Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

A Study on the Residence Time Calculation Method of a Decay Tank in a Research Reactor

Minkyu Jung [a*], Hong-Beom Park [a], Kyoungwoo Seo [a], and Seong-Hoon Kim [a]
[a]*Korea Atomic Energy Research Institute, Daejeon 34057, Korea*
[*]*Corresponding author: minkyujung@kaeri.re.kr*

1. Introduction

Research reactors are intended to produce and utilize radio-isotopes, thus cooling systems are required to remove heat generated from the reactor. The primary cooling system, which performs the cooling function through the reactor directly, includes the radionuclides, corrosion products, fission products that are produced by radiation through the core. N-16 comprises a majority of radiation level for PCS due to the generation of high strength γ-rays. Depending on intensity of the radioactivity, shielding design of the area where system piping and equipment are installed is carried out. Because the half-life of N-16 is very short as 7.13 seconds, the shielding design could be performed efficiently by using large volume tanks such as the decay tank to keep the coolant for the required time and reduce the radioactivity [1].

In order to analyze the performance of the decay tank, the residence time of the coolant shall be evaluated. Our research group have evaluated and compared various methods of numerical analysis for the residence time assessment with the simple geometric cases [2]. Several time calculation methods, such as streamline, discrete phase method (DPM), scalar transport method, and multi-component method, are compared. And, the DPM and scalar transport methods were assessed to be appropriate for the residence time calculation.

In the present study, residence time evaluation methods are described the characteristics of each method. The residence time of the decay tank was compared using the time assessment methods.

2. Numerical Methods

A commercial computational fluid dynamics (CFD) software, ANSYS FLUENT is utilized for the calculation [3]. The fluid motion is modeled by incompressible Reynolds-averaged Navier-Stokes equations. The numerical domain is discretized using cell-centered finite volume method.

2.1 Discrete Phase Method

The Discrete Phase Method (DPM) utilizes Lagrangian particles in the Eulerian flow field to track the passage time of particles. The trajectory of a discrete phase particle could be predicted by integrating the force balance on particle like the equation [3].

$$\frac{d}{dt}u_p = F_D\left(u - u_p\right) + \frac{g_x\left(\rho_p - \rho\right)}{\rho_p} + F_x$$

where F_x is an additional acceleration and $F_D\left(u - u_p\right)$ is the drag force per unit particle. The subscript p means massless particles.

After the flow field is converged, the DPM field also need several iterations. The particle tracking method tracks the motion of individual particles by computing the force balancing equation, thus this approach is clear and physically simple.

2.2 Scalar Transport Method

To predict the residence time by the experimental approach, tracer is injected for a very short time at the inlet boundary, then the concentration of tracer is measured at the outlet boundary. From the measured concentration, the residence time distribution could be obtained by dividing the injected amount at the inlet boundary. Scalar transport method could be utilized to estimate the residence time by the tracer. For an arbitrary scalar ϕ_k could be solved by the scalar transport equation

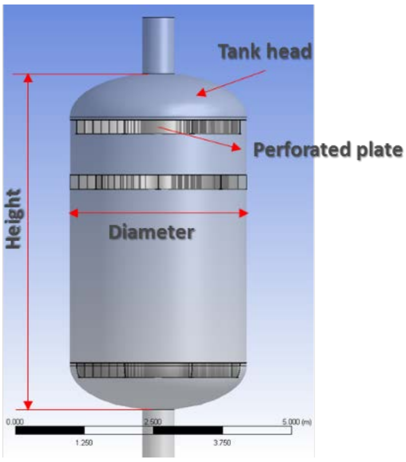
$$\frac{\partial \rho \phi_k}{\partial t} + \frac{\partial}{\partial x_i}\left(\rho u_i \phi_k - \Gamma_k \frac{\partial \phi_k}{\partial x_i}\right) = S_{\phi_k}$$

where Γ_k and S_{ϕ_k} are the diffusion coefficient and source term for the scalar equations. To obtain the time distribution, the transient flow simulation should be conducted.

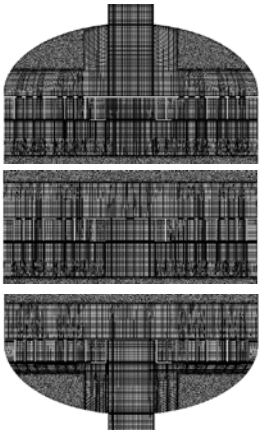
3. Results and Discussions

3.1 Modeling and Numerical Meshes

The decay tank in the present study consists of a cylindrical shape body with an upper and lower 2:1 elliptical head as shown in Fig. 1 (a). The perforated plates are installed to evenly distribute the flow in the decay tank to decrease the flow velocity. The I-beam for securing the structural integrity and flow guide for maintaining vertical flow were installed at the bottom of the perforated plates. The numerical meshes were shown in Fig. 1 (b). The mixed meshes were utilized such as hexahedral, prism, tetrahedral meshes, with a total of about 106 million. As shown in the figure, the hexahedral meshes were used to resolve the flow more accurately around inlet, outlet and perforated plates.



