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Novel structured packing for vapor-liquid contacting

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Abstract

Structured packings have been widely used in the carbon capture process under liquid-based solvents. It commonly provides large surface areas to facilitate chemical reactions in the absorption process. Conventional structured packings consist of corrugated and overlapped sheets with less prominent differences (e.g., corrugations, surface features as holes and dimples, etc.). There are two typical challenges that conventional packings face, i.e., liquid channeling and high-pressure drop, which further constrain the mass transfer performances. In this study, a novel structured packing, SpiroPak, patented by Curtin University, has been investigated. The packing can provide a pack surface area from 200 to 1000 m^2/m^3. Both experimental and numerical studies have been taken as research methodology. Its unique topology and spiral structure can significantly reduce the pressure drop by 50% plus compared to conventional packing without compensating mass transfer performances. The packing also provides excellent resistance from fouling and forming. Its mass transfer performance was tested in a CO_2 absorption column and showed a 30% improvement compared to widely-used commercial packings.

Keywords: Structured packings; CO_2 capture; Pressure drop; Mass transfer.

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1. Backgroud and SpiroPak Topology

Commercial packings are typically arranged in stacked layers, with each layer twisted at a 90° angle between neighbouring elements along the column height, as illustrated in Figure 1a. While this arrangement enhances gas-liquid contact, it exerts additional pressure on the system [1, 2]. Furthermore, conventional packings used in column operations often suffer from channelling issues, causing the liquid to accumulate at the column wall due to inclined packing plates. This necessitates the use of a redistributor to guide the liquid back to the bulk region [3]. To address these challenges, SpiroPak, a patented structured packing, has been developed at Curtin University. The novel design aims to reduce pressure drop, enhance liquid distribution, and increase mass transfer. The design principle involves applying a base profile (depicted in Figure 1b) that revolves along the vertical axis, creating a 3D model with continuous gas and liquid flow channels. SpiroPak is designed with open hexagonal channels through which both gas and liquid are expected to contact. Notably, this design concept can be adapted to other base profiles, such as squares, circles, hexagons, and tessellations, as demonstrated in Figure 1c. The key design parameters of SpiroPak include corrugation size (S), gap size (h), column diameter (D), column height (L) and the number of revolutions (n).

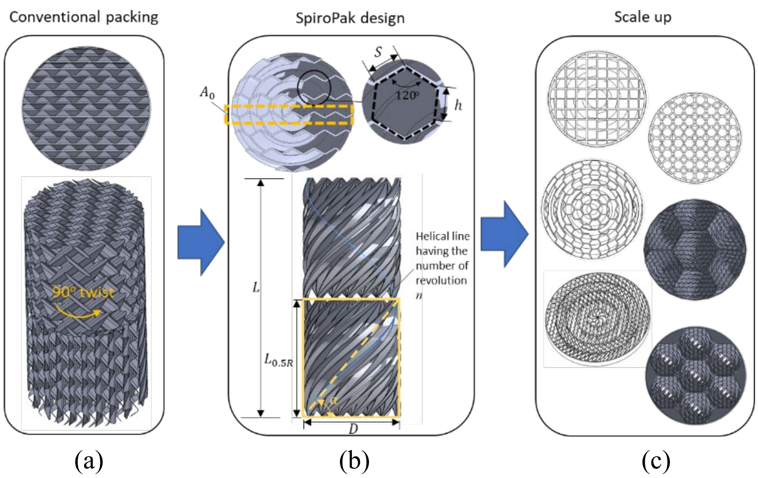


Figure 1 Design concept of SpiroPak structured packing.

