A NEW STRUCTURED PACKING FOR REACTIVE ABSORPTION

PAPER PRESENTED AT 10\textsuperscript{TH} INTERNATIONAL CONFERENCE ON DISTILLATION & ABSORPTION
Friedrichshafen (Germany) 14 - 17 September 2014

J. Esquier, G. Perdu, & L. Normand
PROSERNAT
Paris, France

J. Roesler, L. Raynal, P. Alix, & P. Broutin
IFP Energies nouvelles
Lyon-Solaize, France
A new structured packing for reactive absorption

1 IFP Energies nouvelles – Lyon, Solaize, France
2 PROSERNAT, Paris La Défense, France

Abstract
Improving efficiency and flow capacity of structured packings can help reduce absorption column investment costs in acid gas treatment and CO₂ capture plants. IFPEN has recently patented a structured packing geometry with concepts that were applied to manufacture a number of packing elements with a geometric area of 200 m²/m³ named IFPACC 2X™. Hydrodynamic properties and effective area properties were evaluated in a 1 m diameter column. The performance results are compared to those of commercial packings. Relative to the Sulzer's Mellapak 250.X, for example, this new packing can offer a 10% higher flow capacity with the same effective area yet with less geometric area.

Keywords
Structured packing, gas sweetening, distillation, CO₂ capture, IFPACC

1. Introduction

One of the main investment costs in natural gas sweetening and CO₂ capture plants is associated with the absorption column. This cost can be reduced with more efficient and more capacitive packings. To this avail, IFPEN has recently developed a new structured packing geometry that provides high fractional areas (ratio of effective to geometric areas) while maintaining a high flow capacity. The base geometry is a classical assembly of wavy metal sheets as with many other commercial structured packings (Sulzer Mellapak, Koch-Glitsch Flexipac or equivalent...). The specific features that provide the improvements are the inclusion of indentations or "windows" in the packing that generate flow discontinuities. As a consequence, droplets will be generated that will enhance the effective surface area analogously to observations made on random packings. Mixing within the liquid film will also be enhanced at the nodal points, or window edges, thus potentially increasing the liquid side mass transfer coefficient by reducing the contact time as used in the Higbie penetration theory. The concepts were applied to produce a number of packing elements named IFPACC 2X™. A picture of a sample packing bloc is shown in Figure 1. The geometric features of the packing are shown in Figure 2. The base structure has vertical corrugations angled at 30° that provide a geometric area of 200 m²/m³ from stainless steel sheets with surface embossing. A regular pattern of windows has been sheared through the sheets to achieve the improved performances. These openings do not add any surface area but generate flow discontinuity points. To date tests have been performed to determine pressure loss, flooding points and effective surface area.
2. Results and discussion

2.1 Materials and methods

The tests were performed in a 1 m diameter transparent column operating in a counter flow mode at near ambient pressures and temperatures. The bed consisted of 15 layers of IFPACC 2X packing blocks 210 mm high for a total height of 3.15 m. For comparison purposes, a 3 m bed of Mellapak 250.X (hereafter M250X) was also tested. The successive block layers were arranged at 90° angles. The liquid phase was recirculated with a maximum flowrate of 80 m³/h and injected at the top through a commercial collector-distributor purchased from a packing supplier with 0.19 m ID liquid tubes and 81 injection points per square meter. The air was supplied by a series of compressors at a maximum flowrate of 9,000 Nm³/h and rejected into the atmosphere after cyclonic separation of entrained liquid droplets. The gas was injected axially from the bottom through a 0.20 m diameter duct located 1.2 m bellow the packed bed.

The pressure drop measurements were performed using the air-water system. The effective area measurements were performed using the air/NaOH (0.1N) system. The inlet gas phase CO₂ concentration is thus near 400 ppmv and the liquid phase inlet NaOH concentration is close to 0.1 mol.L⁻¹. The chemistry for this system is well described by a pseudo-first order irreversible reaction in the fast reaction regime. In these structured packing systems the gas side resistance is negligible, therefore the local absorption flux is given by:

\[ \phi_{CO_2} = \frac{\sqrt{D_{CO_2} \cdot k_2 \cdot C_{OH}^0}}{He} \cdot P_{CO_2} \cdot a_e \]  

The column absorption rate is calculated based on column inlet and outlet gas phase CO₂ concentrations that are measured using an on-line NDIR gas analyzer. The column inlet and outlet liquid solutions are also sampled and analyzed by HCl titration for every data point in order to determine the OH⁻ and CO₃²⁻ concentrations. This allows to check the mass balance between gas and liquid phases and to properly account for the loading effect on the kinetics. The experimentally measured
column absorption rates are compared to those from a one-dimensional column model that assumes isothermal, isobaric and stationary plug-flow conditions. The effective area is then determined by matching the calculated and measured global absorption fluxes.

The kinetic parameters for $k_2$ have been determined in the literature for virgin solutions of sodium hydroxide $^7$. For our low concentration solutions there does not appear to be a well proven method of accounting for the effects of carbonation by CO$_2$, whether on $k_2$, $D_{CO_2}$, $He$ or on the onset of reversible reactions. It is therefore important to operate only at low loadings in order to limit uncertainties on the determination of the effective area. The acceptable limit of carbonation in our laboratory has typically been 0.015 mol/L of CO$_3^{2-}$ representing a 15% loading rate. However this limit represents an operational constraint and even at 15% loading the measured effective areas are altered by several % as will be shown below.

