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ScienceDirect

Procedia Chemistry 21 (2016) 461 – 465

Procedia Chemistry

5th International ATALANTE Conference on Nuclear Chemistry for Sustainable Fuel Cycles

Development of optical techniques for chemical engineering applications

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Abstract

The design of separation processes for nuclear spend fuel treatment, dedicated to either R&D studies or industrial applications, is currently based on a phenomenological approach, relying on Computational Fluid Dynamics, and complemented by validation tests achieved at small-scale. Indeed, most of the steps of the PUREX® process involve multiphasic flows (dissolution, leaching, liquid-liquid extraction, precipitation, filtration, etc.). Therefore an accurate knowledge of the dispersed phase properties is required in order to assess their coupling with the flow features, to predict the process performance and efficiency and to achieve size reduction or extrapolation.

Hence, the measurements of particulate flows properties, and especially the particles (or drops or bubbles) size distribution, concentration (*i.e.* hold-up) and velocity has become a growing issue. Relevant techniques for measuring these flow properties are multiple, from the high-speed video acquisition coupled to image processing to the laser-induced fluorescence, including the particle imaging velocimetry or interferometric techniques (digital in-line holography, rainbow refractometry, etc.). In this communication, different techniques developed at CEA Marcoule for the characterization of multiphase flows, will be introduced. The strong interaction with computational fluid dynamics, in the scope of a multiscale approach, will be discussed through typical results of gas-liquid, liquid-liquid and solid-liquid flows possibly encountered in nuclear fuel reprocessing process.

Peer-review under responsibility of the organizing committee of ATALANTE 2016

Keywords: Multiphase flow, optical measurement

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1876-6196
Peer-review under responsibility of the organizing committee of ATALANTE 2016
doi:10.1016/j.proche.2016.10.064

Nomenclature

CFD	Computational Fluid Dynamics	PSD	Particle Size Distribution
DH	Digital holography	PTV	Particle Tracking Velocimetry
PIV	Particle Imaging Velocimetry	RD	Rainbow Diffractometry
PLIF	Planar laser induced fluorescence.		

1. Introduction

The design of the separation processes for the nuclear fuel cycle is based on an approach involving tests and developments on small-scale prototypes[1] as well as a phenomenological approach, relying on computational fluid dynamics[2] (CFD) and chemical engineering. Moreover, most of these separation processes are based on multi-phase flows (liquid-liquid extraction, dissolution, leaching, filtration, precipitation, etc.). As a consequence, the determination of the flow properties in the related apparatus, especially the velocities of both phases and properties of the dispersed phase (concentration, size distribution and shape, etc.) is mandatory and becomes a growing issue. For our nuclear applications, relevant techniques for measuring these flow properties are multiple, from the high-speed video acquisition coupled to image processing to the laser-induced fluorescence, including the particle imaging velocimetry or interferometric techniques (digital in-line holography, rainbow diffractometry, etc.). Optical techniques can be easily applied on dedicated experimental setups and fluids; extrapolation from the lab-scale to the industrial one is obtained thanks to similitude rules.

In this paper, different techniques developed at CEA Marcoule for the characterization of multiphase flows, will be introduced. They are strongly linked with Computational Fluid Dynamics (CFD), one of the pillars of the multiscale approach, discussed in another communication[2]. This paper is divided in three sections, 2- flow velocities measurement, 3- mixing mechanisms and transfer between phases and 4- the particle size distribution and shape of the dispersed phase. Finally some conclusions and outlooks are given.

2. Velocity measurement techniques

Since the behavior of the dispersed phase is strongly dependent on the turbulent properties of the flow, measuring the dispersed phase velocity in a given flow is a key issue. Velocity of the continuous phase is classically measured by particle imaging velocimetry (PIV). PIV is a flow-field technique providing instantaneous velocity vector measurements in a cross-section of a flow, based on the measurement of the displacement of seeding particles between the two images thanks to a camera and a laser light. Associated to high speed imaging, PIV can be a time resolved technic allowing the measurement of flow features in time as well as space. Moreover, when performed with sufficient accuracy, PIV can be used to determine turbulent quantities and help in choosing the most accurate numerical model of the flow[3].

The velocity of the dispersed phase, in another hand, can be measured by particle tracking velocimetry (PTV) or PIV depending of the hold-up. For low hold-up (e.g. <1% of dispersed phase), PTV provides an individual tracking of the particles displacement, strongly linked to instantaneous velocity variations. Using a stereoscopic setup, PTV can be a tool for particle's trajectory reconstruction allowing evaluation of more quantitative information like the residence time in a specific area of the reactor.

For high hold-up, cross-correlation process used in PIV can be directly applied to image acquisition, considering the dispersed phase as a seeding (see Fig. 1).

3. Mixing and local flow properties measurement techniques

Mixing mechanisms, local flow properties and interaction between phases, are of major importance in chemical engineering studies, especially in so far as mass transfer is concerned. Mixing is generally characterized by mean of