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Relevance of digital in line holography for multiphase flows characterization

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Abstract

Digital in-line Holography for investigating multiphase flows is reviewed and discussed in the scope of the development of apparatus convenient for nuclear fuel reprocessing. As a volumetric imaging technique, it allows to measure the 3D-position, dynamics, shape and size of flowing micron- to millimeter-sized particles, even considering complex pipe flows. Besides addressing this typical issue of multiphase flows characterization, it can also be, when considering transparent particles, a way to recognize materials and/or to monitor exchange between phases.

Context

A significant part of the chemical processes involved in recycling industry are based on multiphase flow (liquid-liquid extraction, dissolution, leaching, filtration, precipitation, etc.). Therefore, complementing the chemical investigations, achieved at lab-scale, fluid mechanics studies are carried out, where possible at a larger scale, to apprehend the possible flow effects on the chemical processes efficiency. Such studies are conducted using computational fluid dynamics (CFD) but an experimental validation, especially regarding the properties of the dispersed phase (concentration, shape and size distribution, etc.), remains mandatory. Many techniques are implemented and adapted in this aim and, among them, digital in-line holography (DIH) is particularly relevant as it allows to get simultaneously a detailed geometrical description (size, shape, trajectories, etc.) of the dispersed phase and information about transfer (heat, mass, etc.) between phases thanks to refractive indexes measurements.

Digital In-Line Holography principle

Digital in-line Holography (DIH) is based on the diffraction intensity pattern, called hologram, produced by the interaction between the diffracting particles and a coherent laser beam. Thanks to a digital processing of the hologram, proper images of the particles can be reconstructed and the particles parameters estimated (mainly their size and 3D position in the setup). As it provides size, tridimensional position of particles, and the related quantities (velocity, acceleration, hold-up, etc.), DIH is becoming a reference technique for the characterization of multiphase flow at lab scale (Hinsch

2004; Pan 2003; Tian 2010). Moreover, thanks to the direct illumination of the sensor, the use of high speed imaging is achievable, allowing the monitoring of transient phenomena.

Relevance for multiphase flows characterization

With a limited number of particles (fewer than 30), individual tracking is achievable by analyzing a series of reconstructed holograms separated by time intervals. In this case, hologram optimization by inverse approaches (Lamadie 2014), makes it possible to obtain submillimeter resolution on particle's center position in space. Such a precision allows particle's path reconstruction with only one sensor and the visualization and can reveal interactions between particles as well as local phenomena in time and space (changes in direction and/or speed) with a good sensitivity. When a larger number of particles is considered (around 80), mean values can be computed from several holograms. The number of measurable particles is mainly limited by overlapping diffraction patterns, which is exacerbated when large-diameter particles mask the signals from smaller ones. Basically, for the 1-mm diameter particles considered here, the method remains accurate until 1% in volume fraction of dispersed phase. Fig. 1 displays the 3D visualization of both the position and the diameter of more than 70 oil droplets rising in water and ranging from 0.5mm to 1.5mm. Using current holograms processings, DIH remains dedicated to the characterization of diluted media. This limitation is quite similar to that of a conventional one point-of-view imaging setup while retaining a complete 3D reconstruction including a focus capacity in any plane of the observed volume like a plenoptic camera (Lamadie 2012).

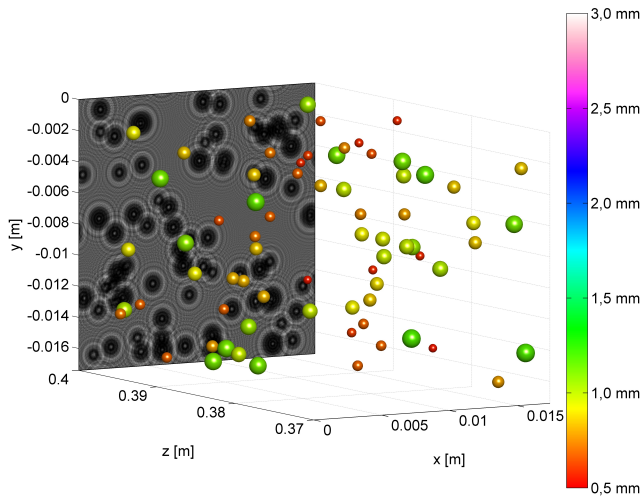


Figure 1: 3D visualization of around 70 millimeter-size oil droplets rising in a water phase at rest processed from a single shot hologram - Color-coding: particle diameter

As holograms are digitally processed, it is easy to take into account optical elements included in the imaging setup even considering a strong astigmatism. By combining the Rayleigh-Sommerfeld integral and the ABCD transfer matrix of the optical system (Sentis 2017), DIH becomes totally suitable for a multiphase flows characterization in any kind of optical system, including cylindrical tanks and pipes. Using this approach, Sentis et al. have recently proved that DIH can retrieve easily the exact 3D position of droplets flowing in a strongly curved pipe (Sentis 2017).

Finally, DIH can also provide an evaluation of the composition of spherical transparent particles. Indeed, refracting particles, when they are illuminated by a coherent light beam, produce a photonic jet with a maximum of intensity whose relative position depends on the optical properties of the particle material. When reconstructing the near field of the particles using DIH, it is possible to detect this maximum and, to retrieve the particles refractive index using a simple geometrical optics approximation. Considering such an approach, it has been recently proved that DIH can differentiate several oils in a liquid-liquid flow (Sentis 2017b) or discriminate between gas, liquid and solid particles in multiphase flows (Sentis 2018), see for instance Fig. 2.

Conclusions

Nowadays, the design of the chemical engineering processes is based on an approach involving tests and developments on small-scale prototypes as well as a phenomenological approach relying on CFD. As illustrated in this communication, DIH, in this framework, is an indisputable source of information on the properties of multiphase flows encountered in process engineering. Associated to CFD, it forms a relevant tandem for R&D studies and provides a new approach for understanding and studying fluids dynamics in chemical engineering application.

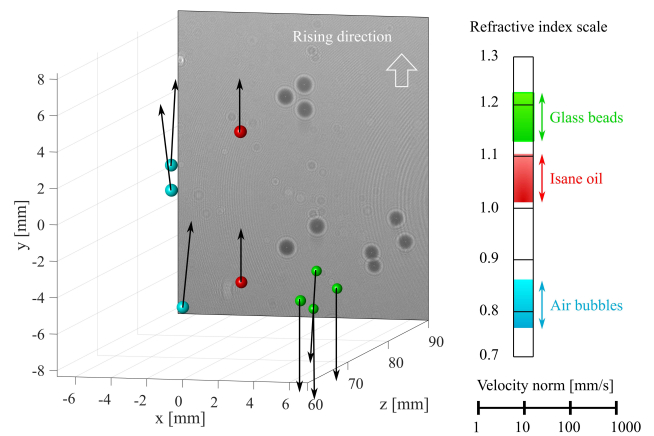


Figure 2: Complete reconstruction of a diluted multiphase flow, i.e. 3D-position, velocity, size and composition of each particle detected in the recorded hologram.

Acknowledgments

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