A New Industrial Tomography System Combining Simultaneously the Emission and Transmission Tomography Systems

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ABSTRACT

The tomographic techniques can be used in many industries to explore the interior of their objects, for example, (a) to act as the quality control of industrialized products or (b) to diagnose and identify failure in their production devices. Commonly, the industrial objects are chemical reactors, packaging of foods, encapsulated medicaments, columns of petroleum distillation, combustion engines, among other industrial objects. A portable tomography system known as instant-non-scanning type, a similar version of the fourth generation CT, was developed in this work. It comprises 70 NaI(Tl) detectors with the same number of multichannel type acquisition boards.One of the advantages of industrial tomography is that it allows inferring the quality of the production line without interrupting the production. The tomographic system described in this work is capable to obtain measurements in real time and requires no movement of radiation sources and detectors. The tomographic system, proposed in this work, allows the introduction of a radioactive tracer inside the industrial object, for example a tube or chemical reactor and then the user will obtain the reconstruction images of a tomographic emission system together to the transmission image. By means of radioactive sources positioned externally to the object the user will obtain the reconstructed images of the transmission tomographic system. Therefore, this article describes an innovative hybrid industrial tomographic system, capable of generating both emission and transmission tomographic images simultaneously.

Keywords Emission and transmission tomography, Industrial tomography system, Instant-non-scanning tomography, Multichannel acquisition and pulse processing.

1 INTRODUCTION

The industrial production systems can involve fast dynamic processes containing solid, liquid and gas mixtures. Also, the majority of industrial production resources consist of relatively dense materials, usually, built with steel which have large diameters and thicknesses. For these reasons, gamma radioactive sources in the energy ranges of 317 keV (^{192}Ir), 662 keV (^{137}Cs) and 1173 keV, 1332 keV (^{60}Co) are preferable, instead of low X-ray energy sources [VELO et al, 2017]. While in the practice of medical tomography the patient goes to the tomographic device (CT), on the contrary, in industrial tomography applications the CT device must be transported to the object (chemical reactor, tube, column or any other industrial objects) and it must be mechanically adapted around to the object. In addition, industrial tomography system should be adapted for different sizes of objects that are usually located in a hostile environment, containing flammable superheated materials, occasionally subjected to high internal pressure and presenting many difficulties for placing CT devices around these objects [MESQUITA, et al, 2010;VELO et al, 2017]. Besides, the phenomena related to multiphase processes are usually fast, requiring high time resolution of the CT data acquisition [HJERTAKER et al 2008, FISCHER & HAMPEL, 2010]. In this case, the tomographic device must be fixed around the object and if the experimental objective is to evaluate rapid transient phenomena inside the object then the tomograph must be designed so that to have no movement both of the radioactive sources and the detectors placed around the object. Portable instant non-scanning (fourth generation CT like) and fifth generation tomography systems [HJERTAKER et al 2008, FISCHER & HAMPEL, 2010, MESQUITA et al, 2010] meet these requirements. Additionally, the system should be light enough to be portable and easily installed. Nowadays, most tomography systems do not meet these requirements and are used restrictedly in laboratory environment to study and to optimize column designs and industrial processes; however, in practice, these devices are not suitable to be used in industrial plants for real time measurements.

