Study of Heat Transmission Characteristics of Cavity Water of the Spent-Fuel Package

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INTRODUCTION

Dense structure spent fuel baskets for transport packages are now commonly used to enclose spent fuels effectively. Recent designs for transporting spent fuels with Channel Boxes (C/B) reduce the fluid area of the water cavity inside the packages and the heat transfer ability of the cavity water is expected to decrease. Therefore, it is very important to study the detailed heat transmission characteristics of the cavity water with experiments. As reported in this study, heat transfer experiments by natural convection with a modeled part of inside of actual transport package and the verification by analysis were performed.

GENERAL DESCRIPTION OF EXPERIMENT

Figure 1 shows a conceptual drawing of the relationship between this experiment and actual package. Figure 2 shows a drawing of the experimental equipment used in this study. This equipment was modeled on one lodgement of a fuel-loading basket on the inside of a package. In the radial direction, the experimental equipment was of actual size including the fuel bundle, the fuel-pin diameter, the fuel pin pitch, the space between the C/B and the fuel bundle, and the C/B. The axial flow of the water was blocked by the two plates on both ends of the fuel basket to allow measurement of the heat transfer coefficients of two-dimensional natural convection, and a water cooler jacket around the outer equipment was prepared to stabilize the phenomena of natural convection. The end plate of this equipment was made of a transparent acrylic panel so that the inside of the equipment could be observed. The maximum power and the cooling water temperature were chosen as the parameters of this experiment. The steady state temperatures of each part of this equipment was measured to find the average measuring value, one hour after the steady state.

THE FEATURE OF THE EXPERIMENTAL EQUIPMENT

The following are the feature of this experimental equipment.

(1) This equipment is a simulated model of one basket lodgement inside of package.

(2) It is planned that there is no axial direction cavity water flow in this equipment. It is a conservative plan to compare it with the case of axial direction flow because the heat transfer will occur only on the two-dimensional section. Therefore, both edge faces of the fuel basket are closed by the square plate.

(3) The length of axial direction is about one meter.

(4) The cross sectional dimensions of fuel pins, channel box, spacers, and basket are all actual dimension of the fuel package.

(5) All of 60 fuel pins have an electrical heater.

(6) The fifty-eight thermocouple are installed including on the three points of the axial direction.

(7) The water cooler jacket is attached to the outside surface of the equipment in order to stabilize the heat transfer phenomena by natural convection to the atmosphere.

(8) The experiment is performed under normal pressure because of no influence of the inside pressure of the equipment.

(9) The heat flux measurements are installed to measure the heat flux of four directions(upper, lower, right, left)

EXPERIMENTAL CASES

Table1 shows this experimental cases. There are four parameters which are calorific power per fuel pin, basket heater's on/off, cooling water temperature, and existing or nonexisting basket edge plate. The basket heater is used to simulate the heat flux from next door fuel bundles.

EXPERIMENTAL PROCEDURE

The summary of this experimental procedure is as follows.

(1) The digital value of heating power on the control board shall be set to the fixed value.

(2) The cooling water temperature shall be set to the fixed value, and circulation of water shall be started.

(3) The switch of the heating system shall be turnel on, and the experiment shall be started.

(4) The equilibrium state shall be confirmed according to the recorded temperature of each part.

(5) After the equilibrium state is confirmed, the temperature data shall be put on to a floppy disc.

RESULTS OF EXPERIMENT

Table2 shows the summary of results of this experiment. Figure3 shows an image drawing of cavity water flow by natural convection in the equipment body. It is predicted that there are three types water flow in the basket. One is a releasing flow, one is impinging flow, and one is raising flow. Generally, it is said that impinging flow is the highest heat transfer efficiency. Figure4 shows the relationship of Nu and Ra with regards to fuel bundle water and channel box. Figure5 shows the relationship of Nu and Ra with regards to channel box and basket. The heat transfer coefficients, which were taken on this experiment, were higher than the value from conventional experimental formula.

The formulas which were predicted from this experiment are as following.

$Nu=3.04Ra^{1/4}$ (fuel bundle water and channel box)

$Nu=0.19Ra^{1/3}$ (channel box and basket on the top side)

$Nu=0.25Ra^{1/4}$ (channel box and basket on the side)

DISCUSSION

The summary of results of this experiment is as follows.

