

Results of Process Equipment Imaging by Tomographic Gamma Scan

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Gamma scanning is a nuclear inspection technique widely used for troubleshooting industrial process equipments in refineries and petrochemicals. A radiation source and detector move vertically along the height of the vessel and the radiation readings are used to plot the graph of density profile. In recent years, many improvements have been added to this technique, but essentially the result of gamma scanning still consists of a 1-D density plot. Developed in 2012, the tomographic gamma scan uses image reconstruction techniques to show the result of gamma scan as a 2-D density distribution image. In this work, we present the current status of the technology and the results obtained by applying the technique to real operating process equipment. The results present images that match well with the 1-D density plots obtained by the conventional gamma scan and reveal process and operational problems that has never been visualized before with the traditional technique. The tomographic gamma scan can be immediately applied in practice with low financial investment.

1. Introduction

Distillation column density profiling or "column scanning" (Charlton, 1986) is commercially available for more than 30 years (Severance, 1981) and has been successfully applied in many countries around the world. Gamma scan results can be used for several purposes inside a plant such troubleshooting problems (Kister et al., 2017), operational and turnaround planning, and design studies (Outili, et al., 2013).

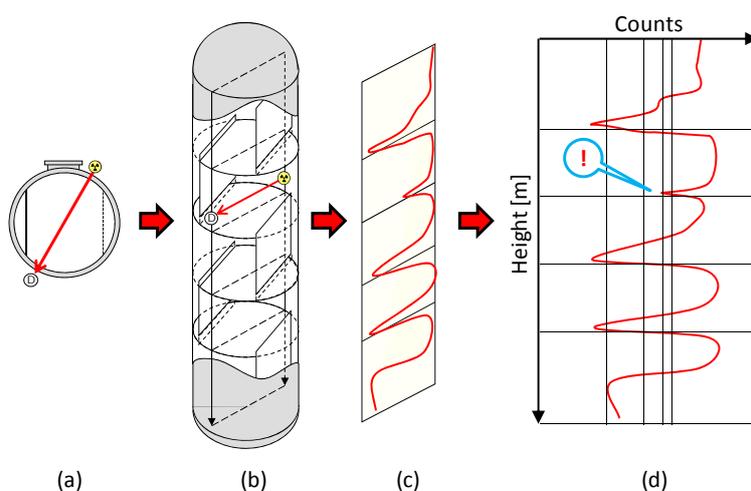


Figure 1: Typical gamma scanning process: job planning (a), field data acquisition (b), plotting (c), reporting and interpreting (d)

The main concept of the gamma scan is simple. It consists of a gamma source and radiation detector capable of moving to the same height with the aid of a positioning apparatus. An electronic interface for power supply and counting system is often connected to a computer for data storage and graphic plotting. A typical gamma scan job process is presented in Figure 1.

The results obtained are represented by one or more lines in XY plot with counts, or relative densities, on the abscissa axis and heights on the ordinate axis. Low count peaks represent high density areas and high count valleys represent low density areas. The density profiles represent the vessel, internals and hydraulic profile of the column, which correspond to the average radiation absorption at each height.

Over the years, this inspection service has incorporated advances such as portable computers, improved acquisition software, wireless detection, automatic positioning, data interpretation (Pless, 2014), etc. However the basic concept remains the same and the results still consist of a 1-dimensional density profile of the column. New technologies such as industrial tomography (IAEA, 2008) had been also introduced (Xu et al., 2009) and although became commonly applied in research works (Busciglione, et al., 2017) there are still few cases in the Non Destructive Test (NDT) industry (Wolschlag et al., 2010).

2. Image improved gamma scans

In 2012, an innovative concept (Haraguchi et al., 2012) was proposed to obtain a 2-dimensional density profile of an industrial equipment at the same vertical plane as the regular gamma scans. This proposal was part of requirements for the Master of Science program at Center of Radiation Technology (CTR) of Institute for Nuclear and Energy Research (IPEN), Brazil. This technique, shown in Figure 2, resulted in a patent deposit and Petrobras Technology Prize 2013 (in Refining and Petrochemicals category, Master Degree) was granted to the inventors.

