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A Study on Thermal Performance using Conjugated Heat Transfer Analysis for the OASIS-32D Spent Nuclear Fuel Cask

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1. Introduction

The purpose of the present study is to evaluate the heat transfer capability of the spent nuclear fuel (SNF) cask, OASIS (**O**ptimized **A**nd **S**afe **I**nterim **S**torage **S**ystem)-32D, which contains 32 fuel assemblies of pressurized water reactors.

A few previous researches have been suggesting that heat transfer characteristics in a spent fuel transportation cask affect the Peak Clad Temperature (PCT) and integrity of the internal structure. A numerical analysis has been performed considering a conjugate heat transfer which includes conduction, radiation, and natural convection.

To evaluate PCT and conjugated heat transfer phenomena, the CFD has been performed considering Effective Thermal Conductivity (ETC) of fuel assemblies. Also, and temperature distribution in the cask structure are calculated.

2. Methods and Results

A SNF cask shall be designed to provide adequate heat removal capacity according to 10 CFR Part 71, 72 and NUREG-1536, 1617. The fuel cladding is an important radiation barrier and its temperature shall not exceed 400 °C during normal conditions. A maximum PCT and temperature of material for different decay heat generation rates shall be calculated to ensure that it does not exceed the allowed limit.

2.1 Computational Model

The OASIS-32D is a SNF transportation and storage cask developed by KEPCO-E&C. The OASIS-32D cask mainly has a fuel storage canister, ask shell, basket and heat transfer fin. Fig 1 shows that inside canister is composed of basket, support of basket, fuel bundles, Neutron Absorber (NA) and NA sheathing plate. The basket has 32 fuel storage space for PWR fuel

CFD simulations were performed using the commercial code, STAR-CCM+ [1]. Also A mesh with about 30 million cells is generated and polyhedral mesh was chosen so as to predict wall bounded turbulent flow for the best computational accuracy for conjugated heat transfer. The turbulence models selected for evaluating thermal performance are below;

Case 1: realizable k- ε model with all y+ wall treatment
Case 2: k- w SST model with all y+ wall treatment

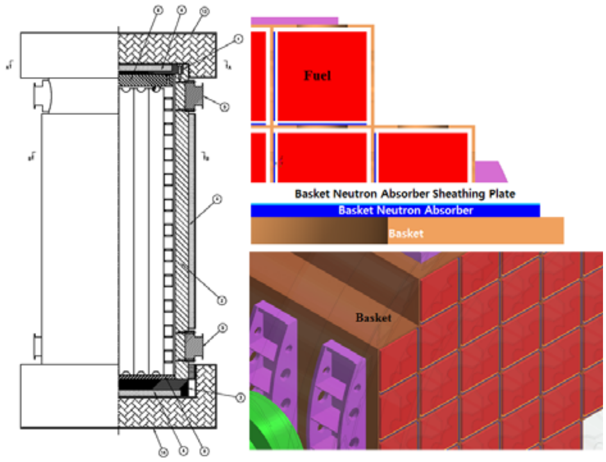

Fig. 1. Geometry of Computational Model

2.2 Boundary Conditions

Manteufel and Todreas [2] developed an analytical model for one-dimensional conduction and radiation within a rectangular array of heated fuel rods immersed in stagnant gas.

Bahney and Lotz [3] performed 2D finite element simulations of conduction and radiation heat transfer within the fuel assembly and backfill gas region. The surface emissivity of the fuel rod cladding and the basket cell walls also need to be considered in developing an appropriate effective conductivity model for a particular application.

The appropriate radial and axial fuel ETC for a given application depends on the fuel assembly geometry, the assembly decay heat, and the geometry of the basket configuration.

The ETCs for fuel assemblies are below;

$$k_{eff\ radial} = 0.1147\exp(0.0034T)$$
$$k_{eff\ axial} = 0.9738\exp(0.0008T)$$

k : *effective thermal conductivity* (W/m^2K)
T : *Temperature* (K)

A fuel bundles region was constructed by porous media, which are homogenous model, for a spent nuclear fuel assemblies which has 17x17 fuel bundles. The porous model was used to determine the axial and radial pressure distribution across the fuel assembly for different input velocities [3]. Porosities of fuel bundles were assumed that the void fraction of 0.6 was calculated from fuel assembly design. The radial and axial porosity coefficient was taken from previous study [3].

$$\frac{\Delta P}{L} = -(\alpha v + \beta)v$$

$$\alpha : inertial\,coefficient\ (kg/m^4)$$

$$\beta : viscous\,coefficient\ (kg/m^3 - s)$$

$$v : velocity (m/s)$$

The total amount heat source is 27.68 kW. A peak heat ratio per assembly is applied to the interior of the fuel bundles along the height of y-axis. The maximum peak ratio is 1.131 and minimum peak ratio is 0.376.