At the University of Bergen, Norway, a high speed tomography system was developed [MAAD et al, 2008, 2010], fact that served as inspiration for the portable instant non-scanning tomography designed and developed in laboratory of IPEN. The Bergen tomography system uses semiconductor detectors of CdZnTe (CZT) and five ^{241}Am sources. The CZT detectors are fixed on the printed circuit board and collimated on a complex system what makes it difficult their use for larger objects. The system was designed for a maximum pipe diameter of 80 mm. In addition, the use of CZT low-sensitivity (~ 1 mm) semiconductor detectors and low energy radiation sources, such as 59.3 keV from 241 Am radiation, which makes this system unsuitable for use in object measurements high density and larger size. In industrial process plants, the analyzed objects have, typically, high density materials and large dimensions in their structure, such as the columns/pipes used in oil refineries, chemical, textile and in petrochemical areas. Consequently, high energy radiation sources are required to cross the object. Usually, ^{192}Ir (317 and 468 keV), ^{137}Cs (667 keV) and ^{60}Co (~1252 keV) sources are used for these applications. Therefore, dense detector material may be necessary to absorb the gamma photons from these sources. Scintillation detectors, such as: NaI(Tl) (3.76 g/cm^3), BGO ($Bi_4Ge_3O_{12}$, 7.13 g/cm^3), LYSO ($Lu_{0.6}$ $Y_{1.4}SiO_{0.5}$:Ce, 5.37 g/cm^3), LSO (7.35 g/cm^3) and GSO (6.71 g/cm^3) are widely used in tomography applications [VELO, et al 2017]. In our laboratory, a portable instant non-scanning tomograph, that is, intrinsically, a fourth generation like tomograph system was developed, comprising five sets of fourteen ∅2.5×5.0 cm (diameter and length) NaI(Tl) detectors and five shielding cases for radioactive sources (Fig. 1). Each shielding case is placed diametrically opposite to a fan detector set, as showed in Fig. 1. All scintillating detectors cited meet the requirements for this project. The main criterion of choice of the NaI(Tl) was its relatively low cost compared to the other detectors suitable for the proposed application. Furthermore, it is capable to detect a large range of energies, i.e. from 59.3 keV ^{241}Am to ~1252 keV ^{60}Co and it has higher light output. The choice of the source to be used depends on the object material densities, wall thickness and dimension of the object to be evaluated by tomography measurements. In addition, the proposed tomography system can be adjusted for different object dimensions (columns or tubes) by changing the number of detectors or the distance between the object and the detector. Thus, the tomography system has the capacity of being adapted and applied for objects of different shapes and dimensions, such as, column or pipe sizes found, usually, in the industrial plants. The tomography system can be mounted on a lightweight and inexpensive wooden platform to be replaced in subsequent applications that require new challenges, for example new geometries and object dimensions.

2 METHODOLOGY

The emission and transmission tomography measurement were carried out using an instant-non-scanning tomography shown in Figure 1. The tomograph is composed of 70 NaI (Tl) ∅2,5 x 5,0 cm (diameter and thickness) detectors with 5 cm thick lead wall and 5 mm diameter septum hole. Each NaI(Tl) crystal (Kinheng Crystal, Shanghai-CHN) is coupled with silicone grease to photomultiplier (Figure 2-A) (Enterprises, UK, mod. 9924SB, ∅2.5cm). The electronic acquisition board (Figure 2-C) for signals processing generated by the photomultiplier is a, multichannel type analyzer, which was designed and built at IPEN.

Five radiation shielding cases were constructed with tungsten, as shown in Figure 3. In the present study, 40 GBq (≅1.08 Ci) of ^{99m}Tc were used as radiotracer injected into the chemical reactor to generate the emission tomographic images and 11.1 GBq of ^{192}Ir (≅300 mCi) inside each one of the five tungsten shielding cases (Figure 3) in order to act as external radiation sources to generate the transmission tomographic images.

This industrial tomography system comprises of 70 NaI(Tl) radiation detectors with the same number of multichannel input board and five shield cases containing ^{192}Ir which was placed around the chemical reactor in a pentagonal geometry, as showed in Fig. 1. All tomographic images were reconstructed with the Maximum Likelihood Estimation Method (MLEM) algorithm [LANGE et al. 1984; BRYANT, et al 2002; AARSVOLD, 2004] ; using a grid matrix of 32 x 32 pixels.

