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Development of External Fin Structure for Transport and Storage Cask and Verification of Its Heat Dissipation Performance

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ABSTRACT

To improve heat dissipation performance for the transport and storage cask, applicability of short and compact external fins (micro fins) was investigated. The fins have an effect on increase of surface area, have advantages in designing cask with geometric control, and are available for cask both in vertical position and horizontal position.

Heat transfer tests with fin elements were conducted to verify their heat dissipation performance after estimating optimal shape with the maximum heat dissipation performance of micro fins (the maximum heat transfer on the surface) with CFD analyses. The results showed that increase of heat transfer was not proportional to multiplication factor of area in these fin structure. In addition, a cask equipped with micro fins was designed, and thermal analyses during transport and storage were conducted. The analyses results proved that the cask equipped with the micro fins satisfies the prescribed performance during both transport and storage conditions.

1. INTRODUCTION

Recently, demands for cask with high-capacity to store spent fuel of short cooling term have been increasing. To deal with this high heat load, heat dissipation performance for the cask needs to be improved. Therefore, applicability of micro fins was investigated because they have an effect on increase of surface area, advantages in designing cask with geometric limitation, are available for cask both in vertical position and horizontal position, and are simply manufactured. An example of the applicability is shown in Figure 1. Micro fins are equipped to overall outer shell except trunnion area in axial direction.

In case of using these fins, air flow on the surface of the cask tend to retain at the bottom part between fins. Moreover, increase of heat transfer is not proportional to multiplication factor of area. Therefore, the verification is essential in conducting safety analysis for thermal evaluation of cask.

2. ANALYSES AND VERIFICATION OF FINS

An optimal point showing the maximum heat dissipation performance, which is the maximum heat transfer on the surface, was estimated with CFD analyses. Then, heat transfer tests with fin elements were conducted to verify the performance.

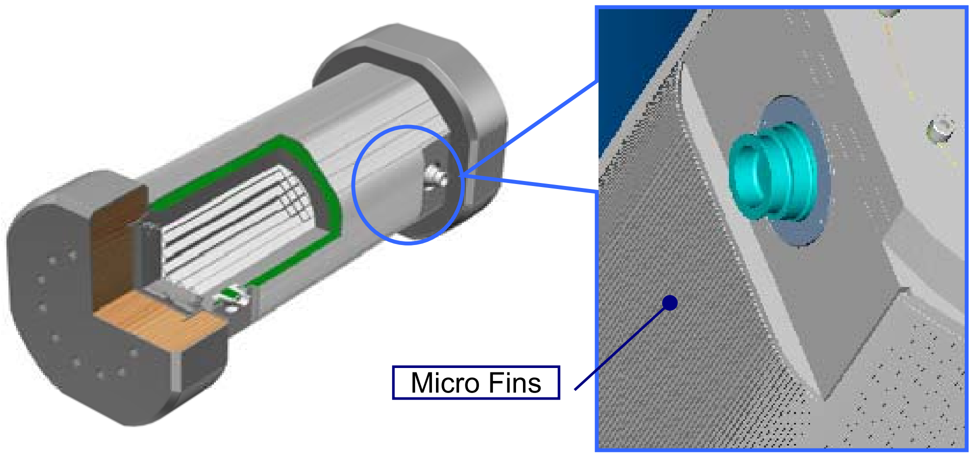


Figure 1. Overview of micro fins for cask

2.1. Analysis of Fins

Parameter of fin height (H), thickness (T) and width of groove (W) was changed from 10 to 25 mm. Air flow parallel to rows of fins in vertical position of cask and that crossing fins in horizontal position were estimated with CFD analyses. Moreover, the optimal point showing the maximum heat dissipation performance, which is the maximum heat transfer on the surface, was also estimated. FLUENT codes were used for the analyses.

