Experiments on Thermal Conductivity in Buffer Materials for Geologic Repository

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INTRODUCTION

Engineered barriers for geologic disposal for HLW are planned to consist of canister, overpack and buffer elements. One of important physical characteristics of buffer materials is determining temperature profiles within the near field in a repositry. Buffer materials require high thermal conductivity to disperse radiogenic heat away to the host rock. As the buffer materials, compacted blocks of the mixture of sodium bentonite and sand have been the most promissing candidate in some countries, e.g. Sweden, Switzerland and also Japan. 1)2)3)4)

We have been carrying out a series of thermal dispersion experiments to evaluate thermal conductivity of bentonite/quartz sand blocks. In this study, the following two factors considered to affect thermal properties of the near field were examined.

1) effective thermal conductivities of buffer materials
2) heat transfer characteristics of the gap between overpack and buffer materials

As far as effective thermal conductivities of buffer materials are concerned, Marvin 5) measured them in the temperature range up to 300 ℃, taking mixing ratios of bentonite and quartz sand as parameters. And Radhashna 6) measured effective thermal conductivities of buffer materials consisting of coarse and fine granules, as the function of composition, density, water contents and surrounding temperature. However, there are few studies measuring them in heating and drying processes as the function of water content, porosity or quartz sand diameter.

Moreover, the gap between overpack and buffer materials are considered to be comparatively high heat resistance in dispersion performance of radiogenic heat. From this viewpoint, heat transfer experiments of cylindrical buffer materials, using electric heater simulating waste form, were carried out in this study. And two-dimentional axial symmetric analysis was also performed to simulate the experiments.

EXPERIMENTAL FEATURE

Buffer materials were the mixture of sodium bentonite and quartz sand (mixing ratio 6:4), and compacted into cylinders (50.8 mm dia., 152 mm high). Schematic of experimental apparatus is shown in Fig. 1. A sheath heater simulating wastes was installed at the center of a test piece block covered by heat insulating material. Four thermocouples were set in radial direction in

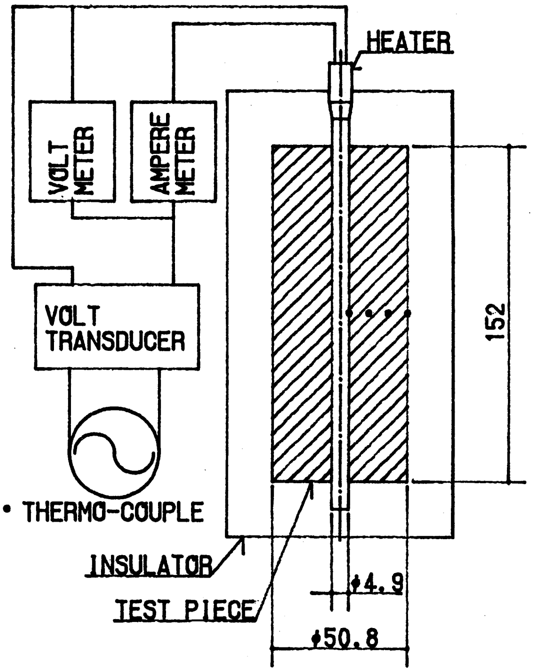


Fig.1 Schematic of test apparatus

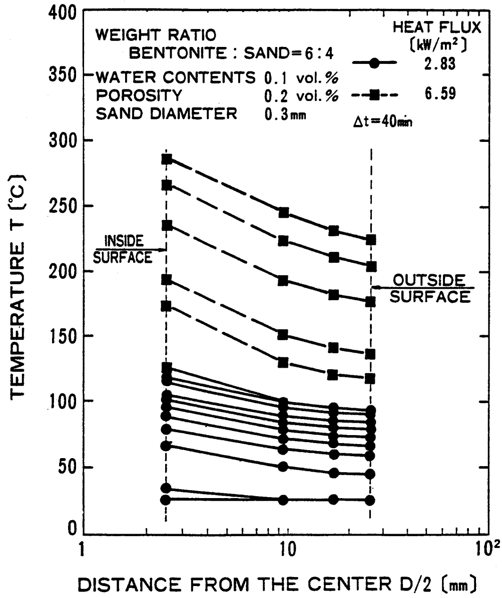


Fig.2. Temperature Distribution Profile in A Test Piece

the block. At first, heat flux was kept at 2.8 kW/㎡ for four hours, and then it was increased to and kept at 6.5 kW/㎡ for 4.5 hours to extend temperature range.

EXPERIMENTAL RESULTS AND DISCUSSION

Temperature and Effective Thermal Conductivity Profiles

Typical results of radial distribution profiles of temperature in a test piece every forty minutes are shown in Fig. 2. Since temperature changed very slowly, thermal transfer phenomena in this procedure are considered to be treated as a steady state. Effective thermal conductivities have been calculated by taking a test piece as three-layered cylinders between measurement points. These three cylinders were named A, B and C from the inner one to the outer.

