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Increasing the accuracy of radiotracer monitoring in one-dimensional flow using polynomial deconvolution correction

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HIGHLIGHTS

- A deconvolution method was used to improve the results of radiotracer monitoring.
- The proposed method can increase the time resolution of the system.
- The method does not require physical and structural analyses of the system.
- Mathematical solutions were used to predict the system behavior like a black box.
- The precision of monitoring results was improved.

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ABSTRACT

Factors such as type of fluid movement and gamma-ray scattering may decrease the precision of the radiotracer monitoring as the response to a short tracer injection. Practical experiences using polynomial deconvolution techniques are presented. These techniques were successfully applied for correcting the obtained experimental results and increasing the time resolution of the method.

1. Introduction

Radiotracer monitoring is a method used for the characterization of flow systems (Levenspiel, 1999; Villermaux, 1985; Schweich, 2001). It is performed by injecting a tracer material to the system, thereby determining the tracer concentration in the fluid leaving the system. Compared with other tracers, γ-ray-emitting radioisotopes possess several advantages such as specificity, low detection limit, and transparency (IAEA, 1990; Thyn et al., 2000; Thyn and Zitny, 2002).

Monitoring can be performed by three different methods: (1) injection of the tracer in a very short time interval at the entrance of the system (pulse injection), (2) introduction of a concentration change in the form of a step function, and (3) introduction of a periodic concentration fluctuation in the inflow. The behavior of a certain element of fluid can be determined from the information obtained from any of the aforementioned methods (Andez-Sempere et al., 1995; IAEA, 2008).

Standard practice requires a detector to be placed at the inlet and outlet of the system, although in more complicated applications more detectors may be required.

For a simple flow from the inlet to outlet of the system, usually one-dimensional pipe flow, the signals from the detectors are quite unambiguous. Some special cases require monitoring the interior of a system more accurately, thereby requiring more detectors to be installed on the system. Interpretation of the results could be difficult in such cases. Depending on the ultimate goal and the arrangement of the detectors, different parameters can affect the obtained results. For example, response time of the detectors can affect the results in smaller tanks or higher flow speed. The amount and type of the interference depend on the design of the system and arrangement of the detectors, which provides inaccurate results. The source of this problem cannot be found easily; furthermore, the reason for the interference is not the same in all occasions. In such a situation, the system appears truly like a “black box.”

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In this study, a deconvolution method was used to correct the time response of radiotracer-based monitoring. This method increases the accuracy of measurement, and it eliminates the need to know the details and complexity of the system under study.

2. Experimental setup

A closed loop including a small cylindrical laboratory-scale tank with diameter and height of 20 and 100 cm, respectively was designed. Water was made to flow into the loop using a pump (CALPEDA, Q min/max 0.96/4.6 m^3/h, 0.7 kW, 220 V, 4 A). The pressure inside the loop was set to 1.6 bar using a feedback valve. Fig. 1 shows a schematic of the setup designed for performing the experiments.

As shown in Fig. 1, six NaI(Tl) detector (2.5-cm diameter and 5-cm height) are installed at different positions of the loop inside a 1-cm-thick lead shield. The detectors 1 and 6 were placed at the inlet and outlet of the tank to monitor the inflow and outflow, respectively. The remaining four detectors (2–5) installed vertically on the tank wall were used to monitor the tracer inside the tank. The detector response signals were transmitted to a data acquisition system and recorded on a notebook computer. The nuclear electronic system consisted of a high-voltage (HV) power supply (CC228 01Y BEIJING Hamamatsu, China), preamplifier, amplifier, fast single channel analyzer (SCA) with a response time of 100 ms (Nuclear Science and Technology Research Institute (NSTRI), Iran), and an 8-channel receiver for data acquisition (NSTRI, Iran).

3. Results and discussion

Technetium-99 m with an activity of 80 mCi was injected to the closed loop as the radiotracer. The detector values were recorded for 23 min using the analyzer. Fig. 2 shows the obtained spectra for detectors 1 and 6 as inlet and outlet responses.

The radioactive material was injected near detector 1, and therefore the radiotracer passed quickly in front of the detector, which induced a spectrum with a narrow peak. On the contrary, the outlet detector recorded a wide peak because the radiotracer was homogenous after passing the tank and exited from the tank slowly.

The spectra recorded on detectors 2–5, which were installed on the tank wall, are presented in Fig. 3.

