USE OF PROCESS TOMOGRAPHY TECHNIQUE FOR CHARACTERISING FLOW DISTRIBUTION IN A COLD FLOW TRICKLE BED COLUMN

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ABSTRACT

In the petrochemical industry, many processes are carried out using fixed bed reactors with concurrent upward and downward gas and liquid flows. For a catalytic trickle bed type of process column, capturing representations of steady-state flow features as well as unsteady situations like plug formation and preferential flowing is a challenging task. In order to characterize the liquid and gas flow distribution through a mock-up column, data on planar and volume density distribution can be very useful. This information can be obtained by employing Gamma-ray tomography or process tomography (PT). PT makes use of advanced computational procedure on directly measured data indicating the gamma rays transmitted through a planer section of the column in multiple angular orientations. The resultant reconstructed image gives the planer distribution of the effective attenuation coefficient in the region of interest which in turn helps in judging the flow patterns in multiphase flow. Isotope Applications Division of BARC has developed a gamma ray transmission tomography system in collaboration with the Indian oil Corporation Ltd (IOCL R&D Unit, Faridabad). The newly designed and developed system makes use of thirty two scintillator based gamma ray detectors in addition to a host of other sub-systems. This paper describes the capabilities of the reconstruction software using a mathematically simulated specimen as well as an experimental setup of process column to map the approximate attenuation coefficients of materials contained across a specified plane. The reconstructed data represents cross-sectional image representing the approximate density distribution. This is a first of its kind of collaborative project in the country to demonstrate PT capabilities and its applications in process industries.

Keywords: Process tomography, Trickle bed column, flow characterization, tomography, two phase flow.

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INTRODUCTION

Process Tomography (PT) using electromagnetic radiations is one of the few techniques to study multi-phase flow systems in laboratories and process industries. PT is an advanced diagnostic NDE technique based on a computational procedure operating upon directly measured data. The measured data represents some characteristics of the physical state or process as a result of interaction with one or more types of external probing radiation. The information extracted from such data and represented in tomographic form gives vital information on the steady state fluid dynamics thereby making it useful for optimizing process column design, control and monitoring. In order to characterize the liquid and gas flow distribution through a mock-up column, data on planar and volume density distribution using computed tomographic measurements are very helpful [1,2,3,4].

Fig. 1 : Process Tomography with fan beam geometry in block diagram form (a). Mechanical manipulator (b) and the process column with catalyst alumina (c).
A multi-detector Cs\textsuperscript{137} radioisotope based in-situ PT manipulator; shown in Fig. 1 (b), suitable for 600mm diameter cold flow trickle bed column containing alumina balls of size around 1 to 1.5 mm as catalyst shown in Fig. 1 (c) has been specially designed and installed at IOCL R&D Unit at Faridabad [7]. This paper is in continuation of the preliminary studies carried out and reported earlier [7] and describes, through some experiments under controlled conditions, the overall performance evaluation studies in actual working environment of the column.

**EXPERIMENTAL SETUP**

The radioisotope source based tomographic system makes use of 662 KeV monochromatic gamma rays from a fan-beam collimated beam generator containing approx. 300 mCi of Cs\textsuperscript{137}. The radiation detector sub-system consists of total 32 BGO scintillator-PMT integral assemblies and associated Data Acquisition (DAQ) system. A computer controlled mechanical manipulator has been designed and fabricated to operate in synchronization with the data acquisition system. The mechanical movements and data acquisition of the transmitted radiation through the column takes place in a pre-defined sequence and geometry. It is controlled automatically through a master computer located about 15 m away from the actual column. The Graphic User Interface (GUI) of the control software, PROTOM, is shown in Fig. 2. There is a provision of vertical movement of the mechanical assembly to scan at different levels of the column. The detectors are positioned along an arc with a gap in between, such that by activating a pneumatic actuator the 32 detectors can acquire data for 64 positions. The data is automatically written in a text file and saved on the hard disc at predefined location through a USB interface. Analytical reconstruction technique is used to reconstruct the tomographic images after preprocessing the transmission data [5, 6]. The GUI of the reconstruction software, PRATIMA, is shown in Fig. 2.