The external surface of the cask considered heat exchange by convection and radiation with an ambient temperature of 85°C. And radiation heat transfer between the external surface and the ambient environment is evaluated in the model by applying an emissivity of 0.8 for surface of cask. Total heat transfer coefficient was used to calculate the convection heat transfer and radiation between the environment and external surface [4]. Fig. 2 shows the distribution of heat transfer coefficient on exterior surface. The operating pressure selected for this study is 101.325kPa, gravity is specified as 9.81m/s^2 and working fluid gas in canister is helium.

2.3 Results

There is no significant fluid temperature of realizable k-ε and k- w SST model as shown in Fig. 3, Fig. 4 and Fig.5. Also temperature profiles of same position for material is similar. Temperature of outer surface is 134°C which is based on environment temperature 85°C in which the convection and radiation were conservatively included.

Fig. 3 is temperature distribution of in the cask. The center temperature of fuel basket is very high according to heat source and peak factor for spent fuel bundles. A maximum temperature of fuel bundles is 327.5°C that its temperature does not exceed 400°C during normal conditions. Also allowable operating temperature of internal materials were satisfied under normal operating.

Fig. 4 shows that a different temperature of between top of y-axis and bottom of y-axis is about 42°C. The top of y-axis is lower than bottom of y-axis because fluid region area between bottom of basket and fuel bundle is small so heat transfer performance is poor. The temperature distribution of z-axis is asymmetry by reason of buoyancy effect as shown in Fig. 5.

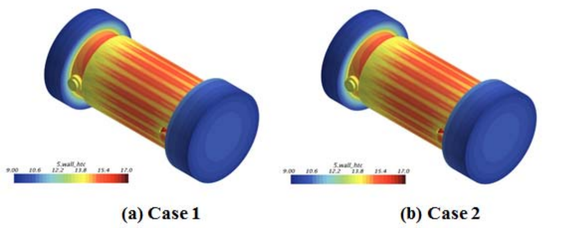

Fig. 2. Heat transfer coefficient for CASK outer surface wall

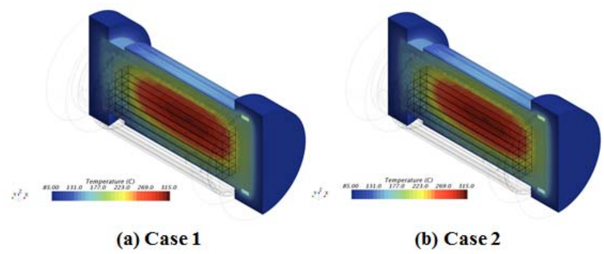

Fig. 3. Result of temperature for interior cask

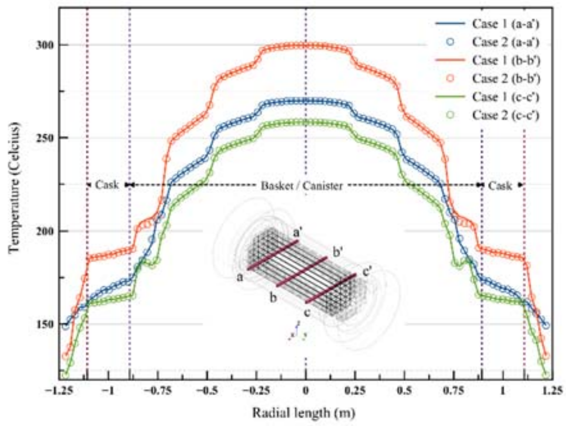

Fig. 4. Result of temperature profile (x-axis)

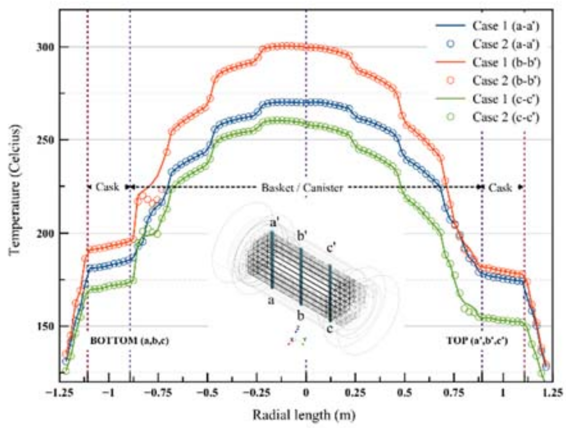

Fig. 5. Result of temperature profile (z-axis)

3. Conclusions

The OASIS-32D is a spent nuclear fuel transportation and storage cask developed by KEPCO-E&C.

There is no significant fluid temperature of realizable k-ε and k- w SST turbulence model. The temperature profile of position for material is similar. Therefore the CFD simulation for SNF cask is unaffected by turbulence model.

The temperature distribution of cask is asymmetry by reason of buoyancy and the geometry effect of fluid region area between basket and fuel bundles.

The maximum temperature of fuel bundles is 327.5°C that its temperature does not exceed 400°C. Also allowable operating temperature of internal materials was satisfied during normal conditions.

In the future, accident analyses considering fire condition for SNF cask will be carried out.

REFERENCES

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