Effects of T-type Channel on Natural Convection Flows in Airflow-Path of Concrete Storage Cask

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1. Introduction

A concrete storage cask to store spent fuels has drawn research attentions as spent fuels in wet storage pool are expected to be saturated. As shown in Fig. 1, the concrete storage, one of the dry storage casks, consists of an over-pack and a canister for housing spent fuels, and passive heat removal system as airflow-path is designed for the decay heat from spent fuels to be passively removed by natural convection flows.

Airflow-path in concrete storage cask is formed by four air inlets and outlets at top and bottom of over-pack, and annular flow-path between the outer surface of canister and the inner surface of over-pack. The natural convection flows occurring in airflow-path are not simple due to complex flow-path configurations such as horizontal ducts, bent tube and annular flow-path. In addition, 16 T type channels acting as the shroud are attached vertically and 16 channel supporting the canister are attached horizontally on the inner surface of over-pack. The existence and nonexistence of T type channels have influences on the flow fields in airflow-path. The concrete storage cask has to satisfy the requirements to secure the thermal integrity under the normal, off-normal, and accident conditions [1,2]

The present work is aiming at investigating the effects of T type channels on the flows in airflow-path under the normal conditions using the FLUENT 16.1 code. In order to focus on the flows in airflow-path, fuel regions in the canister are regarded as a single cylinder with heat sources and other components are fully modeled.

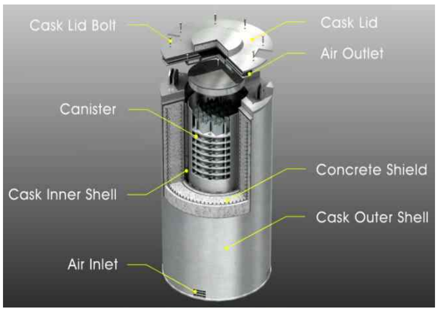
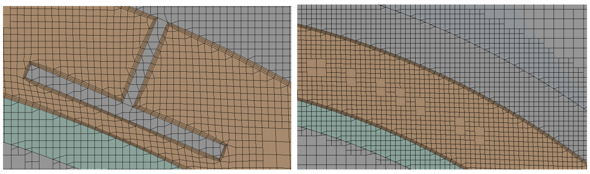


Fig. 1. Configuration of concrete storage cask.

2. Analysis model and boundary condition

Using ANSYS DM and meshing program, a 3-D 1/4 symmetry finite volume model was constructed for performing thermal analysis under normal condition.



(a) With T type channel (b) Without T type channel

Fig. 2. Constructed mesh on existence and nonexistence of T type channel at cross-section of annular flow-path.

Fig. 2 showed the constructed mesh on with T type channel and without T type channel in annular flow-path. Since the boundary layer is confined in an extremely thin region along the heated wall, the concentrated grids are given in the boundary layer. The number of produced mesh is about 2,800 and 2,000 million respectively. The simulation is carried out using the incompressible ideal gas. It used the Realizable k-ε turbulent model and employed standard wall function. Air inlets and outlets were pressure inlet and outlet, respectively. In order to simulate heat exchanges with environment, convective heat transfer coefficient (h) of 5 W/m^2K was employed to the outer surface of over-pack as the boundary condition. An ambient temperature of 22℃ was used according to the NUREG-1536 [2]. The heat sources in the canister were about 1,759W/m^3. Discrete ordinates (DO) model was used for radiation heat transfer. For pressure-velocity coupling, the SIMPLE algorithm was adopted while for pressure the body force weighted was used. For momentum and energy, second order upwind algorithm is used.

