Distillation Column Troubleshooting with Improved Gamma Scan Technique

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ABSTRACT

Gamma scanning is a nuclear inspection technique used to troubleshoot industrial equipments in refineries and petrochemicals plants around the world. In this technique, a sealed radiation source and detector move along an equipment, and the intensity readouts generate a density profile of the equipment. The simplicity of this technique has made it popular in many countries. In recent decades, many improvements have been proposed, from automated scanning to wireless detectors, new collecting software and improved data presentation. However, the technique concept has not changed since it was proposed decades ago, and the results still consist on a one-dimensional mean density profile of the target. The present work, developed in a master degree project, describes a new approach for gamma scanning. The innovative technology shows the result of a gamma scan as a two-dimensional density distribution plot. Clearly, a two-dimensional image reveals more features of the equipment under analysis, representing an advance in the non-destructive testing, as many problems that could not be troubleshooted using conventional gamma scanning can now be seen with this imaging technique. The innovative technology, patent pending, received an award from a recognized petroleum company.

Keywords Distillation Columns, Gamma Scanning, Industrial Tomography.

1 Introduction

In continuous production plants like refineries and petrochemical sites, process equipment performance is analyzed with the help of a process model, based on the operational variables, quality of feed and products (Eldridge 2006). With increasing complexity and restricted boundaries of process, design and operations, the use of NDT (Non-Destructive Testing) has been widely used to validate on-line, check and troubleshoot these process equipments and models.

Among the available technologies, nuclear techniques stand out by not perturbing or affecting the process under analysis, and allowing to perform online testing. Modern equipments and methods permit that nuclear techniques found only in literature migrate to the field. Distillation column gamma scanning, neutron backscattering, chemical and radioactive tracers and industrial computerized tomography are commercially available nowadays and represents one of the most powerful techniques to on-line analyze process equipments.

Within these technologies, the distillation column profiling was consolidated as one of the best options to perform mechanical and operational troubleshooting. Although it relies on simple principles, the practical use is complex due to the high specific knowledge required in all phases of a typical project. This barrier also turns out to be an extra difficulty for a wider divulgation and acceptance by the market, as the final customer also must have a good experience with the technique.

To solve technical difficulties and searching for a competitive edge, the inspection industry developed several new solutions for the gamma scanning. However, they did not result in information of higher quality. All technologies on the market are based on the same principle: register gamma ray attenuation to generate a mean density profile. If a new technology presents the results in a more direct and understandable way, this paradigm would break and the gamma scanning would have a wider acceptance.

The computerized tomography has been available for medical use for more than 30 years and now it reaches surprising level of complexity and precision. Using tomography for imaging industrial equipments appears to be a good alternative for the gamma scan profiling. Although medical tomography and industrial tomography use the same concepts, gamma scan that produces 2-D images faces a series of new challenges, difficulties and limitations. The initial achievements of this research are described in this article.

2 Process Equipment Analysis

2.1 Process equipment

The performance of equipments can be measured, understood and designed through process models, where input variables can be directly measured (temperature, pressure and flow rate) or determined (composition, heat consume, mixture, reaction and feed stock). These models are built considering some project premises, and are robust enough to account for the normal measuring errors and parameter variations.

However, the process model cannot account for random, uncontrolled, unknown and even human error events:

- Physical – corrosion, mechanical damage and faulty assembly;
- Process – contamination, unexpected physical-chemical phenomena, fouling and saturation;
- Operational – operational disturbance, instrument lecture error and coking;
- Human – project problems, homemade repair solutions and human mistakes.

This is the context where some special Non-Destructive Testing (NDT) has their main focus, permitting to check process and to troubleshoot the equipments online (Charlton 1986). Nowadays the use of these techniques had spread beyond the process and operations engineering to other fields of industrial plant engineering:

- Maintenance – online evaluation of equipments;
- Shutdown planning – opening equipments, supply parts purchasing and extent of field work;
- Projects and revamps – critical points verification, start up monitoring, baselines and performance study;
- Predictive practices – critical equipment monitoring.

2.2 Gamma ray profiling or gamma scan

Gamma ray column profiling or simply gamma scan is one of the most used NDT techniques to evaluate the online mechanical and operational behavior of process equipments. In this technique, a radioactive source and detector are positioned in opposite sides of the equipment and move simultaneously along its length. The measured radiation attenuation values result in the profile of longitudinal density. The profile or scan plot is then analyzed and the results are present in a report (Pless 2001, Urbanski 1999).

Figure 1 shows an example of a column gamma scan plot. The density profile is shown at left and the sketch of the column is presented at right.

