Extended Abstract

Design and Optimization of the Radioactive Source Arrangement for the Level Gauging of Petrochemical Urea Reactor

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Abstract

Measuring the level and height of liquids in industrial reactors at high temperature and pressure in the oil, gas, and petrochemical industries has particular importance due to the complexity of the production process. The height of Urea in the vessel can be measured using the nuclear level gauging method, which is a non-destructive method. Therefore, the energy of the gamma emitting source, the design, and arrangement of the geometry of the source, including the point or rod, and the detector material including the use of sodium iodide crystal or plastic scintillator are important. In this research, firstly, a nuclear level gauge system—comprising a source, detector, and a reactor with urea and high-temperature, high-pressure gases—was simulated using the MCNPX Monte Carlo code. The simulation results were then validated against experimental data. The study then optimized the detector's response by testing different arrangements of the radioactive source and its distances, as well as various detector types and geometries, to find the best configuration. The analysis revealed that using three strategically placed point sources is a superior and more cost-effective alternative to a rod source. This setup offers high accuracy and stability at a significantly lower production cost.

Keywords: Design and optimization, Radioactive source, Level gauge, Urea Reactor, Gamma-ray, Simulation, MCNPX Monte Carlo code

1. Introduction

Accurate measurement of liquid levels in high-temperature and high-pressure industrial reactors, such as those in the petrochemical industry, is critical for process efficiency and safety. Non-destructive nuclear level gauging, utilizing gamma-ray sources, offers a reliable solution for such challenging environments. This study focuses on optimizing the design and arrangement of radioactive sources (point or rod) and detectors (sodium iodide crystal or plastic scintillator) for precise level measurement in urea reactors. The research employed

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Monte Carlo simulations (MCNPX code) to validate experimental results and identify the most effective configuration [1-4].

2. Methodology

For a more appropriate response and consequently accurate level gauging, the design of the geometry, type of source, and detector are of particular importance. In this study, due to the high cost of producing radioactive rod sources, the possibility of using point sources with specific distances instead of rod sources was investigated. The study involved two main phases:

2.1 Simulation and Validation: A nuclear level gauge system, comprising a gamma-ray source, detector, and a reactor containing urea and gases under high temperature (210°C) and pressure (168.8 bar), was simulated using MCNPX, as shown in **Fig. 1**. The results were compared against the experimental data to ensure accuracy.

2.2 Optimization: The detector response was evaluated under various source arrangements (point and rod), source-detector distances, and detector types (NaI(Tl) and plastic scintillator). Key parameters such as contrast, resolution, field of view, MRE(%), and regression quantities were analyzed to determine the optimal configuration.

The Beer-Lambert law was applied to model gamma-ray attenuation, accounting for the linear attenuation coefficients of urea and gases (NH_3, H_2O, N_2, CO_2). The experimental setup included a plastic scintillator detector (BC-400) and a Co-60 rod source, with measurements taken at different urea levels (0–100 cm).

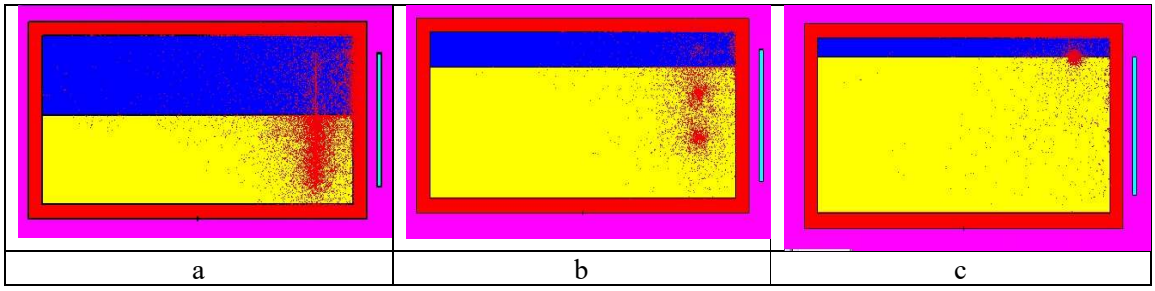


Fig. 1. A view of the vessel simulation, plastic scintillation detector with rod design and source design as a) rod, b) three-point, c) single-point.

3. Results and discussion

3.1 Source Arrangement:

- **Rod Source**: Provided the best field of view, contrast (0.89), resolution (0.562), and regression (0.9959). However, its high production cost and complexity are significant drawbacks.
- **Three-Point Source**: Demonstrated comparable performance (contrast: 0.881, resolution: 0.568, regression: 0.9706) to the rod source, with lower cost and simpler structure.
- **Single-Point Source**: Was limited to measuring levels above 80% height, making it unsuitable for precise gauging.

3.2 Detector Type:

- **Plastic Scintillator (BC-400)**: Exhibited superior performance with a wide field of view and high regression (0.9959), enabling accurate measurements even at low urea levels.
- **NaI(Tl) Detector**: was restricted to levels above 80% due to its narrow field of view and lower regression (0.6147).

3.3 Validation: The simulation results showed an 11% relative error compared to the experimental data, confirming the reliability of the MCNPX model.

4. Conclusion

Since the urea level gauging in the petrochemical vessel contains materials and gases with very high temperature and high pressure, a non-destructive nuclear method, including a source and a detector, can be used. To achieve a suitable response and, as a result, accurate level measurement, the design of the geometry, type of source, and detector are of particular importance. In this design, considering the high cost of producing radioactive rod sources and, in some cases, the lack of manufacturing rod sources in the country, the possibility of using point sources with specific distances instead of rod sources was investigated. According to the obtained results, the level gauging measurement and response of the plastic scintillating rod detector to the three-point source design are in good agreement and close to the rod source design. Therefore, a source with a three-point design can be a suitable alternative to high-cost rod sources.

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