Proceedings of the 19th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2019
August 4-9, 2019, New Orleans, LA, USA

Paper No.1334

Study on shortening vacuum drying time by heating with external heater

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ABSTRACT

Before transport or storage of spent fuels by transport/storage casks, it is necessary to dry the cask cavity. Vacuum drying is one of the methods to dry. The vacuum drying equipment developed by OCL can be designed to reduce residual moisture below limit by continuous 8 hours drying operation, as long as the residual water after drainage can be kept at approximately 50°C or more. However, when the decay heat of spent fuels is low or the initial temperature of the cask is low, the supply of latent heat necessary for evaporation of the residual water is insufficient. As a consequence, the vacuum drying time is prolonged. In order to shorten the drying time in the state of little initial latent heat, it is effective to continuously supply heat to the residual water. And as one of the means, we propose to supply heat to the residual water from the outside of the cask by the additional heating device. In consideration of ease of the device handling, integrity of the cask, and heat supply with efficiency to the residual water, the external heater is designed. And thermal analysis is performed using the decay heat of spent fuels and the initial temperature of the cask as parameters. As a result, it is expected that the use of external heater brings to drastically shorten the vacuum drying time.

INTRODUCTION

A transport/storage cask contained spent fuels is raised up from pool, and the cavity water of the cask is drained. At this time, a certain amount of water remains adhering to the cask cavity.

The residual moisture may cause mechanical strength deterioration due to oxidation reaction with the fuel cladding during long storage. Therefore, it is necessary to dry the cask cavity using vacuum drying which is one of the methods to dry.

In the process of vacuuming, the latent heat of vaporization is taken away from the residual water in the cask cavity, and a temperature drop occurs. Therefore, if the initial temperature of the cask and contained fuels is not high enough for the amount of water to be evaporated, freezing of the moisture occurs and the drying efficiency may be significantly reduced.

In addition, when the decay heat of spent fuels is low, the factor that raises the temperature of the cask cavity against the temperature drop due to evaporation of residual water is reduced. Therefore, the drying efficiency may be significantly reduced until the heat is transferred from the surrounding air to the cask body and the cask cavity gets warm.

As described above, when the drying efficiency is significantly reduced, there is a problem that the working time for drying the cask cavity is prolonged to 3 to 4 days or more. Such a problem depends on the ambient temperature of the cask, so the effect is particularly noticeable in winter.

In order to shorten the drying time in the state of little initial latent heat, it is effective to continuously supply heat to the residual water. And as one of the means, we propose to supply heat to the residual water from the outside of the cask by the additional heating device.

EXTERNAL HEATER

INSTALLATION POSITION

Since drainage and vacuum drying for the cask are performed in the condition the cask is set in vertical position, the residual water in cask is accumulated at the bottom of the cask cavity. Therefore, it is effective to install the external heater at the bottom of the cask in order to provide a sufficient amount of heat to the residual water in the case the heat is provided from the outside of the cask.

In addition, residual water tends to be accumulated in the pocket provided on the outer periphery of the bottom to increase drainage efficiency. And in order to heat the residual water it is more efficient to avoid the neutron shield provided on the bottom of the cask. For this reason, the installation position of the external heater that can maximize the drying efficiency is the outer peripheral surface of the bottom of the cask.

As mentioned above, we decided to design an external heater installed on the outer peripheral surface of the bottom of the cask.

COMPOSITION

The external heater is composed of silicone-rubber heaters and thin metallic plates etc. (See Figure 1)

The silicon rubber heater has the advantages of being thin and light, and is capable of uniformly heating the outer peripheral surface of the cask. A temperature sensor such as a thermocouple is provided on the heater installation surface, and the heater output is controlled to keep the surface temperature at a constant temperature.

In order to press and attach the heater to the outer peripheral surface of the cask, a thin plate made of stainless steel is provided outside the heater. In order to be easy in handling, the thin plate is divided into about three in the circumferential direction as shown in Figure 1. And radially projecting flanges are provided at both circumferential end portions of each thin plate. The heaters each other can be pressed against the outer peripheral surface of the cask by tightening the adjacent flanges with a bolt, a nut to bring the adjacent flanges into close proximity.

The outside of the external heater is covered with a heat insulator in order to improve heating efficiency and for safety considerations.