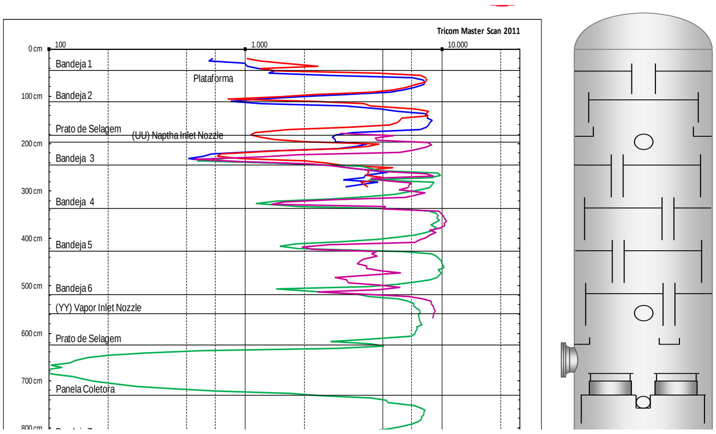

Figure 1. gamma scan plot example.

2.2.1 Limitations of the technique

Column gamma scanning has some limitations that restrict its use in some applications:

- Count rate – as the time available in field tests is limited, gamma scans are limited to the cases where a statistically significant count rates can be obtained. Source activity and energy, detector size and efficiency, column diameter and length, wall thickness and the constitution of the analyzed equipment must be analyzed to verify the viability of the project. Radiation safety issues are equally relevant due to limitation of personal equivalent doses (Sanches 2007);
- Mean density – every point of a gamma scan plot represents the mean density along a gamma ray path. Any analysis of a gamma scan data should take into account the mean behavior of the density profile. Additionally, in bigger or trickier equipments, the gamma ray profile tends to smooth problems and phenomena. This limitation has been partially contoured with baseline scanning, a common practice for the most critical equipments. Baselines can be obtained with equipment off-line (dry-scan) or online (operational baseline) at optimum operational conditions;
- Positioning – since the gamma scan is a mean density profile, a data interpretation is possible only where the proprieties of the object are kept constant during the test and along the gamma ray path. This considerably limits the positioning possibilities and the types of density profile that can be obtained. Many times, complex equipments are hard or impossible to be properly scanned;
- Dimensions – a density profile offers a one-dimensional view (elevation-wise) of the mean density of equipment. Multiple scans or grid pattern scans are often utilized to obtain some spatial notion of the density distribution.

2.2.2 The art of gamma scanning

Although conceptually simple, the technique of gamma scanning requires a combination of knowledge, skills and talent of the crew that directly interfere in the quality of the gathered information and trueness of the written report. These characteristics are so restrict that historically training a crew is one of the biggest difficulties that the industry faces. With this scenario the industry of gamma scan has invested in some solutions:

- Field work – automatic movement systems, wireless detectors and pre-adjusted electronics;
- Data view – automatic report and plot generation, online web visualization of data gathering.

Even though there was a clear advance using some of these improvements, there are some remarks:

- User-friendly equipments and procedures normally implies on less flexible systems and thus harder to adjust in the field;
- As a result of an easier training, less experienced crews reach the field;
- Distance monitoring do not eliminate the presence of a specialist on gamma scan, as many tests cannot be repeated;
- Frequently, some improvements resulted in loss of quality of the collected data.

2.3 Industrial Computed Tomography

The advent of conventional industrial tomography inspections opened new possibilities in troubleshooting industrial equipments (Peyton 1999, Xu 1999, Xu 2000, Wiens 2009), either as a complementary tool to regular gammas scanning, or to directly identify the distribution cross pattern of the target (Xu 1999). Manual movement, with single source and single or multiple detectors are the standard field equipment arrangements due to its simplicity (IAEA 2005, IAEA 2008, Johansen 2004, Kim 2006). Logistics (due source activity and right plant operational conditions) and infrastructure (with extensive use of scaffoldings) play key roles in a typical project.

3 Improved gamma scan imaging

In principle, as long as the emission and detection coordinates are known, it is possible to obtain a tomographic image of any spatial arrangement. Historically, linear or circular geometries are the most common layouts due to construction convenience, image reconstruction algorithm or shape of the object to be scanned. In this work, we explore the possibilities of a non-conventional arrangement designed to develop new inspection techniques for industrial equipments like distillation columns and reactors.

The Improved Gamma Scan Imaging concept arises from the development of a conventional industrial tomography methodology back in 2008, carried out by Tricom Tecnologia and the Department of Electronic Systems Engineering, University of Sao Paulo (USP). In 2010 the project was developed as part of the requirement for a Master of Science degree at Center of Radiation Technology (CTR) of Institute for Nuclear and Energy Research (IPEN). The inventors were granted with 2013´s Petrobras Technology Prize, for Master Degree at Refining and Petrochemicals category.