(1) Vertical position (flow parallel to rows of fins)

A part of configuration of fins was modeled considering symmetric properties in the analyses. The model was made considering half pitch width of fins in cross-section, and fins of approx. 5 mm of actual length and sufficient space for wake flow in axial direction.

Examples of analyses results for 10 mm high fins are shown in Figure 2. Fins with gap of 10 mm have low increase rate of heat transfer in spite of the same multiplication factor of area (twice) because fluid of high temperature is accumulated between fins.

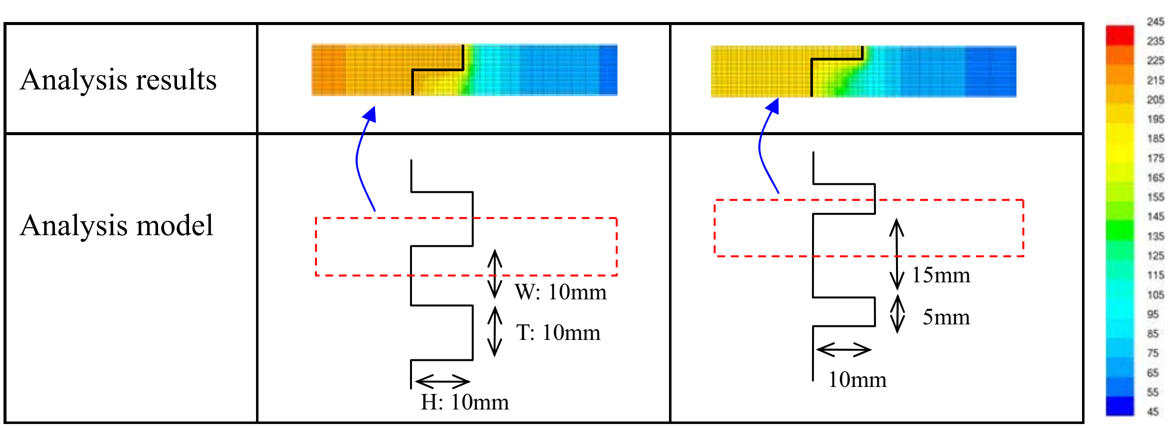


Figure 2. CFD analysis results of 10 mm high micro fin (in vertical position)

Analyses results for dimensional optimization of fins are shown in Table 1. The results show that the maximum efficiency is obtained by reducing fin thickness and leaving appropriate gap between fins when fin efficiency (β) is defined as multiplication factor of area (γ) × area efficiency (η) compared with multiplying factor to flat plates.

Table 1. CFD analysis results of performance of various micro fins (in vertical position)

Configuration (T × W × H) (mm)	Heat transfer coefficients (W/m^2K)	Fin efficiency to flat plates β(-)	multiplication factor of area γ(-)	Area efficiency η(-)
Plane	5.9	1.00	1.00	1.00
10 × 10 × 10	6.4	1.09	2.00	0.55
5 × 15 × 10	7.1	1.23	2.00	0.61
5 × 15 × 15	8.3	1.41	2.50	0.57
5 × 20 × 15	9.1	1.55	2.20	0.70
5 × 25 × 15	8.6	1.47	2.00	0.73
5 × 20 × 20	10.4	1.77	2.60	0.68
5 × 25 × 20	10.7	1.82	2.33	0.78
5 × 20 × 25	12.0	2.04	3.00	0.68

(2) Horizontal position (flow crossing fins)

Analyses in horizontal position of cask with fins of 5 mm in thickness, 15 mm in width, and 10 mm in height were conducted. Middle area of a cask body was modeled to use in the analyses considering uniformity in axial direction as a two-dimensional cross-section model. Heat load was applied from inside of the cask body as uniform heat flux.

