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Thermal Analysis of Concrete Storage Cask with Bird Screen Meshes

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1. Introduction

A spent fuel concrete storage cask loaded with 21 spent PWR fuel assemblies has been developed by the Korea Radioactive Waste Agency (KORAD). The concrete cask consists of an overpack, and a sealed canister including the fuel baskets as shown in Fig. 1. The overpack consists of a structural material, a concrete shielding, and a ventilation system. Heat is removed from the cask to the environment by a passive means only. Air inlet and outlet ducts are installed at the bottom and top of the cask for a ventilation system. Bird screen meshes are installed at the air inlet and outlet ducts to inhibit intrusion of debris from the external environment. The presence of this screens introduce an additional resistance to air flow through the ducts. Table 1 shows the specification of bird screen mesh. Five types of meshes for bird screen were considered in this study. The bird screen meshes at the inlet and outlet vents reduce the open area for flow by about 44 ~ 79 %.

In this study, a thermal analysis of the cask with bird screen meshes has been performed using a porous media model.

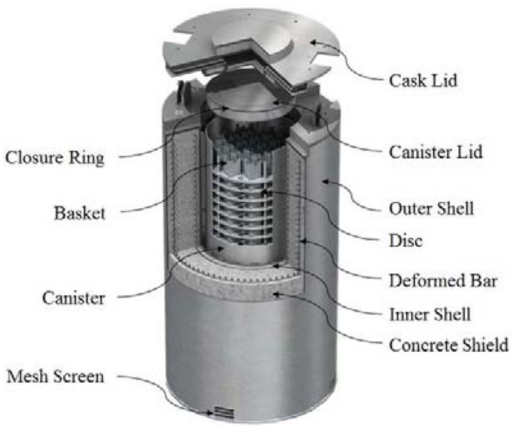


Fig. 1. Configuration of concrete storage cask

Table 1. Specification of bird screen mesh

Mesh No.	Wire dia. (mm)	Opening (mm)	Open area (%)
#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

2. Porous Media Model for Bird Screen Mesh

In general, the porous media model is used to simplify the bird screen meshes. Analytical model has been developed to simulate the fluid flow through porous media and to calculate the pressure drop for the fluids.

Darcy introduced a 1-D empirical model for laminar flow through porous media. For turbulent flow in porous media, viscous and inertial effects cause more nonlinear behavior. Forchheimer added a term to Darcy's law in order to take account of this nonlinearity. His equation is generally accepted as the extension to the Darcy equation for high flow rates[1]. The Forchheimer equation is expressed in Equation 1[2].

$$\frac{\Delta P}{L} = \frac{\mu_f}{\alpha} v + C\left(\frac{1}{2}\rho v^2\right) \quad \text{------------------ (1)}$$

Where,

$\triangle$P : pressure drop [Pa]

α : permeability [m²], (1/α : viscous resistance coeff.)

C : inertial resistance coefficient[m^{-1}]

μ : viscosity [kg/m-s]

ρ : density [kg/m³]

v : superficial velocity [m/s]

For calculation the flow and pressure drop through porous media, the inertial resistance coefficient(C) and the viscous resistance coefficient(1/α) should be obtained. Fig. 2 shows the analysis model for calculation of pressure drop through the mesh screens. The velocities at the inlet were considered with 0.4 m/s ~ 0.8 m/s.

Fig. 3 and Table 2 show the fluid flow analysis results for bird screen meshes according to the mesh sizes. Pressure drops were calculated as a variation of the velocities for each screen mesh. Viscosity resistance coefficients and inertial resistance coefficients were calculated from the polynomial curve of the second order as shown Fig. 3(b) and Equation 1.