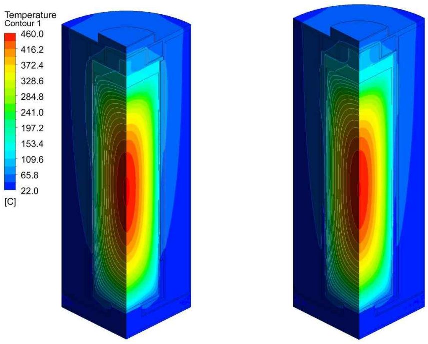
3. Results

3.1 Temperature distribution

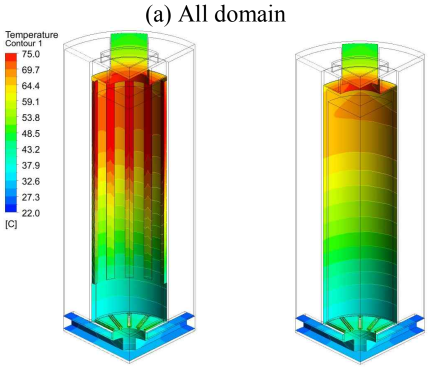
Table 1 compared the maximum temperatures on main components with allowable values for two cases. Regardless of the existence and nonexistence of T type channels, the maximum temperatures were almost similar to each other. Excepting for fuel regions, they were within the allowable values. The reason of increasing temperatures in fuel region may be explained below. The fuel region model used in this study was considered as a single heated cylinder and the heat was transferred by only conduction. Actually, fuel regions were composed of fuel assembly, basket, disks and support rods, and were filled with helium gas. The heat was transferred by both conduction and convection to the outer surface of canister. Fig. 3 (a) and (b) showed surface temperature distributions in all domain and airflow-path, representatively. In Fig. 3 (b), the thermal stratification was observed as thermal plume flows upward, and thermal distributions were different due to narrow airflow-path by the existence of T type channel.

Table 1. Thermal analysis results.

Components	With T channel	Without T channel	Allowable values
Concrete(°C)	74.8	73.4	93(Local)[3]
T channel(°C)	80.3	-	371[4]
Canister°C)	149.9	150.2	427[4]
Fuel region(°C)	462.9	460.8	400[2]



(a) All domain



(b) Airflow-path

Fig. 3. Temperature distribution on concrete storage cask.

3.2 Velocity distribution

Fig. 4 showed the velocity fields in airflow-path and those for two angles (45°, 32.5°), respectively. The maximum velocities occurred near the support channels. Since the flows in airflow-path were complex as shown in Fig. 4, the detailed investigation was required.

The angle of 45° is the flow cross-section adjacent to the channels disturbing the flows and The angle of 32.5° for the fields between the channels. In two cases, the different flow pattern was observed with showing different maximum velocities.

Fig. 5 (a)~(e) compared the velocity fields for cross-section of airflow-path on flow directions for two cases. The left is the velocity fields for with T type channel and the right for without T type channel. The flows entering the air inlets passed through annular flow-path with forming the plumes and escape to air outlets. For the nonexistence of T type channel, flows in both air inlet and annular flow-path showed the similar pattern at low heights in Fig. 5 (a) and (b) despite the fact that T type channel does not exist. Noticeable differences for flow patterns occurred at above the height of 3m in Fig. 5 (c). With increasing the heights, the flumes occurring from the lower region were gradually merged with neighboring plumes. Its phenomena were clear in the height of 5 m of Fig. 5 (d). For the existence of T type channel, the plume shape was kept at its configuration without flow dispersion because the T type channel played a role as the shroud. The mass flow rates at air inlets were 0.0477 kg/s and 0.0491 kg/s for the existence and nonexistence of T type channels, respectively. It was because the flow areas for the nonexistence of T type channels were larger than that of the existence of T type channels, and the flows accelerated fluids due to the shroud acting as a chimney. It was remarkable that up to 3 m, the plume shape remained uniform. It was due to the flow effects passing through the support channels attached horizontally on the inner surface of over-pack as shown in Fig. 5 (a).

These flows approached at the lower region of annular flow-path with unconverted flow pattern and developed along annular flow-path with consistently obtaining the buoyancy forces. In less than 3 m the flows depended on only the flows developing from the bottom areas. It was found that the flow distributions in annular flow-path were determined by the support channel.