Calculated results of effective thermal conductivity of each layer are shown in Fig. 3. Effective thermal conductivities show the tendency to decrease with the rise of temperature. It is considered that this is because,

(1) water contained in the test piece moved with the rise of temperature, and water contents became low,

(2) the effective thermal conductivity of quartz sand which occupied 30 vol.% of a test piece has the characteristics of decreasing with the rise of temperature.

As shown in Fig. 3, effective thermal conductivity of the innermost layer, named A, was lower than those of other layers. It is assumed this difference resulted from water transport by heating. Water contained in the nearest layer A is considered to move upward or outward, and to make effective thermal conductivity of layer A lower than those of outer layers.

Effects of Water Contents, Porosity and Quartz Sand Diameter

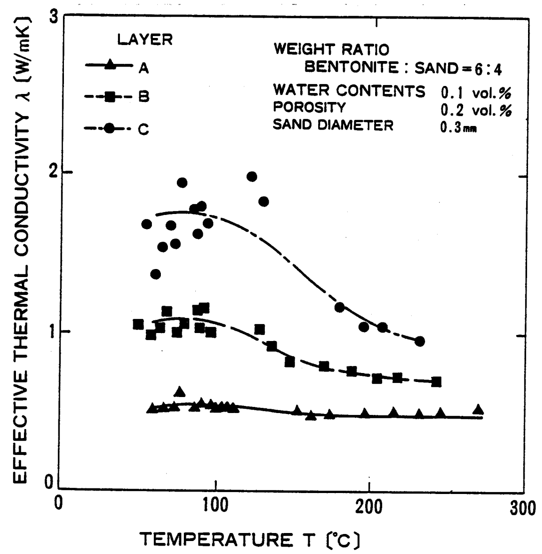
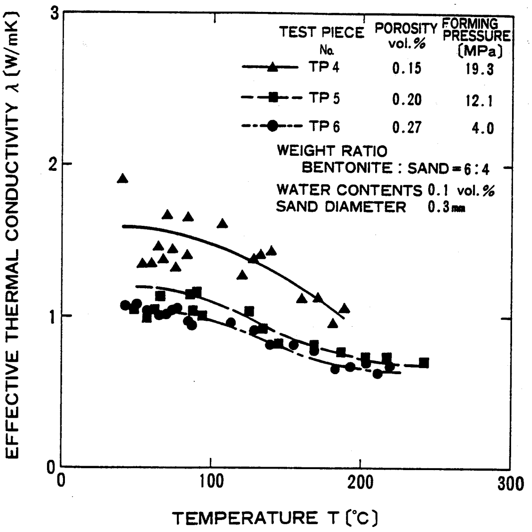
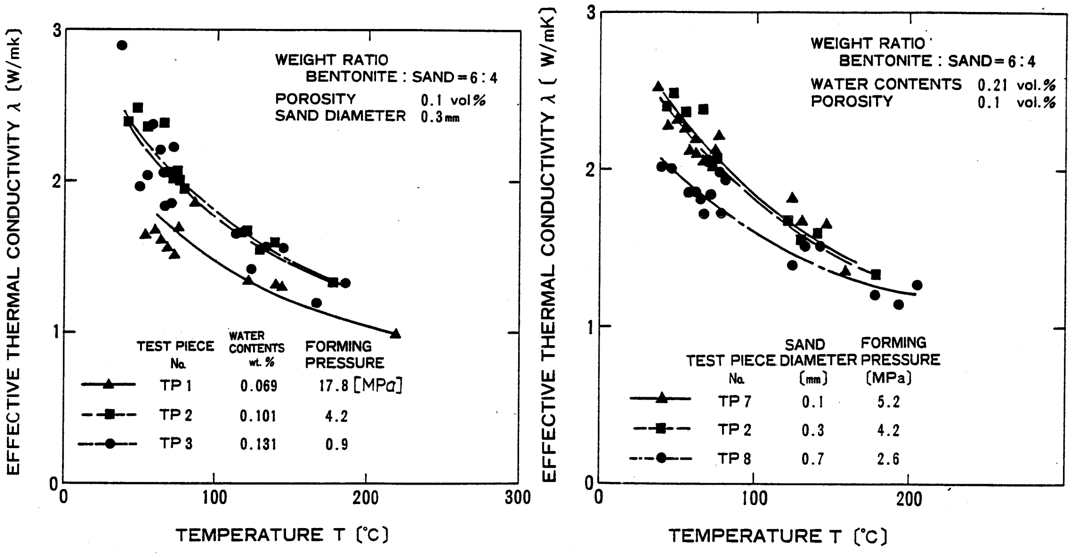


Fig.3. Effective Thermal Conductivity Distribution Profile



(b) Influences of Porosity



(a) Influences of Water Contents

(c) Influences of Sand Diameter

Fig.4. Influences of Water Contents, Porosity and Sand Diameter

Figures 4 (a),(b) and (c) show the results of effective thermal conductivities of experiments in which water contents, porosity and grain size of quartz sand were taken as parameters. In these figures, effective thermal conductivity data of the middle layer, named B, are used.

