hr natural gas stream entering the absorber has a pressure of 60 bar and comprises 8 mol% CO_2. A piperazine-activated MDEA solvent was used to absorb CO_2 from the natural gas, down to 50 ppm (vol). Details on the inlet streams are given in Table 2. Using Optimized Gas Treating Inc.'s ProTreat® simulator, the absorber column was designed with the 2A model in the MellapakCC family. For comparison, an absorber design with I-Ring™ #50 was also performed. The column diameters were sized for a maximum capacity of 70%, and the results are summarised in Table 3.

A considerable column size reduction is obtained with MellapakCC-2A, with a 11% reduction in the packing height and a 23% reduction in the column cross-sectional area simultaneously. With regards to absorption efficiency, it outperforms I-Ring #50 by achieving the same CO_2 removal despite a significantly lower packing volume. In terms of hydraulic capacity, MellapakCC-2A can handle a 30% increase in both the gas and liquid flowrates.

For the MellapakCC-2A design, the optimised column diameter also resulted in a 30% increase in the specific liquid load, pushing the value slightly above 100 $m^3/m^2 \cdot hr$. It is worthwhile to understand the capacity trend of this design at high liquid loads. Figure 3 shows an adapted capacity diagram, which plots the F-factor vs the specific liquid load in a column. Essentially, Figure 3 presents the achievable gas load for a liquid load, given that the column is operating at 80% hydraulic capacity. Comparing MellapakCC-2A and I-Ring #50, the former packing can allow a 40 to 70% increase in the gas load over the specific liquid load range of 80 to 160 $m^3/m^2 \cdot hr$.

There is some trepidation in the industry when it comes to installing structured packings in high-pressure, high liquid load applications. However, these two factors are not in themselves the reasons to avoid structured packings, especially for aqueous systems. Sulzer has accumulated extensive references in the use of the Mellapak™ and MellapakPlus packing families in these

Table 2. Absorber feed stream conditions and compositions

Natural gas feed	
Flow rate (kg/hr)	280 000
Pressure (bar(a))	60
Temperature (°C)	40
CO_2 concentration (mol%)	7.9
Lean amine	
Flow rate (kg/hr)	615 000
Temperature (°C)	
Lean loading of CO_2 (mol/mol)	0.05
Amine composition (wt%)	40% MDEA, 5% piperazine

Table 3. Comparison of the column designs using MellapakCC-2A vs I-Ring #50 for the CO_2 absorber in case study 1

	MellapakCC-2A	**I-Ring #50**
Column dia. (m)	2.8	3.2
F-factor ($Pa^{0.5}$)	1.76	1.35
Specific liquid load ($m^3/m^2 \cdot hr$)	101	78
Total packing height (m)	12.5	14
Capacity (%)	67	69
Packing pressure drop (mbar)	18	19
CO_2 concentration of gas outlet (ppm [vol])	43	40
CO_2 loading of rich amine (mol/mol)	0.48	0.48

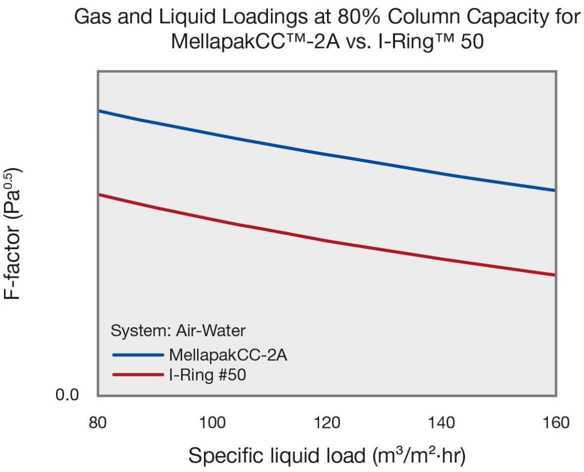

Figure 3. Adapated capacity diagram showing the gas load (F-factor) at 80% column capacity for a given specific liquid load, for MellapakCC-2A and I-Ring #50.

applications, and case study 2 showcases a successful revamp with MellapakCC.

Case study 2: revamp of an existing CO_2 absorber in a fertilizer plant

A CO_2 absorber in a fertilizer plant typically looks more complicated compared to one in an LNG plant. Very often, besides the lean solvent inlet at the top of the absorber, a semi-lean solvent is also fed to the middle of the absorber. The semi-lean solvent flow rate is significantly larger than the lean solvent flow rate, resulting in a bigger column diameter below the semi-lean solvent feed point, as shown in Figure 4. This larger diameter section performs bulk CO_2 absorption using the semi-lean solvent. The specific liquid load is usually higher than 100 $m^3/(m^2 \cdot hr)$, and random packings are commonly chosen as the mass transfer equipment.