2. Hydraulic and mass transfer evaluation

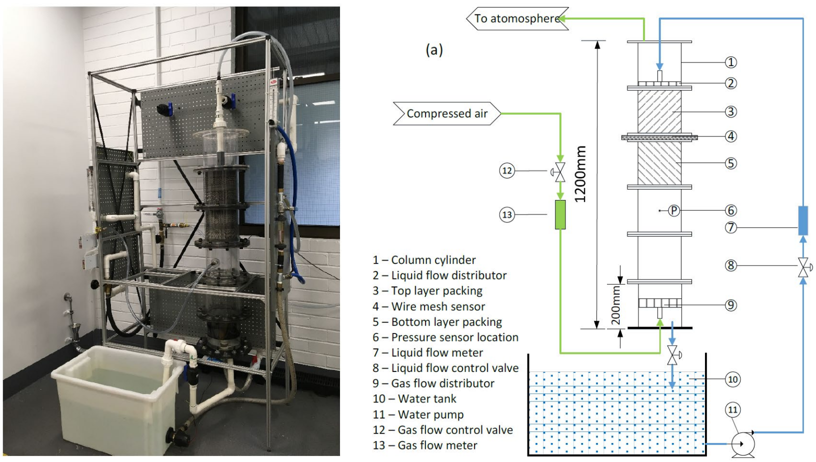


Figure 2. Experimental setup of testing facility of structured packing.

Both experimental and numerical studies were conducted to understand the performances of hydraulics and mass transfer. Both dry and wet pressure drop, liquid distribution and mass transfer were measured and recorded. The pressure drop is measured using a small-range manometer (0~15mmH_2O, with a resolution of 0.1mmH_2O) located at 100mm distance from the packing element (Figure 2). SpiroPak in the test was printed in the material of polylactic acid (PLA) using an FDM 3D printer. Replicas of the two commercial packings (Mellapak 250Y and Montzpak B1-500) were printed by using the same printing parameters, such as nozzle size, wall thickness, printing speed, etc.

CFD simulations demonstrates the agreement of the experimental pressure-drop change with air flow rate, as shown in Figure 3. SprioPak shows an average deviation of 19.6%, which is less than that of Mellpak and Montzpak of 29.1% and 35.3%, respectively. A relatively higher deviation is observed for denser packings (i.e., Montzpak B1-500) that the simulation overestimates the pressure drop. It is because there is an amount of air flow bypassing from the gap between packings and column walls. Although the packings were printed to fit the size of column, it is very challenging to seal the gap entirely in the experiments. Both experiments and simulations suggested that SpiroPak can reduce the pressure drop by ~40% and ~65% compared to Mellapak 250Y and Montzpak B1-500, respectively.

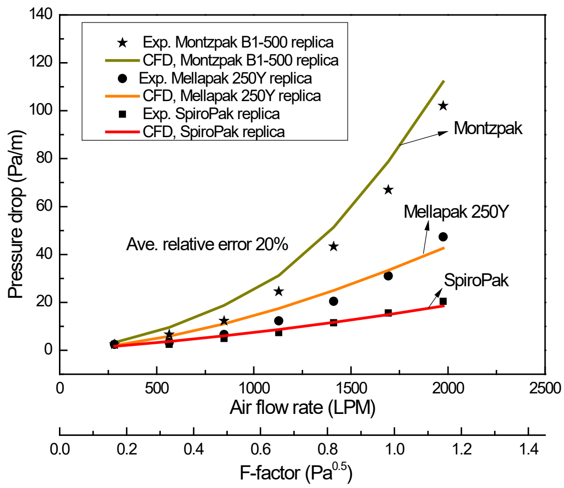
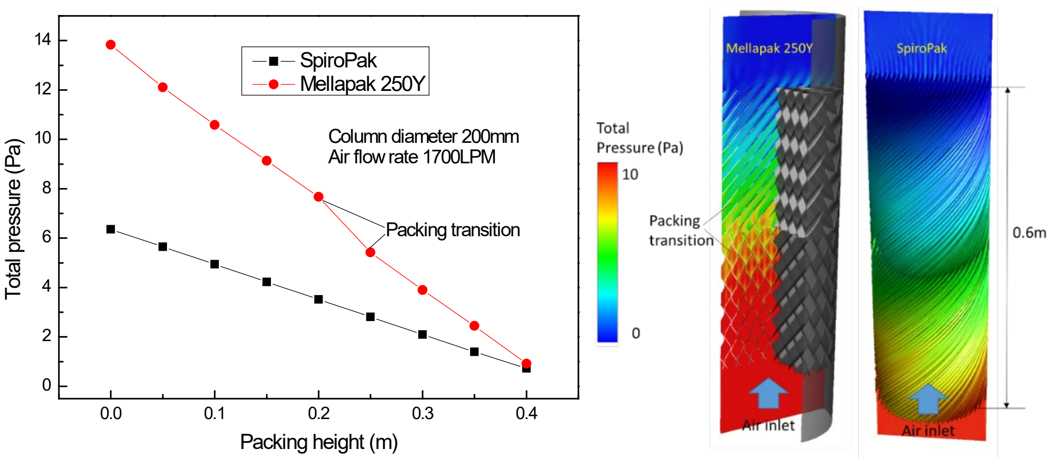