Distribution of heat transfer coefficients in circumferential direction is shown in Figure 3. The heat transfer coefficients were low at the top and the bottom of the cask. Heat transfer coefficients on the top surface with upward heat flow and the bottom surface with downward heat flow are respectively evaluated as 7 W/m^2K and 3 W/m^2K according to existing correlating equations. Heat transfer coefficients at the top are underestimated in CFD analyses. Heat transfer coefficients in other area were approx. 8 W/m^2K, which is equal to those of cask in vertical position.

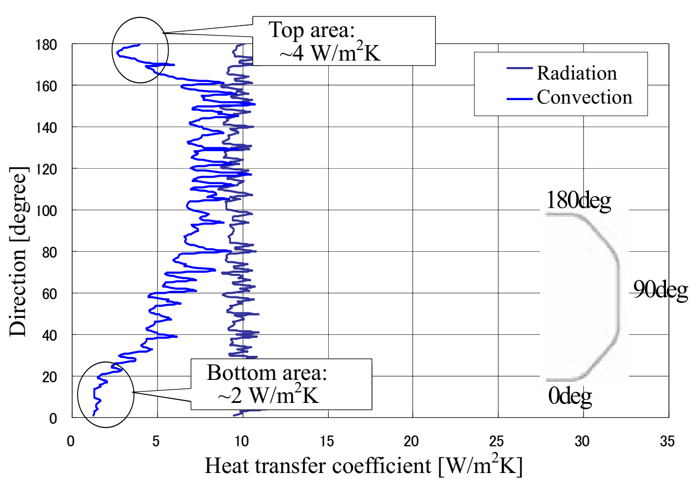


Figure 3. Distribution of heat transfer coefficients of 10 mm high fin (in horizontal position)

2.2. Verification of Fins

(1) Test apparatus and experiment methods

Test walls are shown in Figure 4. Heated walls consist of 5 brass square plates of 0.5 meter on each side. Heaters installed in backside of brass plate are able to be controlled independently. These walls can be inclined to simulate heated walls under the transport conditions. These test walls were located surrounding enclosure.

Nine thermocouples are installed in each heated wall to measure temperature. Side plate heaters located on both sides can compensate heat loss of main plates through side directions by means of making temperature equal to main and side plate heaters. Also, heat loss through backward can be estimated by measuring temperature of insulation. To avoid temperature distribution in each plate, test walls are made of thick brass.

To simulate the micro fin, fin blocks are put on test wall surface.
Bakelite partitions of 30 mm in height and 2 mm in width are placed between main plates and side plates to avoid effects of transverse flow.

Heat transfer coefficient, α, is derived from the following equation (1).

$$\alpha = \frac{Q}{A(T_w - T_a)} \qquad \text{---------} \quad (1)$$

Where Q, A, T_w and T_a are energy of convective heat transfer, heat transfer area, wall temperature and the ambient air temperature, respectively.
Uncertainty of heat transfer coefficient could mainly result from the measurement of energy of convective heat transfer. Convective heat transfer Q is estimated by deduction of heat loss through backward Q_{loss} and radioactive heat transfer Q_{rad} from supplied energy Q_e.

$$Q = Q_e - Q_{loss} - Q_{rad} \qquad \text{------} \quad (2)$$

Quantity of heat loss through backward Q_{loss} could be estimated as small as possible. Also, radioactive heat transfer could be estimated to be negligible because surface emissivity of test wall and surrounding enclosure is extremely small.