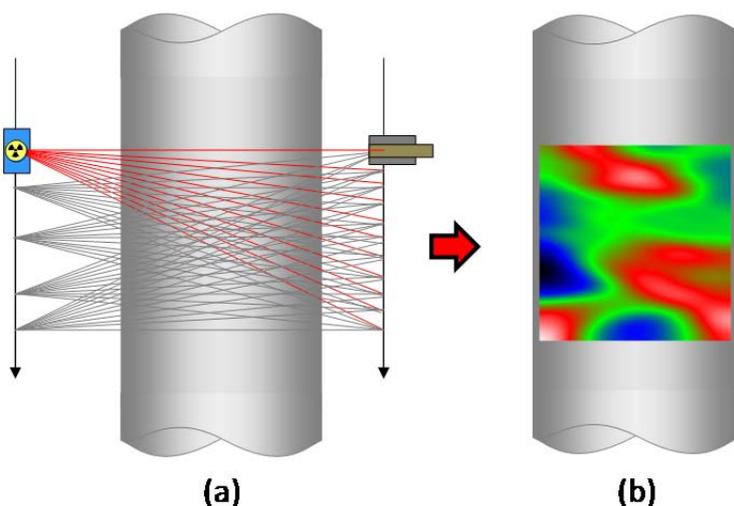


Figure 2: Tomographic Gamma Scan: Movement of source and detector and positioning scheme (a), sketch of an reconstructed image (b).

The concept was tested at CTR's laboratories with the irradiation of two column models designed to simulate situations difficult to be investigated with the regular gamma scan: a one-pass trayed column scanned perpendicularly through the downcomer area (Figure 3) and a random packing bed with empty areas, dense spots and unlevered packing simulating a severe liquid maldistribution (Figure 4). Image reconstructions were done in the Signal Processing Laboratory (LPS) of Escola Politécnica, Universidade de São Paulo. To facilitate visualization, we use pseudo-colors in the density distribution images with different colors representing different linear attenuation values. E.g.: black = air ($\mu = 68 \times 10^{-6} \text{ cm}^{-1}$), green = water ($\mu = 63 \times 10^{-3} \text{ cm}^{-1}$) and white = steel ($\mu = 420 \times 10^{-3} \text{ cm}^{-1}$).

A 2-dimensional image of an industrial equipment represents an advance over the conventional gamma scan techniques, because:

- Dimensional – since conventional gamma scan registers only the mean density at each height, vertical features cannot be spatially localized. The tomographic scan overcomes this limitation by adding one more dimension. Equipments difficult to be inspected by conventional gamma scan (Urbanski et al., 1999) have now new possibilities of testing;

- Interpretation – internals, problems, process and phenomena are easier to understand in an image than in a conventional gamma scan plot.

As a secondary result of the project, other important capabilities were also developed:

- Irradiation simulation of the process and the internals of the equipment.
- A priori density distribution can be used to improve the results.
- The choice of reconstruction method and image filter to minimize errors (Kim et al., 2016).