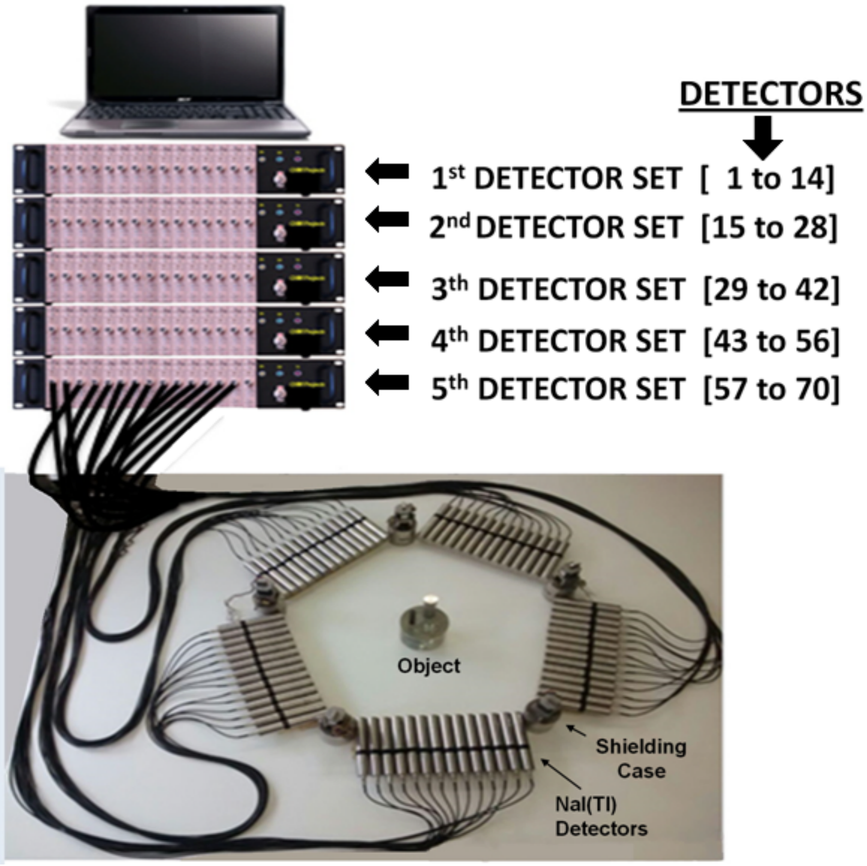

Figure 1. The instant-non-scanning tomography system

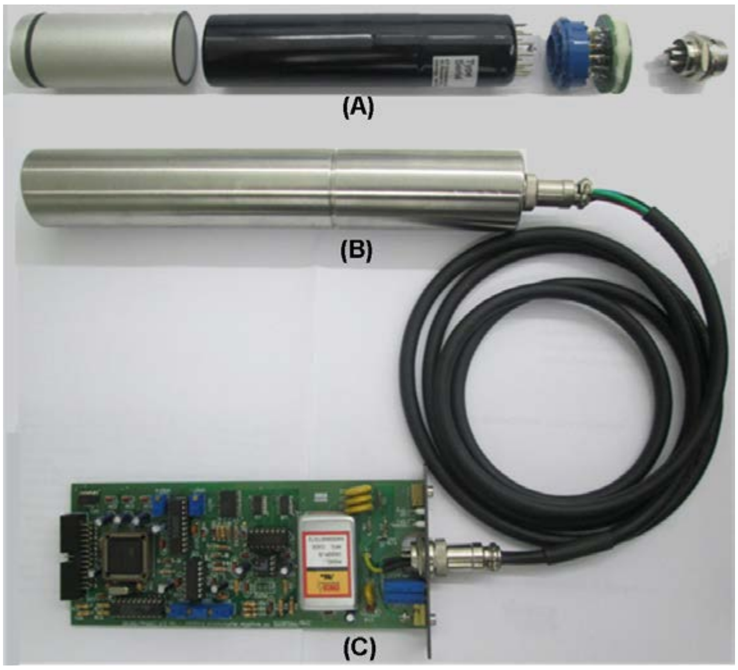

Figura 2. Detector system comprises the NaI(TI) crystal with photomultiplier, voltage divider and connector (A). System encapsulated in stainless steel tube (B). Multi-channel electronic signal processing board containing high voltage generator circuit (0 to 2000 V) (C)