(1) The difference of surface temperature of fuel pin and water temperature around the fuel pin is about 0.5℃. It is a very small difference.

(2) The cavity water temperature is about several degrees different in the fuel bundle.

(3) In regard to the vertical direction, the maximum temperature in the cavity water is situated on the upper side of the inside of the equipment.

(4) In regard to the horizontal direction, the cavity water temperature is almost the same degree.

(5) The heat transfer coefficients, which are between each part, are almost the same level. However, it seems that the coefficients between the average temperature of cavity water in the fuel bundle and channel box are higher than the others.

THERMAL ANALYSIS OF THIS EXPERIMENT

A thermal analysis using the finite element method calculation code "ABAQUS" was performed in order to verify the above experimental results. The calculation was performed using heat transfer coefficient data and other boundary conditions from the above experiments. The calculation model was a two-dimensional, cross-section model of the experimental equipment. Table3 shows the comparative evaluation between the results of this thermal analysis and experimental data. The calculation results using this method agreed well with the experimental data.

CONCLUSION

The heat transfer experiment by natural convection was performed by using the scale experimental equipment which was modified for inside the actual spent fuel packaging. It became clear from this experiment that the heat transfer by natural convection of cavity water was actively produced. And the thermal analysis of this experiment was performed by using "ABAQUS" code. The results of the analysis agreed well with the experiment.
For future work, it is necessary that the experiment by an actual size model will be performed in order to get more detail data as regards heat transmission

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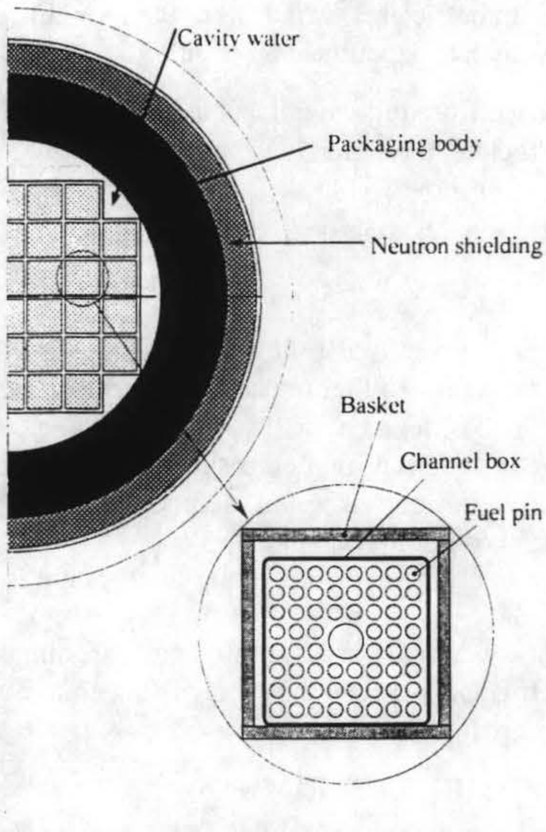

Figure1. The relationship between the experiment and actual packaging.

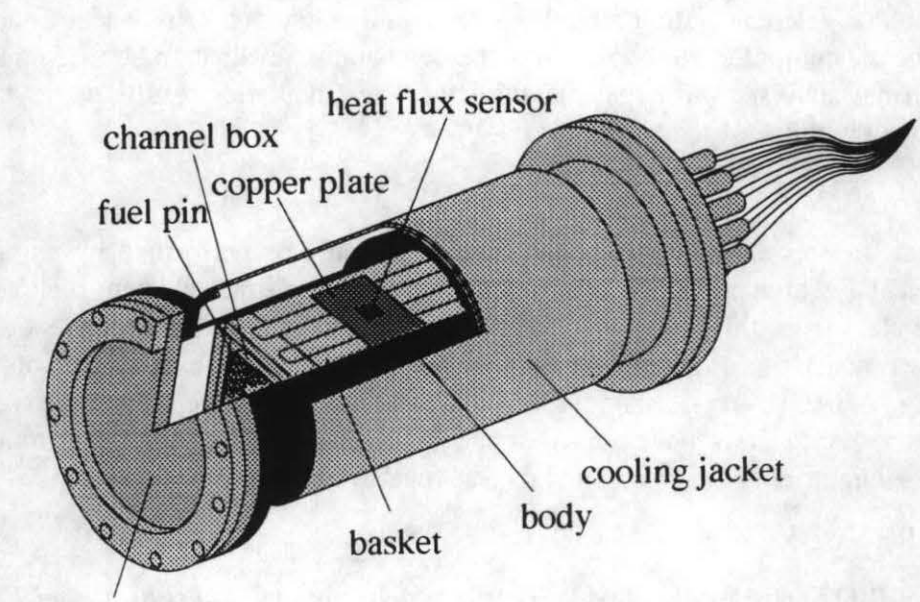

Figure 2. Experimental equipment drawing.

