Radiation Measurements 61 (2014) 1–5

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

Impact of measurement approach on the quality of gamma scanning density profile in a tray type lab-scale column

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HIGHLIGHTS

- The quality of density profile in gamma scanning technique has been studied.
- Quality of density profile depends on the measurement approach.
- A laboratory distillation column has been used as an illustrative example.
- MCNP4C Monte Carlo code has been used for simulations.

ARTICLE INFO

Article history:
Received 16 June 2013
Received in revised form
27 October 2013
Accepted 5 December 2013

Keywords:
Tray type distillation columns
Gamma scanning
Density profile

ABSTRACT

This article presents a study for investigating impact of the measurement approach on the quality of gamma scanning density profile in tray type columns using experimental and computational evaluations. Experimental density profiles from the total and the photopeak count measurements, as two approaches in gamma ray column scanning technique, has been compared with the computational density profile from Monte Carlo simulation results. We used a laboratory distillation column of 51 cm diameter as an illustrative example for this investigation. ^{137}Cs was used as a gamma ray source with the activity of 296 MBq (8 mCi), with a NaI(Tl) detector. MCNP4C Monte Carlo code has been used for simulations. The quality of the density profile in the photopeak count approach is relatively within 155–204% better than that of the total count approach for experimental results. The same comparison for simulation results leads to a relative difference within 100–135% for the density profile.

1. Introduction

Gamma ray scanning has become a popular diagnostic tool for troubleshooting of distillation columns. The unique and most powerful aspect of using this technique for the troubleshooting of distillation columns is that it is online and completely nondestructive. This technique is also a fast, efficient and cost-effective tool to better understand dynamic processes taking place in industrial columns and to examine inner details of a distillation column (Pless and Asseln, 2002; Vasquez et al., 2005).

This technique, often refer to as “column scanning”, can be used for any type of columns such as tray-type columns (one pass tray and double pass tray columns) and packed columns. The size of these columns in this technique varies in a large range. In order to scan these columns, no pre-preparation is usually required and the scanning can be performed by accessing the platform while it is operating (Abdullah, 2005; Walinjkar and Singh, 2011).

The main beneficiaries of this technique are Petrochemical and chemical process industries because distillation columns are one of their main components and the efficiency of the industrial plant relies on the ability of these columns to work as they were projected (Pless and Asseln, 2002; Zahran et al., 2011).

For troubleshooting of distillation columns, the mechanical drawing of the columns should be known. Understanding the inner details of a distillation column and their effects on density profiles obtained by gamma scanning technique help us to inspect structure of columns before its operation and also gives a good reference to better analyze the density profiles of the column when it is in operation. This scan as well as the gamma scans performed after startup or when the column is running normally can help us for better understanding and interpretation of density profiles when a malfunction occurs.

The quality of Density Profile and its capability in interpretation of structural specifications and diagnosis of the malfunctions is

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1350-4487/$ – see front matter
http://dx.doi.org/10.1016/j.radmeas.2013.12.002

affected by utilization of total count or photopeak count in gamma ray column scanning.

Comparison of the photopeak and total count rates in gamma-ray transmission measurements has been discussed for Industrial gamma-ray tomographic scans (Kim et al., 2011).

In this work the difference between utilization of the photopeak count in comparison with total count in the quality of the obtained Density Profile has been evaluated experimentally and computationally for determination of the tray type columns structural specifications.

2. Principles of gamma ray column scanning technique

Column scanning is carried out using a small suitable sealed gamma-ray source, which is placed diagonally opposite to a radiation detector across the column. Both the source and the detector are moved simultaneously in small increments on opposite sides, along the exterior length of the column. Fig.1 shows a schematic diagram of principle of the column scanning technique by gamma rays.

The intensity of the transmitted gamma rays under ideal narrow-beam conditions is expressed by the following equation:

$$I = I_0 \exp(-\mu\rho t) \tag{1}$$

Where, I is the gamma-ray intensity transmitted through the material of thickness t, I_0 is the incident gamma-ray intensity, μ is the mass attenuation coefficient and ρ is the density of the material. The situation of a well-collimated source and detector are referred to as narrow-beam conditions. In this case, scattered photons are precluded from the measurement and thus the transmission measured reflects the bulk attenuating properties of the object alone.

For scanning a thick material, for example in column scanning, the assumption of ideal narrow beam is not valid because a significant number of photons may be scattered by the material into the detector. In this condition the intensity of gamma rays reaching the detector can be estimated by modification of Equation (1), through the use of a buildup factor B (is always greater than 1) according to Eq. 2 (Knoll, 2000).

$$I = B \times I_0 \exp(-\mu\rho t) \tag{2}$$

If we utilize total count to obtain the Density Profile, all the detector pulses from should be considered, while the photopeak counts, however, assumes only those source particles that have not any interaction before and deposit their full energy in the detector.