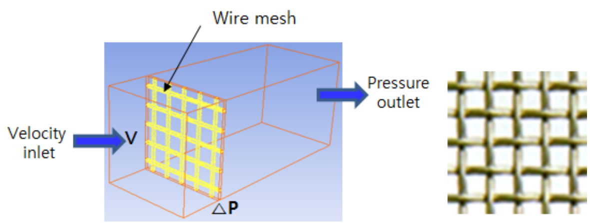
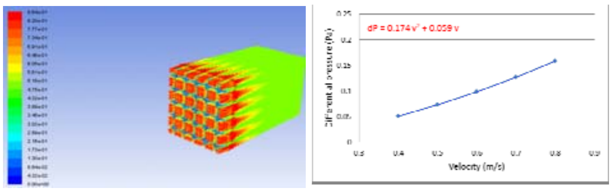


Fig. 2. Fluid flow analysis model for screen meshes



(a) Velocity vector (b) Polynomial curve

Fig. 3. Fluid flow analysis results for screen meshes

Table 2. Fluid flow Analysis results and flow resistance coefficients

		Mesh #4	Mesh #8	Mesh #12
		△P[Pa]	△P[Pa]	△P[Pa]
Superficial velocity (v), [m/s]	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
Approximation formula		$\triangle P = 0.174v^2 + 0.059v$	$\triangle P = 0.556v^2 + 0.164v$	$\triangle P = 1.531v^2 + 0.375v$
Permeability (α), [m²]	Inlet	2.20E-07	7.90E-08	3.46E-08
	Outlet	2.66E-07	9.56E-08	4.18E-08
Inertial res. factor (C), [1/m]	Inlet	406	1,299	3,576
	Outlet	468	1,494	4,115

3. Thermal Analysis of Concrete Cask

Thermal analyses have been carried out for the concrete cask using a porous media model. Also, the thermal tests have been carried out for the concrete cask with the meshes. Bird screen mesh sizes are considered with #4, #6, #8, #10 and #12 meshes in the thermal test and analysis. Decay heat from the 21 spent PWR fuel assemblies is considered as 16.8 kW. Ambient temperature was assumed as 20 °C.

Table 3 shows a comparison of the thermal test and analysis results for the mesh #4 and mesh #12. The analysis results agreed well with the test results. Therefore, it was shown that the porous media model for the bird screen mesh was successfully established to estimate the cask temperature. The cask 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. The heat transfer rates through the air duct are calculated with 68.8 % ~ 84.8 % and 73.6 % ~ 75.3 % in the thermal test and analysis, respectively. Therefore, the heat removal performance was proved for storage cask with bird screen meshes.

Table 3. Comparison of thermal test and analysis results

Location		Mesh#4		Mesh #12	
		Test	Anal.	Test	Anal.
Canister surface		131℃	138.7℃	136℃	141.1℃
Over-Pack	Inside	54 ℃	56.0 ℃	60 ℃	58.9 ℃
	Outside	31 ℃	35.4 ℃	34 ℃	36.5 ℃
Air outlet	Temp.	60.7 ℃	63.8 ℃	71.8 ℃	67.5 ℃
	Velocity	0.74m/s	0.73m/s	0.53m/s	0.68m/s
Heat transfer rate		84.8 %	75.3 %	68.8 %	73.6 %

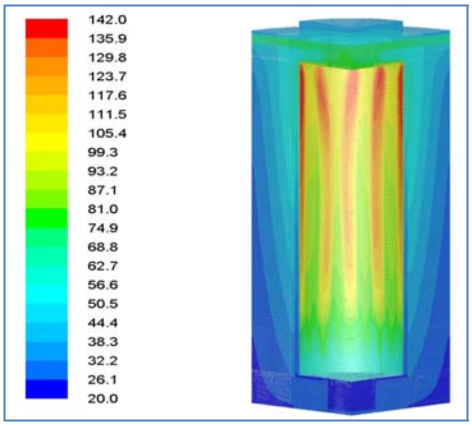


Fig. 4. Temperature contours of concrete cask

4. Conclusions

Flow resistance coefficients for porous media model were deduced from the fluid flow analysis of bird screen meshes. Thermal analyses for the concrete cask have been carried out using a porous media model. The analysis results agreed well with the test results. Therefore, it was shown that the porous media model for the screen mesh was established to estimate the cask temperatures. The heat removal performance was proved for storage cask with bird screen meshes.

Acknowledgement

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