A Study on Thermal Performance for the OASIS-32D Spent Nuclear Fuel Cask under Severe Fire Accident Conditions

Jaehyung Park*, Kunwoo Yi, Hochel Jang, Byungryul Jung, Seongchan Park

KEPCO E&C, 111 Daedeok-daero 989 Beon-gil Yuseong-gu, Daejeon, Korea
**Corresponding author: fogmans@kepco-enc.com*

1. Introduction

The purpose of present study is to evaluate the heat transfer capability under severe fire accident conditions for the Spent Nuclear Fuel (SNF) cask, which is OASIS (Optimized And Safe Interim Storage System)-32D, which contains 32 fuel assemblies of pressurized water reactors. OASIS-32D is the SNF transportation and storage cask model developed by KEPCO-ENC. In the previous study, the numerical analysis for normal condition was evaluated [1].

Title 10 of Code of Federal Regulations Part 71.73 section(c)(4), (10 CFR 71.73(c)(4)) requires that transportation packages shall be designed to resist an engulfing fire (800°C) during 30 minutes and prevent release of radioactive material to the environment. NUREG-1536 requires that the cladding temperature shall not be exceeded 570°C for severe fire accident conditions.

The CFD analysis has been performed considering a conjugate heat transfer which includes conduction, radiation and convection.

2. Methods and Results

CFD analysis has been performed to evaluate the temperature distribution of the cask body with fire flame condition for 30 minutes. To evaluate the temperature change of structures, CFD analysis results with 10, 20, 30 minute were compared.

The ambient temperature of OASIS-32D cask is the 800 °C and the heat transfer coefficient considering the fire flame conditions such as flame velocity, flame convection and flame radiation emissivity, convection and surface radiation, was applied for the surface. The fill gas inside the canister is helium.

Maximum temperatures of structures and fill gas during exposed fire condition shall be calculated to ensure that they do not exceed the allowed limit.

2.1 Computational Model

The OASIS-32D cask mainly has a fuel storage canister, cask shell, basket, and heat transfer fin and neutron absorber. The basket has 32 fuel storage space for PWR fuel. The model is composed of basket, support of basket, fuel bundles, Neutron Absorber (NA) and NA sheathing plate as shown in Fig. 1.

The thermal model is 3-dimensional and CFD simulations were performed using the commercial code, STAR-CCM+ [2]. Also a mesh with about 18.2 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 [1].

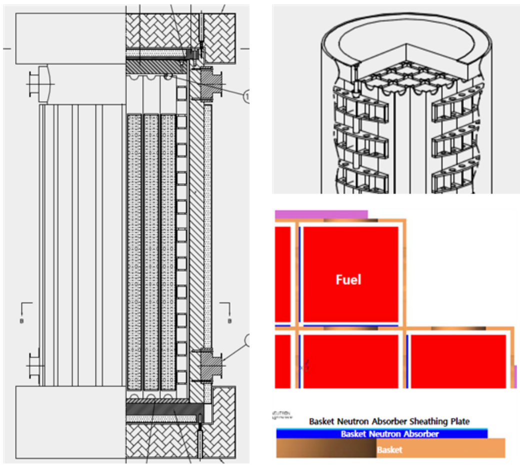

Fig. 1. Geometry of Computational Model

2.2 Boundary Condition

The heat transfer coefficient of external surface is considered that the convection and radiation with an ambient temperature is 800°C. And the radiation emissivity of 0.8 for surface is applied [3]. Also, the gravity is specified as 9.81m/s^2.

Total heat transfer coefficient (h) of OASIS-32D cask surface is below;

$$h = -0.1335(T_{air} - T_{sur}) + 152.44$$

T_{air} : ambient temperature
T_{sur} : OASIS-32D surface temperature

The temperature and pressure distribution during normal condition which is the result from previous study [1] was applied to initial condition of this CFD analysis.

The fuel bundle region is modeled as porous media, which is a homogenous model. The porous model was used to determine the axial and radial pressure distribution across the fuel assembly for different input velocities.

$\Delta P/L = -(\alpha v + \beta)v$

α: inertial coefficient (kg/m^4)
β: viscous coefficient (kg/m^3-s)
v: velocity (m/s)

The void fraction of fuel bundle region was assumed 0.6 from the geometry of the fuel assembly. The radial and axial porosity coefficient from previous study is used in this CFD analysis. The total heat generation of fuel regions was applied to 27.68 kW.

2.3 Result

In this study, the temperature distributions with time in the cask structure are described as follows.