Figure 3. Comparison of pressure drops between different packings.



(a) (b)

Figure 4. Sectional pressure drop through parking height.

The total pressure obtained from simulation results is plotted with packing heights, shown in Figure 4a. The height at 0.0m means the inlet of air flow. The packing transition of Mellapk is located at 0.2m of packed bed height. Compared to the smooth section, one transition can provide 30% more pressure drop, which can be accumulated if the packed bed has more transitions. SpiroPak can solve the issue as the packing offers spiral and smooth flow channels, as shown in Figure 4b. SpiroPak shows much lower pressure drops while providing more specific surface area as commercial packings.

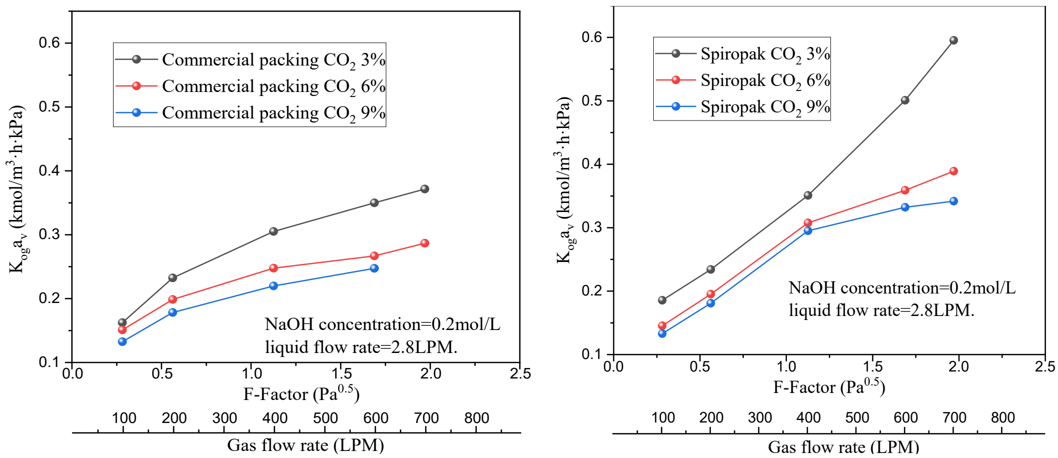


Figure 5. Sectional pressure drop through parking height.

The mass transfer performances of SpiroPak and commercial packings under varying operating conditions were investigated. A series of lab experiments were executed, including air-CO_2 mixtures with CO_2 volume fractions of 3%, 6%, and 9%, liquid flow rates of 1.3~2.8 LPM, NaOH concentration 0.1 ~0.3 mol/L, and gas flow rates of 100 ~700 LPM. Figure 5 illustrates a comparison of mass transfer between SpiroPak and commercial packing by varying gas loads and CO_2 volume fractions. The mass transfer coefficient ($K_{og}a_v$) for both packings showed an increase with gas flow rate, displaying a discernible upward trend across all tested CO_2 concentrations. It was observed that SpiroPak consistently demonstrated a higher mass transfer coefficient than the commercial packing, though the rate of increase slowed with higher gas loads. Specifically, at a 3% CO_2 volume fraction, SpiroPak reached a noticeable mass transfer coefficient at gas flow rates of 100, 200, 400, 600, and 700 LPM, recording values of 0.19, 0.23, 0.35, 0.50, and 0.60 kmol/m^3·h·kPa, respectively (shown in Figure 5B).

