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Effect of Natural Convection on Equivalent Heat Conductivity of a Vertical Layer Packed with Glass Wool

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Abstract

This report deals with the effect of natural convection on heat transfer in a vertical layer packed with glass wool of heat insulating material.

Experiments are carried out with air or water as a saturating fluid in the range of the specific weight of the glass wool, γ, from 3 to 50 (kg/m^3) and the aspect-ratio H/W from 5 to 47.5.

The effect of the dimensions of cavities, the specific weight of the glass wool γ and the surface temperature of the cold wall T_c on the apparent heat conductivity λ_{eff} is investigated.

The results of the experiments show a strong influence of natural convection on λ_{eff} in the range of $\gamma=3\sim20$ (kg/m^3).

It is clarified that the results for water show a very complicated behavior as compared with those for air.

1. Introduction

The apparent heat conductivity λ_{eff} for glass wool is generally used as 0.036～0.057 (kcal/mh°C) in a range of γ from 10 to 96 (kg/m^3) by the Standard Method of Test of the JIS.

However, these values can be adopted only in the case of heat conductive conditions, for example, where the heat insulating materials are used horizontally and the heating surface is on the upper side and the condensation of water or ice formation does not exist on the cooling surface.

In case of other arrangements, especially vertical arrangement, the influence of natural convection on heat transfer between two vertical walls should be larger.

This study investigates experimentally the effect of natural convection which is induced by the temperature difference between the hot and the cold wall surfaces on the increase of λ_{eff} according to each γ.

Experimental conditions are selected with consideration to practical usage, that is, the present experiments are carried out in case of the vertical layer of glass wool saturated with air or water. Moreover, the effect of the device dimensions on λ_{eff} is examined.

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2. Nomenclature

q	Heat flux, Input (kcal)/Heating surface (m^2)
H	Height of cavity, (m)
W	Width of cavity, (m)
H/W	Aspect ratio
T_h	Surface temperature of the hot wall, (°C)
T_c	Surface temperature of the cold wall, (°C)
λ_{eff}	Apparent heat conductivity, $\frac{qW}{(T_h-T_c)}$, (Kcal/mh°C)
γ	Specific weight of glass wool heat insulating material, (kg/m^3)

3. Experimental devices and Test procedure

Experimental device is depicted in Fig. 1. The main parts of experimental device consist of the test section, heating and cooling parts. The test section is shown in the center part on the left side in Fig. 1. The samples of glass wool with prescribed γ are packed in this section.

In order to maintain each wall-surface tempature uniformly, the hot wall and the cold wall are constructed by copper plates (5 mm in thickness).

Heating of the hot wall is performed by using the main heaters. The guard heaters are mounted on the main heaters in order to minimize the heat from the main heaters to the environment.

Surface temperature of the cold wall is uniformly maintained by using devided cooling chambers.

In order to investigate the influence of the dimensions of the cavities on heat transfer, the divices are selected as shown in table 1.

Surface temperature of the hot wall is uniformly kept at 20 (°C) in all of the runs, and surface temperature of the cold wall is changed from 10 (°C) to −15 (°C). Test samples of the glass wool which passed the Standard of the JIS 9505 are used. The fibrous direction of glass wool is arranged to be perpendicular to the heat flow.

Heat transfered is measured after a steady state in the test section is reached thermally and hydrodynamically. In each of the runs, it requires about 2∼5 hrs to obtain the steady state.

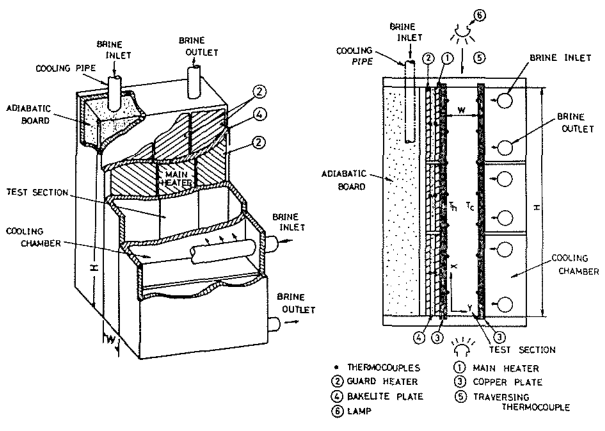

Fig. 1 Schematic diagram of the experimental devices

H (mm)	W (mm)	H/W
300		15
600	20	30
950		47.5
300	10	30
	50	6
	22	26
571	59	9.7
	116	5

Table 1 The dimensions of the cavities used

4. Experimental results and Discussion

4.1 The effect of the dimensions of the cavity on λ_{eff}

It is impossible technically to enlage the height of cavity and the width of glass wool infinitively. Therefore, the dimensions of the cavities are limited in the present study.