3.1 Objectives

In this work, we propose to obtain a two dimensional longitudinal density profile of industrial equipments representing an advance in the conventional gamma ray profiling technique:

- Dimensional – a two dimensional density distribution image makes easier the visualization and identification of problems, process and phenomena of an equipment;
- Positioning – as a second spatial dimension is added, the number of longitudinal profiles can be reduced. Furthermore, features hidden in a conventional gamma scan, due to the mean density

values, can be revealed in an image. Similarly, density profiles or equipments that cannot be scanned with gamma ray profile can now be tested; and

- Interpretation – images are much easier to analyze and present compared to the conventional 1-D density plot. This can make easier the acceptance of the inspection by the customer and also facilitate the training of field personal.

3.2 Simulation studies

Several resources and tools from previous experience in industrial tomography were revised or adapted for this new technology. One direct application was the ability to simulate irradiations and reconstruct images that opened possibilities to:

- Compare several different source-detector positions with resulting image quality;
- Fine-tune reconstruction algorithm parameters;
- Reduce personal radiation exposition

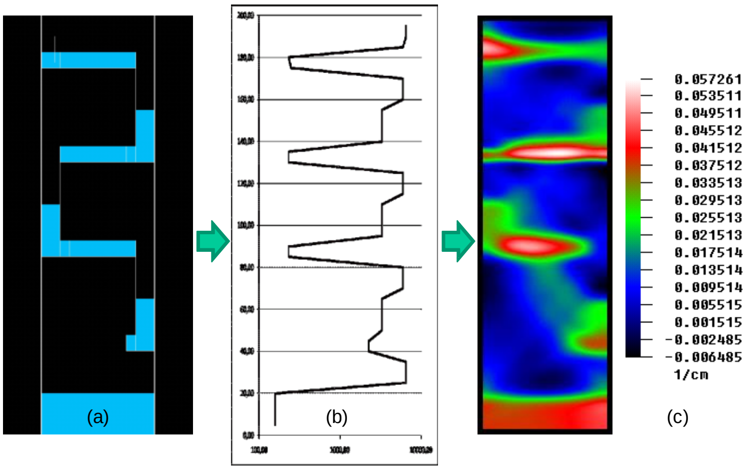

Figure 2. Computed simulated column arrangement (a), resulting gamma ray profile (b) and reconstructed tomographic image of a trayed column (c).

Figures 2 and 3 show examples of two simulated column arrangements, the resulting conventional gamma scan plot and the reconstructed image of the column. In Figures 2 and 3, the images at left represents the two types of typical distillation columns cross sections, with tray and packing assembly. The simulations are performed numerically, where each pixel color represents different μ (linear attenuation coefficients). In those simulations air, water, steel, steel packing and liquid distribution were considered. The software simulates the count rate obtained from a Cobalt 60 source with NaTl detectors.

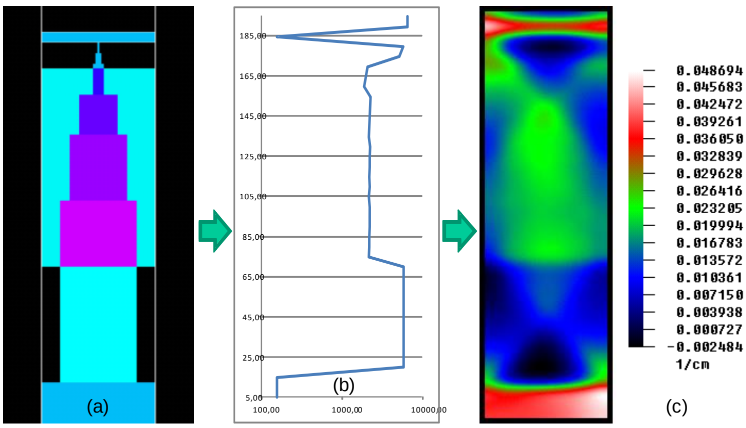

Figure 3. Computed simulated column arrangement (a), resulting gamma ray profile (b) and reconstructed tomographic image of a packed column (c).

3.3 Column model scanning

Two types of column layouts (one pass trayed and single packing bed - Figure 4) were build at CTR facilities in order to research several key aspects of data gathering:

- Source size and type
- Calibration and statistics
- Detector size and type
- Scanning pitch and angle
- Radioprotection safety
- Acquisition software

Figure 4. Column models: trayed (a), packed (b)

The distillation column models were constructed to simulate scans perpendicular to the downcomers in the trayed column, and severe maldistribution of liquid with dense and empty regions in the packed column. The resulting images obtained through model irradiation and image reconstruction are shown in Figures 5. Important features observed by analyzing the images are noted.