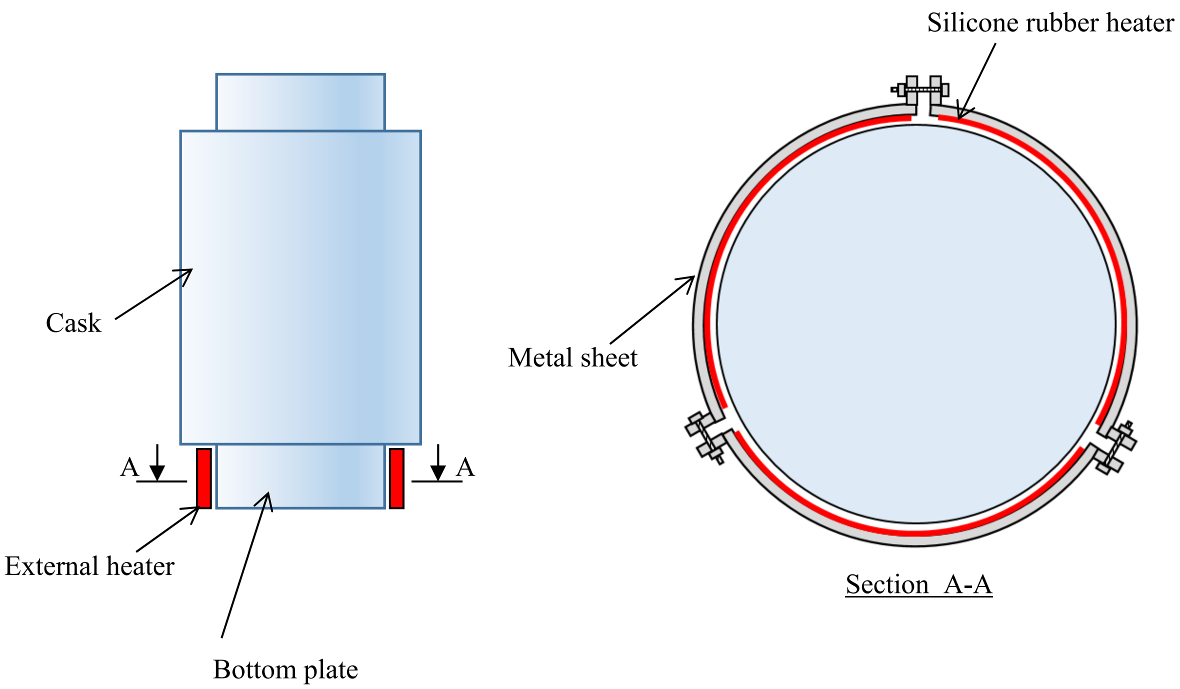


Figure 1. Installation position and configuration of external heater

HEAT TRANSFER ANALYSIS

ANALYSIS CONDITION

It is possible to dry approximately 50 kg of residual water below limit (for example, 10wt.% in helium filling state [1]) by continuous 8 hours drying operation of our vacuum drying equipment, as long as the residual water after drainage can be kept at approximately 50°C or more. Thermal analysis is conducted focusing on the temperature of residual water during vacuum drying with and without the external heater. The decay heat of the spent fuels and the initial temperature of the cask, which are predicted to have a large effect on the temperature of residual water, are used as parameters. Analysis conditions are shown in Table 1.

Table 1. Analysis Conditions

Item	Content
Evaluation position of temperature of residual water	Upper surface of bottom plate in the cask cavity
Events considered in unsteady analysis and their operating time	See Table 2
Ambient temperature of the cask	5°C, 20°C, 35°C
Initial temperature of the cask and the spent fuel	20°C, 35°C, 50°C *1
Decay heat of the spent fuel(/Cask)	15.9 kW, 11.0 kW
Amount of residual water after drainage	30 kg
Heat absorption rate	2.5 kW *2

*1 Assuming that the temperature is uniform at the pool water temperature, and the pool water temperature is 15°C higher than the ambient temperature.
*2 Assuming uniform evaporation during vacuum drying

Table 2. Events considered in unsteady analysis and their operating time

Event	Leave filled with water*	Drainage	Vacuum drying
Operating Time	16h	3h	8h
Heat absorption by evaporation	No	No	Yes
Heat generation of external heater	Yes	Yes	Yes

*Conducted to raise the initial temperature of the cask at the start of vacuum drying

ANALYTICAL MODEL

Thermal analysis is conducted using the ABAQUS code by the finite element method.

