Magnetic Resonance Imaging of Structured Packings: Overcoming Spatial, Signal, and Geometric Challenges

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Introduction: Structured packings are widely employed in trickle beds to improve the mass transfer between the liquid and gas phases in absorption and distillation processes. While integral experiments, such as pressure drop measurements and collector experiments, offer overall insights, they lack spatial and temporal detail on liquid distribution. Magnetic Resonance Imaging (MRI) overcomes this by providing resolved flow visualization, though its application is challenged by low liquid content, the need for high temporal resolution, and difficulty achieving spatial resolution on the order of hundreds of micrometers with large-bore scanners [1]. These issues are mitigated through optimized imaging sequences, doped aqueous solutions, and tailored radiofrequency coils, enabling MRI to deliver detailed insights into liquid behavior and packing efficiency.

Methods: All experiments were conducted with a 3 Tesla vertical large-bore MRI system with the ability to measure samples with a height of several meters. The trickle bed included a one meter structured packing bed with a diameter of 54 mm. 3D-printed corrugated sheet packings (480 m²/m³) were studied under varying gas and liquid loadings. To shorten T_1 relaxation time to 50 ms and match the magnetic susceptibility of the gas phase, which is air, the aqueous solution was doped with 16.27 mM dysprosium(III) nitrate and 1 mM gadolinium(III) chloride. The liquid distribution was measured using a gradient echo imaging sequence. Two coil designs were compared, the system-integrated Transmit - Receive bird cage body coil and a tailored single-channel surface coil.

Results and discussion: The coils were compared with regard to signal-to-noise ratio (SNR) and spatiotemporal resolution. Unlike the body coil, which suffers from low spatial resolution and long acquisition times, the single-channel coil enables significantly higher spatiotemporal resolution (Fig. 1). The shortened T_1 relaxation times allow faster signal recovery, enabling higher temporal resolution. Using a single-channel coil, doped aqueous solution, and gradient echo sequence enables MRI with spatial resolution up to 0.25 × 0.25 × 0.3 mm³. Combining data from partially and fully filled packings (Fig. 1) enables differentiation of liquid, gas, and structured packing, allowing the determination of the gas-liquid interfacial area, which is critical for the separation efficiency. MRI-derived maldistribution factors were validated against collector experiments at the column bottom, demonstrating good agreement.

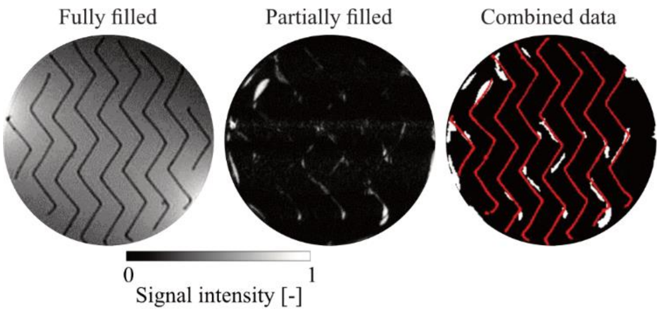

Fig. 1: MRI measurements are conducted with a spatial resolution of 0.5 × 0.5 × 1 mm³ with a temporal resolution of 1.4 sec per frame. The combined data consider the information of the fully filled and partially filled bed enabling to differentiate between packing (red), air (black), and aqueous solution (white).

Conclusion: This study shows the use of MRI for temporally and spatially resolved measurements of liquid distribution in structured packings within trickle beds. A tailored surface coil, doped aqueous solutions, and optimized imaging enabled high-resolution imaging. MRI allows to distinguish between gas, liquid, and packing phases, enabling the determination of the gas–liquid interfacial area. The comparison with collector experiments showed good agreement, with MRI offering enhanced insight along the column height and improved radial resolution.

References: [1] Hampel et al., *Sensors* (2022).