Influences of water contents on effective thermal conductivity are shown in Fig. 4 (a). Effective thermal conductivity of each test piece was rapidly decreased with the rise of temperature and showed the tendency to saturate. Effective thermal conductivity was high with high water contents. The difference between data of water contents of 6.9 wt.% and 10.1 wt.% was extremely large, while data of water contents of 10.1 wt.% and 13.1 wt.% were almost the same.

Figure 4 (b) shows influences of porosity. Effective thermal conductivities were almost constant at low temprerature below 100 ℃ , decreased above 100 ℃ and seemed to saturate. Effective thermal conductivity was low with high porosity.

Influences of grain size of quartz sand are shown in Fig. 4 (c). Effective thermal conductivities were rapidly decreased with the rise of temperature similarly to Fig. 4 (a). Effective thermal conductivity in case quartz sand diameter was 0.7 mm became the lowest, and in the case of 0.1 mm and 0.3 mm, they were almost the same. In high temperature region, effective thermal conductivities of all test pieces seem to saturate a same value. It is considered this is because the porosity of test pieces became almost the same after water moved or evaporated.
Thus, it is confirmed experimentally that effective thermal conductivity becomes high in case of high water contents, low porosity and small quartz sand diameter.

TWO-DIMENSIONAL AXIAL SYMMETRIC ANALYSIS

In this study, to evaluate effects of the gap between overpack and buffer materials on heat transfer characteristics in a repository, unsteady heat transfer analysis was carried out by FEM method using,
(1) effective thermal conductivity data of buffer materials in this study,
(2) two-dimensional axial symmetric model.

Analytical Conditions

Figure 5 shows the calculation meshes of this analysis. This model includes the gap between heater and buffer materials. Width of the gap was set almost the same as experiments in this study, and heat transfer by radiation was taken into considration in the gap. Upper and lower boundaries of the heater element are set as adiabatic, and heat transfer coefficients of other boundaries were assumed to be the same as that of insulation material used in these experiments. Initial temperature was set to the room temperature, 30 ℃ . For thermal characteristic data of heater, those of stainless steel were used, and for effective thermal conductivity of buffer materials, experimental data of this study were used. In this calculation, heat generation density set to the same value as experiments was larger than those of actual wastes.

Analytical Results and Discussion

Isotherms in the heater and buffer material at the time of 4 and 8.5 hours were shown in Figs. 6 (a) and (b). Difference in temperature between heater surface and inner surface of buffer mterial were 15 ℃ at 4 hours, and 27 ℃ at 8.5 hours. Difference in temperature resulting from the gap are obtained clearly. Figure 7 shows the temperature distribution profiles from heater surface to outer surface of buffer material. This shows that the temperature gradient in the gap between heater and buffer material were greatly larger than that in buffer material, and temperature at the heater surface became high by the presence of the gap.

In this calculation, width of the gap, set to experiments, was very small (0.14 mm). Therefore, effects of convection are considered to be negligible in this case. However, in an actual repository, the gap seems to be wider than this. In such case, analysis including the heat transfer due to convection will be required.