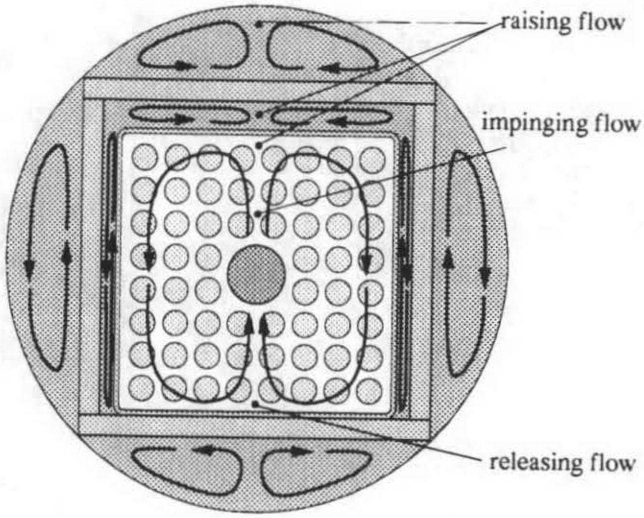

Figure3. Cavity water flow by natural convection in equipment body.

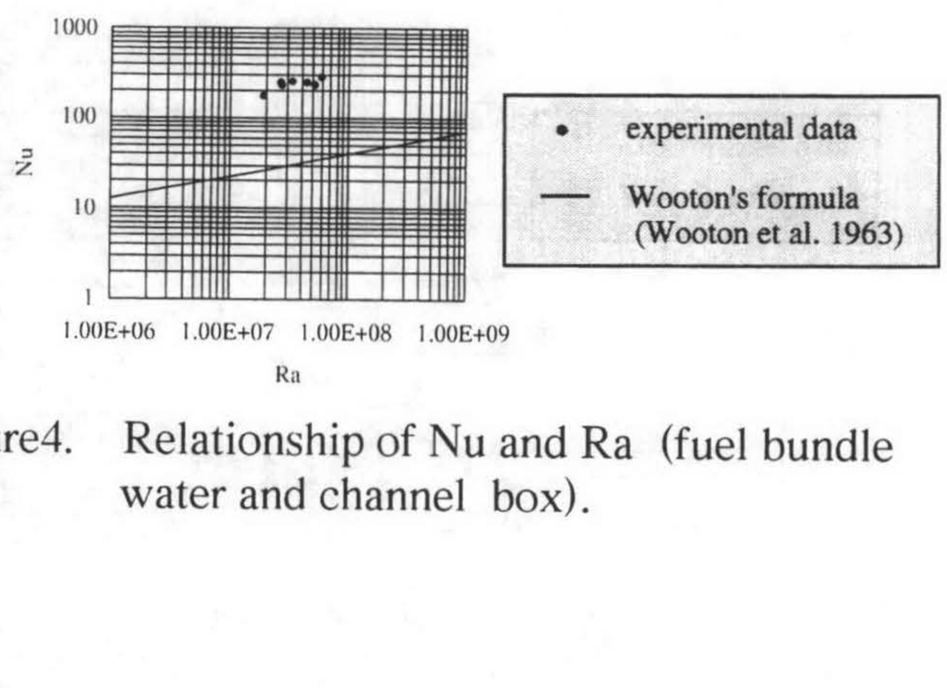

Figure4. Relationship of Nu and Ra (fuel bundle water and channel box).

