# Feasibility study of radioactive particle tracking in a draft tube column

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## 1. Introduction

A radioactive particle tracking (RPT) technique measures the flow field by tracking a small radioactive particle that is made specifically to follow the interested phase in the reactors [1]. Using external radiation measurements, the location of the tracer with time can be determined. With further data processing, detailed information about the flow pattern of the selected phase can be obtained. Moreover, Lagrangian particle trajectories can be transformed to a classical residence time distribution, time-averaged velocity flow fields, the fluctuating velocities, turbulence, etc. The RPT technique is non-invasive, and can be performed in non-opaque systems where other techniques, like ultrasonic methods, laser velocimetry technique, etc., fail [2].

In this study, RPT experiments were carried out with a propeller driven draft tube column. 24 NaI scintillation detectors strategically placed around the vessel are used to monitor the position of the tracer particle. The positions of the particle were determined by a Monte Calro based reconstruction method from the radiation measurement data. The results were compared with Computational Fluid Dynamics numerical simulations for validation.

## 2. Methods and Results

### *2.1 Draft tube column*

To investigate the characteristics of water flow in the mixer, RPT experiments have been carried out in a draft tube column. The column was built with double transparent acrylic tubes, an inner draft tube with a 14 cm diameter and a 104 cm height, and an outer column tube with a 20 cm diameter and 130 cm height. A draft tube was mounted coaxially to the outer column by three tube supports installed on the column base. Clearance between the lower end of the draft tube and the bottom of the column was 2 cm. A two blade propeller with a 3.4 cm diameter was used for the single phase circulation condition. The propeller is located at 6 cm above the bottom of the column, which is filled with water up to a 111 cm elevation. During the experiment, the rotation speed of the propeller was set to 1000 rpm.

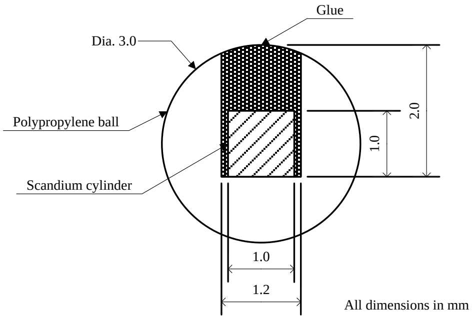


Fig. 1 Configuration of the tracer particle

### *2.2 Radioactive particle*

Polypropylene was chosen as a base material of the tracking particle for the RPT experiments since it can be easily prepared as a particle that will trace the liquid phase carrying a radioactive material inside it. Scandium exists naturally and exclusively as $^{45}Sc$, and radioactive $^{46}Sc$ can be produced by a (n, γ) reaction in a research nuclear reactor. It has an adequate half-life (83.8 day) and gamma energies (0.889 MeV and 1.13 MeV) for RPT experiments. As shown in Fig. 1, the tracking particle was fabricated by embedding a cylindrical scandium metal piece (Φ1mm×1mm, 2.5 mg) into a polypropylene sphere with a 3 mm diameter. The density of the tracking particle was adjusted to be very close to that of water to make sure of its neutral buoyancy. The tracking particle was bombarded with neutrons in a nuclear research reactor at the Korea Atomic Energy Research Institute, HANARO (neutron flux: $3.54\times10^{13}/cm^2\cdot s$), and its activity was 75 μCi.