The analytical model (see Figure 2) is a three-dimensional model simulating our designed transport/storage cask, capable of loading 24 fuel assemblies of PWR. The basket is made of carbon steel and has boron aluminum plates as neutron absorber. The features of analytical model are shown in Table 3.

Table 3. Analytical model features

Item		Content
Fuel assembly		Homogenization
Heat distribution	Radial direction	No (All the same burnup)
	Axial direction	Yes (Consider axial burnup distribution)
Heat transfer mode outside the container	Other than the bottom of the cask	Natural convection heat transfer and radiation
	The bottom of the cask	Adiabatic boundary
Heat transfer mode inside the container	Leave filled with water	Heat conduction of water
	Drainage/Vacuum drying	Heat conduction of low pressure water vapor and radiation
Heating by the external heater	Simulation method	Boundary temperature applied to the outer peripheral surface of the bottom
	Boundary temperature	100°C *1
Heat absorption by evaporation	Simulation method	Negative heat flux applied to the upper surface of the bottom plate
	Heat flux	Approximately 1kW/m^2 *2

*1 This value is set with adequate margin for the usable temperatures of the paint and the neutron shielding material.

*2 This value is calculated by dividing the energy required to evaporate 30 kg of water by the vacuum drying time and the area of the upper surface of the bottom plate.