CONCLUSIONS

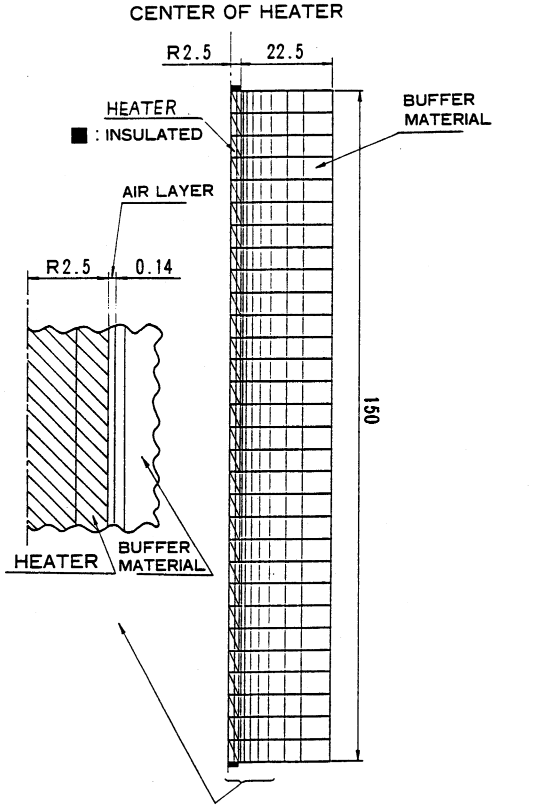
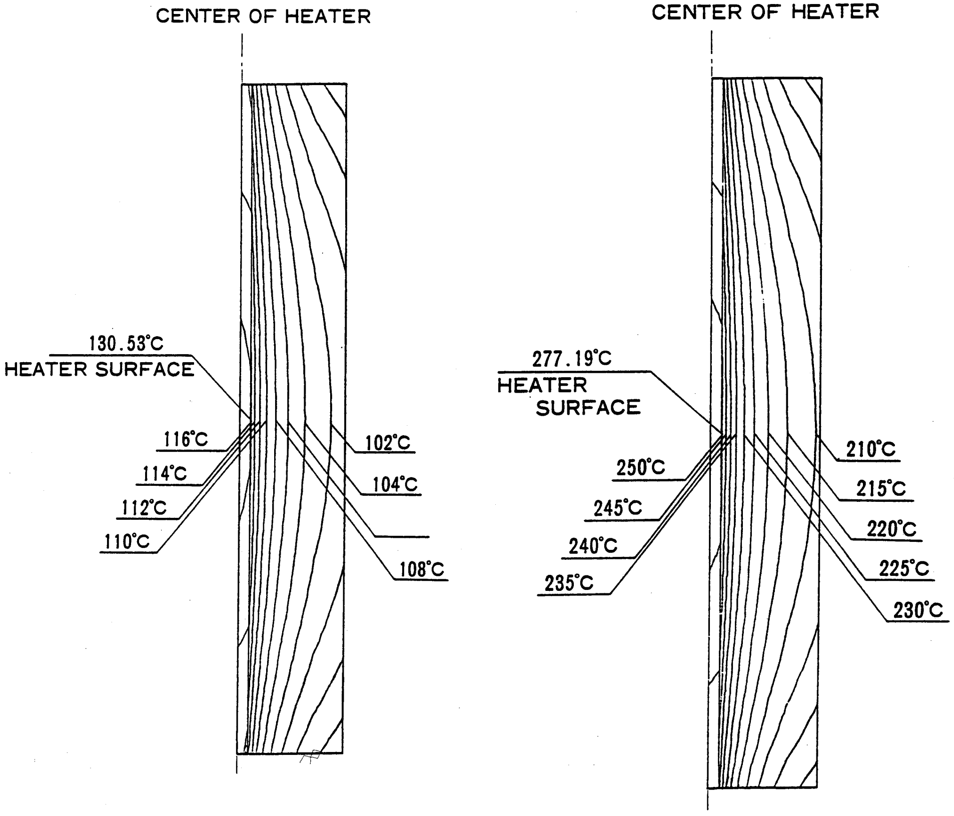


Fig.5. Meshes and Conditions for Calculation



(a) at 4 hours

(b) at 8.5 hours

Fig.6. Calculated Results of Isotherms in the Heater and Buffer Material

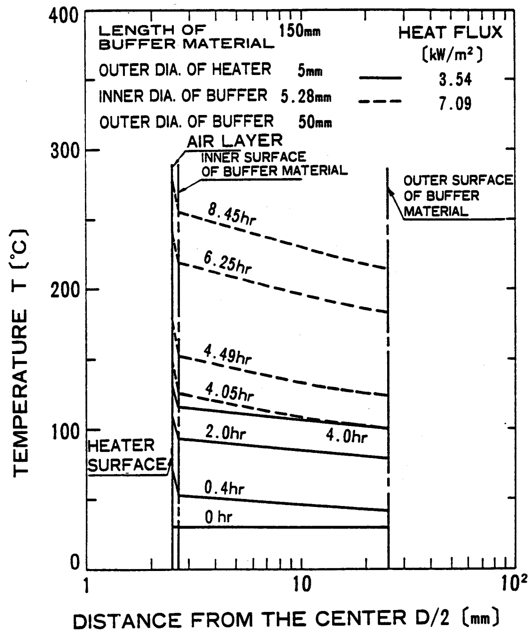


Fig.7. Calculated Results of Temperature Distribution Profile in Buffer Material

The experimental studies and two-dimensional axial symmetric analysis on heat transfer in engineered barriers were carried out. Three main conclusions were obtained from this study as follows.

(1) Within a compacted bentonite/quartz sand block, the effective thermal conductivities at a point near the heat source become lower than those at far points.

(2) Effective thermal conductivity of compacted bentonite/quartz sand block is high in case of high water contents, low porosity and small quartz sand diameter.

(3) It is confirmed that presence of the gap between overpack and buffer materials affects the temperature of overpack surface greatly.

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