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► **To cite this version:**

Sophie Charton, Marouan Nemri, Eric Climent. Mixing and axial dispersion in Taylor-Couette flows: a multi-scale study. AICHE Annual Meeting, Nov 2013, San Francisco, United States. pp.0. hal-04103921

**HAL Id: hal-04103921**

**<https://hal.science/hal-04103921>**

Submitted on 23 May 2023

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**To cite this version** : Charton, Sophie and Nemri, Marouan and Climent, Eric Mixing and axial dispersion in Taylor-Couette flows: a multi-scale study. (2013) In: AIChE Annual Meeting, 03 November 2013 - 08 November 2013 (San Francisco, United States)

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# Mixing and axial dispersion in Taylor-Couette flows: a multi-scale study

S. Charton, M. Nemri, E. Climent

Liquid-liquid extraction in an industrial apparatus is a complex process involving chemistry, interface dynamics, mass transfer and fluid mechanics. Among these phenomena, transport processes, which are size-dependent, deserve a particular attention in the scope of R&D studies (where size-reduction is encouraged, as in the nuclear industry) and for scale-up purpose. Hence, flow patterns and properties in extraction devices are the subject of increasing interest, involving numerical as well as experimental studies. In this aim, we choose to take advantage of Taylor-Couette flows, already used to perform small-scale solvent extraction studies, in order to investigate the specific hydrodynamic issues: mainly mixing and axial dispersion.

Taylor-Couette flows take place in the annular gap between two concentric cylinders with the inner one rotating and the outer one fixed. This flow is known to evolve towards turbulence through a sequence of successive hydrodynamic instabilities. These different flow-patterns are likely to influence dramatically the mixing properties. Moreover, the simple and periodic geometric configuration of Taylor-Couette flows allows Direct Numerical Simulations to be performed.

Prior to the study of the mixing properties, the sequence of flow instabilities has been determined using a visualization technique for both the small-gap and large-gap columns we used. Thanks to a spectral analysis, the transition Reynolds and hydrodynamic characteristics of the achieved flow states were identified. Start-up procedures were also established in order to confidently reproduce these flow states.

At the reactor scale, it is commonly admitted that all the mechanisms responsible for flow non-ideality and mixing are represented by a single and assumed linear process, and are quantified by a lumped parameter: the axial dispersion coefficient  $D_x$ . The  $D_x$  evolution along the successive flow states encountered in the small-gap R&D apparatus ( $g = 1.5$  mm), was investigated thanks to dye's Residence Time Distribution measurements. In agreement with literature results related to different aspect ratio configurations, axial dispersion was observed to increase with cylinder rotation. Moreover, although the results reproducibility was checked, different  $D_x$  values have been measured, for a given Reynolds number, depending on the initial condition and start-up procedures. This flow hysteresis effect is well-known, although its effect on axial dispersion had not yet been demonstrated experimentally. The measured  $D_x$  evolutions were confirmed by Direct Numeric Simulations results, which highlighted furthermore that the larger the cylinder's gap, the higher the influence of the flow regimes.

The local mechanisms involved in mixing have been characterized by means of simultaneous PIV (particle image velocimetry) and PLIF (planar laser induced fluorescence) measurements. A specific apparatus, with a large-enough gap to perform accurate optical measurements ( $g = 11$  mm) was specifically designed for this purpose. Simultaneous PIV and PLIF measurements were performed in different flow patterns: Taylor vortex flow, wavy and modulated wavy vortex flow.

PLIF visualizations showed clear evidences of different transport mechanisms going from diffusion-like intravortex mixing to fluid bundle transport between neighboring vortices. Moreover, the PLIF results have confirmed the occurrence of intervortex mixing in the steady Taylor Vortex Flow regime, especially in the near-wall regions and at inflow boundaries. The relative importance of each mechanism, as well as their evolution, depending on the flow structure and wave state, have been studied and elucidated, thus supplementing the conclusion of the “macroscopic” studies. The results confirmed that the occurrence of different wavy regimes, depending on flow history (hysteresis), may have a dramatic effect on mixing for a given Reynolds.

This study demonstrates that the commonly used 1-parameters chemical engineering models (e.g. the “well-mixed stirred tanks in serie” model) are not valid to model Taylor-Couette reactors: two parameters are at least required for an efficient description of mixing in Taylor-Couette flows.