# Comparison of Permeability Calculation Inside a Spent Nuclear Fuel in a Dry Storage

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## 1. Introduction

The porous media model and effective thermal conductivity are used to simplify the fuel assembly. USNRC, 2010 recommend that an approach to calculate the friction factors should be to perform a computational fluid dynamics (CFD) analysis for a fuel assembly. From the detailed CFD analysis of a single fuel assembly, the friction factors could be calculated by wall shear stresses.

In this study, computational modeling of a fuel assembly was used to numerically investigate the fluid flow characteristics in a basket containing a nuclear fuel assembly. Three different methods of calculating the permeability were used and their results compared.

## 2. Calculation model

The calculation model represents a spent nuclear fuel assembly loaded in a fuel basket. The canister in a dry storage system is filled with helium. Helium flows from the bottom to the top of the basket because of the natural convection produced by the decay heat of the spent nuclear fuel. The complex geometry of the nuclear fuel assembly induces a shear stress on the helium flow.

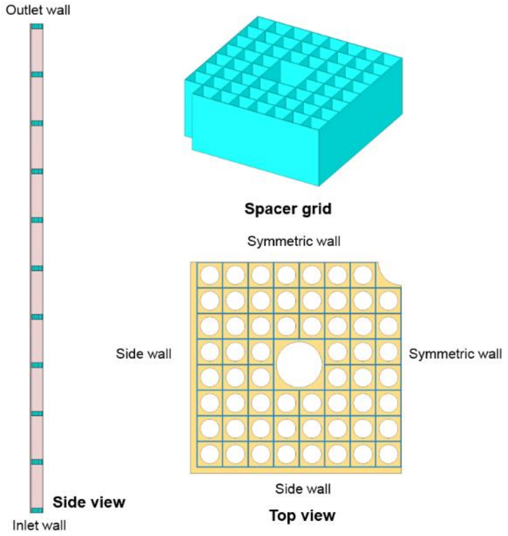

Fig. 1. Modeling of fuel assembly.

Fig. 1 shows a model of the fuel assembly. The target fuel assembly for modeling was a PLUS7 fuel assembly (16 × 16 type). The PLUS7 fuel assemblies were for OPR1000 and APR1400s in Korea. More than 2,300 PLUS7 fuel assemblies were supplied to the OPR1000 nuclear power plants from 2006 [1]. The fuel cladding had a diameter of 9.5 mm. A total of 11 spacer grids were located at regular intervals along the fuel rod, except at the upper and lower end fittings. The vanes and other small parts of the spacer grid were not considered. The purpose of the vanes was to enhance the heat transfer rate by introducing a turbulent water flow in the reactor vessel of a nuclear power plant. However, the effect of the vane on the flow was negligible in the dry storage cask because the flow velocity of helium was very slow compared to that of the water flow in the reactor vessel. The lengths of the upper and lower end fittings were relatively short compared to the total height of the fuel assembly. The flow resistance inside the basket was inversely proportional to the flow area. The flow resistance generated by the upper and lower end fittings was negligible. Therefore, the upper and lower end fittings were not considered in the fuel assembly model.

## 3. Permeability calculation

Permeability was calculated using three different methods. The first method was a theoretical approach using the friction factor. The second method was a CFD calculation using the wall shear stress, while the third method was a CFD calculation using the pressure drop.

The porous media flow resistance model was defined by the Darcy–Forchheimer law [2]:

$$\frac{\Delta P}{L} = D\mu V + C\left(\frac{1}{2}\rho V^{2}\right) \tag{1}$$

where ΔP is the porous media pressure drop; V is the superficial fluid velocity; L is the length of the porous media; D is the viscous resistance parameter (permeability); and C is the inertial resistance parameter. In the dry storage cask (vertical type), the flow velocity inside the basket was very low. D was more dominant than C because of the low velocity. Therefore, the permeability (D) is defined as follows:

$$D = \frac{\Delta P}{L \mu V} \tag{2}$$

The frictional pressure drop is defined by the following equation:

$$\frac{\Delta P}{L} = \frac{f}{D_h} \frac{1}{2} \rho V^2 \tag{3}$$

The Reynolds number is as follows:

$$\mathrm{Re} = \frac{\rho V D_h}{\mu} \tag{4}$$

The frictional pressure drop is rearranged by the Reynolds number as:

$$\frac{\Delta P}{L} = \frac{f\,\mathrm{Re}}{2} \frac{\mu}{D_h^2} V \tag{5}$$

The Darcy friction factor (f) was experimentally obtained by [3] when the flow was laminar and the rod bundle was as follows:

$$f = \frac{110}{\mathrm{Re}} \tag{6}$$

The permeability could be obtained in Eqs. (1) and (6) as follows:

$$\frac{\Delta P}{L} = \frac{55\mu}{D_h^2} V \tag{7}$$

Thus,

$$D = \frac{55}{D_h^2} \tag{8}$$

The friction factor can be expressed as follows:

$$f = \frac{4\tau_w}{\frac{1}{2}\rho V^2} \tag{9}$$

The permeability could be calculated from the combination of Eqs. (1), (2), and (8) as follows:

$$D = \frac{4\tau_w}{\mu V D_h} \tag{10}$$

Table 1 shows the calculated permeability using each of the three different methods described earlier. The result obtained by the friction factor method was 30%, which was 32% less than that acquired by the CFD calculations using the wall shear stress and the pressure drop. The effect of the spacers could be the reason for the difference. Accordingly, the Darcy friction factor needs to be modified to calculate the exact shear stress of the fuel assembly, including the effect of the spacer grid.

Table 1. Results of permeability calculation

| Method | Friction factor | Wall shear stress | Pressure drop |
|---|---|---|---|
| Permeability | $3.61 \times 10^5$ | $5.17 \times 10^5$ | $5.34 \times 10^5$ |

## 4. Conclusions

The flow inside a fuel basket that contains a fuel assembly is analyzed using CFD. Three different methods were used to calculate the permeability and their results were compared. The friction factor method could be used to determine the approximate permeability without performing a CFD calculation. However, the permeability from the friction factor method is 50% less than the permeability from wall shear stress and pressure drop using CFD.

## ACKNOWLEDGEMENT

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