Fig. 2 shows the relation between W and λ_{eff} for $H=571$ (mm), $T_h=20$ (°C) and $T_c=-5$ (°C).

When air as a saturating fluid is used as shown in Fig. 2 (a), the value of λ_{eff} increases in a curve fashion with increasing W when $W \leqq 20$ (mm). But when $W > 20$ (mm), the value of λ_{eff} increases linearly with the increasing W. On the other hand, when water is used and glass wool is packed as shown in Fig. 2 (b), the value of λ_{eff} increases monotonously over the entire range of W and the rate of increase of λ_{eff} is very small.

Fig. 3 shows the relation between H and λ_{eff} for $W=20$ (mm), $T_h=20$ (°C) and $T_c=-5$ (°C).

The value of λ_{eff} without glass wool decreases sharply with the increasing H when $H \leqq 1$ (m). But when $H > 1$ (m), the value of λ_{eff} decreases at a much slower pace. From Fig. 3, it is understood that these tendencies have the same

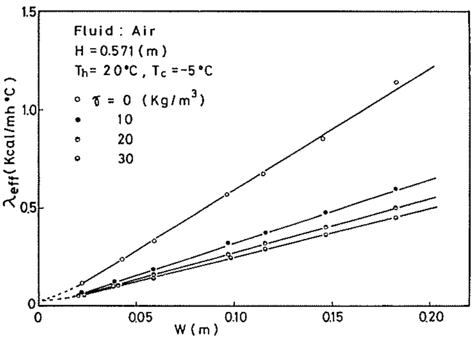

Fig. 2 (a)

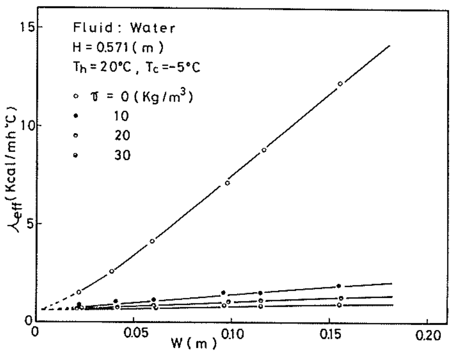

Fig. 2 (b)

Fig. 2 Effect of W on λ_{eff}, (T_h=20°C, T_c=−5°C)
(a) H=571 mm, Air, (b) H=571 mm, Water

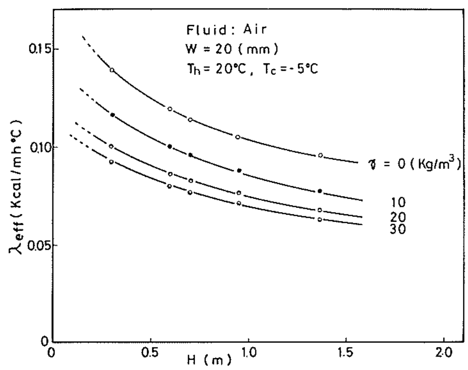

Fig. 3 (a)

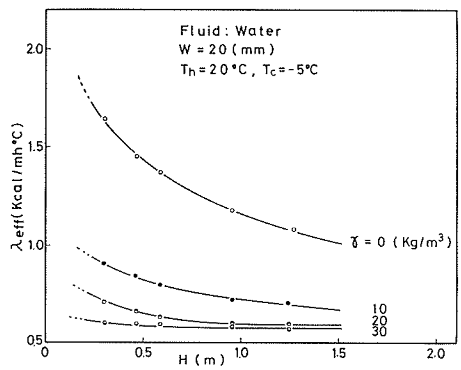

Fig. 3 (b)

Fig. 3 Effect of H on λ_{eff}, (T_h=20°C, T_c=−5°C)
(a) W=20 mm, Air, (b) W=20 mm, Water

characteristics as in the experimental results with glass wool. As mentioned above, it is clear that the increase of H results in the decrease of λ_{eff} which represents the apparent mean heat conductivity of the packed layer. This result is due to the fact the natural convective heat transfer caused by the movement of a saturating fluid has a significant role in the lowest part of the hot wall and in the highest part of the cold wall.