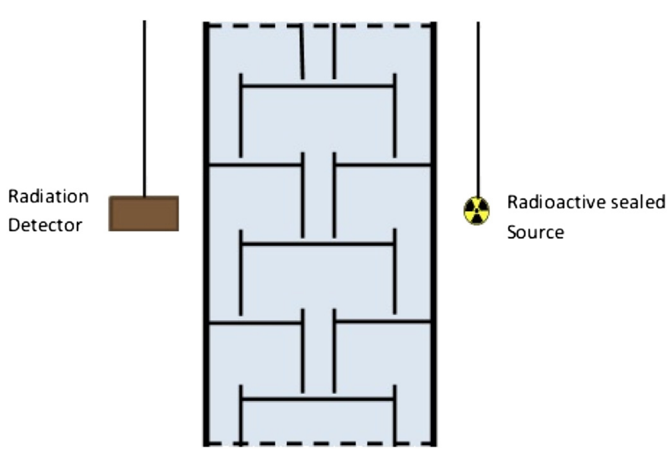

Fig. 1. A schematic diagram of principle of the column scanning technique by gamma rays.

Thus, in earlier case, the buildup factor in Equation (2) is almost1 and we can use Equation (1) as a good approximation. The difference between total count and the photopeak count has been shown in Fig. 2.

The photopeak count is not sensitive to some perturbing effects such as scattering from surrounding materials or spurious noise. Thus, utilization of photopeak count reduces the requirements for detector shielding in distillation columns scanning.

As we can see from Equation (1), the intensity of the gamma rays received at the detector decreases exponentially with increasing in the density and the thickness of the material between the source and the detector. In tray-type columns when the radiation passes through the trays or liquid, a great part of this radiation is absorbed and the radiation intensity reaching the detector is relatively small and when the radiation passes through steam, its intensity is relatively large.

3. Material and methods

As shown in Figs. 3 and 4, a laboratory one pass tray-type column of 51 cm diameter which has 6 steel made trays and downcomers has been used as an illustrative experimental example for investigation of the difference between utilization of photopeak count in comparison with total count in the quality of the obtained Density Profile. The thicknesses of the column and trays as well as their downcomers are 6 and 3 mm respectively. We used a Cs-137 gamma ray sealed source housed in cylindrical container having collimator role with the activity of 8 mCi (296 MBq). Also a 1 × 1 inch NaI (Tl) scintillation detector (Amcrys, 12s12/3) was used in this experiment.

Measurement system includes radiation detector the standard NIM units such as High Voltage power supply, Spectroscopy

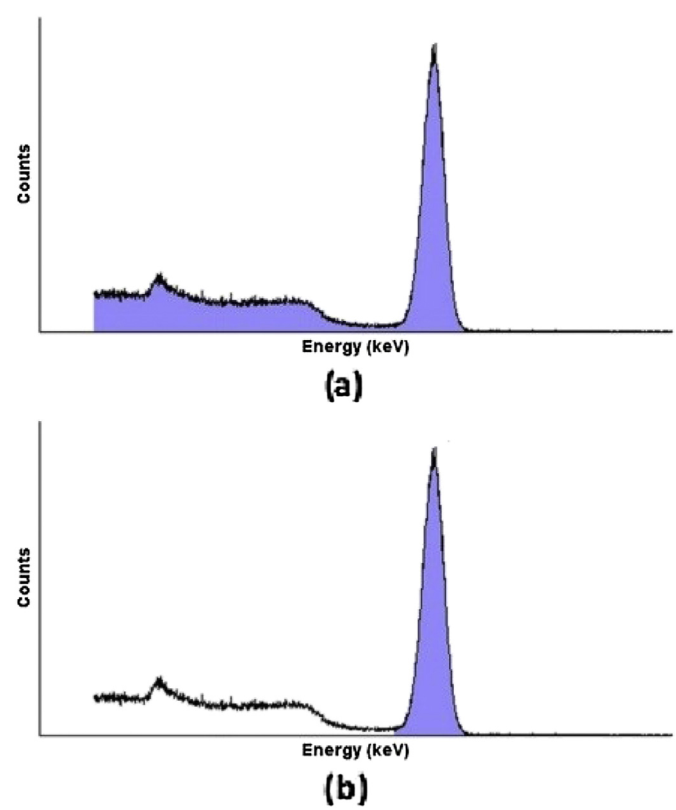

Fig. 2. Representation of (a) total count and (b) photopeak count of ^{137}Cs spectrum.

