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ANALYSIS OF AN INDUSTRIAL PROCESS SIMULATOR COLUMN USING THIRD-GENERATION COMPUTED TOMOGRAPHY

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ABSTRACT

The CT methodology must be tested using a simulator column in the laboratory before applying it in the industrial plants. In this work, using the third-generation industrial computed tomography developed at the IPEN, a gas absorption column, used as a simulator column for industrial process was evaluated. It is a glass cylindrical tube of 90 mm diameter and 1400 mm height constituted the following parts: random packed column, liquid circuit (water), gas circuit and analysis was used as a simulator column. Gamma ray tomography experiments were carried out, using this simulator column empty and filled with water. In this work the scanner was setting for 90 views and 19 projections for each detector totalizing 11970 projections. The resulting images describe the presence of liquid or gas phases and are possible to evaluate the linear attenuation coefficients inside the column. In this case, linear attenuation coefficient for water was 0.0813 cm^{-1}. It was established that the newly developed third-generation fan-beam arrangement gamma scanner unit has a good spatial resolution acceptable given the size of the column used in this study.

1. INTRODUCTION

The gamma ray computed tomography techniques for industrial processes evaluation has been indicated as the most promising in order to visualize the structure and the distribution of solids, liquids and gases inside multiphase systems such as industrial columns, capable to obtain measurements in real conditions without interrupting the operation. The multiphase systems are structures that contain dynamic and complex mixtures inside reactors or pipes (packed and bubble columns, fluidized beds, porous media, etc) increasing the heat and mass transfer, rate reaction, etc. [1,2,3,4,5,]. These systems are widely used for many industries, such as chemical, food pharmaceutical and oil sectors. The objective of the computed tomography (CT) applied is visualization the flow pattern of multiphase flows by of imaging aiding to improve the design, operation and troubleshooting of industrial processes [2,3,6]. Computed tomography for multiphase processes is now a promising technique and has been studied for advanced research laboratories [1,2,3,4]. To follow this trend and to keep update, the IPEN laboratory has carried out a study for the development and advance the computed tomography methodology [5,67,8,9].

Scanners for transmission tomography employ radiation isotropic sources, such as an encapsulated gamma ray source, positioned in one side of the object to be scanned, and one or a set of collimated detectors arranged on the other side [11,12]. In the tomography of third generation, the source is collimated so that the path crossed by beams is similar to a fan. The system moves around the targeted object, obtaining a particular view for each position of the source-detector array. In this type of system, several sources and arrays of multiple detectors may be used, in fact this depend of the spatial or time resolution required. [8,9,11]

Usually, the analyzed objects in the industrial tomography field have high density and large dimensions, such as the column diameters in oil refining process. Consequently, a high energy radiation source is required in order to across the material. Commonly, a dense detector material can be necessary to absorb the photons from the source [13,14]. Scintillation detectors as NaI(Tl) (3.8 g/cm^3) and CsI(Tl) (4.3 g/cm3) or BGO Bismuth-Germanium-Oxyde (Bi4Ge3O12, 7.13 g/cm^3) are widely used in tomography applications.

A third generation computed tomography was developed for industrial applications at the CTR-IPEN (8,9]. In its configuration, an array of seven 2" NaI(Tl) detectors are placed in an arc concentric at the center of the ^{137}Cs gamma source and the entire apparatus rotates around the object. In order to increase the number of projections measurements in one view of the column, the number of detectors in the arc was effectively increased by using a collimator that moves across the detector arc. The whole assembly of the detectors and the radiation source are mounted on a gantry capable of being rotated round the test section axis through a stepper motor interfaced with a host computer. For testing the developed tomography, experiments were carried using a laboratory scale industrial process column.

2. EXPERIMENTAL PROCEDURE

Tomography measurements were performed using the third generation CT developed at the CTR/IPEN [IEEE2011]. Each of the seven 2" NaI(Tl) detectors has an individual collimator made in lead, so that the detectors are completely shielded by the collimator. Each collimator has a hole of 5 mm diameter for sampling beams. These dimensions for the collimator holes were optimized based on considerations of providing adequate area for detecting photons with good statistic into the chosen sampling period. The radioactive sealed ^{137}Cs (662KeV) source is 3.7 GBq placed inside a lead shield collimated system providing a 45° fan beam arc Fig. 1.