4.2 The effect of the specific weight γ on λ_{eff}

Fig. 4 illustrates the effect of the specific weight γ on λ_{eff}.

It may be understood that λ_{eff} decreases sharply as γ increases in the range of $\gamma=0\sim20$ (kg/m^3). This result means that the influence of natural convection on heat transfer is predominant in this range. If $\gamma>20$ (kg/m^3), λ_{eff} decreases at a slow rate due to the increasing resistance of the movement of the saturating fluid.

It can be seen in Fig 4 (a) and Fig. 4 (b) that a decreasing rate of λ_{eff} for water having a large viscosity is larger than that for air.

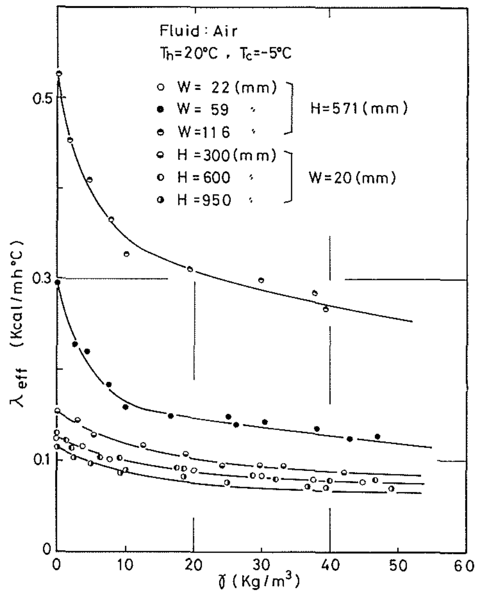

Fig. 4 (a)

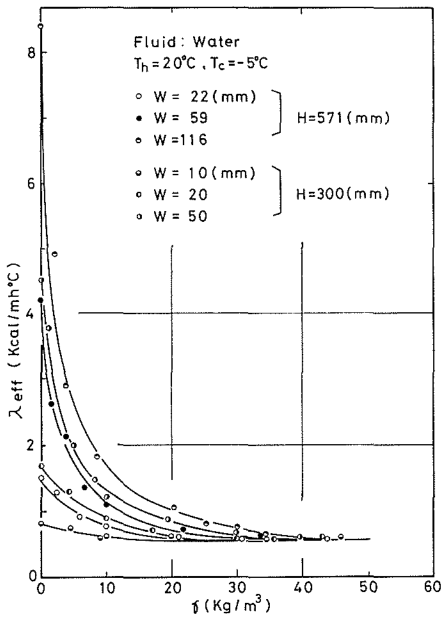

Fig. 4 (b)

Fig. 4 Effect of γ on λ_{eff}, (T_h=20°C, T_c=−5°C)
(a) Air, (b) Water

4.3 The effect of the cold wall surface-temperature T_c on λ_{eff}

In order to investigate the intensity of natural convection caused by the temperature difference between the surface temperatures of the hot and the cold walls, experiments are carried out under the condition that the hot wall surface temperature T_h is maintained at 20 (°C) and the cold wall surface temperature T_c is changed variously in a range of $T_c=-15\sim10$ (°C). Experimental results are shown in Fig. 5.