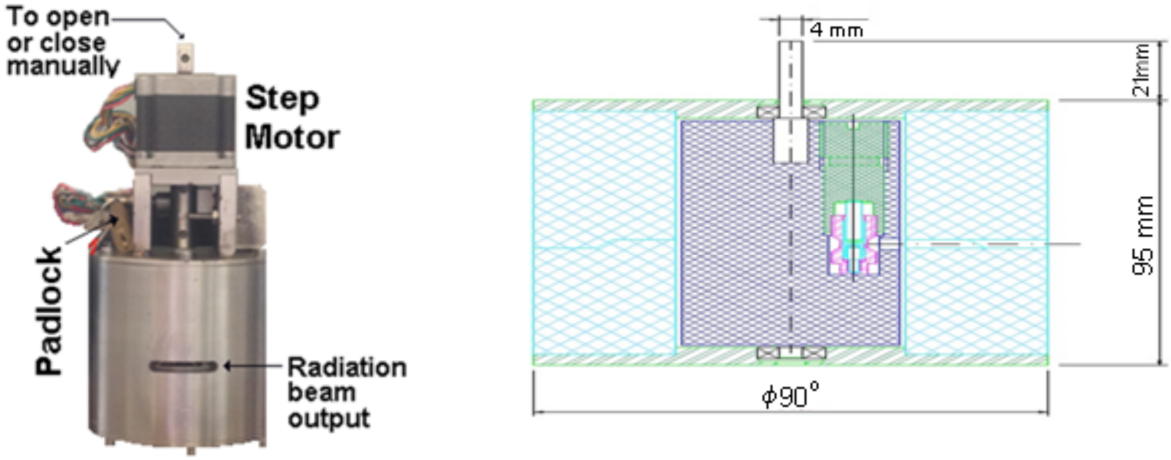

Figura 3. Shielding case constructed with tungsten. The exposure of the radioactive source can be controlled by the computer through the action of the step motor as shown on the left side.

3 RESULTS AND DISCUSSION

Figure 4 shows the composite spectrum of ^{99m}Tc and ^{192}Ir sources measured for one second for one of 70 detectors. All detectors presents similar spectrum.

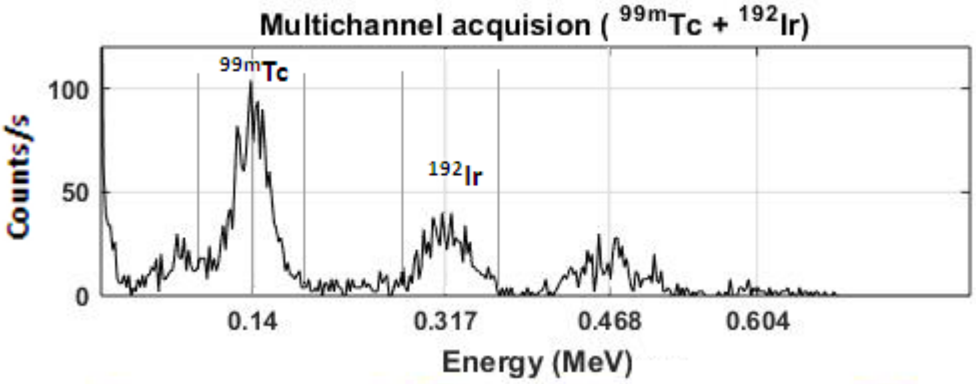

Figure 4. Spectrum obtained by one of the NaI (Tl) detectors of the accumulated radioactivity measurement for one second of the two radioactive sources: (i) ^{99m}Tc contained internally into the chemical reactor and (ii) ^{192}Ir inside to the shielding case in front of the detector.

In the present study, it was established that the accumulation time of the radioactivity counts was one second. After that time the data from the 70 acquisition multichannels transfer their data to a computer (PC) that processes the reconstruction of the image in that time using the MLEM algorithm [LANGE et al. 1984; BRYANT, et al 2002; AARSVOLD, 2004] (or another previously selected by the user). In the present study, the chemical reactions are occurring in aqueous medium, then the density of the reaction products do not differ significantly from the density of the aqueous medium contained in the reactor. Therefore, images of transmission tomography from sources external to the object (^{192}Ir) are not observed in the reconstructed images. In this case the images may only highlight the reactor walls and eventually bubbles generated inside the chemical reactor. In contrast, on emission tomography if a suitable tracer is used and it is able to accurately mimic the chemical reaction of interest, then this tomographic version will be able to provide important information about the chemical process that occurs in the chemical reactor. According to the Figure 5 and 6 the transmission image shows the morfology chemical reaction used clearly, while the emission tomography image ilustrate that reaction chemical product is concentrate mainly the center of the reactor and the concentration decreases as it approaches the reactor wall as can be inferred from Figure 6.