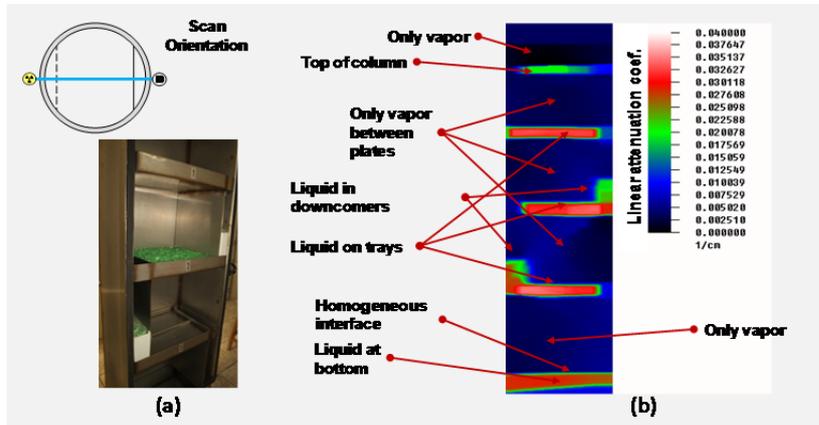


Figure 3: Trayed column model (a), image reconstructed after irradiation (b).

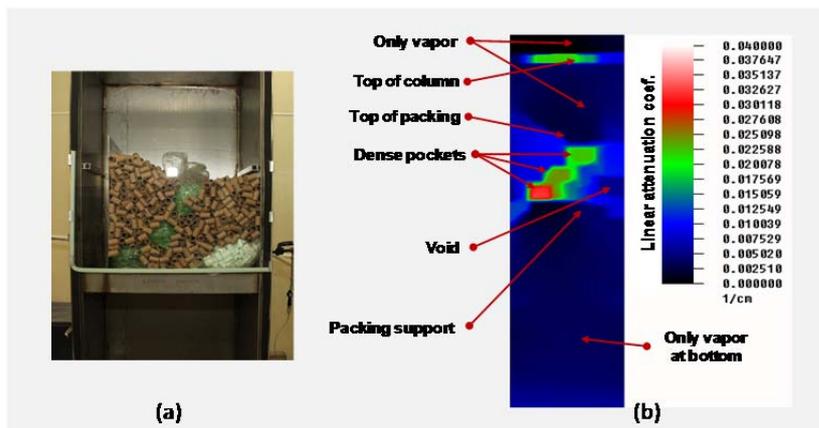


Figure 4: Packed column model (a), image reconstructed after irradiation (b).

3. Field testing

In 2014, a Ph.D. thesis was proposed with the objective to make the tomographic gamma scan available in real field conditions. The quest involved not only technology issues as reconstruction techniques and image quality, but considered other aspects involved on a typical field job such as scanning time; equipment characteristics (cost, weight, simplicity, robustness) and setup; and radiation safety into the decision matrix. A standard gamma scan equipment, with proper setup and minor modifications, was used to collect data of both cases presented in this paper.

3.1 Case 1 - Ripple Trayed Column

The first tomographic gamma scanning in a real industrial equipment was carried out in a water stripping column located in a petrochemical plant in Brazil. With 1,300 mm internal diameter and equipped with 10 ripple trays as shown in Figure 5, this column has been already scanned several times with conventional technique but results could not pinpoint any specific problem to explain the operational limitations. Only the top section of the column, including a 8" diameter fish bone type liquid distributor and 6 trays, was scanned with 10 cm spacing between consecutive positions of radiation source and detector, resulting in 908 data

points collected in approximately 2 hours. The tomographic scans were performed in the same direction of previous conventional gamma scanning of this equipment to allow a direct comparison. The result of the tomographic gamma scanning, shown in Figure 6, is consistent with the conventional scans. Imaging analysis should take into account the ideal operation of each internal and whether it contains, or not, liquid or aerated liquid. Any deviation from the ideal profile may indicate a mechanical or operational problem. The results of the analysis can be summarized as follows:

- The liquid distributor is in the correct place, with liquid and leveled. The scans crossed it diagonally and a symmetric shape can be seen at the corresponding elevation as expected, indicating that the central tube and lateral pipes are at their right places.
- An area of low density can be seen above the distributor, indicating that there is no liquid entrainment to the top of the column.