(a) Geometric configuration



(b) Numerical meshes

Fig. 1. Geometric configuration and numerical meshes for decay tank

3.2 Residence Time Comparison

Steady state simulations were conducted to calculate the residence time for the decay tank. To evaluate the residence time using the DPM method, massless particles were used as many as the number of face in the inlet boundary. The behavior and flow characteristics of the massless particles are shown in Fig. 2.

On the other hand, the scalar transport method injects tracer in a very short time, which is measured at the outlet boundary. The material properties of the tracer are applied as same as the coolant in order to avoid affecting the flow field. The snapshots of tracer fraction contour are shown in Fig. 3. It can be shown that the tracer injected at the inlet was passed through the plates and exited to outlet boundary.

A comparison of the residence time distribution using scalar transport method and DPM is shown in Fig. 4. The residence time distribution (RTD) is defined as the probability distribution of time that solid or fluid materials stay inside one or more unit operations in a continuous flow system [4]. It is shown that time distributions are similar except for peak magnitude. The DPM shows a higher peak value, which can be attributed to the use of a finite number of particles. For same reason, the mean residence time using DPM is shorter than scalar transport method.

Fig. 2. 3D massless particle contour using DPM method

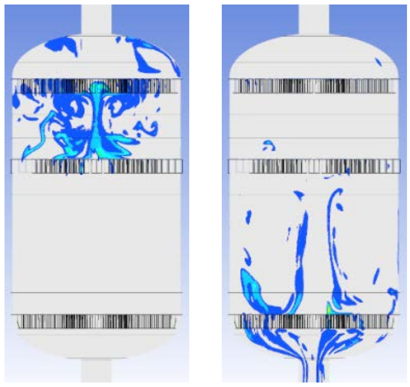


Fig. 3. Snapshots of tracer fraction contour using scalar transport method

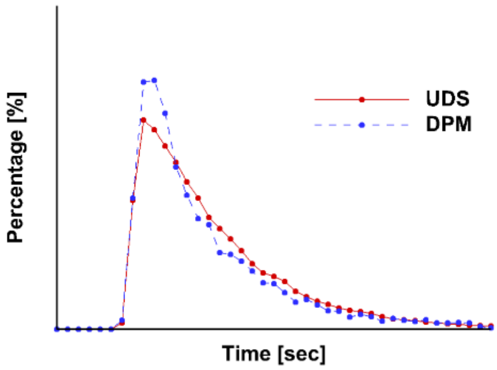


Fig. 4. Comparison of the residence time distribution using scalar transport method and DPM

4. Conclusions

This paper describes a comparison of residence time calculation methods for the decay tank configuration. In the present study, DPM method using massless particles and scalar transport method utilizing tracer were applied to compute the residence time. The DPM method utilizes Lagrangian particles to track the passage time after steady state simulations. The scalar transport method measures the concentration of the tracer through the transient analysis. Two methods show similar performance for evaluating the residence time and conservation for particles and scalar, respectively. Therefore, it is concluded that the DPM is more proper at the stage of initial design with only steady state solution. And at detailed design phase, scalar transport method could be utilized to assess the accurate tank performance and verify the DPM method. This study will be applied to design the decay tank and internal flow devices.

ACKNOWLEDMENT

This work has been conducted as a part of the Development of Research Reactor Technology project sponsored by Ministry of Science and ICT of Korean government.

REFERENCES

[1] M. K. Jung, K. W. Seo, and S. H. Kim, Flow Residence Time Analysis for Decay Tank by the Design Parameters, Transactions of KNS spring Meeting, 2016.
[2] M. K. Jung, K. W. Seo, and S. H. Kim, A Study of Residence Time Calculation Methods in Decay Tank Design, Korean Journal of Air-Conditioning and Refrigeration Engineering, Vol.29, p. 220-230, 2017.
[3] ANSYS FLUENT theory guide, ANSYS Inc., 2019.
[4] Y. Gao, F. J. Muzzio, M. G. Ierapetritou, A review of the Residence Time Distribution (RTD) applications in solid unit operations, Powder Technology, Vol. 228, p. 416-423, 2012.