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Design, optimization and performance of source and detector collimators for gamma-ray scanning of a lab-scale distillation column

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HIGHLIGHTS

- Design and optimization of the source and detector collimators.
- MCNP4C simulations of collimators for gamma scan of distillation columns.
- Optimization of the pinhole and panoramic collimators for source.
- Optimization of pinhole and semi-quartic collimators for detector.
- Investigation the effect of the designed collimators on the density profiles.

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ABSTRACT

When using source and detector collimators for gamma ray column scanning, it is important to obtain an acceptable density profile quality. This paper consists of two main works. The first is devoted to describing the designs used to optimize the source and detector collimators for a lab-scale distillation column, and the second is devoted to investigating the effect of designed collimators on the quality of the density profiles obtained using the gamma scanning technique. Simulations using the MCNP4C Monte Carlo code were performed to model the collimators and obtain the density profiles. The source and detector collimator designs were developed for a cylindrical volume source with the energy of 0.662 MeV and 1 in. × 1 in. NaI, respectively. The pinhole and panoramic collimator designs and the pinhole and quartic collimator designs were considered for the source and the detector, respectively. The source container, with an opening angle of 60°, has the capability of substituting the collimator for high resolution, general and high sensitivity purposes. The pinhole collimator parameters for the source that were obtained were generally quite coarse and were 1.2 cm in diameter and 4 cm in length. Additionally, the detector pinhole collimator thickness and length obtained were 4 cm and 5 cm, respectively. Using the semi-quartic collimator for the detector, the weight of required lead was reduced by over 33% compared with the pinhole collimator.

The simulation results of the column scanning in abnormal operation condition have been validated by experimental measurement results. The obtained results from scans demonstrated that the optimized panoramic source collimator and semi-quartic detector collimator in this study could help us to obtain an acceptable density profile quality in total count approach.

1. Introduction

Distillation columns are one of the main components of the petrochemical and chemical processing industries, and the efficiency of the industrial plant relies on the ability of these columns to work as they are projected to do so (Pless and Asseln, 2002).

Gamma ray scanning is an online and completely non-destructive tool for troubleshooting distillation columns. This technique is also a fast, efficient and cost-effective tool for better understanding the dynamic processes that occur in industrial columns and examining the inner details of a distillation column (Pless and Asseln, 2002; Vasquez et al., 2005).

To perform gamma scanning of a distillation column or a similar reservoir, a small sealed gamma source, with an appropriate collimator, is positioned on one side of the column and a radiation detector, with an appropriate collimator, on the opposite side

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(Knoll, 2000).

Photopeak and total count rates in gamma-ray transmission measurements ('single-point' measurements as well as imaging and tomography) have been previously discussed (Shahabinejad et al., 2014a, 2014b; Kim et al., 2011, 2012a, 2012b).

In our previous works, the effectiveness of utilizing computational density profiles from Monte Carlo simulations in analyzing and troubleshooting of a lab-scale distillation column has been demonstrated. Additionally, we demonstrated that both the total and photopeak count approaches distinguished the malfunctions in their positions effectively. According to the results of our previous works, although the utilization of photopeak count approach improves the density profile quality, it leads to higher statistical error compared with the total count approach. Consequently, total count approach can be used in conventional gamma scanning technique if the minimum scanning time is important (Shahabinejad et al., 2014a, 2014b).

If we utilize the total count to obtain the density profile, all of the detector pulses should be considered. The total count is sensitive to some perturbing effects, such as scattering from the surrounding materials or spurious noise. Thus, the utilization of total count increases the requirements for detector shielding and collimators in distillation columns scanning.

Much work has been performed to improve the gamma ray collimators used in medical imaging systems (Park et al., 2014), but for industrial applications, the required research has not been sufficiently performed.

Single-hole and multi-hole collimators have been well characterized by various authors (Cook, 1959; Keller, 1968; Lee, 1982; Causer, 1975). Although multi-hole collimators require less shielding material than do single-hole collimators, they have poor performance at the high energies of gamma rays (Lee and Wehe, 2005).

Pinhole collimators, such as knife-edge and channeled collimators, have been designed and constructed for the application of environmental monitoring systems (Lee and Cho, 2002; Baek et al., 2010, 2013). Additionally, an active collimator has been constructed to develop a gamma camera (Lee and Lee, 2014). To increase the spatial resolution, the diameter of the pinhole collimator should be smaller than the detector diameter. Consequently, the number of counted photons is considerably reduced when using this type of collimator.

