Desublimation in Packed and Tray Columns for Gas Mixture Separation and Carbon Capture

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Desublimation, the direct phase transition from vapor to solid, represents a powerful (and not deeply explored) mechanism for separating components from gaseous mixtures, especially in the context of gas purification, carbon capture and environmental remediation. For example, the CO_2 desublimation from syngas and flue gases offers several advantages compared to other technologies as follows: i) high selectivity; ii) temperature-driven separation (avoiding solvents, adsorbents or membranes); iii) dense-phase product recovery (avoiding the downstream compression/liquefaction); iv) good thermal integration potential; v) low water consumption and waste disposal. Despite its industrial significance, desublimation remains absent from classical chemical engineering textbook and curricula. This paper provides a first-of-its-kind educational and research-oriented framework for desublimation as a unit operation in gas-liquid contact columns and similar equipment. In this context, preference is given to equipment that generates direct contact between a gas and a cryogenic fluid, and then the discussion is extended to the particular cases of equipment with heat-exchange surfaces. Designed for advanced students, PhD researchers, and educators, the work develops rigorous thermodynamic and transport models, encompassing non-equilibrium phase change, solid deposition kinetics, and coupled heat and mass transfer phenomena. This last aspect in particular, is addressed with an innovative approach that allows us to highlight short-cut equations useful for design but also for educational purposes. In this work, the main process schemes and innovative equipment are described on the basis of an in-depth literature analysis with emphasis placed on the impact of hydrodynamics, pressure drop, and fouling. Applications to CO_2 and contaminant removal in gas purification and carbon capture processes are explored, highlighting desublimation's potential as a selective, energy-efficient, and scalable separation strategy. By addressing this overlooked topic, the paper expands the scope of chemical engineering education and initiates a critical discourse on solid-gas cryogenic separation as a unit operation.

Keywords: *gas-slurry contact equipment, unit operation, design method, short-cut equation, heat & mass transfer*