
Microwave Assisted CO₂ Desorption from Solvent Flowing into Hollow Fiber Membrane

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Résumé

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Keywords: EM modelling, separation process, Amine scrubbing, CO₂ capture, Gas absorption, Microwave regeneration, process intensification.

A Promising Alternative for Carbon Capture

Chemical absorption is considered as one of the most mature technologies for carbon capture from flue gases, it is composed of the absorption stage where CO₂ is dissolved chemically into the solvent and the desorption stage where the latter is regenerated at high temperatures. Despite its technological maturity it suffers from several drawbacks most noticeably the large equipment footprint and the high operating cost of the desorption stage. This is presented by the intensive steam consumption that provides heat for the desorption reaction of CO₂ and acts as a sweeping gas. Lately, application of microwave technology (MW) to chemical absorption has been receiving increasing attention owing to increased operational flexibility, small footprint, and most notably its intensification potential (2), (3). Successful scale-up of the process depends on the choice of the gas-liquid contactor. Hollow fiber membrane modules can be used in MW assisted CO₂ desorption due to their inertness to MW irradiation. In addition, they provide a further potential for process intensification thanks to their high surface area in comparison to packed columns(4), (5). This original research

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aims at studying the potential of MW technology for improving the chemical desorption of CO₂ from aqueous ethanolamine solution, while using hollow fiber membrane modules as a gas-liquid contactor.

MW-Assisted Solvent Regeneration: Experimental Investigation at the Scale of a Single Fiber

The MW assisted regeneration of the solvent was first studied at the single fiber scale, this was done to examine the effect of the local temperature/concentration gradients and hydrodynamic conditions on the CO₂ desorption flux at steady state. To this end, a single hollow fiber (PTFE), was placed in a microwave cavity, in a concentric manner relative to a quartz tube as shown in Figure 1. A CO₂-rich solvent and an N₂ stream were circulated through the fiber lumen and the annular area between the fiber and quartz tube respectively. Incident MW irradiation bypasses the inert membrane material and are dissipated in the solvent, this increases the latter's temperature and reverses the absorption reaction to release gaseous CO₂. The released CO₂ diffuses through the unwetted gas-filled pores of the membrane only to be swept by an N₂ flow on the annular side similar to a "sweeping gas membrane distillation" mode. Experimental campaigns focused on characterizing the response of the system with respect to:

- Solvent flow rate: set to similar hydrodynamic conditions as in a membrane module unit
- Solvent CO₂ loading: varied over the range of operating conditions of a classical stripping column
- MW power: controlled to achieve different average outlet liquid temperatures
- Sweeping gas flow rate

Results show the increase of the desorption flux with respect to all tested parameters.

MW-Assisted Solvent Regeneration: Numerical Modeling at the Scale of a Single Fiber

Considering the multitude of the involved coupled physical phenomena, a progressive step-by-step approach was applied in accounting for all physical phenomena. COMSOL® Multiphysics 6.0 software was used to solve the Maxwell's equations to obtain E-field maps throughout the MW cavity and solvent. Afterwards, heat transfer and Naviers-Stokes equations were coupled with Maxwell's equations and solved over the fiber domain to generate spatial temperature maps in the solvent. Numerical results show that strong radial temperature gradients exist in the solvent, most notably at the stagnant film region near solvent-fiber boundary, this is contrary to the liquid bulk where the temperature is somewhat homogenous (figure 2). In parallel, a 1D mass-transfer model for reversible isothermal absorption of gases in reactive liquids proposed by Weiland(6) was coded using MATLAB® using finite different method. Mass-transfer is modeled using the film theory (7) by considering liquid film with membrane thickness, while neglecting gas side resistance. The transfer mechanism in the membrane was described by combined molecular/Knudsen diffusion. The desorption reaction was accounted for through an enhancement factor assuming an instantaneous reaction regime (8). The temperature map latterly obtained was transformed into two longitudinal 1D T-profiles, representative of the liquid bulk and film regions respectively. Incorporating the obtained T-profile pair into the 1D transfer model permits the desorption to be simulated at non-isothermal conditions. Simulation results show that local desorption flux J increases as a function of the temperature along the fiber length (figure 3). The average flux showed considerable deviation existed with the experimental results, but perfect agreement was achieved through application of partial wetting condition on the membrane where the wetted fraction was varied to minimize the gap with experimental data.

Conclusion and Perspectives

The MW assisted CO₂ desorption was investigated experimentally on the scale of a single

hollow fiber to validate a model simulating desorption rates function of different operating parameters. Future challenges will focus on upscaling the modeling approach from the scale of a single fiber to that of a membrane module containing a bundle of fibers in a non-uniform E-field, or even different desorption configurations such vacuum decompression stripping.

Figure 1: MW assisted regeneration of CO₂ rich solvents at the scale of a single hollow fiber.

Figure 2: Radial temperature map of solvent under MW irradiation

Figure 3: Simulated local desorption/T profiles function of fiber length

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JEMP 2023-IFPEN, Rueil-Malmaison, France_17-19 Octobre 2023