Non-linear dynamics of CO₂ absorption in aqueous solutions of NaHCO₃ and Na₂CO₃ in a Hele-Shaw cell

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Context : study of CO₂ absorption in the Solvay process

- During the production of refined sodium bicarbonate NaHCO₃ by the Solvay process, CO₂ is absorbed in an aqueous solution of NaHCO₃ and Na₂CO₃ and is consumed by several chemical reactions
- CO₂ absorption is the limiting step in the whole process → a better understanding is sought in order to optimize the CO₂ transfer rate

Experimental tool : a Hele-Shaw cell in a Mach-Zehnder interferometer

- A Hele-Shaw cell, containing an aqueous solution of NaHCO₃ and Na₂CO₃, is set in a Mach-Zehnder interferometer
- Liquid forms a horizontal free surface along which a pure CO₂ gas is forced to flow
- The gas to liquid CO₂ transfer is coupled with chemical reactions in the liquid phase, which consume CO₃⁻ and produce HCO₃⁻
- A dynamic fringe bending is observed with the Mach-Zehnder interferometer

Observation of instabilities during the CO₂ transfer

- Interferometric fringe patterns are converted into refractive index maps, using a 2D-Fourier transform method
- A zone with lower refractive index is observed below the interface during the CO₂ transfer, corresponding to the formation and growth of a boundary layer originating from the change of the composition caused by the chemical reactions in the liquid
- It is observed that after some time, the initially quiescent liquid sets in motion and a highly dynamical variation of the overall refractive index field is observed in the liquid :

Origin of the instability ?

A linear dependency of the refractive index on the density of the solution was measured → one can translate the observed refractive index variations into liquid density variations (neglecting in first approximation the influence of the temperature variations)

Perspectives

- Taking into account the temperature variations for the refractive index conversion
- Flow visualization during the transfer
- Ongoing analysis based upon the Navier-Stokes-Darcy model in the Boussinesq approximation:

\[ \rho \left( \frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} \right) = -\nabla p + \eta \nabla^2 \vec{v} - \frac{12}{5} \rho v^2 + \frac{\partial \rho}{\partial \rho} \nabla \rho \]

+ appropriate convection-diffusion equations with chemical reactions
+ the equation of state :

\[ \Delta p = \Delta p(C_1, C_2, ...) \]