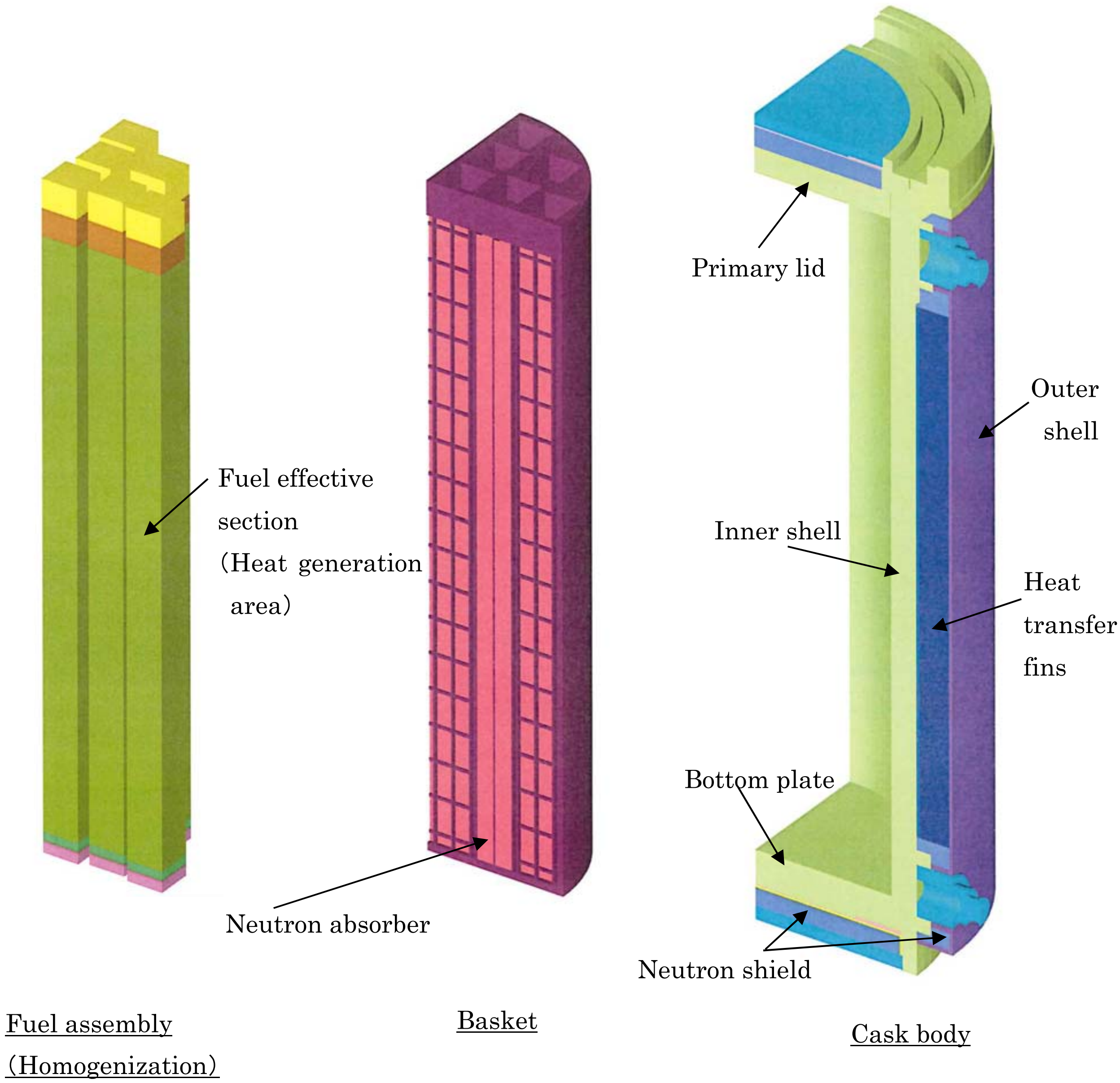


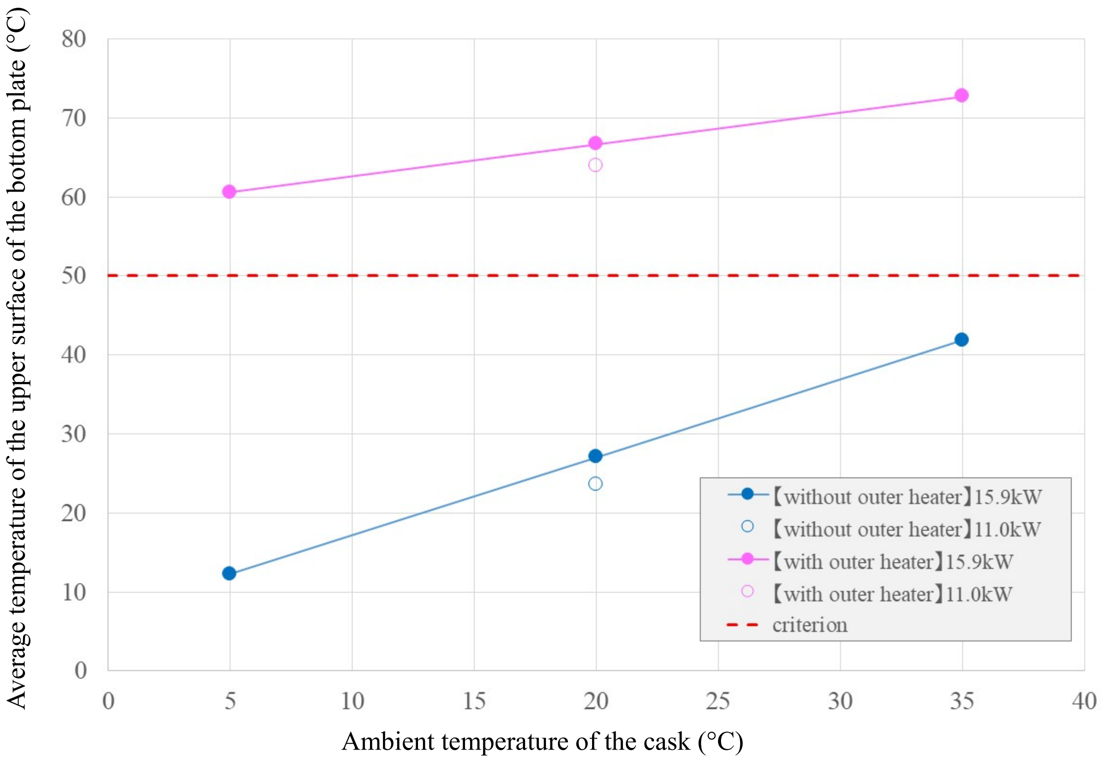
Figure 2. Thermal analytical model

ANALYTICAL VALUE

The temperature of residual water at the end of vacuum drying operation, that is, the temperature of the upper surface of the bottom plate in cask cavity is shown in Figure 3. It can be seen from Figure 3 that the effect of the decay heat of the spent fuel is not large, but the effect of the ambient temperature and the initial temperature is large. Also, when the external heater is not used, the temperature of the upper surface of the bottom plate falls below 50°C even if the ambient temperature is high, but by using the external heater, it is higher than 50°C even if the ambient temperature is low.