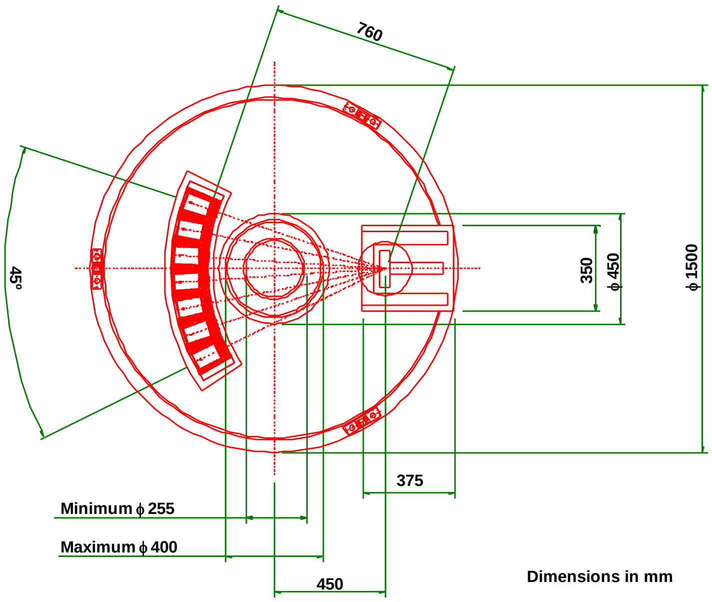


Figure 1. Top view drawing of the CT used.

The CT methodology was tested using a laboratorial absorption column Mod. UOP7, Armfield Limited, USA, (Fig. 2) widely applied the industrial plants. The system is built with gas and liquid flow and pressure meters and its possible increase random packing inside it. The column is made in Perspex glass with 90 mm diameter and 1400 mm.

Figure 2 – Gas absorption column.

The array of seven NaI(Tl) detectors and the ^{137}Cs source were placed on the rotatable gantry and the absorption column was installed in the center between the array of detectors and the source. The gantry can be rotated around the axis of the column by a stepping motor that is controlled through a microprocessor. The size of the array of detectors is sufficiently large so that the entire column was within the field of view of the detectors all the time. Moreover, the whole assembly can be moved in the axial direction along the column to perform a scan at different axial levels of the column. Fig. 3 shows a illustration of the third generation CT with the absorption column in the center of the gantry. The data acquisition board and the mechanical control used were developed at CTR/IPEN also. [8,9].

The tomographic measurements were carried out using the empty and water filled column. To obtain statistically significant results, and to reduce the effect of the position the CT scans were obtained rotating around the column the plate with the source and detectors 360° in 90 views, each view provided 4°. The movement of the detector–collimator assembly was controlled by another steeper motor, in each movement, this assembly rotated by 0.39° generating 19 projection per detector or 133 (19x7) projections per view. The totalizing 11970 projections per image. Previously, each NaI(Tl) detector was evaluated by gamma spectrometry techniques using a associated multichannel electronics and data acquisition board developed by CTR/IPEN.

The reconstruction algorithm used was the Alternative Minimization (AM) technique and was implemented in MATLAB and VB platforms [11, 12]. This reconstruction algorithm is used, since, it has the following advantages: (1) it accounts for statistical variations associated with the radiation decay measurements; (2) it readily incorporates non-uniform beam effects; ans (3) it ensures that the final reconstruction contains only positive values.

Figure 3. Picture of the third generation CT with the column installed.

In order to validate the CT methodology developed, the linear attenuation coefficient of the water was determined by attenuation measurements of the water using the third generation CT. A 15 cm height and 5 cm diameter Beaker glass filled with water was placed in the centre of the gantry, between the source and the array of detectors. The water attenuation coefficient was measured in order to confirm the CT results obtained with the column.