It can be understood in Fig. 5 (a)∼5 (c) for air that value of λ_{eff} decreases linearly as T_c increases. On the other hand, experimental results for water as shown in Fig. 5 (d)∼5 (f) show a very complicated behavior as compared with those for air, that is, in the range of $T_c<0$ (°C), it is clear that the heat transfer

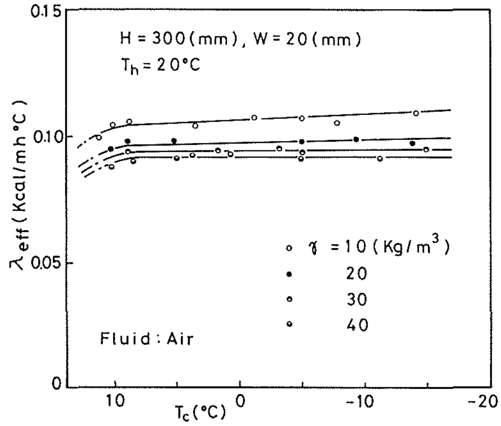

Fig. 5 (a)

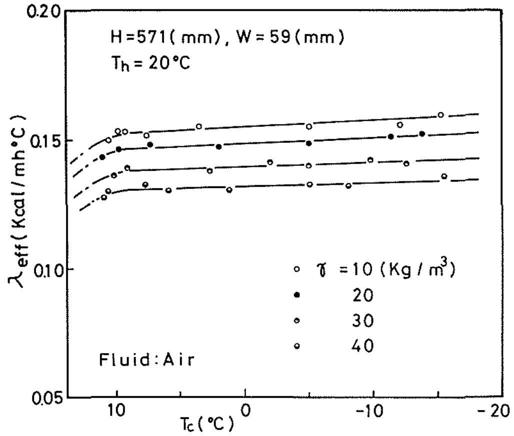

Fig. 5 (b)

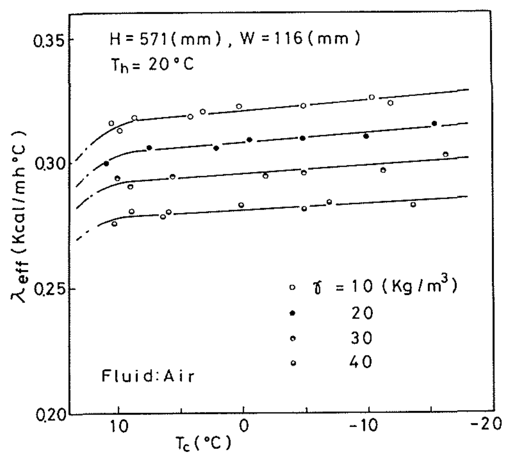

Fig. 5 (c)

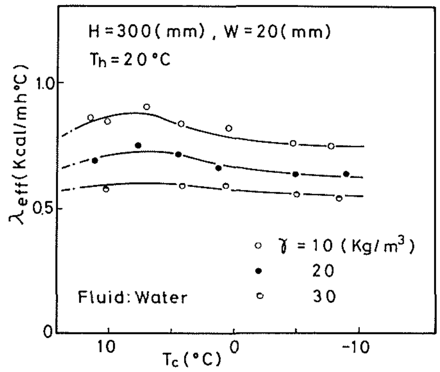

Fig. 5 (d)

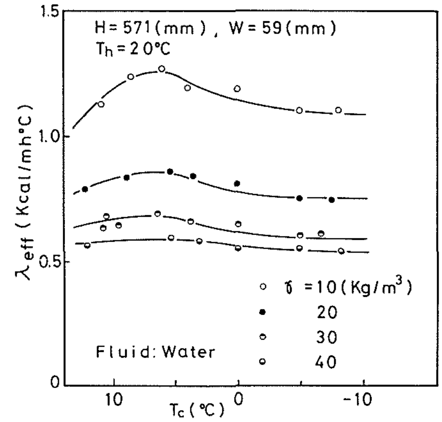

Fig. 5 (e)

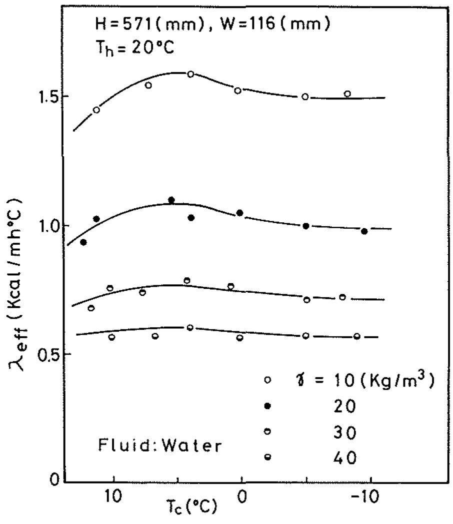

Fig. 5 (f)