Fig. 3. Constructed laboratory one pass tray-type column accompanied by the sealed source and the detector.

Amplifier (SPA), Multi Channel Analyzer (MCA) and related software for data acquisition.

The source and detector were lowered simultaneously along the opposite sides of a column in steps of 5 mm. The counter time interval of detection system was fixed to 10 s. For all steps, the total count and the photopeak counts, corresponded to the photopeak energy of 662 keV, have been recorded. The measurements have been repeated for three times. The average count value has been reported for each height, and then the relative density profiles for total count and the photopeak count were obtained, by plotting the graphs as: normalized counts vs. column height.

Monte Carlo simulations were performed using MCNP4C code to calculate the same graphs based on the experimental setup. MCNP is a Monte Carlo N-particle code that is widely used for neutron, photon, electron, or coupled neutron/photon/electron transport problems (Briesmeister, 2000). We use the details of the column showed in Fig. 4 for modeling in MCNP4C. In simulations, the source and detector were lowered simultaneously along the opposite sides of a column in 1 mm steps. The source model for simulations is a cylindrical volume source with the energy of 662 keV, diameter of 6.3 mm and 8.9 mm in height. The simulated detector is a 1 inch $\times$ 1 inch NaI that covered with a 3.1 mm thickness of Aluminum and 4.2 mm polyethylene. Calculations were done per source particle using Tally F8 in MCNP4C code.

Statistical uncertainty associated with the Monte Carlo transport simulation results presented in this paper, with 60 million histories per simulation run, is less than 4%.

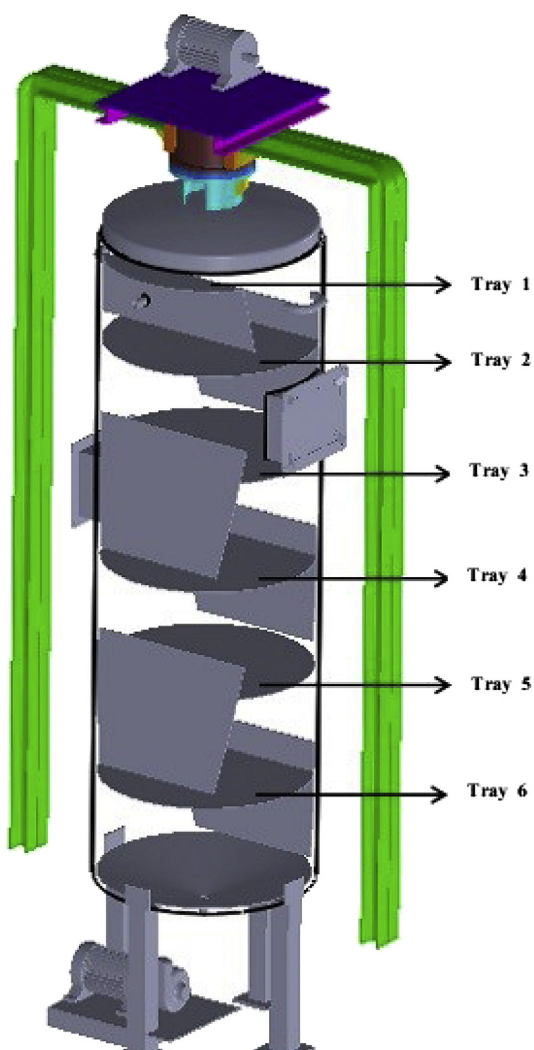

Fig. 4. 3-D layout of simulated column.

4. Results and discussion

The density profiles obtained from the experiment and Monte Carlo simulation of the scanned column have been shown in Fig. 5 using the photopeak and the total count approaches.

According to the results, 6 attenuation peaks are related to the column trays from top to bottom. Other small attenuation peaks can be seen in the positions between the trays. These peaks represent the overlap of the downcomers for two successive trays. In this figure, we can see that attenuation above tray 1 is less than the other positions. The reason is that there is no downcomer or other material in this position.

By comparing the experimental results for photopeak and total count measurements of density profile, we can see that the count difference between the tray attenuation peaks and downcomers overlap attenuation peaks in photopeak count measurement is greater than total count measurement. In addition, the difference between the magnitude of attenuation above tray 1 and the attenuation of downcomers in photopeak count measurements is greater than that of total count. These differences are theoretically due to the difference in buildup factor for these two approaches.

In the total count approach, buildup factor varies with respect to the column height due to different geometrical conditions, while the buildup factor for photopeak count approach was considered almost unity. The buildup factor variation with respect to the column height has been calculated by dividing the total counts over photopeak counts. These variations are shown in Fig. 6.