In order to develop a correction for carbonation effects a test was performed at constant gas and liquid flow conditions to track the absorption flux evolution over an extended period of time. The results are shown in Figure 3. The square symbols show the change in global absorption flux as a function of CO$_3^{2-}$ relative to the first measurement made at a carbonation level of 0.01 mol/L of CO$_3^{2-}$. This value was selected as a reference for lack of data with a perfectly virgin solution and because the residual correction to zero carbonation, 1.5%, falls largely within the experimental uncertainties. As expected, calculated effective areas decrease with carbonation due to a reduced CO$_2$ absorption flux. No detailed analysis has been made to determine specific corrections to either $k_2$, $D_{CO_2}$, $He$ which operate as a whole in equation (1). A curve fit to these data simply serves as the basis for applying a global correction factor to back calculate the absorption flux at a reference carbonation load of 0.01 mol/L. The carbonation data extend to 0.04 mol/L, however, the carbonation limit for the tests was set to 0.025 mol/L.

![Figure 3: Calculated effective area variation as a function of liquid carbonation relative to a reference point defined as $[CO_3^{2-}] = 0.01$ moles/L for a 0.1N solution of NaOH.](image-url)
2.1 Pressure drop and flood points

Pressure drop and flood points are compared to those of commercial packings Mellapak 2X (hereafter M2X), from the literature\(^{10}\), and M250X, from this work, in Figure 4 (a) at a liquid load of about 60 m\(^3\)/h/m\(^2\). The new packing shows initially the highest pressure drop, however, the flood point ends up between those of the other packings. The 10% higher gas flow capacity relative to the M250X is due to the lower geometric area. The lower capacity and increased pressure drop relative to the M2X, which has an equivalent geometric area, is due to the flow obstruction generated by the windows. At a higher liquid load of 90 m\(^3\)/h/m\(^2\) the capacity gain relative to the M250X remains 10% and the pressure drop curves match up to the flood point as shown in Figure 4 (b).

![Figure 4](image)

Figure 4: Comparison of IFPACC 2X™ pressure drop to measurements on commercial structured packings with geometric areas of a\(_g\)=200 and 250 m\(^2\)/m\(^3\) at liquid loads of (a) 60 m\(^3\)/m\(^2\)/h and (b) 90 m\(^3\)/m\(^2\)/h.

For practical design purposes the flood limit, \(F_{s,f}\), can be represented as a function of flow parameter, \(FP = \dot{m}_L / \dot{m}_G \sqrt{\rho_G / \rho_L}\), the value of which is determined by the gas treatment plant processing requirements. Figure 5 shows the capacity gain of IFPACC 2X relative to M250X as a function of \(FP\). The % gain in capacity is given by the dashed curve and is observed to be higher at lower \(FP\) values, i.e., for lower liquid to gas loading requirements.

2.2 Effective area

The measured effective areas are reported in terms of fractional areas (a\(_e\)/a\(_g\)) and compared to values of existing commercial packings in Figure 6. The IFPACC 2X packing is found to produce a 20 to 25% higher fractional area. Compared to the M2X (Figure 6a) which has the same geometric surface, this increase translates directly into a gain in effective area. Since the two packings also have the same basic corrugation geometry the area gain results most likely form the formation of liquid droplets at the windows. In Figure 6b comparisons are made relative to M250X with both literature and in-house results. The latter are the most reliable for a quantitative comparison as they were obtained in the same facility and under the same conditions as for the IFPACC 2X. Relative to our measurements, the results of
Figure 5: Comparison of flood limits as a function of FP for IFPACC 2X and M250X. Solid lines are curve fits to the data. The dashed line represents the % gain at a fixed FP value.

Tsai\textsuperscript{8} extend the data coverage to lower liquid loads but are 10% higher in the area of overlap. Based on the in-house results the IFPACC 2X has the same effective areas as the M250X as shown in Figure 7 where a power law fit through the data of either packing is observed to yield virtually the same curve. This is explained by the obviously higher fractional area than the M250X, that compensates for the lower geometric area. Note that in this figure the data of Tsai\textsuperscript{8} have been reduced by 10% to match and provide continuity to the in-house data with M250X.

Figure 6: Fractional area comparisons of IFPACC 2X to other commercial packings with geometric areas (a) near 200 m\textsuperscript{2}/m\textsuperscript{3} (M2X = Mellapak 2X, F2YHC = Flexipac 2Y HC) and (b) near 250 m\textsuperscript{2}/m\textsuperscript{3} (M250X = Mellapak 250.X) for $F_s$ from 1.5 to 2.6 Pa\textsuperscript{0.5}.

3. Conclusions

A new structured packing geometry concept has been developed targeting high capacities for gas sweetening and CO\textsubscript{2} capture applications. The performances of a first design, IFPACC 2X, are under assessment. The current results are very promising as flow capacities were found to exceed those of structured packings for similar applications while maintaining the effective area owing to the higher fractional
This last characteristic will allow future IFPACC generations to achieve yet better performances. Further testing is underway to determine liquid and gas side mass transfer coefficients. Associated correlations will be implemented in rate-based simulation software for the design of gas sweetening units and CO₂ capture plants under the IFPEN technology brands, marketed by Prosern.

Figure 7: IFPACC 2X and Mellapak 250.X (M250X) intrinsic effective areas (the small geometric contribution of the column internal area, 4/D, has been subtracted out of the base measurement).

Nomenclature

References

8. Tsai R. E., Mass Transfer Area of Structured Packing, University of Texas at Austin, Austin, TX, 2010. PhD dissertation.