Fig. 5 Effect of T_c on λ_{eff}, (T_h=20°C)
(a) W=20 mm, H=300 mm, Air, (d) W=20 mm, H=300 mm, Water
(b) W=59 mm, H=571 mm, Air, (e) W=59 mm, H=571 mm, Water
(c) W=116 mm, H=571 mm, Air, (f) W=116 mm, H=571 mm, Water

between two vertical walls is affected by the ice formation on the cold wall surface and the density inversion effect of water which has its maxim density at 4 (°C). When T_c becomes larger than 4 (°C), the effect of density inversion disappears, while λ_{eff} reaches its maximum value at about 5 (°C). However, the maximum value of λ_{eff} becomes relatively small due to the resistance of the movement of saturating fluid with the increasing γ.

4.4 The effect of the relative humidity of moist air on λ_{eff}

Fig. 6 shows the relation between the relative humidity of moist air on λ_{eff}. When moist air exists in packed layers, it is generally said that the circulation of vapor diffusion, that is, diffusion in the vicinity of the hot wall - condensation or ice formation on the cold wall - the movement of water to the hot wall by capillary action - evaporation in the vicinity of the hot wall, is formed in a testing layer. This movement of moisture promotes the effect of natural convection on heat transfer.

It shoud be understood from the reason mentioned above that the values of λ_{eff} for 100% relative humidity are larger than those for 50% relative humidity.

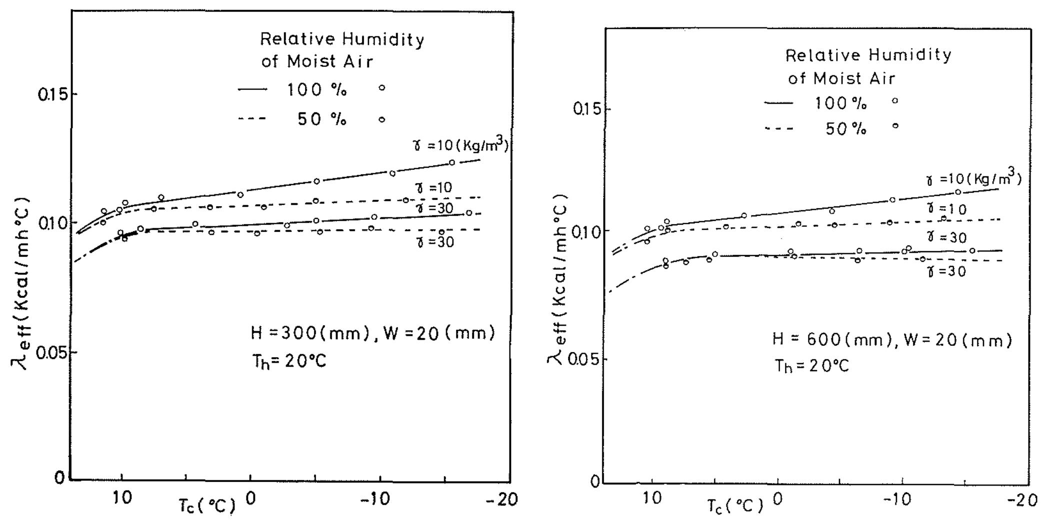

Fig. 6 (a) **Fig. 6** (b)

Fig. 6 Effect of the relative humidity of moist air on λ_{eff}
(a) W=20 mm, H=300 mm, (b) W=20 mm, H=600 mm

5. Summary and Conclusions

It can be clarified that the heat conductivity of $\lambda_{eff}=0.036\sim0.057$ (kcal/mh°C) generally used is not always applicable when the natural convection exists in the layer of glass wool:

(1) The influence of natural convection on λ_{eff} is remarkable in the range of $\gamma=3\sim20$ (kg/m³).

(2) For air, the relation between T_c and λ_{eff} is linear. On the other hand, experimental results for water show a very complicated behavior having a maximum value of λ_{eff} at about $T\simeq5$ (°C).

(3) For moist air as a saturating fluid, the movement of water promotes the effect of natural convection on the apparent heat conductivity between two vertical walls.

References

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