Another difference between these two approaches is that the attenuation peaks for photopeak count approach are sharper than that of total count approach. This leads to a better spatial resolution in determining the position of the trays in the column.

On the other hand due to rejection of the collided photons in photopeak count measurements, results of this approach is associated with a greater statistical errors compared with total count approach for equal sampling time.

If we consider the difference between the tray attenuation peaks and downcomers overlap attenuation peaks as a measure of the quality of profile density, the relative difference between photopeak count approach and total count approach from quality point of view is within 155–204% for experimental results. The same comparison for simulation results leads to quality relative difference within

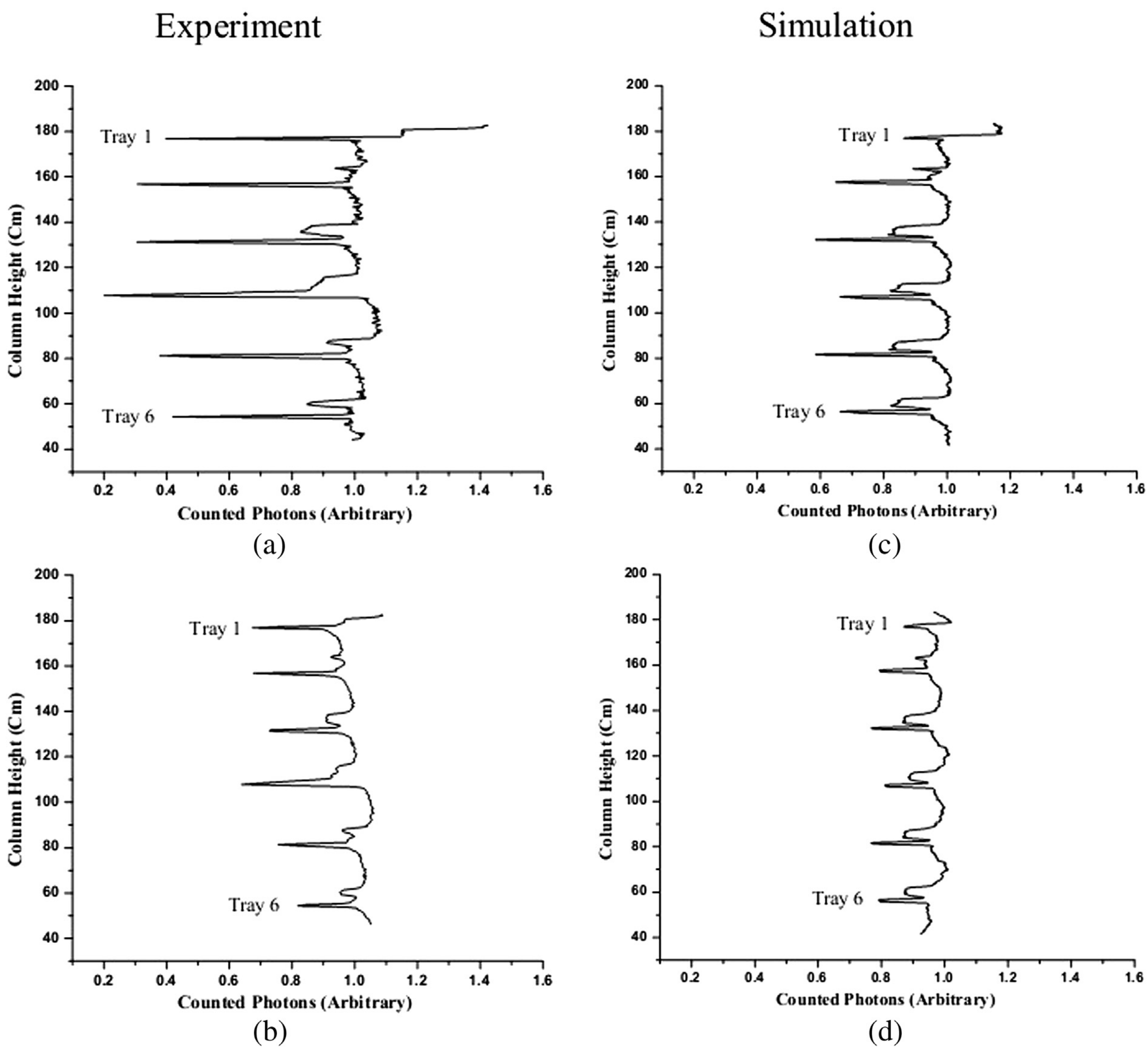

Fig. 5. Obtained density profiles by experiments and Monte Carlo simulations using photopeak count approach ((a), (c)) and total count approach ((b), (d)).

