Porous Media Modelling for Thermal Analysis of Storage Cask with Bird Screen Meshes

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1. Introduction

A concrete storage cask has been developed for dry storage of 21 spent PWR fuel assemblies [1]. The cask consists of a concrete overpack, which has an air cooling system and a sealed canister including the fuel baskets as shown in Fig. 1. Air inlet and outlet ducts are installed at the bottom and top of the concrete overpack. Bird screen meshes are installed at the air inlet and outlet ducts to prevent the intrusion of debris from the external environment.

The presence of this screens introduce an additional resistance to air flow through the ducts. Porous media model can be used to simulate the flow effects in the bird screen meshes. The purpose of this study is to develop the porous media model for the simulation of bird screen meshes and to prove the validation of the porous media model.

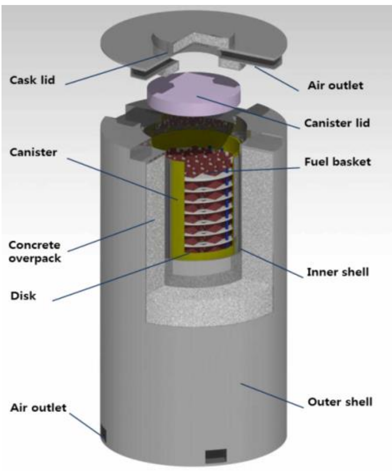


Fig. 1. Overview of concrete storage cask.

2. Porous Media Modelling

The theoretical pressure drop between the inside and the outside of a bird screen mesh can be predicted using following relation [2].

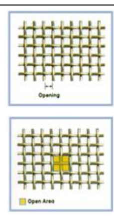
$$\frac{\Delta P}{t} = \frac{\mu_f}{\alpha} v + C\left(\frac{1}{2}\rho v^2\right) \qquad (1)$$

Where,

ΔP : pressure drop [Pa],
t : thickness of bird screen mesh [m]
μ : viscosity of air [kg/m-s]
α : permeability [m^2] (1/α : viscous resist. coeff.)
C : inertial resistance coefficient [m^{-1}]
ρ : density of air [kg/m^3]
v : superficial velocity [m/s]

In this study, pressure drops through the bird screen meshes were calculated by CFD analysis. Inertial resistance factor (C) and a viscous resistance factor (1/α) were predicted by pressure drop correlation. Five types of the meshes were considered in this study. Table 1 shows the specifications of bird screen meshes. Fig. 2 shows the flow analysis model for calculation of pressure drop, and the result of velocity vector for the bird screen mesh.

Table 1. Specifications of bird screen meshes

Mesh no.	Wire dia. (mm)	Opening (mm)	Open area (%)	Mesh Shape
#4	0.71	5.64	78.9	
#6	0.71	3.53	69.6	
#8	0.71	2.46	60.2	
#10	0.71	1.83	51.8	
#12	0.71	1.40	43.6	

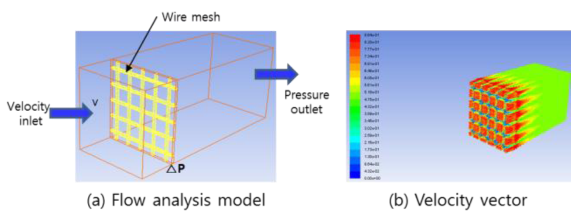


Fig. 2. Flow analysis model and velocity vector.

Table 2 and Fig. 3 show the fluid flow analysis results for bird screen meshes. The velocities at the inlet of bird screens were considered with 0.4 m/s ~ 0.8 m/s. Pressure drops were calculated as a variation of the velocities for each screen mesh. Viscosity and inertial resistance factors were calculated from the polynomial curve of the second order and Equation (1). Table 3 shows the flow resistance coefficients for porous media models of bird screen meshes.

Table 2. Fluid flow analysis results for bird screen meshes

Velocity [m/s]	Pressure drop [Pa]		
	Mesh #4	Mesh #8	Mesh #12
0.4	0.0509	0.1543	0.3948
0.5	0.0730	0.2213	0.5700
0.6	0.0981	0.2991	0.7761
0.7	0.1265	0.3877	1.0126
0.8	0.1581	0.4871	1.2795

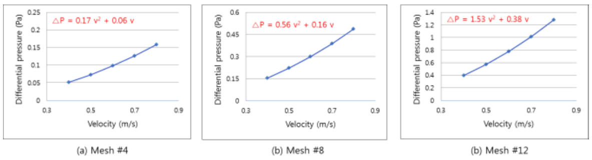


Fig. 3. Pressure drop - velocity and approximation formula.

Table 3. Flow resistance coefficients for porous media model of bird screen meshes

Mesh size	Permeability (α), [m²]		Inertial res. factor (C), [1/m]	
	Inlet	Outlet	Inlet	Outlet
#4	2.20E-7	2.66E-7	406	468
#8	7.90E-8	9.56E-8	1,299	1,494
#12	3.46E-8	4.18E-8	3,576	4,115

3. Verification of Porous Media Model

Thermal tests have been carried out for the concrete cask with bird screen meshes. Also, thermal analyses have been carried out for the concrete cask using a porous media model to prove the validation of the analysis model. Decay heat from the 21 fuel assemblies was considered as 16.8 kW. Ambient temperature was assumed as 20°C.

Fig. 4 shows the comparison of the thermal analysis and test results for the mesh #4 and mesh #12. The analysis results agreed well with the test results. The analysis temperatures were slightly higher than the test temperatures. Therefore, the reliability and conservatism of the analysis results for porous model have been demonstrated. The temperatures for mesh #12 are slightly higher than the temperatures for mesh #4. It was shown that the screen mesh sizes don't significantly affect the cask temperatures.

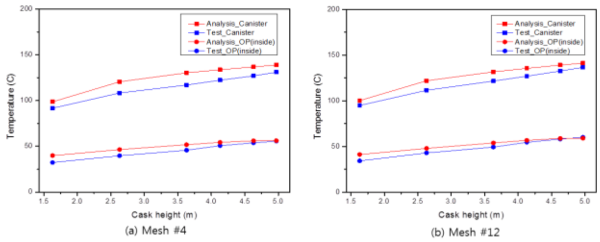


Fig. 4. Comparison of thermal analysis and test results.

4. Conclusions

Porous media model was developed to simplify the bird screen meshes. Flow resistance coefficients for porous media model were derived from the fluid flow analysis. The analysis temperatures for the storage cask were slightly higher than the test results. Therefore, the reliability and conservatism for the porous model have been demonstrated. The porous media model developed in this study can be used to estimate the temperatures for concrete cask with bird screen meshes.

REFERENCES

[1] Topical Report for Concrete Storage Cask (Rev.2), KORAD, 2014.

[2] Macini, P. et al. "Laboratory Measurements of Non-Darcy Flow Coefficients in Natural and Artificial Unconsolidated Porous Media", Journal of Petroleum Science and Eng. 77, pp.365-374, 2011.