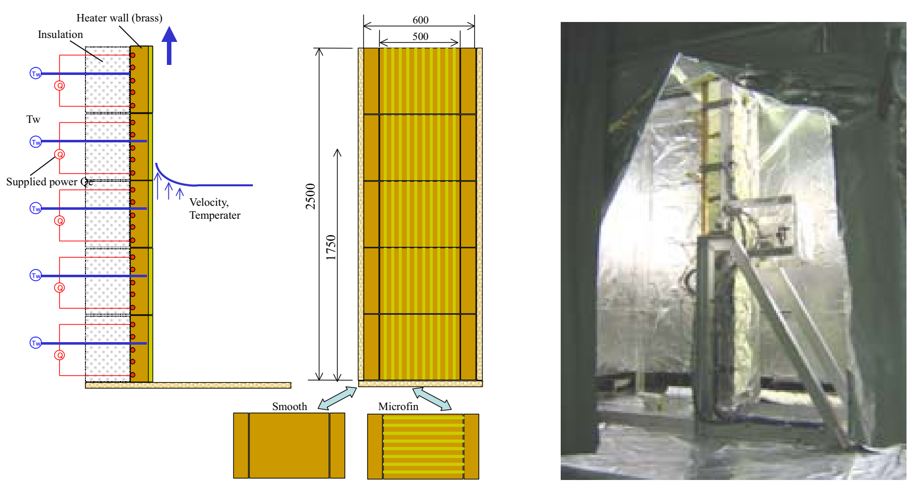


Figure 4. Test apparatus

(2) Experiment results of vertical condition

Micro fins of 10 mm, 15 mm and 25 mm in height were tested under vertical condition. Experimental results of heat transfer coefficients of vertical wall are shown in Figure 5. In each condition, the smallest heat transfer coefficient is chosen among heat transfer distribution in order to estimate conservatively.

According to good agreement with heat transfer coefficients by Jakob's formula (3)[1] in the condition of smooth wall, our procedure and estimation methods are considered to be valid.

Vertical plate of smooth wall: Jakob's formula

$$\alpha = 0.129 Ra^{1/3} \lambda / L \quad (W/m^2K) \quad \text{------} \quad (3)$$

Fin efficiencies to flat plates of 10 mm, 15 mm and 25 mm high fins were 1.35, 1.6 and 2.0, respectively.

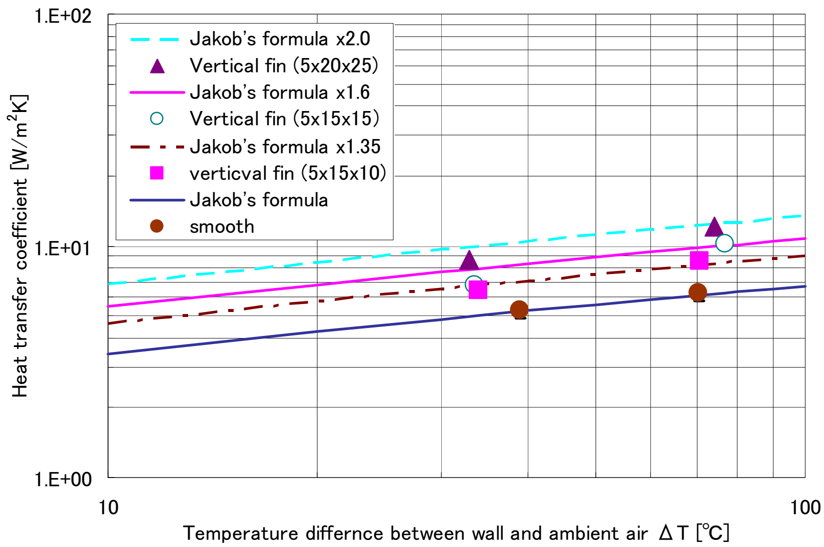


Figure 5. Heat transfer coefficient of vertical fin wall

(3) Experiment results of horizontal condition

Micro fins of 10 mm and 15 mm in height were tested under horizontal condition. Measured heat transfer coefficients of 0 degree to 180 degree inclination are shown in Figure 6 and summarized in Table 2.

At 0 degree, heat transfer coefficient with smooth wall could be estimated as $0.14Ra^{1/3}$ [2]. Heat transfer coefficients of 10 mm and 15 mm high fins were about 1.7 and 1.9 times larger than that without fins, respectively.

At 45 and 90 degree, heat transfer coefficients with smooth wall could be estimated as $0.13Ra^{1/3}$. They were about from 1.25 to 1.7 times larger than those without fins.