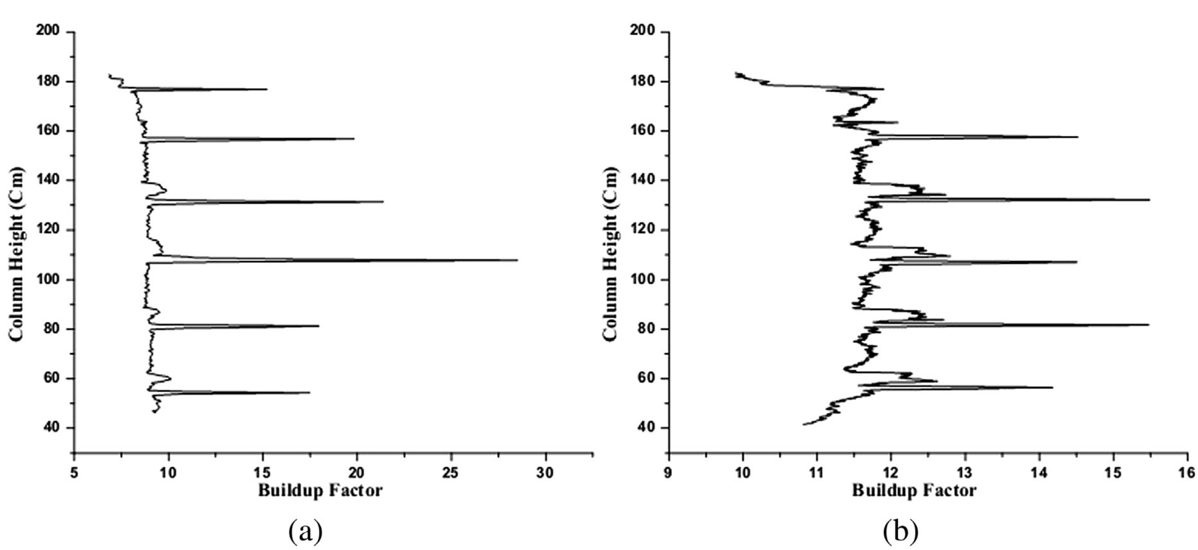

Fig. 6. Buildup factor vs. column height for both: (a) experiments and (b) Monte Carlo simulations.

100–135%. The difference between simulation and experimental results are due to the difference in real and simulated buildup factors in the problem. Another source of differences can be due to inaccuracies in construction from column layout.

The results are indicative of the fact that utilizing photopeak count approach, theoretically and experimentally improves the quality of density profile and accuracy of the system, considerably. Photopeak count approach would be more effective in diagnosis of slight defects.

As we know, the statistical error of one measurement is proportional to $1/\sqrt{N}$, in which N is the number of counts (Knoll, 2000). Smaller statistical error of total count approach due to its higher counts, leads to lower statistical fluctuations in the density profile in comparison with the photopeak count approach. In our work, statistical fluctuation is not a limiting factor because we have sufficient time to obtain the density profile with low fluctuations and reasonable statistical error.

In simulation, if we wish to have a clean profile of photopeak count, we should increase the number of particle sources or running time of Monte Carlo code. It should be noted that the dose rate near the column would be increased with the increasing in scanning time. So a compromise should be considered between scanning time and statistical fluctuation in obtained profile.

5. Conclusion

The impact of measurement approach on the gamma scanning density profile quality in tray type columns has been investigated using experimental and computational evaluations. The difference between the tray attenuation peaks and downcomers overlap attenuation peaks has been considered as a measure of the quality of density profile.

The difference between utilization of total count in comparison with photopeak count of ^{137}Cs source in the quality of the density profile has been investigated by experimental measurements and Monte Carlo simulations. These evaluations have been performed for structural inspection of a laboratory one-pass tray type column using gamma scanning technique. Experimental and simulation results show that the quality of density profile in photopeak count approach is at least 155% and 100% better than that of the total count approach respectively. Additionally, photopeak count approach has a better spatial resolution in determining the position of the trays in the column.

According to the results, utilization of photopeak count approach improves the quality and accuracy of the system, considerably. Although photopeak count approach is more efficient in diagnosis of slight defects, it leads to higher statistical error than that of total count approach.

In addition, simulation results have been evaluated by experiment ones. It is the necessary step to demonstrate utilization of MCNP Monte Carlo calculation for efficiently modeling in optimization, troubleshooting and analysis of this type of column.

Our forthcoming papers will be devoted to troubleshooting techniques using gamma ray scanning.

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