**EXPERIMENTAL STUDIES**

A set of simulations were carried out earlier [7] to test the accuracy of reconstruction software, DAQ, mechanical assembly. For further validation of the complete system, which includes mechanical manipulator, detector & DAQ system and the software module working in sync with each other, some experiments were carried out using objects of known shape, size and relative densities. Such a trial was taken in actual industrial operating conditions. Six different materials with relatively lesser density variations among themselves were used as specimen. The materials were CLO (clarified oil), HSD (High Speed Diesel), VGO (Vacuum gas oil), water, dry alumina and alumina with water arranged here in the ascending order of density. Figure 3 shows their relative positions and sizes arranged in a circular formation as seen in the photograph. FIGURE 4 Evaluation study with four measuring cylinders containing Alumina + Water immersed in dry alumina bed. Image in (a) is with raw data and (b), (c), and (d) includes data processing.

In a second experiment, to determine the overall sensitivity of the system, four different cylinders of size approximately 150 mm, 80mm, 65mm, and 30mm containing alumina and water were immersed in dry alumina bed. This was done because the main goal of the set-up is to find the liquid (water) and gas flow distribution in the presence of catalyst (alumina). The density difference in such a case is narrow and it was our aim to observe the minimum size of such a region that can be spotted using the current PT system.

Later, in another study the column was filled with catalyst alumina and liquid and gas was allowed to flow in only one half of the column by completely blocking flow in the second half. A thin partition of aluminium was introduced to prevent any cross flow of liquid in the column. During the study, liquid collected from several small regions of the column at the drain was measured. This distribution is shown in Fig. 5 (b).

![Fig. 2: Graphic User Interface (GUI) of PT system controller (left) and PT reconstruction software (PRATIMA).](image-url)
RESULTS AND DISCUSSIONS

The tomographic images after reconstruction reproduce different scenario in a satisfactory manner as shown in Fig. 3, 4 and 5. The images in Fig. 5 (d), (e) and (f) are obtained after some processing of the projection data using 3 point averaging, 5 point averaging and ‘loess’ (10%) data filter. These filters introduce some smoothening reducing the effect of any minor detector calibration issues or effect of scattering and noise in the reconstructed image. It is observed in general that there is improvement in the images after such filtering. In the course of the above experiments we have observed some anomalies in one of the detector’s response. Hence the response from that particular detector has been interpolated from the neighboring detectors on either side in all the above results.

As seen in Fig. 3 (g), the tomographic cross section indicates not only the variations in the size of the cylindrical containers
and their relative positions but also distinguishes their density difference in the order given earlier.

In case of Fig. 4 it can be seen that using the raw data cylinder with 30mm diameter filled with alumina and water buried in dry alumina bed is not clearly distinguished compared to the other cylinders. However, on some data processing the same cylinder may be just distinguished.

Finally, the same trend is observed in the results of the study where liquid and gas is made to flow in only one half of the column. The images are shown in Fig. 5. The data preprocessing is clearly indicating favorable results.

For accurate reconstruction in PT, just as in case of any other tomography system, the alignment of the mechanical system w.r.t. the column, accuracy of its motion in a single horizontal plane and synchronized operation of the other subsystems is of paramount importance. It has been observed from the data that there may be some misalignment in the positioning of the mechanical system and the overall span of the fan beam of detectors may be modified to further enhance the sensitivity of the final cross-sectional images.

The overall spatial resolution is limited here by the size of the detector crystal (~19mm) but is sufficient for the current application. The typical data acquisition time is around 60 minutes depending on the counting time settings for detector response and the flow is assumed to be at a steady state condition during this period for the interpretation of the final results.

CONCLUSIONS

The reconstructed images obtained from the system are in reasonably good agreement with the actual specimen with specific regard to shape, size and distribution of relative attenuation coefficient within the circle of reconstruction of the column. The sensitivity of this system can be assumed to be approximately 5-7% based on the available results. However further trials are needed to conclude on it definitively.

It has to be noted here that the accuracy of the final results after reconstruction completely depends on the quality of data being provided to the reconstruction module. The accuracy of the data in turn depends on the appropriate positioning and motion of the mechanical system and precise calibration and functioning of the detectors and data acquisition system in the field conditions.

FUTURE PLANS

Many experiments have been planned on the setup to systematically establish the troubleshooting abilities of the PT technique to process columns of industrial size. More test scans are being planned with controlled flow conditions in the column as well as with some artificially induced flow.

![Fig. 5](image)

PT on liquid and gas flow in one half of the column. The liquid collected at the drain is shown in (b) and (c), (d), (e), (f) show the PT images with raw, 3 pt, loess and 5 pt data filter resp.
distributions using different types of flow distributors. Such results can also be verified using appropriate computational fluid dynamics modeling studies.

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