Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

The Analysis of Transient Heat Transfer in MACSTOR/KN-400 Module Considering Environmental Conditions at Wolsong Site

Kyung-Ho Lee, Sang-Jin Lee, Jeong-Mook Kim
KHNP Co., Ltd. Nuclear Engineering & Technology Institute, Daejeon, Korea
E-mail : suhong@khnp.co.kr

1. Introduction

This paper covers the heat transfer analysis in MACSTOR/KN-400 on a basis of transient state. Transient state reflects actual operation conditions such as solar loads, daily temperature variations. The heat transfer analysis has usually been performed under steady state, but transient state would be considered as crucial factor in thermal analysis in the future. Therefore, much attention needs to be paid on how transient effect affects the results of heat transfer. Analysis model includes all parts of concrete module consisting of wall, top slab and storage cylinders.

2. The Descriptions of Storage Module

The layout of MACSTOR/KN-400 is shown in figure1. Heat generated by the spent fuel stored in MACSTOR modules goes out through the storage cylinders. The temperature of the air surrounding the storage cylinders increases and its density decreases. The density difference causes the air to move upwards along the storage cylinder. At the top of the modules, there are twelve openings through which the hot air can escape to the environment. The air going out of the module is replaced by air coming in through the ten air inlets located at the bottom of the module. This is called natural convection. The mass flow rate of the air due to natural convection is relatively small compared to forced air cooling, but enough to maintain adequate cooling of the spent fuel and the concrete structure appropriately.

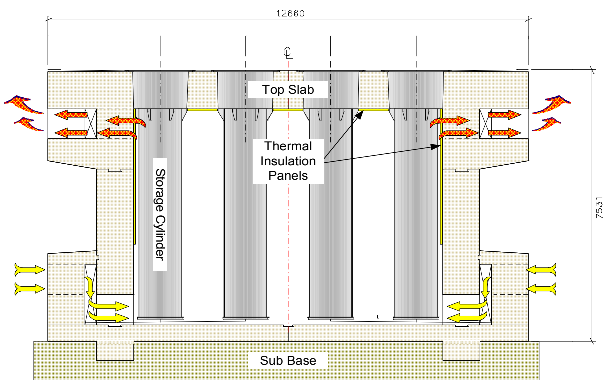

Figure 1. MACSTOR/KN-400 layout

3. Environmental Conditions

In the heat transfer analysis, environmental conditions such as solar loads and daily temperature variations at Wolsong site were taken into account in transient analysis. Environmental conditions would reflect real situations on the conditions of heat transfer in the module. Solar loads in the horizontal and latitude are shown in figure 2. Ambient temperature varies over one day as shown in figure3. In the day time, the highest solar loads are expected to reach, while no solar loads are considered in the remaining periods. One of the key factors in transient analysis is daily temperature variation of 10℃, it affect the temperature gradient of the concrete module due to the variations of outside concrete temperature. The temperature of outside concrete surface is increased during mid-day time by solar loads while inside temperature affected by decay heat from fuel basket is usually constant. Therefore, temperature gradient due to environmental conditions is called transient gradient in the heat transfer of spent fuel dry storage. It should be carefully understood under site specific environmental conditions.

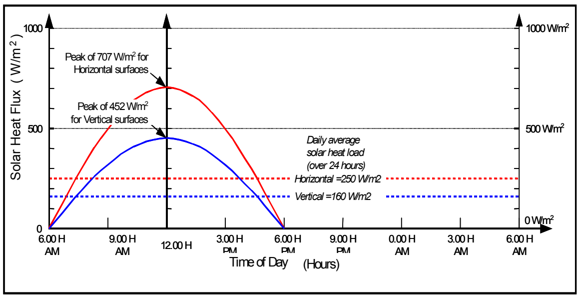

Figure 2. Solar loads variation in the analysis of heat transfer

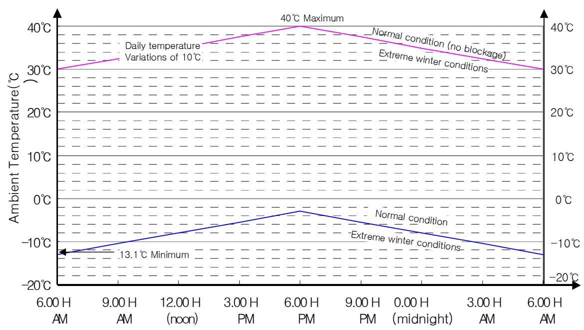

Figure 3. Ambient temperature variation over one day

4. Analysis Code and Model

4.1 Thermal-hydraulic Code

The thermalhydraulic CATHENA which simulates one-dimensional fluid flow and 2-dimensional heat transfer in solid was used to predict concrete, cylinder and fuel temperature.