At 135 and 180 degree, they were almost constant. At 180 degree, whether with or without fins, they were as small as about 3 W/m^2K. There was almost no enhancement of heat transfer by fins.

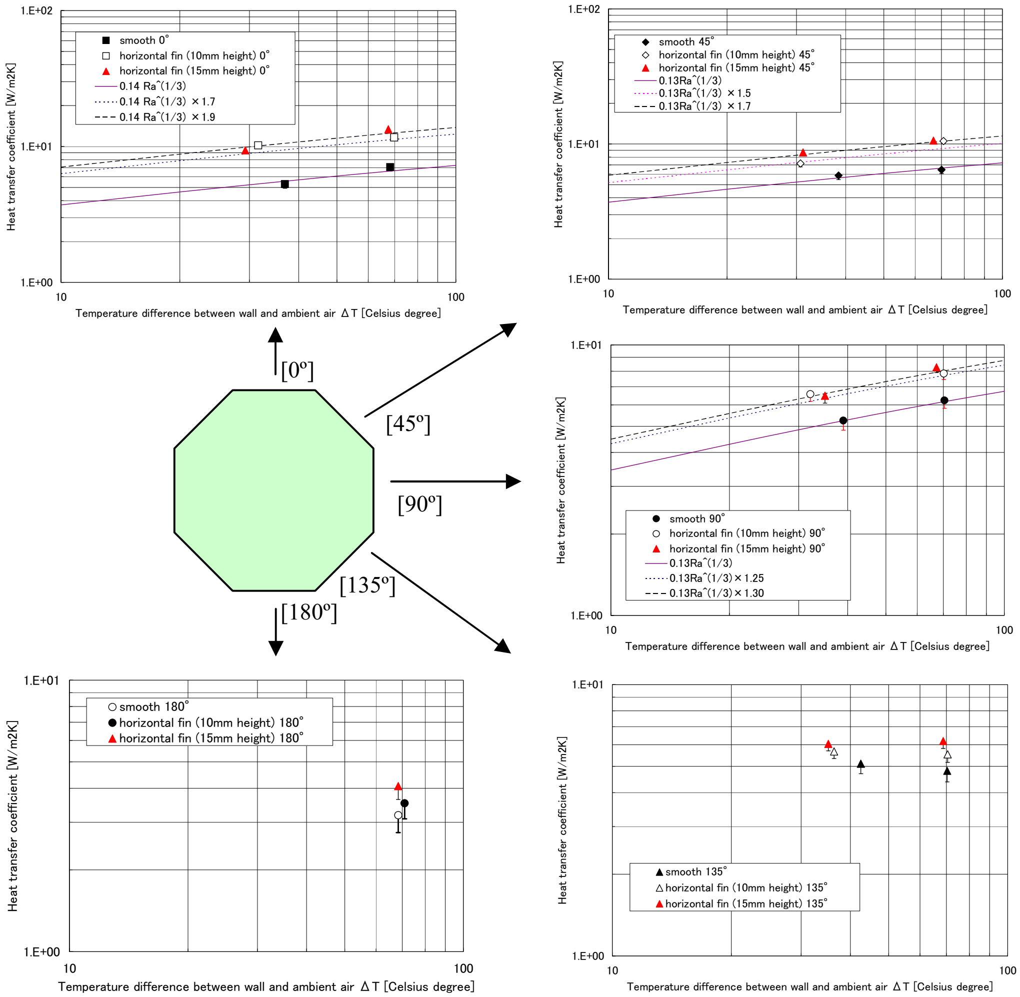


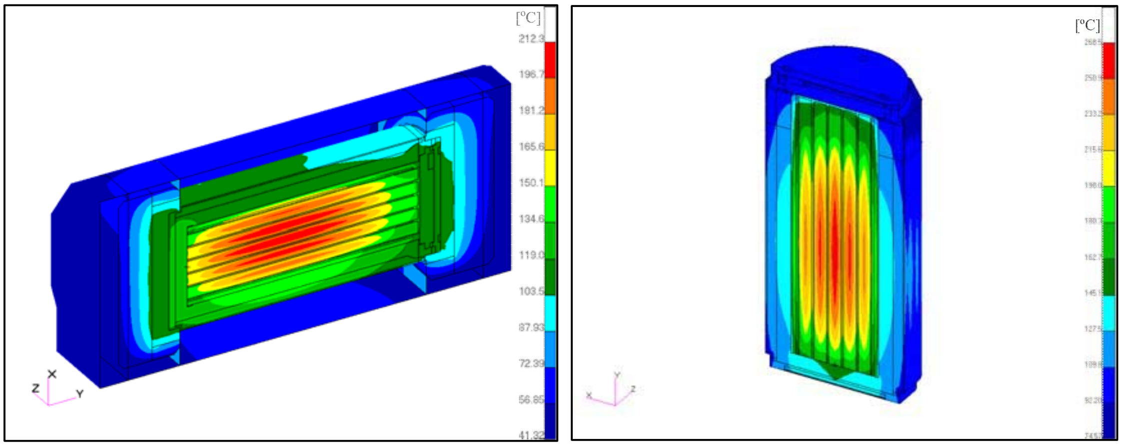
Figure 6. Heat transfer coefficient of fin wall at 0 to 180 degree inclination

Table 2. Heat transfer coefficient of fin wall at 0 to 180 degree inclination (Unit: W/m^2K)

Fin inclination	10 mm height fin	15 mm height fin
0	$1.7 \times 0.14Ra^{1/3}\ \lambda/L$	$1.9 \times 0.14Ra^{1/3}\ \lambda/L$
45	$1.5 \times 0.13Ra^{1/3}\ \lambda/L$	$1.7 \times 0.13Ra^{1/3}\ \lambda/L$
90	$1.25 \times 0.13Ra^{1/3}\ \lambda/L$	$1.3 \times 0.13Ra^{1/3}\ \lambda/L$
135	5.2	5.7
180	3.1	3.6

3. ANALYSES FOR CASK DESIGN

A cask (MSF-57BG) with high heat load of 30 to 48 kW was designed with micro fins of 10 mm and 15 mm verified in the tests, and thermal analyses of the cask during transport and storage were conducted with heat transfer coefficients in consideration of the fins at each degree on each surface. An analysis example of cask with a canopy under transport condition is shown in Figure 7(a). In addition, an analysis example of cask under storage condition is shown in Figure 7(b). Heat dissipation performance of the cask equipped with these micro fins was improved. Therefore, temperature of internal content and at each part of the cask container was below each restrictive temperature under both transport and storage conditions.



(a) Transport condition with canopy (b) Storage condition

Figure 7. Example of thermal analyses of cask equipped with micro fins

4. CONCLUSIONS

To improve heat dissipation performance for the transport and storage cask, applicability of micro fins was investigated.

Heat transfer tests with fin elements were conducted to verify their heat dissipation performance after estimating the optimal shape with the performance with CFD analyses. When 10 to 25 mm high fins are applied, heat transfer coefficients considering area multiplication of fins in vertical position of cask (in case of flow parallel to rows of fins) were 1.35 to 2.0 times compared with those of flat plates, which showed that increase of heat transfer was not proportional to multiplication factor of area. In horizontal direction of cask (flow crossing fins), heat transfer coefficients in inclination of 135 and 180 degrees were nearly constant. And those in inclination of 0 to 90 degrees were organized as multiple numbers of $0.13Ra^{1/3}$ or $0.14Ra^{1/3}$.

In addition, a cask equipped with these compact external fins was designed, and thermal analyses during transport and storage were conducted. The analyses results proved that the cask equipped with the micro fins satisfies the prescribed performance during transport and storage conditions.

REFERENCES

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