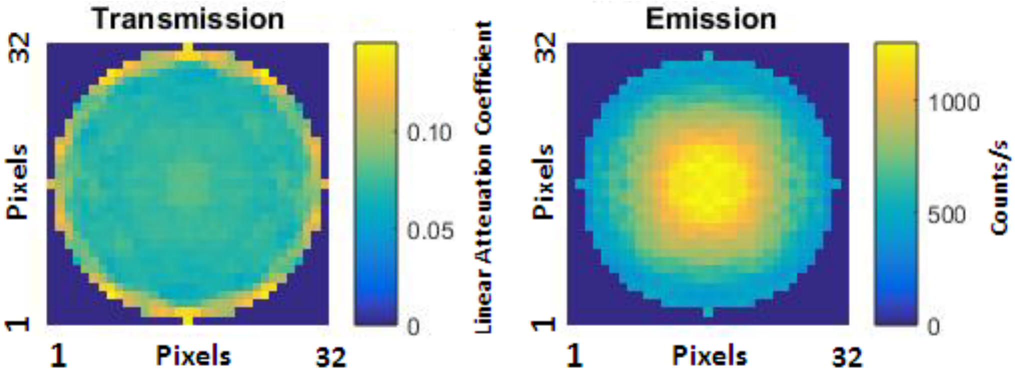

Figura 5. Tomographic reconstructed images by the MLEM algorithm at the end of each one-second measurement.

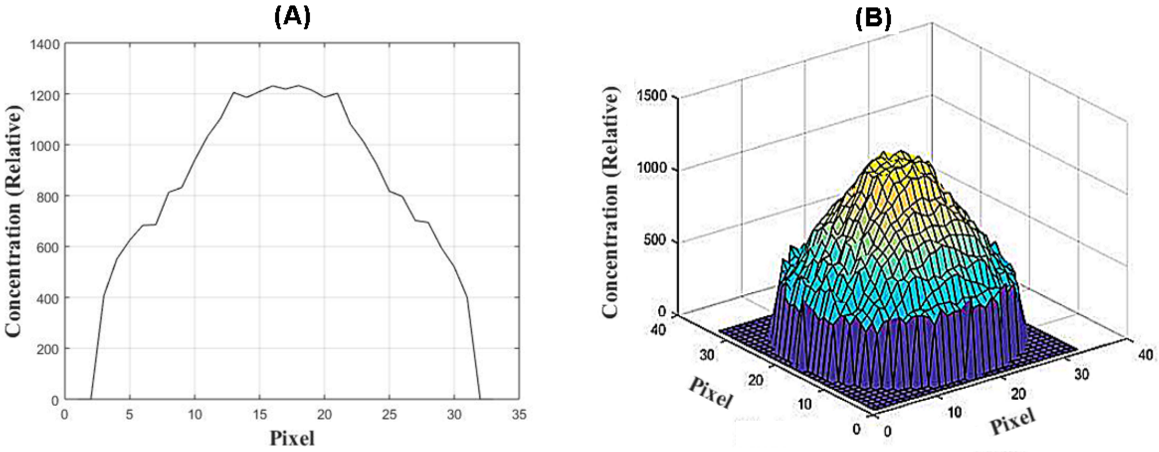

Figura 6. Concentration distribution of the chemical product inside reactor. Linear (A) and 3D (B) evaluation.

The distribution of reaction product concentration, inside the reactor, depends on the design of the reactor and its agitation mechanisms.

4 CONCLUSIONS

The combination of two types of tomographic technologies follows a current trend of instrumentation analysis, for example the combination of PET-CT, PET-RM and GCMS this is intrinsically a combination of gas chromatography with mass spectrometry.

In the present study the emission tomography image shows that the tracer has maximum concentration in the center of reactor, decreasing its concentration radially. This effect is probably caused by the action of the vortex type installed on the reactor floor.

The transmission images can show only the structure of the chemical reactor. However, transmission tomography may be useful for reactors that undergo from bubbling. In such case, the intensity of the bubbles and their characteristics, i.e., the bubles frequency and their shapes can be clarified by the transmission tomography. (in the present study with the aid of five external sources of ^{192}Ir).
The emission tomography would be choice to understand the distribution of the chemical products inside the reactors.

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