3. RESULTS AND DISCUSSION

A typical energy spectrum obtained for the NaI(Tl) detectors used in the building of the third generation CT is presented in Fig.4. All detectors showed to be suitable for their utilization in the proposal application.

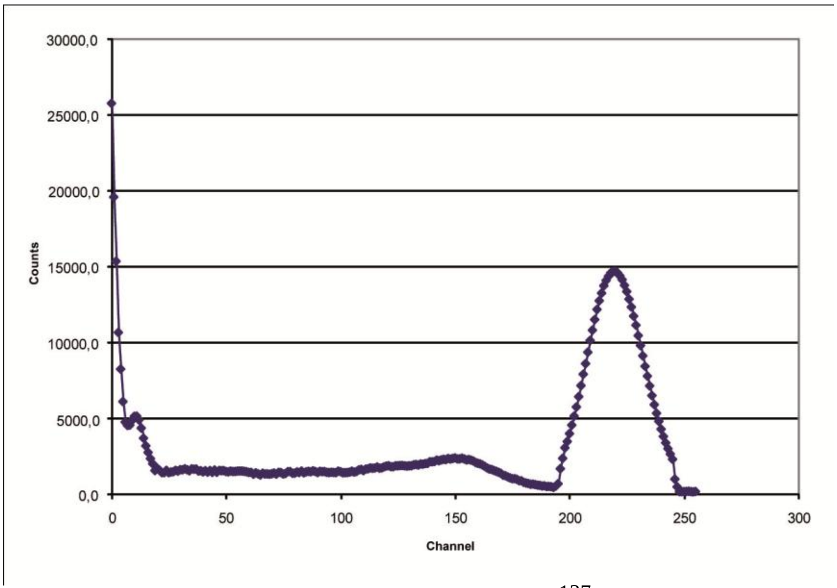


Figura 2. Energy spectrum of the (667 keV) ^{137}Cs gamma radiation.

Fig. 3 is shows the results of the transmittance lines obtained from the tomographic measurements for the empty column (3a) and the column filled with water. It can be seen from this figure, well defined transmittance lines were found for different phases. The lower transmittance value was found inside the column filled with water compared to that the empty column (air). The transmittance due to the polyethylene wall of the column can also be observed with enough evidence for both cases. In the air region (around the outside of the column) the transmittance values were near one.