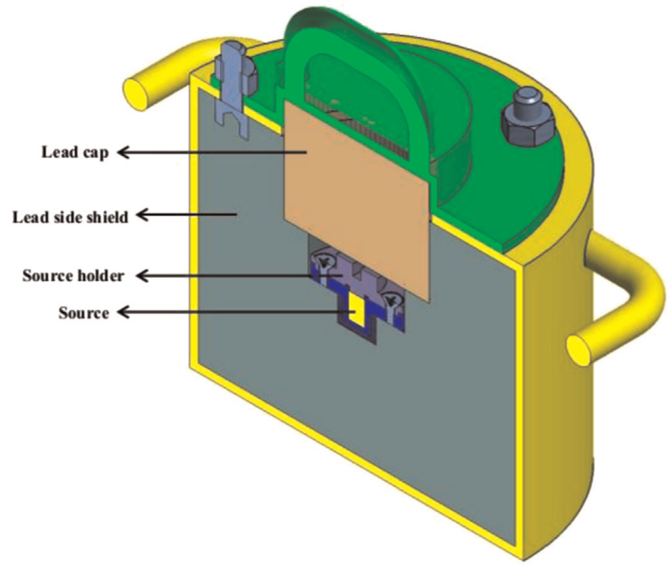

Fig. 2. Schematic of the source container.

Due to the high-energy gamma rays from Co-60 and Cs-137, which are the major sources used in column scanning, the collimator design requirements for column scanning should be different from medical applications. Several types of collimators can be used for both the source and detector, but the panoramic and pinhole collimators for the source and pinhole collimator for the detector are the most widely used ones (Alami and Bensitel, 2012; IAEA, 2008).

Through the proper collimation of high-energy gamma rays, the amount of shielding material can be reduced considerably. The use of a quartic shape collimator has been discussed in various publications and has been shown to reduce the required volume considerably compared with a standard cylindrical collimator (Furey and Morgan, 2010, 2011).

In the present article, two main works have been performed. In the first one, we investigated the effect of different collimator design parameters, such as aperture diameter, length and

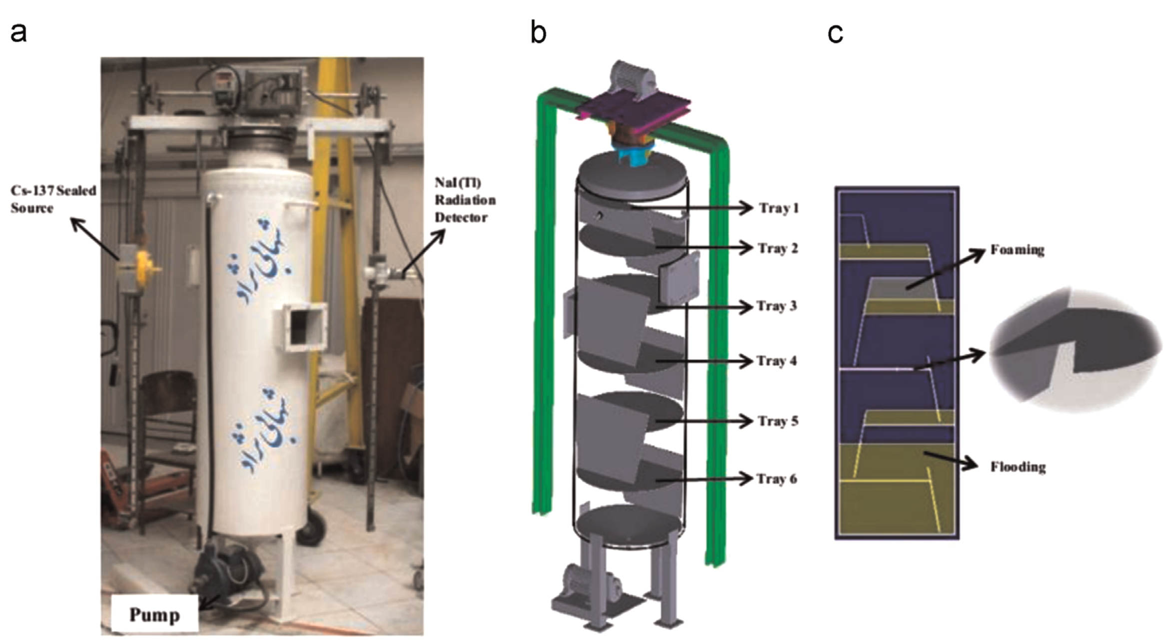

Fig. 1. Setup for column scanning. (a) Experimental setup, (b) a schematic of column structure, and (c) a schematic of the column in abnormal operation condition.