The time history of the temperature of the upper surface of the bottom plate is shown in Figure 4. It can be seen from Figure 4 that it is raised to 50°C or more at the start of vacuum drying operation by using the external heater, and the temperature of the upper surface of the bottom plate during vacuum drying operation can be maintained above 50°C.

If the spent fuel is left in vacuum for a long time, the temperature of the spent fuel cladding continues to rise. However it can be confirmed that the temperature will not exceed the limit if the vacuum drying time is within 8 hours.



Notes) The initial temperature of the cask and the spent fuel is uniform at the pool water temperature, and the pool water temperature is 15 °C higher than the ambient temperature.

Figure 3. The temperature of the upper surface of the bottom plate at the end of vacuum drying operation

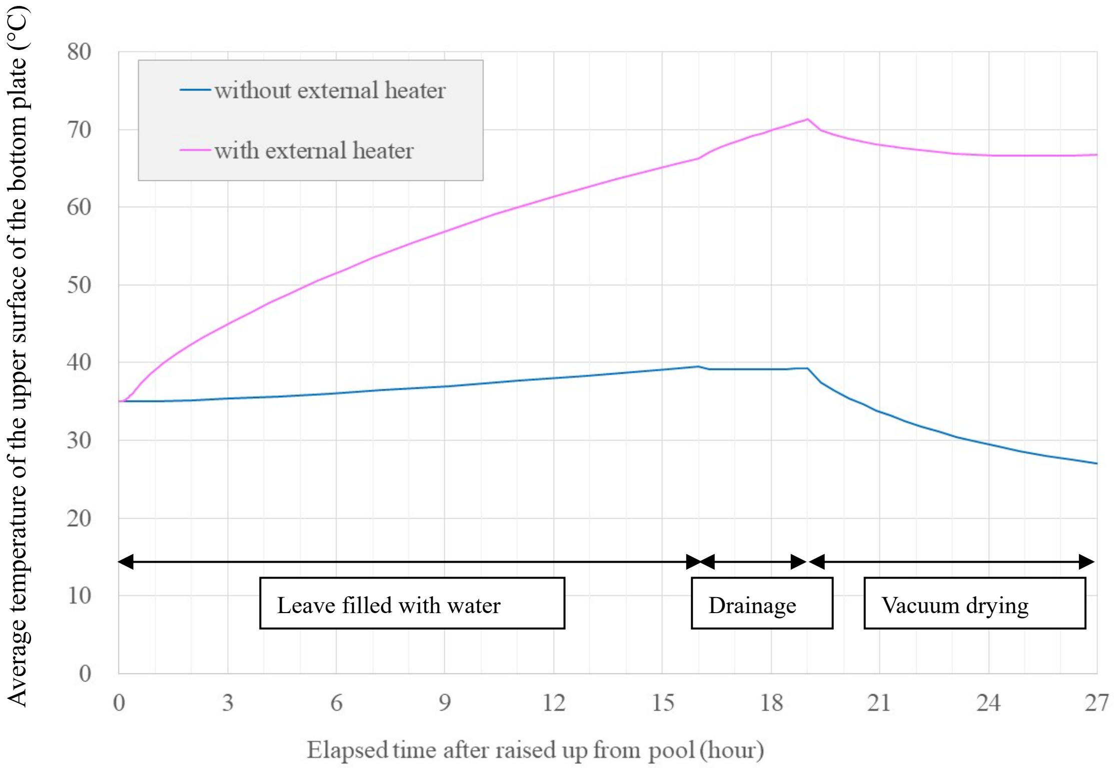


Figure 4. The time history of the temperature of the upper surface of the bottom plate (15.9 kW, ambient temperature 20 °C)

CONCLUSIONS

In the case the external heater installed on the outer peripheral surface of the bottom of the cask is used, residual moisture can be dried by continuous 8 hours drying operation of our vacuum drying equipment even if the decay heat of spent fuels or the initial temperature of the cask is low, so it is expected that it brings to drastically shorten the vacuum drying time.

REFERENCES

[1] Standard for Safety Design and Inspection of Metal Casks for Spent Fuel Interim Storage Facility: 2010, Atomic Energy Society of Japan, 2010.7