In this case study, the CO_2 absorber is operated at ~30 bar(a), using the CATACARB® hot potassium carbonate process, licensed by Eickmeyer & Associates Inc. There are two packing beds in the larger diameter, bulk absorption section, and both beds were initially equipped with a third-generation 2 in. random packing.

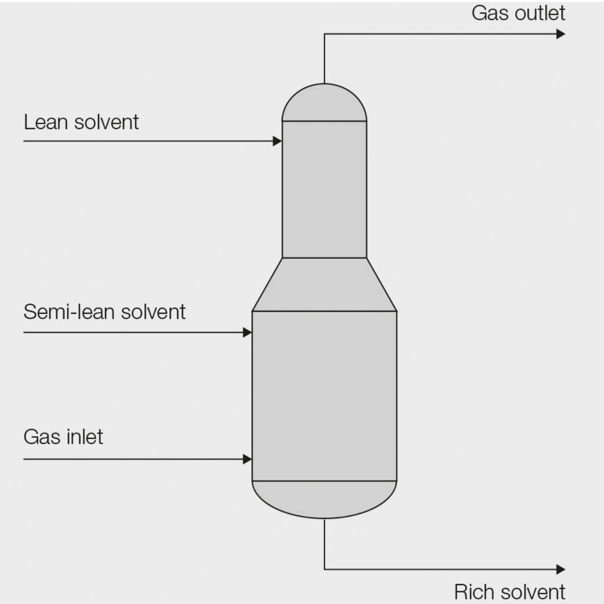

Figure 4. Sketch of a typical CO_2 absorber in a fertilizer plant.

Table 4. Comparison of the hydraulic parameters for MellapakCC-2A and I-Ring #50, for the new loads in the bottom-most packing bed. I-Ring #50 is equivalent to the initially installed random packing

	MellapakCC-2A	**I-Ring #50**
Operating pressure (bar[a])	30	
Column dia. (m)	4	
Packing height (m)	7	
F-factor ($Pa^{0.5}$)	> 1.0	
Specific liquid load ($m^3/m^2 \cdot hr$)	> 160	
Capacity (%)	< 70	> 90
Specific pressure drop (mbar/m)	< 3.5	> 5.0

The end user was interested in increasing the feed gas throughput and approached Eickmeyer to investigate the changes to the process conditions and equipment required to realise this. To achieve the same gas outlet CO_2 concentration, the flowrates of the semi-lean and lean solvents had to be increased as well. With the simultaneous increases in the gas and liquid loadings, the hydraulic capacity limit of the random packing would be exceeded in the bottom-most packing bed. In addition, characteristic to CO_2 chemisorption, increasing the gas throughput requires both the packing capacity and efficiency to be increased, a daunting task when the column dimensions are fixed.

Eickmeyer discussed with Sulzer the possibility to revamp the bottom-most bed with structured packing to increase both packing capacity and efficiency. Mellapak 125.X was the highest efficiency packing that could handle the hydraulic loads in the bed. However, the packing efficiency was insufficient to meet the required CO_2 absorption efficiency at the increased gas throughput. Despite being a relatively new product in this application, MellapakCC-2A was selected as the mass transfer technology to fulfil the required absorption efficiency and hydraulic capacity. Table 4 compares the hydraulic parameters for MellapakCC-2A and the initially installed random packing, which is evaluated with the equivalent I-Ring #50.

In addition to revamping with this new product in the bottom-most bed, several modifications were also implemented. The other bed in the bulk absorption section was revamped with Mellapak 170.X, and the liquid distributors and collectors in both beds were upgraded to accommodate the very high specific liquid loads in both packing beds. Specific liquid loads at this range can be detrimental to liquid distributor performance. In particular, special care must be taken to mitigate the impacts of high liquid velocities and turbulence, which includes uneven and erratic liquid heights resulting in liquid maldistribution.

Increasing absorption efficiency and hydraulic capacity

The MellapakCC structured packing family has been specially developed for post-combustion carbon capture, providing the lowest column pressure drop possible for a given absorption efficiency. Subsequently, the packing was found to handle high gas and/or liquid loads well, enabling its use in high-pressure CO_2 removal applications.

References

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