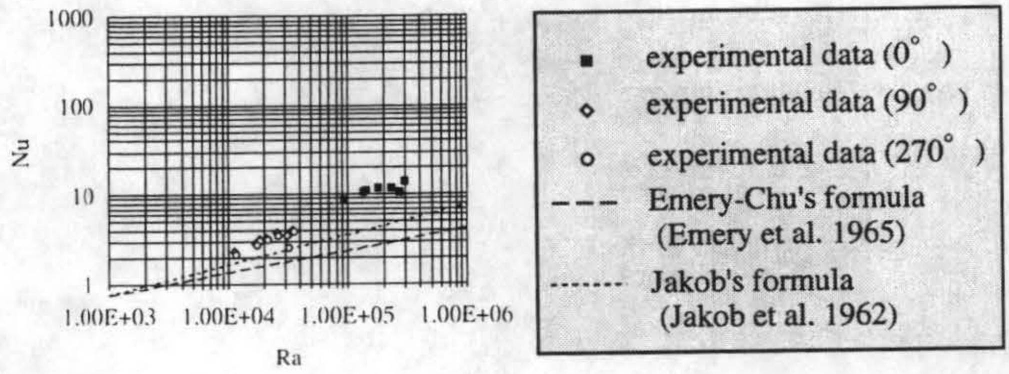

Figure5. Relationship of Nu and Ra (channel box and basket).

Table1. Experimental cases

Run. No.	heat power per fuel pin	basket plate direction				cooling water temperature (℃)
		0°	90°	180°	270°	
1	2.9W/pin	○	○	○	○	20
2		○	×	○	○	〃
3		×	○	○	○	〃
4		○	○	×	○	〃
5		×	×	○	○	〃
6		○	○	×	○	〃
7		×	×	×	×	〃
8	5.0W/pin	○	○	○	○	〃
9		×	×	×	×	〃
10	7.0W/pin	○	○	○	○	〃
11		×	×	×	×	〃
12	2.9W/pin	×	×	×	×	5
~		×	×	×	×	20
13		×	×	×	×	35
14	2.9W/pin	×	×	×	×	20
15	5.0W/pin	×	×	×	×	〃
16	7.0W/pin	×	×	×	×	〃
17	2.9W/pin	○	○	×	×	〃
18	9.0W/pin	×	×	×	×	〃
19	11.0W/pin	×	×	×	×	〃

Table2. Summary of experiment results

Run. No.	average temperature of bandle water (℃)	channel box maximum temperature (℃)	basket maximum temperature (℃)	heat transfer coefficient between bandle water and channel box (W/㎡K)	heat transfer coefficient between channel box and basket		
					0° direction	90° direction	270° direction
1	26.71	27.97	26.65	1593	788	321	314
2	25.90	27.02	25.69	1152	744	271	312
3	26.37	26.71	24.79	945	446	279	263
4	25.21	27.23	25.94	2215	807	330	306
5	25.96	26.14	24.18	736	434	233	277
6	24.90	26.67	25.31	1232	760	252	308
7	24.86	26.05	24.53	784	338	183	173
8	31.86	33.59	31.67	1841	937	371	349
9	26.51	28.55	26.59	1029	431	226	215
10	35.21	37.52	35.25	1957	1001	382	349
11	27.58	30.39	28.04	1156	467	261	249
12	19.93	22.96	20.01	1085	436	242	236
13	41.61	44.20	42.25	1070	435	292	212
14	22.62	23.83	22.89	—	—	—	—
15	24.33	26.23	24.86	—	—	—	—
16	26.06	28.45	26.91	—	—	—	—
17	25.32	27.11	25.92	1201	821	307	247
18	30.15	33.59	30.93	1116	475	300	283
19	32.50	36.40	33.25	1307	569	324	310

Table3. Comparison of experimental results with thermal analysis results

Run No.	maximum temperature of bundle water			average temperature of channel box			average temperature of basket		
	experiment (℃) (a)	analysis (℃) (b)	(b)/(a)	experiment (℃) (a)	analysis (℃) (b)	(b)/(a)	experiment (℃) (a)	analysis (℃) (b)	(b)/(a)
1	28.5	29.3	1.03	26.3	26.5	1.01	25.2	25.4	1.01
2	27.6	28.1	1.02	25.3	25.4	1.00	24.0	24.3	1.01
3	28.0	28.5	1.03	25.7	25.5	0.99	24.4	24.0	0.98
4	27.8	28.3	1.02	24.9	25.7	1.03	23.9	24.6	1.03
5	27.5	27.7	1.01	25.1	24.6	0.98	23.6	23.2	0.98
6	27.4	27.7	1.01	24.4	25.0	1.02	23.2	23.9	1.03
7	26.8	28.2	1.05	24.4	25.2	1.03	23.2	24.0	1.03