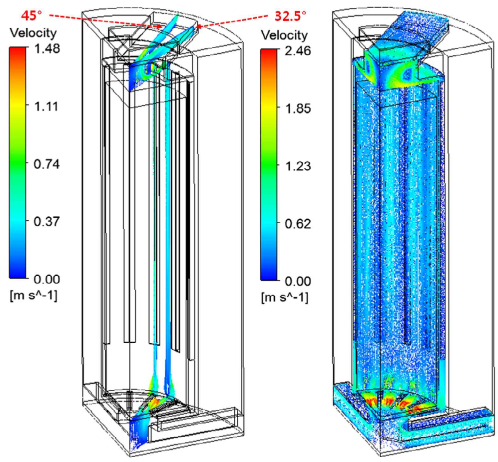
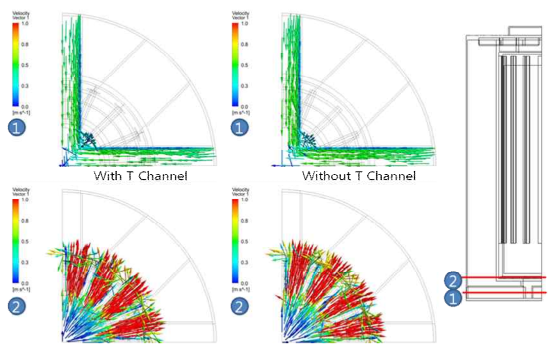
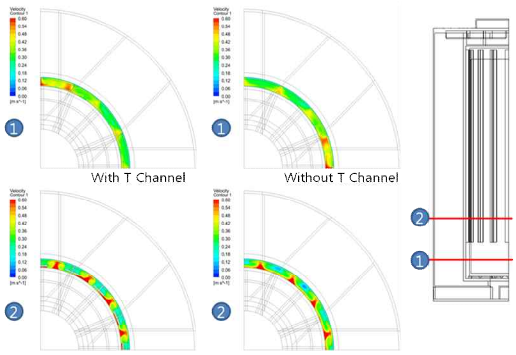


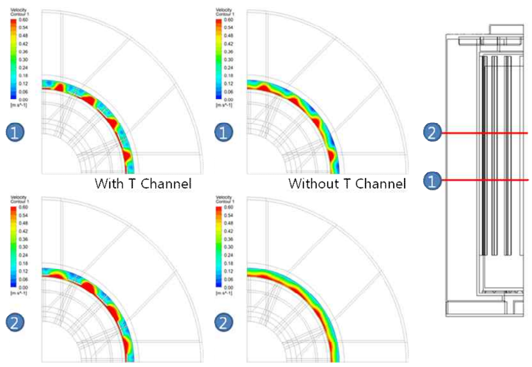
Fig. 4. Velocity fields on airflow-path in concrete storage cask.



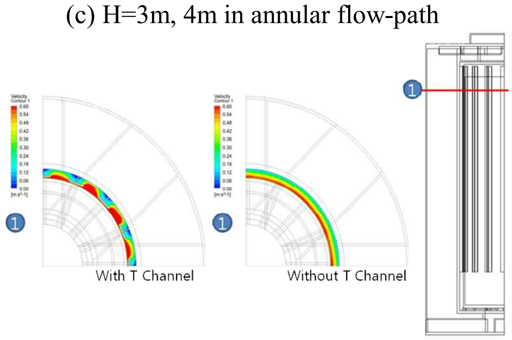
(a) Near air inlet duct



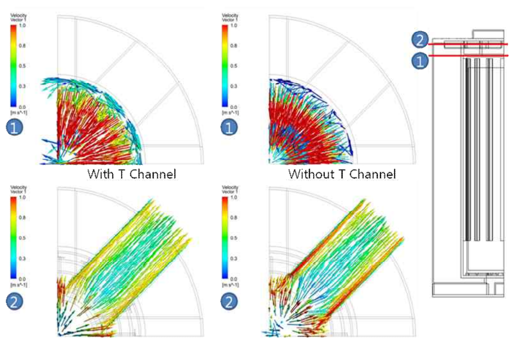
(b) H= 1m, 2m in annular flow-path



(c) H=3m, 4m in annular flow-path



(d) H= 5m in annular flow-path



(e) Near air outlet duct

Fig. 4. Velocity fields on the heights in airflow-path.

3. Conclusions

This study investigated the flow fields in airflow-path of concrete storage cask, numerically. It was found that excepting for the fuel regions, maximum temperatures on other components were evaluated below allowable values. The location of maximum velocities depended on support channels, T type channels and flow area. The flows through air inlets developed along annular flow-path with forming the hot plumes. According to the existence and nonexistence of T type channel, the plume behavior showed the different flow patterns. This study concluded that the flow distributions in annular flow-path were determined by support channels at a low height, and by T type channel at a high height.

REFERENCES

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[5] FLUENT User's Guide, release 16.1 Fluent Incorporated, 2015.