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Experimental assessment of novel packing structures for efficient CO_2 capture using amine scrubbing

Lisa Katharina Hassel[a,*], Martin Greco-Coppi[a], Jochen Ströhle[a], Bernd Epple[a]

[a] *Insitute for Energy Systems and Technology, Technical University of Darmstadt, Otto-Berndt-Str. 2, 64287 Darmstadt, Germany*

Abstract

In the context of climate change, reducing carbon dioxide (CO_2) emissions is a key challenge. In 2024, approximately 41.6 Gt of CO_2 were emitted worldwide, representing an increase of 2.46 % compared to the previous year. The main sources are energy production, cement and lime production and the chemical industry.[1] As these sectors continuously release emissions, they offer a promising basis for the implementation of CO_2 capture technologies, with amine scrubbing currently being the only commercially available method for efficient CO_2 capture.

One of the most established post-combustion capture (PCC) technologies is amine scrubbing, which is characterised by high selectivity and large scale applicability. This technology enables a CO_2 capture efficiency of over 90 % and is already deployed in large-scale facilities processing several megatons of CO_2 per year.[2] The process performance is largely determined by the design of the packing in the absorption and desorption columns, as this influences both the mass transfer between the gas and liquid phases and the pressure drop. The latter, in turn, directly impacts the energy consumption and operating costs of the entire plant. Lower operating costs offer both economic and environmental benefits. An energy-efficient process reduces the energy demand of the capture plant and optimizes the utilization of available energy sources, thereby freeing up more energy for other industrial applications.[3]

This research investigates the experimental evaluation of novel packings for absorption and desorption columns, focusing on the analysis of the influence of geometric modifications of surface structures on the absorption rate and pressure drop. Table 1 presents the types of packings examined and compared. The PallRing 15×15 mm and the RaschigPak 350X were used as reference packings to evaluate the performance of the M33169 brushes and the 10500 strings. The specific surface area of the M33169 brushes is comparable to that of the PallRing (359 m^2/m^3 vs. 360 m^2/m^3), while the free volume of 97 % corresponds to that of the RaschigPak 350X. In contrast, the 10500 Adern exhibit an 86 % higher specific surface area than the PallRing, with an equivalent free volume of 95 %. A larger specific surface area improves mass transfer between the gas and liquid phases by increasing the contact surface. At the same time, a high free volume reduces flow resistance, thereby increasing the energy efficiency of the column.

Table 1: Comparison of the different packing structures in terms of specific surface area and free volume

Packing structures	**PallRing 15x15**	**RaschigPak 350X**	**M33169 Brushes**	**10500 Strings**
Visualization				
Surface area [m^2/m^3]	360	350	359	672
Free volume [%]	95	97	97	95

All experiments were conducted using the absorber test rig at TU Darmstadt, as shown in Figure 1. A detailed description of the test rig can be found in the paper "*Experimental Study of the Influence of Gas Flow Rate on Hydrodynamic Characteristics of Sieve Trays and Their Effect on CO_2 Absorption*".[4] However, modifications were made to adapt the setup to the specific requirements of this study. The setup consists of an absorber column and a desorber column with a reboiler, connected by a pump to enable continuous solvent circulation. The experimental results were analyzed based on the absorption rate and pressure drop to assess the efficiency of the different packing structures. The solvent used had a total concentration of 3 mol/L MDEA and 0.15 mol/L MEA.

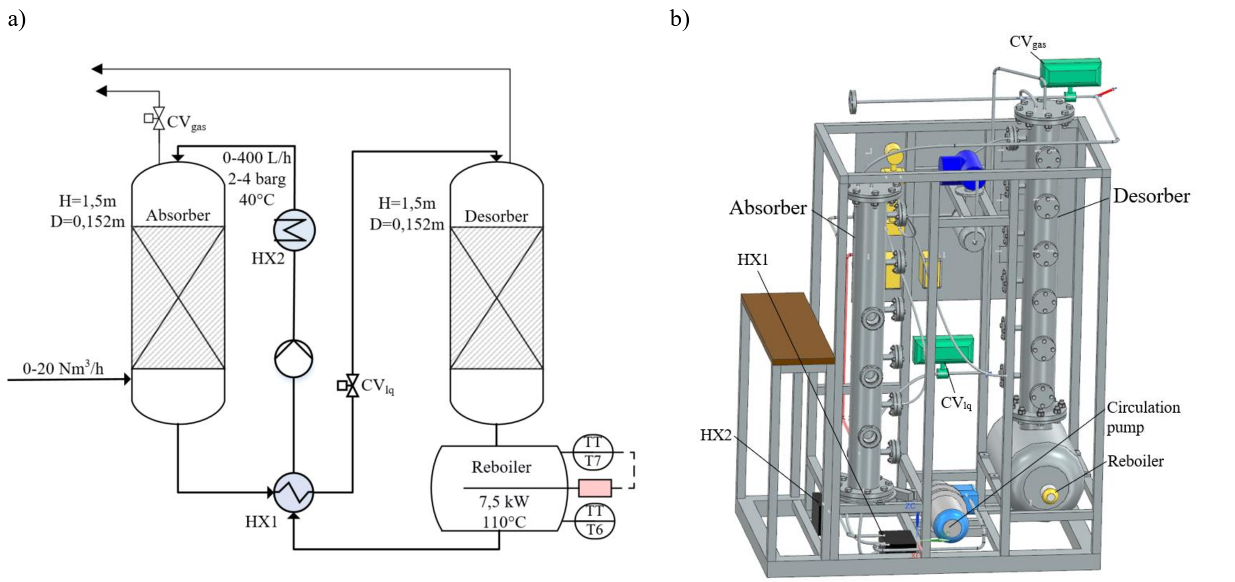

Figure 1: Absorber test rig at TU Darmstadt. (a) Schematic representation of the test rig, (b) CAD model of the test rig.

The main aims of this research are: (i) to evaluate a novel packing structure, (ii) to compare the novel structures with conventional reference tower packings, (iii) to analyze mass transfer performance and pressure drop, and (iv) to draw conclusions regarding the conducted experiments. The experimental investigations demonstrate that the novel packing structures are alternatives to conventional packings. It was shown that the tested structures reduce flow resistance by approximately 44% compared to PallRing 15×15 mm, without compromising mass transfer performance. This significant reduction in pressure drop was achieved while maintaining a comparable absorption rate, highlighting the potential of the novel packing structures for more energy-efficient gas absorption processes.

Keywords: carbon capture, amine scrubbing, novel packing structures

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