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Gamma-ray CT as a complementary technique for structural inspection of tray-type distillation columns

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A B S T R A C T

Gamma-ray scanning method has been already used for troubleshooting analysis of the distillation columns in industries. The obtained density profile in this method will give useful information about either structure or process of the column. However, in situations such as damaged tray, the damage severity cannot be identified using conventional gamma-ray scanning method. In this study, gamma-ray CT technique has been investigated as a complementary technique for structural inspection of a tray-type distillation column. So, a laboratory scale distillation column containing damaged tray and overlapped downcomers along with a transportable tomographic system have been simulated using MCNPX Monte Carlo code. Image contrast higher than 75% was obtained for reconstructed results of simulated data. Furthermore, the damage fraction calculated from reconstruction result showed a difference about 3% in comparison with its true value. To validate the simulations, an experiment was performed on a Lab-scale distillation column for inspection of downcomers overlap which leads to unexpected peaks in the obtained density profile. A reconstruction error of less than 7.5% was obtained for both experiment and simulation reconstruction results. Simulation and experimental image reconstruction results show that structural details of the column inside can be effectively determined using gamma-ray tomographic scan method. The overall results are indicative of the fact that gamma-ray CT technique can be efficiently used as a complementary technique for structural inspection of tray-type distillation columns.

1. Introduction

Diagnostic and measurement systems based on gamma-ray have been widely used in industrial applications such as fluid density measurement, radioisotope tracer techniques, and column scanning [1–3]. Gamma-ray scanning technique has been already used for troubleshooting analysis of the columns in industry [4]. The structural inspection of a tray-type distillation column along with the assessment on the quality of density profiles have been previously reported using conventional scanning technique [5,6]. In conventional gamma scanning technique, the obtained density profile may contain some complications. So, it is not easy to analyze the result without having primary information about the distillation column structure. Unexpected small attenuation peaks, caused by inappropriate selection of the scanning direction, which may be observed in the obtained profile are an example for the source of the complications [6]. To have the simplest feasible profile in column scanning technique, it is necessary to know the orientation of downcomers' and weirs' plates. The optimum scanning direction is one the downcomers' or weirs' plates are not seen by the passing radiation [5]. In addition, if the tray damage is the subject

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matter of inspection in the column, only the damage occurrence will be identified through the comparison of the obtained density profiles from normal and abnormal operation conditions. However, the damage severity cannot be determined from the obtained profiles. Fig. 1 shows a schematic of simplified density profiles for normal and abnormal operation condition of a typical tray-type distillation column. As shown in the figure, comparing the profiles indicates that one tray is damaged in abnormal condition.

In these situations, however, an imaging-based inspection method which is compatible with the properties of the column such as dimensions, and materials densities, is of interest. Where the conventional scanning method is not able to provide more details for troubleshooting analysis, Gamma-ray Computed Tomography (GCT) can be used as a supplement technique. GCT is a non-destructive technique providing cross sectional image from inside of the columns, pipes, chambers, etc., based on radiation attenuation. Over the last decade, GCT has been increasingly used for varies applications [7]. Characterization of changes in soil porous system [8], fluid flow analysis and process tomography [9], gas holdup distribution [10,11], and chemical reactor engineering studies [12] are some examples of its applications. Moreover, developing on the equipment and methods used in GCT has been also attended previously [13–15].

According to the column properties such as its large dimensions and high density materials including metals, the gamma-ray source together with appropriate detectors can be used through a proper design in the tomographic system. For the case of distillation column, simplicity and transportability of the tomographic system is important.

In the present study, inspection of the structure of a tray-type column has been investigated by using gamma-ray tomographic scan method. In this regard, structure of a typical tray-type distillation column along with tray damage and downcomer's overlap as a defect was modeled in simulations. A transportable tomographic system has been also simulated to acquire the projection data for image reconstruction. All the simulations have been performed using MCNPX Monte Carlo code. Furthermore, image reconstruction has been done using a validated reconstruction code [16]. Moreover, the experiment has been performed on the same Lab-scale distillation column to validate the simulation results and capability of the method for inspection aims.

2. Materials and methods

2.1. Monte Carlo simulation

A transportable version of the 4th generation of CT geometry has been simulated containing individual gamma-ray detectors installed around a one pass tray-type distillation column in laboratory scale. Flexibility of this configuration makes it suitable for tomographic scan of various industrial plants along with their fittings [17]. All the simulations have been done using MCNPX 2.6.0 Monte Carlo code. MCNPX is a general-purpose Monte Carlo transport code capable of tracking 34 particle types at nearly all energies. It also allows easy definition of simulation geometry through the input cards [18].

Top view of the simulated tomographic system has been shown in Fig. 2a, schematically. The tomographic system contains 64 NaI(Tl) detectors around the column while due to the geometric situation only 29 detectors are active in each view to generate the projection data. As the spacing between individual detectors is related to the accuracy of modeling as well as computation speed, the detector size was practically chosen as spacing unit to make a compromise between them. Simulated NaI(Tl) detectors have 0.5 in. diameter and 1 in. thickness. ^{137}Cs with monochromatic energy of 662 keV has been introduced as gamma-ray source. To produce the projection data, gamma-ray source is moved in 64 steps on the circular path around

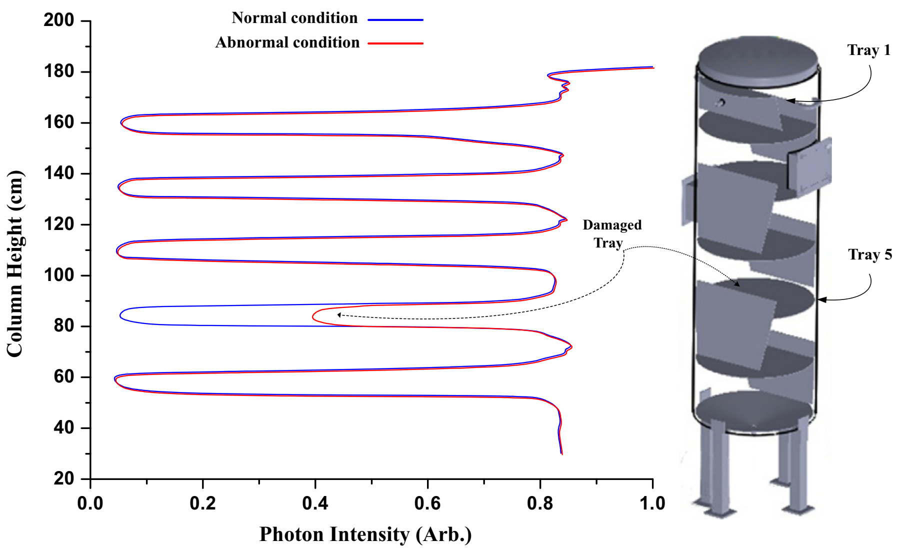

Fig. 1. Density profiles in normal and abnormal operation condition for typical Lab-scale distillation column.