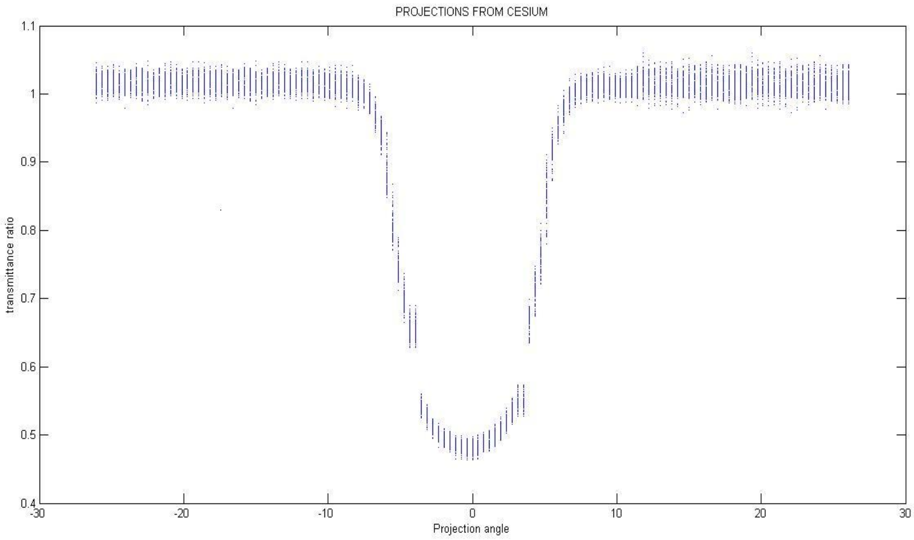
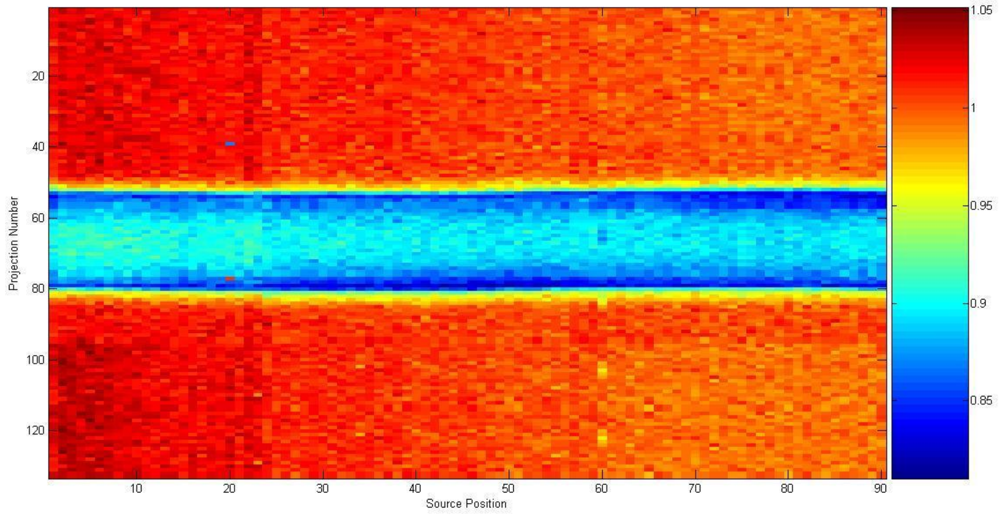
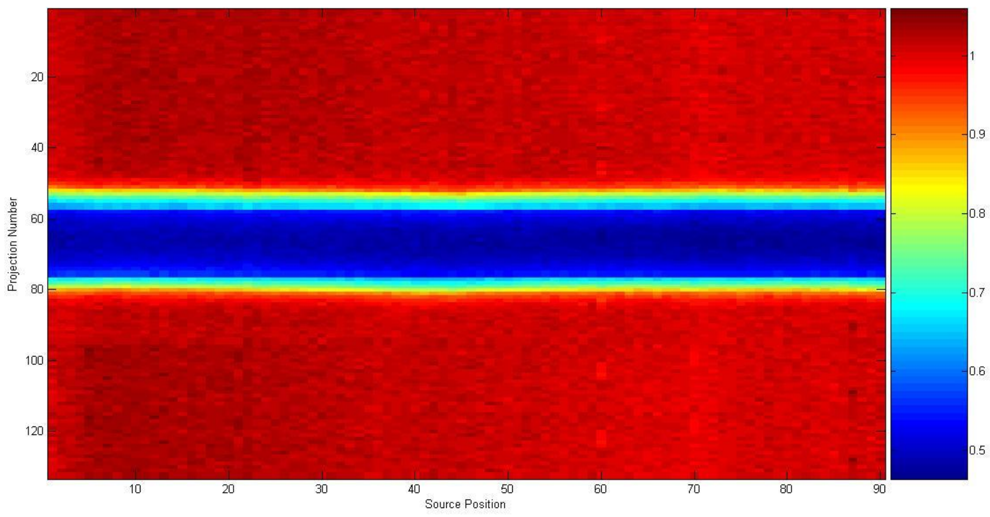


Figure 3 – Transmittance lines obtained for simulator column empty (a) and Filled with water (b)

Figure 4 shows the sinogram obtained for simulator column empty (3a) and filled with water. Each pixel from the sinograms represents the transmission value (I/Io) corresponding to a given projection and position of the source (view) or rotation angle. The sinograms showed dark blue shades to the objects of greater density. A sinogram allows checking the measurements quality obtained in the tomography sampling process. The absence of parallel bands or spots that could be attributed to malfunctioning detectors ensured the end result.