It is evident from the figure that the detectors both began and stopped counting together; however, detectors should start and stop counting with a time lag relative to each other. These interferences are highlighted by blue ovals in the figure.

Two-dimensional (2D) reconstructed images of the obtained spectra showed the position of the fluid inside the tank (Fig. 4). It is evident from the figure that the obtained images were blurring and it could not be accurately determined when the fluid passed in front of the detector.

Data recording was performed in the tank with 100-ms steps using detectors 2–5. This indicates that, for about 1400 s, > 14,000 data rows were recorded with each of them having four members

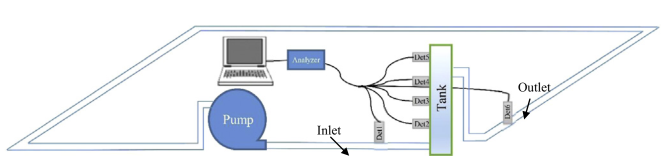

Fig. 1. Schematic of the experimental setup designed for radiotracer monitoring in a tank.

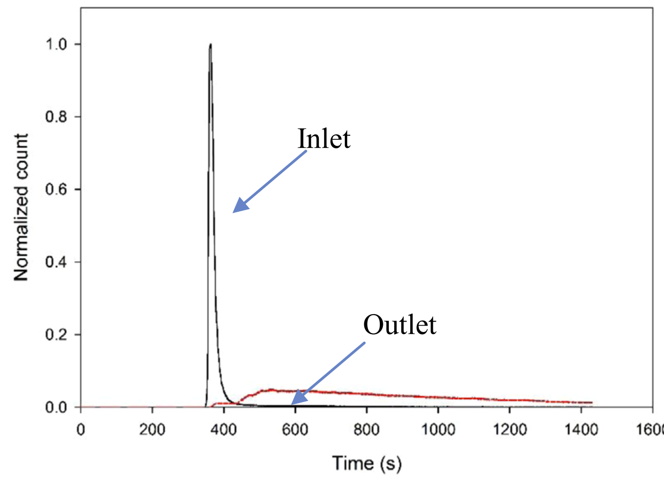

Fig. 2. Obtained spectra for detectors 1 and 6.

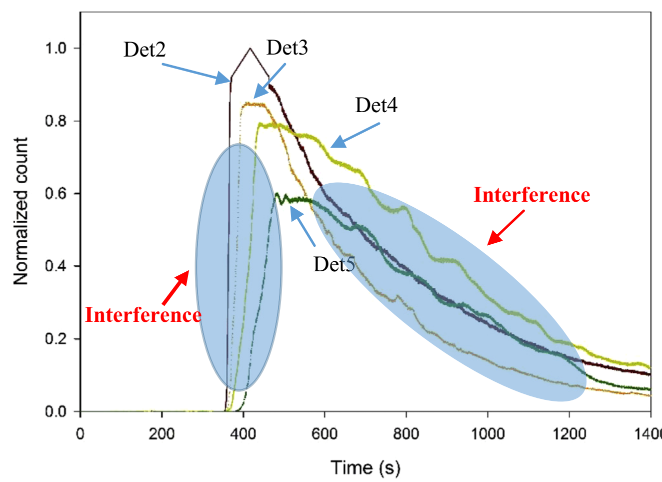

Fig. 3. Recorded spectra of detectors 2–5. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

(each member was related to one detector). Specific rows were selected from the obtained matrix to determine the values for the aforementioned detectors. It is obvious that the obtained results will show the position of the tracer in the tank at different selected times.

However, it can be claimed that the rows are randomly selected in this method, which can cause error in showing the tracer position. For accurate measurement, mean values of 11 rows (five rows before and after the selected row) were used to determine the position of tracer inside the tank. The results presented in Figs. 4 and 8 are obtained using this method.

3.1. Deconvolution

Deconvolution takes place due to factors such as fluid movement within the tank, gamma-ray scattering in the tank, and poor shielding effect of the detector. The aim of this study is not to perform physical and structural analyses of this problem, but to reduce its severity using mathematical methods.

One of the most important purposes of this study was to find an appropriate way to easily determine the behavior of the system as a black box. A careless use of a nonstandard method for extracting the response function of the system can lead to additional errors in the final results.

For complex spectra that are a linear combination of response functions, several deconvolution methods can be used. In general,