Experimental data were also used to fine-tune image reconstruction and filtering routines. As result, a "reiteration process" could be included in the methodology (Figure 6). The reiteration process uses the traditional gamma scanning experience to analyze the first obtained image, propose a possible result represented by this image and uses it as "a priori knowledge" to obtain the second improved image.

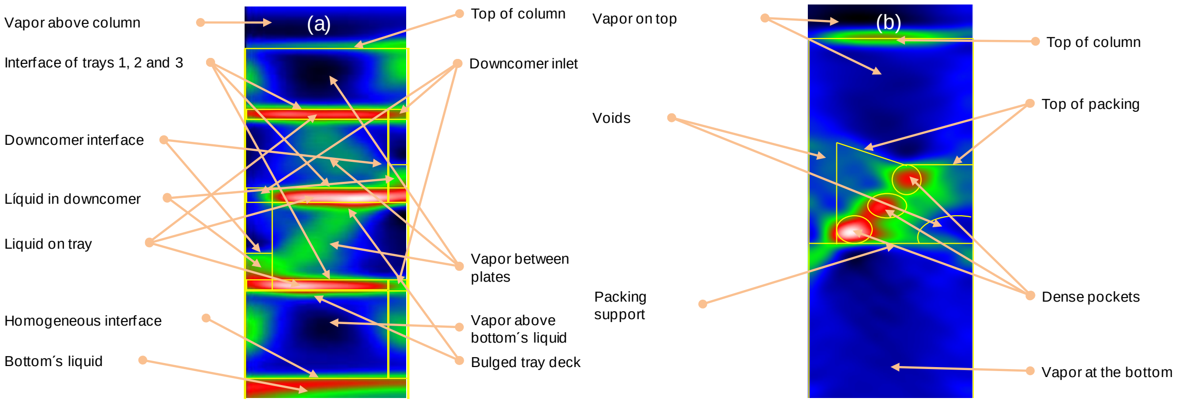

Figure 5. Features observed in a tomographic image of a trayed (a) and packed (b) column

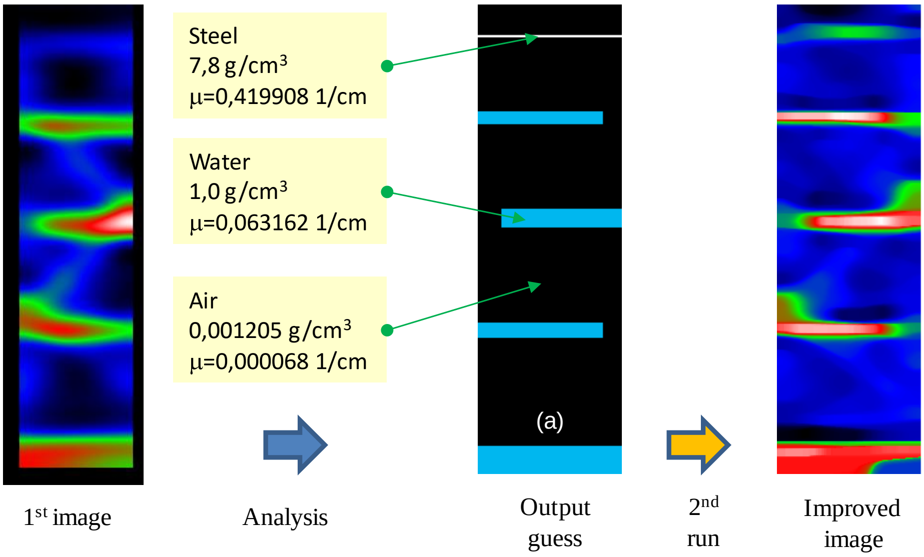

Figure 6. Reiteration process

4 Conclusion

The initial objective of this work was achieved using tomographic images of process equipment, revealing a two dimensional density distribution. Features hidden in a conventional gamma ray density profile could be seen with this technique, adding new perspective in troubleshooting process columns and other industrial equipments where the conventional gamma scanning would only offer limited information and possibilities.

Although promising, more improvements and developments are necessary such as in software, equipments, filters, data acquisition, calibration, resolution, accuracy, etc. The developed simulation tools have proved to be very useful to fine-tune the results and also to plan the irradiation process, saving time and personal exposition. The experience gathered indicated also concepts to be employed when adapting the technology from lab scale to real field application, goal of the current PhD degree research.

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