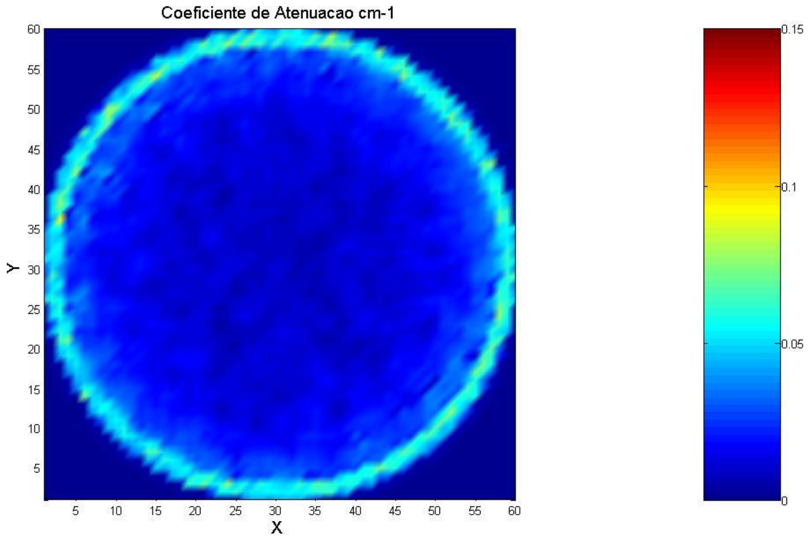
(a)



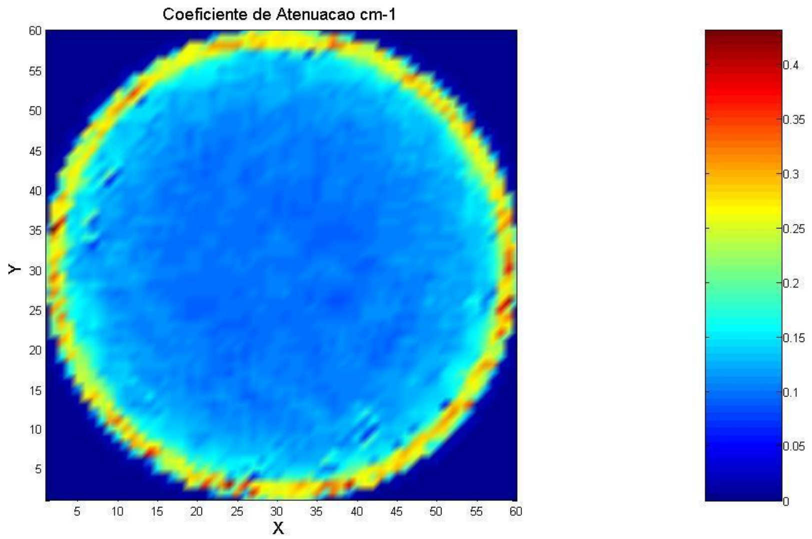
(b)

Figure 4 – Sinogram of the simulator column empty (a) and filled with water (b)

Fig. 5 presents the reconstruction image of the empty column (5a) and water filled (b). A good resolution was observed for both images, as shown in Fig.5. The attenuation coefficient of the water calculated from the image was 0,0813 cm^{-1} which is comparable to the theoretical value described in the literature for this material [14]. By the other hand, as expected, the attenuation found for the air inside the column was the similar of the outside column. Also, the glass wall of the column can be reconstructed well defined.



(a)



(b)

Figure 5 – Reconstruction image from the simulator column empty (a) and filled with water (b)

3. CONCLUSIONS

It was established that the newly developed third-generation fan-beam arrangement gamma scanner unit has a good spatial resolution acceptable given the size of the column used in this study. The CT is capable of providing phase (liquid or gas) composition information in two phase systems. Although the system is only capable of providing time-average data, it can provide unique information concerning the structure of two phases systems. The main advantage of the CT include it's a non-invasive nature, capability for providing local as well as global information and adaptability for automating the entire data acquisition process. However, more experiments need to be done to optimize many parameters and finally operating conditions column such as gas and liquid velocities need to be studied. For the industrial point of view, the design and scale-up of multiphase flow reactors is of great importance. Any research on the hydrodynamics of such reactors therefore needs to enhance our level of understanding of the complex systems.

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