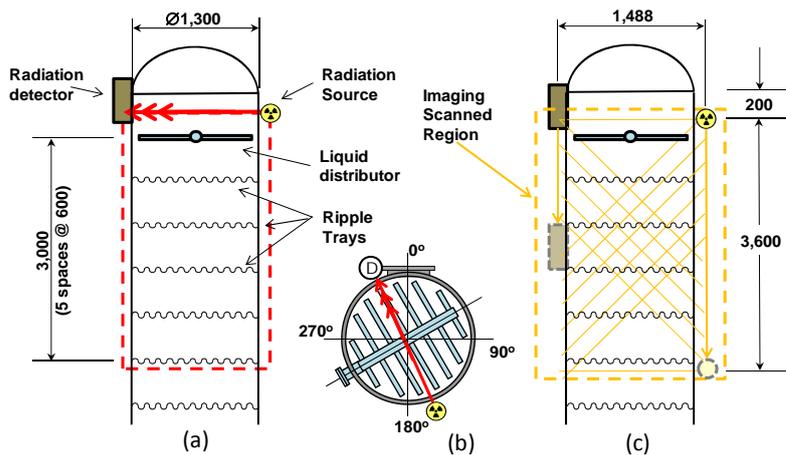


Figure 5: Top of water stripping column layout (a), conventional scan and imaging orientation (b), imaging scanned region (c).

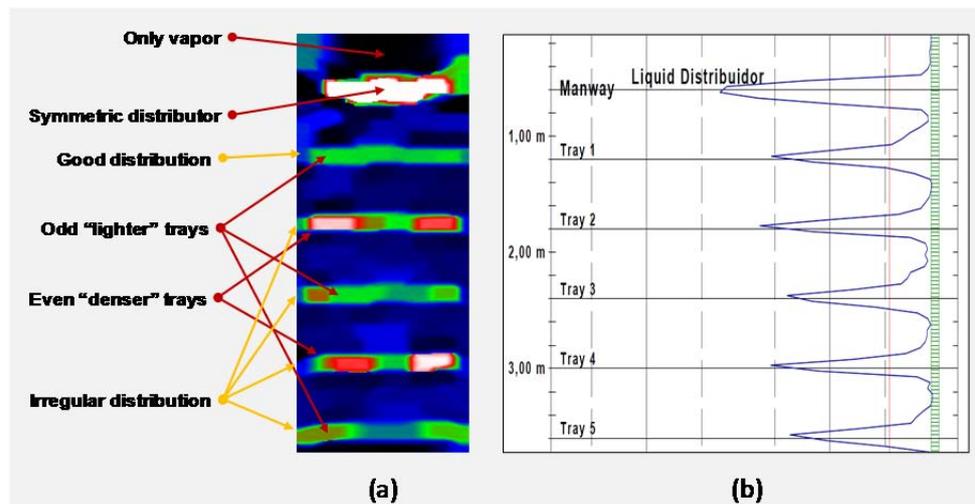


Figure 6: Imaging result (a), conventional gamma scan plot (b).

- Trays 1 through 5 can be seen at their appropriate elevations. The liquid in the trays seems to be leveled and there are no high densities in the spaces between trays that would indicate entrainment, flooding or other abnormal process phenomena.
- Even numbered ripple trays seem to be denser than odd numbered ones as indicated on both tomographic and conventional gamma scans. Ripple tray assembling explains the difference as even numbered trays are mounted 90 degrees shifted in relation to odd numbered trays. In fact, gamma rays cross even ripple trays transversely, hitting the metals of all tray ripples, while they pass almost parallel to the odd tray ripples, hitting mostly aerated liquid.

4. Conclusion

The successfully experimental field tests on registering a theoretical phenomena and revealing an unpredictable equipment problem showed how the tomographic gamma scan opens a new field of opportunities for the research and industry in Non Destructive Test (NDT). In the short time, it would not compete directly with the conventional gamma scan but complement it. However, the cost-benefit may change as technology advances with multi detector gamma systems and multi slice scanning. Another important achievement for the NDT industry is the use of conventional gamma scanning equipment for data sampling, allowing a fast transition to the new technology, with low financial impact.

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