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Computer Assisted Gamma and X-Ray Tomography: Applications to Multiphase Flow Systems

Topical Report
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Contents

Abstract

The application of X-ray and gamma ray transmission tomography to the study of process engineering systems is reviewed. The fundamental principles of tomography, the algorithms for image reconstruction, the measurement method and the possible sources of error are discussed in detail. A case study highlights the methodology involved in designing a scanning system for the study of a given process unit, e.g., reactor, separations column etc. Results obtained in the authors' laboratory for the gas holdup distribution in bubble columns are also presented. Recommendations are made for the Advanced Fuels Development Unit (AFDU) in LaPorte, TX.

Executive Summary

In process vessels, involving two or three phases it is often important not only to know the volume fraction (holdup) of each phase but also the spatial distribution of such holdups. This information is needed in control, trouble shooting and assessment of flow patterns and can be observed noninvasively by the application of Computed Tomogrephy (CT). This report presents a complete overview of X-ray and gamma ray transmission tomography principles, equipment design to specific tasks and application in process industry.

The measurement principle used in gamma ray tomography, based on attenuation of a collimated beam of radiation, is common to densitometry which is frequently employed in the industry for obtaining chordal average phase holdups in multiphase reactors and other process units. The important differences and advantages of CT compared to densitometry are highlighted. The available scanning modes, i. e. strategies for acquiring data for CT are reviewed from the perspective of industrial process units and reactors. All the important elements of the hardware required in the implementation of a CT scanner are discussed. A variety of algorithms for image reconstruction are compared on the basis of results for simulated and physical phantoms (test cases). The superiority of the Estimation-Maximization (EM) algorithm in established.

The measures of CT scanner performance are discussed in terms of the achievable spatial temporal and density resolution. Various possible errors in the measurement and image reconstruction process are outlined, as well as the means for alleviating these errors. The mechanics involved in the CT scanner design is illustrated by discussing the design of the system built at the Chemical Reaction Engineering Laboratory (CREL) at Washington University in St. Louis and the system that was implemented at the Nuclear Engineering Department at Ohio State University (OSU). In the first case the spatial resolution was of importance, in the other case temporal resolution was of prime consideration. Compromises that need to be made to achieve a given design specification are discussed.

The literature on the use of tomography for studies of fluid dynamics in a variety of systems is summarized. The results for the gas holdup distribution in a bubble column obtained at CREL are discussed. Finally, a design for a CT scanner that can be implemented on a large scale industrial reactor is provided . The advantages of implementing this system include the availability of data on gas holdup distribution in greater detail in comparison to what is obtainable by gamma denistometry that is currently being used at LaPorte on the AFDU reactor. This experimental information is essential to verify phenomenological and computational fluid dynamic models as well as scale-up rules used in reactor design. This indeed is the purpose fro which the CT scanner at CREL is used. It is hoped that this report will encourage a more wide spread use of CT technology in R & D and industrial practice.