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Emission and transmission tomography system applied to analyze industrial process inside chemical reactors

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ABSTRACT

The tomography techniques are widely used in many industries, such as: chemical, food, pharmaceutical and oil sectors. In the industries the tomography is used to diagnose the state of the machines of production and also in the control of quality of the produced 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 is capable to obtain measurements in real time conditions without interrupting the operation of the industrial production and it is useful in the quality control of the means of production and the objects produced. This paper describes an innovative hybrid industrial tomographic system, i.e., simultaneous data from the emission of an internal radioactive source introduced inside to the object (^{67}Ga citrate) and tomographic transmission using five sources of ^{137}Cs positioned externally to the object which are distributed at the vertices of a pentagon. The tomographic system described here is useful for studying dynamic chemical phenomena, associated or not with multiphase systems commonly found in chemical reactors and distillation columns.

Contents

1. Introduction

Recently, in the literature, it has been observed that industries are interested in using tomography technology to be used in quality control of their production devices and their produced objects [1]. Industrial gamma ray tomography for the evaluation of industrial production processes has been pointed out as one of the most promising technologies for visualizing the interior of industrial structures without interrupting the production line [2–4]. With this technology of evaluation of the industrial production devices one can study the distribution and proportions of the components (gaseous, liquid and solid) of the multiphase systems present in the industrial distillation columns or in the pipes [2,3]. With the use of industrial tomographs the engineers are able to evaluate, in real time, the quality of the production devices without interrupting the production line [4–8]. Multiphase systems are structures that contain complex mixture of materials (gaseous, liquid and solids) inside chemical reactors or pipes capable to increasing the heat, mass transfer and the velocity of reactions. [2,3,6–8] Thus, a great interest in the development of industrial tomographic systems of gamma rays has been required by the industries to be used in the quality control of their industrial production units and finally for quality control of industrial objects produced, such as encapsulated medical drugs (in this case micro-tomographs) and in rocks containing oil among other industrial products [1].

Nowadays, in the field of instrumentation there is a tendency to associate two different technologies in order to improve the quality of information. For example, to the gas chromatograph was added the mass spectrometer and this combination generated the GC–MS technology which greatly enhancing its capability of the substance analysis. Another significant example of this trend is the association of the PET scanner (positron emission tomography scanner) together with the X-ray CT scanning (a transmission version of tomography) [9]. In such case, the X-ray CT gives the morphological images with high resolution while

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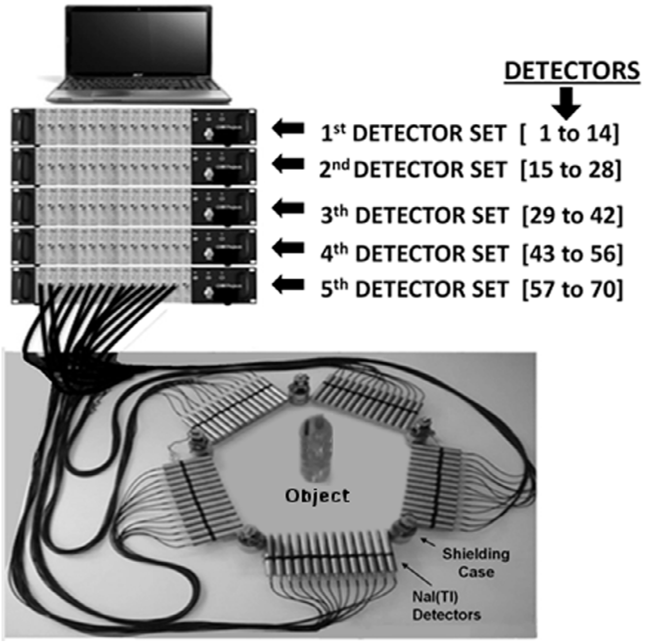

Fig. 1. NaI(Tl) detectors system and multi-channel electronic signal processing board containing high voltage generator circuit (0 to 2000 V).

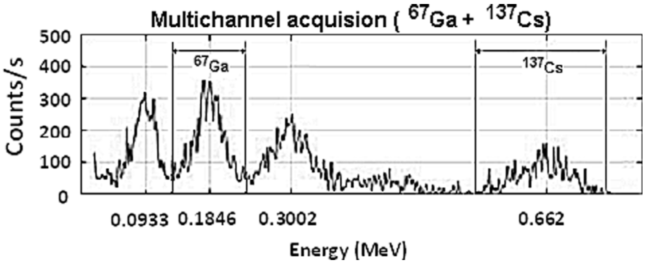

Fig. 2. Combined spectrum of ^{67}Ga and ^{137}Cs measured in one second. ^{67}Ga and ^{137}Cs windows used for emission and transmission tomography system, respectively.

PET provides the physiological state of the tissue. Following this trend, the purpose of the present work is to describe the development of an industrial tomograph capable of generating both images, i.e., emission and transmission simultaneously [9].