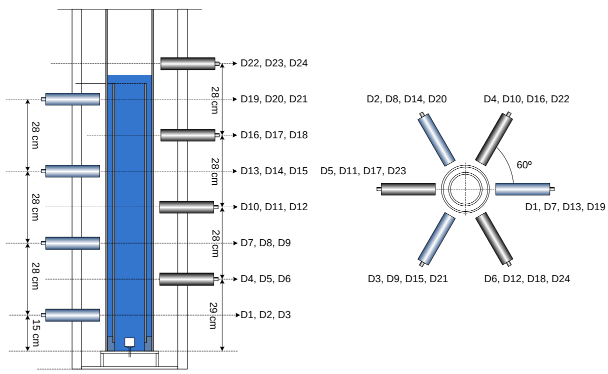


Fig. 2 Configuration of the radiation detectors

### *2.3 Detection system for RPT*

The RPT setup consisted of 24 NaI(Tl) scintillation detectors (Φ5cm×5cm) mounted on stainless steel supports around the draft reactor. To cover the whole flow domain of the draft tube column, 24 detectors were evenly situated on eight equally spaced horizontal layers at different elevations. As shown in Fig. 2, three detectors were installed on each layer with angles of 120 degrees to each other. The gap between the two layers was about 14cm and the distance between each detector and the wall of the outer column was maintained as 10 cm.

### *2.4 Reconstruction algorithm*

In an RPT experiment, the instantaneous positions of the particle are determined by reconstruction procedures from recorded radiation intensities. Monte Carlo based on reconstruction method generates a database for each detector from the source located at various positions using Monte Carlo simulations [2]. In order to reconstruct the tracer particle position, experimentally obtained radiation intensities for each detector are compared to the database, thus searching for the adequate position with the least error between database and measured intensity. More than 1400 positions have been simulated. Each cross-sectional plane has 73 database positions arranged at five different radial locations, and 20 planes in total were considered.

### *2.5 Results*

Figure 3 shows the typical Lagrangian particle trajectory that presents the particle's movement in the draft tube column obtained from the RPT experiment. Since the particle movement has been measured for about 20 hours, during which the particle visited any part of the reactor many times, it is reasonable to assume that the obtained trajectories represent the movement of all cells in the reactor.

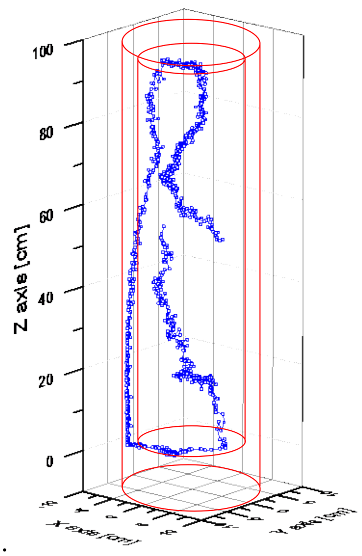


Fig. 3 Single trajectory of the tracer particle from RPT experiments

A single trajectory is defined as one circulation of the particle in the column, which starts from a given plane in the upper part of the draft tube and returns to this plane. More than 1500 trajectories have been observed during the experiment. The mean circulation time was observed to be 48.7 sec. The CFD simulations were also carried out for the same reactor. STAR-CCM+ v7.06 was used for the simulation. In this study, the standard k- ε turbulence model was used because of its general applicability. Figure 4 shows Lagrangian particle trajectories form the CFD simulation, and the mean circulation time was calculated to be 47.7 sec.

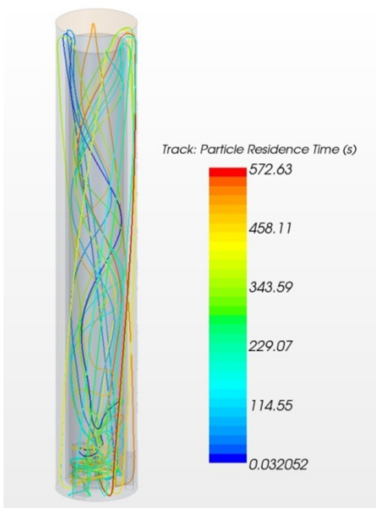


Fig. 4 Trajectories of the Lagrangian particle from the CFD simulation

## 3. Conclusions

The radioactive particle tracking technique was applied to investigate the characteristics of water flow for the draft tube column. The trajectory of the tracer particle was successfully reconstructed using the Monte Carlo method. The mean circulation time was calculated to be about 48 s by both the RPT experiment and CFD simulation.

## Acknowledgement

This work was supported by Radiation Technology R&D program through the National Research Foundation of Korea funded by the Ministry of Science, ICT & Future Planning (NRF-2012M2A2A6007040).

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