3. Fouling and forming performance

A foaming test is conducted in the column with a diameter of 200mm and a packing height of 400mm. The system is air and water mixed with a certain amount of detergent. Compared to commercial packing Mellapak 250Y, SpiroPak shows the superior performance of tolerating forming, as shown in Figure 6.

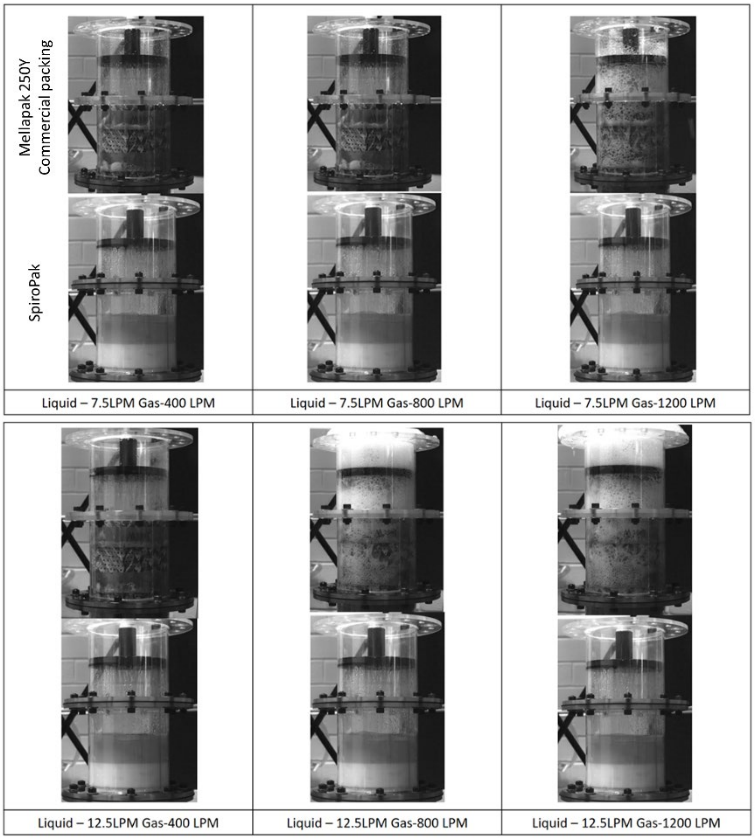


Figure 6. Comparison of foaming tolerance between Mellapak and SpiroPak.

A flooding test is performed in a smaller column with a diameter of 54mm and a packing height of 200mm. By varying both gas and liquid flow conditions, it has been observed SpiroPak can only flood at a much higher liquid load, which is around four-time higher than the Mellapak flooding point, as shown in Table 1.

Table 1 Flooding point comparison of Mellapak and SpiroPak.

	Mellapak	SpiroPak
Diameter of column (mm)	54	54
Gas flow rate (LPM)	250	300
Liquid flow rate (LPM)	2	7.5
F-factor ($Pa^{0.5}$)	2.04	2.45
Liquid Load m3/m2h	52	196

5. Conclusion

In this study, a novel structured packing, namely SpiroPak, has been studied to investigate its hydraulic and mass transfer performance. Experimental studies were conducted to test the packing pressure drops and liquid distributions, while numerical method using CFD method was used to investigate and optimise the packing parameters. Because of its unique topology and structures, SpiroPak can reduce the overall pressure drop by more than 50% compared to widely-used commercial packings. Its mass transfer can be improved by 30% with high resistance of foaming and fouling.

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