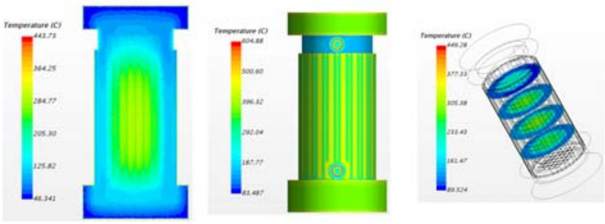

Fig. 2. Temperature distribution on 600 sec

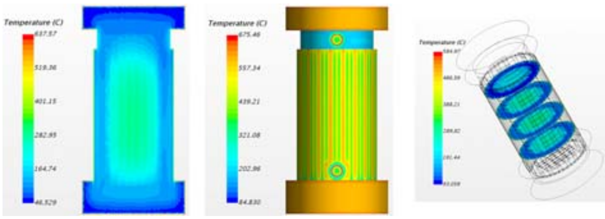

Fig. 3. Temperature distribution on 1,200 sec

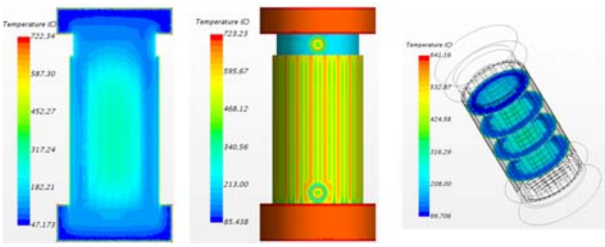

Fig. 4. Temperature distribution on 1,800 sec

Table 1: Outer surface temperature

Time	Max. Temp. (°C)	Aver. Temp. (°C)
600 sec	604.9	325.4
1,200 sec	675.5	457.1
1,800 sec	723.2	521.1

Table 2: Basket frame temperature

Time	Max. Temp. (°C)	Aver. Temp. (°C)
600 sec	270.4	189.4
1,200 sec	270.4	189.6
1,800 sec	270.4	190.0

Table 3: Helium temperature

Time	Max. Temp. (°C)	Aver. Temp. (°C)
600 sec	300.0	161.4
1,200 sec	300.0	161.8
1,800 sec	300.0	162.8

Fig. 2~4 show the temperature distribution in the cask. The surface temperature of OASIS-32D cask is higher than that inside structures. The cask outer temperature rises and is gradually converged over time as shown in Fig 5. In case on 1800 sec, the maximum surface temperature is 723.2°C and average surface temperature is 521.1°C as shown in Table 1.

The temperatures of basket-frame and helium are changed little for 30 minutes as shown in Table 2 and 3. The temperature difference of helium between case 600 sec and case 1,800 sec is 1.38°C. Maximum fuel bundles temperature is 313.9°C and is not changed during accident simulation as shown in Fig 6. As a result, the cladding temperature does not exceed 570°C during fire accident conditions.

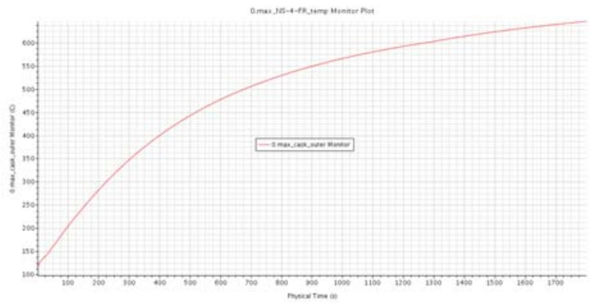

Fig. 5. Max. cask outer temperature (1,800 sec)

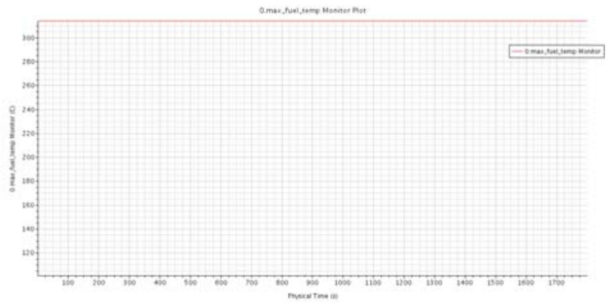

Fig. 6. Max. fuel bundles temperature (1,800 sec)

3. Conclusions

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

In this CFD simulation, though the maximum surface temperature is 723.2°C, the fuel bundles temperature does not exceed 570°C. Also, it can be confirmed that the temperature changes of basket frame and helium is small.

In the future, additional CFD analysis is performed considering cooling condition after fire accident.

REFERENCES

[1] Kunwoo Yi, et al., A Study on Thermal Performance using Conjugated Heat Transfer Analysis for the OASIS-32D Spent Nuclear Fuel Cask, Korean Nuclear Society Autumn Meeting, 2017
[2] STAR-CCM+, Version 11.04 USER GUIDE
[3] IAEA Safety Standards Series, Regulations for the Safe Transport of Radioactive Material, No. TS-R-1, 2009