2. Material and methods

The emission and transmission tomography measurements were carried out using an instant-non-scanning tomography system shown in Fig. 1. The tomography system is composed of 70 NaI(Tl) ∅2.5 × 5.0 cm (diameter and thickness) detectors with a 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 (Enterprises, UK, mod. 9924SB, ∅2.5 cm). The electronic acquisition board 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 of tungsten, as shown in Fig. 1. In the present study, 40 GBq (≅1.08 Ci) of ^{67}Ga-citrate were used as radiotracer injected into the chemical reactor to generate the emission tomographic images and 11.1 GBq of ^{137}Cs (≅300 mCi) inside each one of the five tungsten shielding cases (Fig. 1) in order to act as external radiation sources to generate the transmission tomographic images.

This industrial tomography system consists of 70 NaI(Tl) radiation detectors with the same number of multichannel input boards and five shielded cases containing ^{137}Cs which were placed around the chemical reactor in a pentagonal geometry, as shown in Fig. 1. All tomographic images were reconstructed with the Maximum Likelihood Estimation Method (MLEM) algorithm [9–11] using a grid matrix of 32 × 32 pixels.

3. Results and discussion

The composite spectrum of ^{67}Ga and ^{137}Cs sources measured for one second for one of the 70 detectors is shown in Fig. 2. All other detectors present similar spectra.

Fig. 3 represents the tomographic reconstruction images in the middle region of the chemical reactor. Fig. 3(a) is the result obtained from only transmission tomography while Fig. 3(b) is the result of the emission tomography from the ^{67}Ga citrate inserted into the chemical reactor to act as a radiotracer.

One of the characteristics of the experiment described here is that the ^{67}Ga citrate radiotracer is present in a small concentration and evenly diluted in water, so the transmission tomography using the external sources of ^{137}Cs was not able to detect the Gallium Citrate and highlight it in Fig. 3(a). In this figure the reconstructed image is only capable of identifying the walls of the reactor and the water inside it. Instead, the reconstruction image of the emission tomography system (Fig. 3(b)) shows in detail (i) where the Gallium Citrate is found and (ii) its concentration profile (Fig. 4(a) and (b)).

4. Conclusion

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 GC–MS. In the present study the emission tomograph shows that the tracer has maximum concentration in the center of reactor, decreasing its concentration radially.

The transmission images show only the structure of the chemical reactor. However, transmission tomography may be useful for reactors that undergo bubbling. In such case, the intensity of the bubbles and their characteristics may be clarified by transmission tomography.

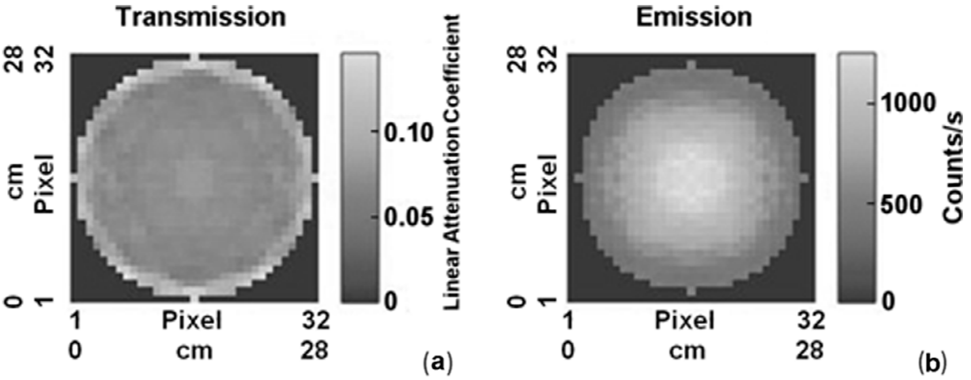

Fig. 3. Transmission (a) and emission (b) tomographic images performed by the MLEM algorithm at the end of one second acquisition time.

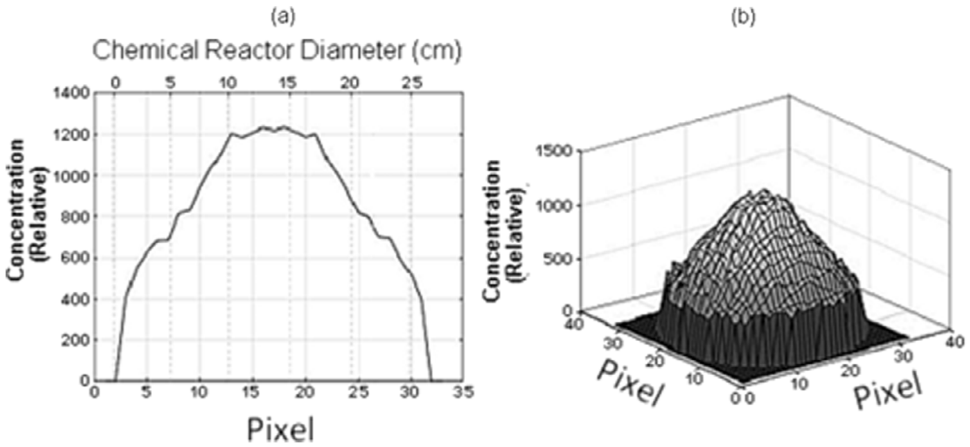

Fig. 4. Concentration distribution of the chemical product inside the reactor. 2D (a) and 3D (b) distribution.

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