4.2 Model

CATHENA model for MACSTOR/KN-400, comprising sixteen cylinders is modeled as shown in Figure 4. Air goes through air circuit and removes the decay heat from the cylinders. The concrete wall, top slap and the storage cylinders are modeled. Thermal radiation between the storage cylinder and concrete wall and roof is modeled. The main mode of heat removal is free convection by air from the storage cylinders. Some of the heat is evacuated by conduction through the wall. All the coefficients like concrete conductivity, loss and convection heat transfer were driven from the measured temperature of MACSTOR-200 in Canada.

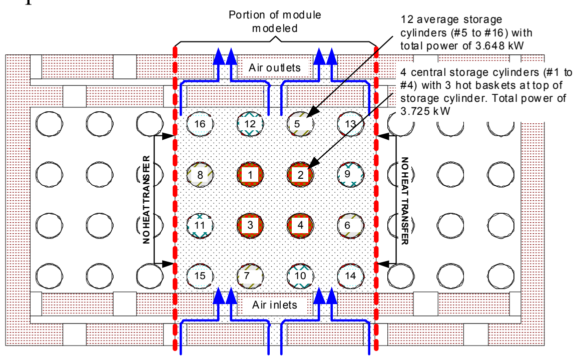

Figure 4. CATHENA Thermalhydraulic Model in MSTOR/KN-400 Module

5. Results

5.1 Summer Off-normal results

The Figure 5 shows temperature gradient variations over one day in the roof, in the wall and in the bottom slab. The maximum temperature gradient was presented at AM 6:00 that was no solar radiation and the lowest ambient temperature of 30℃. In the steady state analysis, the maximum temperature gradient would be expected at maximum ambient temperature of 40℃. The inside concrete temperature is usually constant during normal storage period while the outside one varies according to the variations of ambient temperature. In this analysis, transient gradients due to the daily temperature variation and solar loads which reflect environmental conditions of wolsong were incorporated.

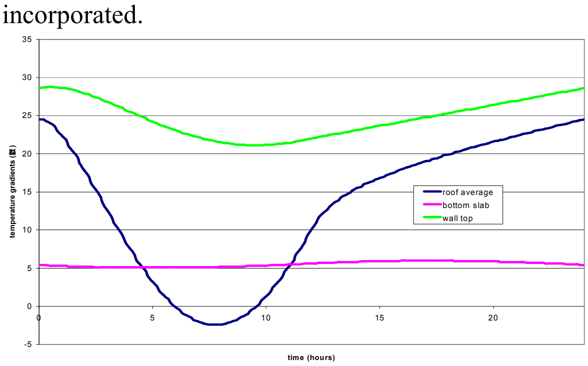

Figure 5. Temperature gradient variation over one day off-normal-summer condition in MACSTOR/KN-400

5.2 Summer blocked mode results

The Figure 6 illustrates the results of the blocked mode in summer condition for temperature gradients variation over five days. The gradient in the roof goes from 24.5℃ at the beginning of the transient to 25.8 at the end of the 5-day period. The increase is thus 1.3℃. The reason that the increase in temperature gradient is low is that even if 100% of inlets are blocked on one side, there is still good air cooling.

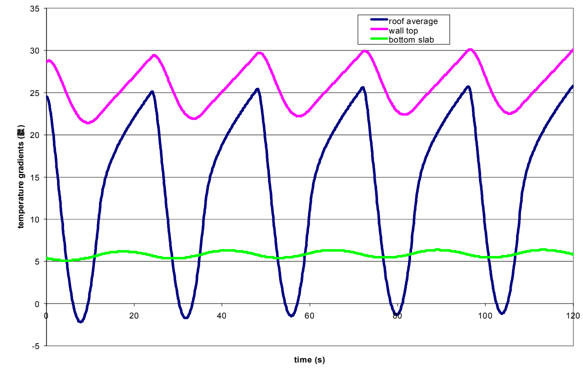

Figure 6. Temperature gradient variation over five days blocked mode-summer condition in MACSTOR/KN-400

6. Conclusions

The heat transfer analysis was performed on a basis of transient state considering Wolsong site's environmental conditions, such as solar loads and daily temperature variations. It appears that transient gradients due to environmental conditions make the results more conservative compared to steady state and reflect actual environmental conditions at Wolsong site. The transient analysis was tried first-ever in the dry storage of spent fuel in Korea. Further study would be followed in the next phase of PWR dry storage project.

REFERENCES

[1] ACI-349-97, "Code Requirements for Nuclear Safety Related Concrete", American Concrete Institution, 1997.