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Effect of Natural Convective Heat Transfer on Effective Heat Conductivity of a Horizontal Fibrous Glass Layer Heated from below

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Abstract

The placement of a heating surface of a confined glass wool layer, including horizontal or vertical, is an important factor affecting the behavior of heat transfer.

In this report the heat transfer in a horizontal glass wool layer heated from below is studied. The effects of the distance W between the hot and the cold walls, the specific weight of the glass wool γ (kg/m^3) and surface temperature of the cold wall T_c on the apparent or effective heat conductivity λ_{eff} are investigated.

The results of the experiments show a strong influence of natural convection on λ_{eff} of a horizontal glass wool layer having $\gamma=0\sim12$ (kg/m^3).
(However, in the case of vertical glass wool layer, the effect of natural convection on λ_{eff} is strong in the range of $\gamma=0\sim20$ (kg/m^3)[3]).

1. Introduction

The effect of heat transfer on λ_{eff} of a confined vertical glass wool layer having one vertical wall heated and the opposing vertical wall cooled has recently been reported by N. Seki et al..[3),4)]

In practice, it can be said that heating surface insulating the ceiling of a room is heated from below. Therefore, clarifing of λ_{eff} in such a case as mentioned above is an important problem in practical design. However, at present time hardly any data are available.

This study investigates experimentally the effects of γ, T_c and W on λ_{eff} under conditions where the bottom surface is heated.

2. Nomenclature

q: heat flux, (kcal/m$^2\cdot$h)
W: distance between the hot and the cold walls, (m)
T_h: surface temperature of the hot wall, (°C)
T_c: surface temperature of the cold wall, (°C)
Nu_W: Nusselt number, $\dfrac{qW}{\lambda(T_h-T_c)}$
Ra_W: Rayleigh number, $\dfrac{g\beta(T_h-T_c)\,W^3}{\nu a}$

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g: gravitational acceleration, (m/s^2)
β: coefficient of cubic expansion, (1/°C)
a: thermal diffusion, (m^2/s)
ν: kinematic viscosity, (m^2/s)
λ_{eff}: effective heat conductivity, $\frac{qW}{(T_h - T_c)}$, (kcal/m·h·°C)
λ: heat conductivity of fluid, (kcal/m·h·°C)
α: coefficient of heat transfer, (kcal/m^2·h·°C)
γ: specific weight of glass wool, (kg/m^3)

3. Experimental device and procedure

The experimental device is as shown in Fig. 1. The main parts of the experimental device are consisted of testing, heating and cooling parts. The hot and the cold walls are constructed with copper plates (300 mm × 300 mm in area and 5 mm in thickness) in order to maintain each wall surface temperature uniformly.

Heating of the hot wall is conducted by divided main mica-heaters by inducing electric current. The guard mica-heaters are mounted on each main heater in order

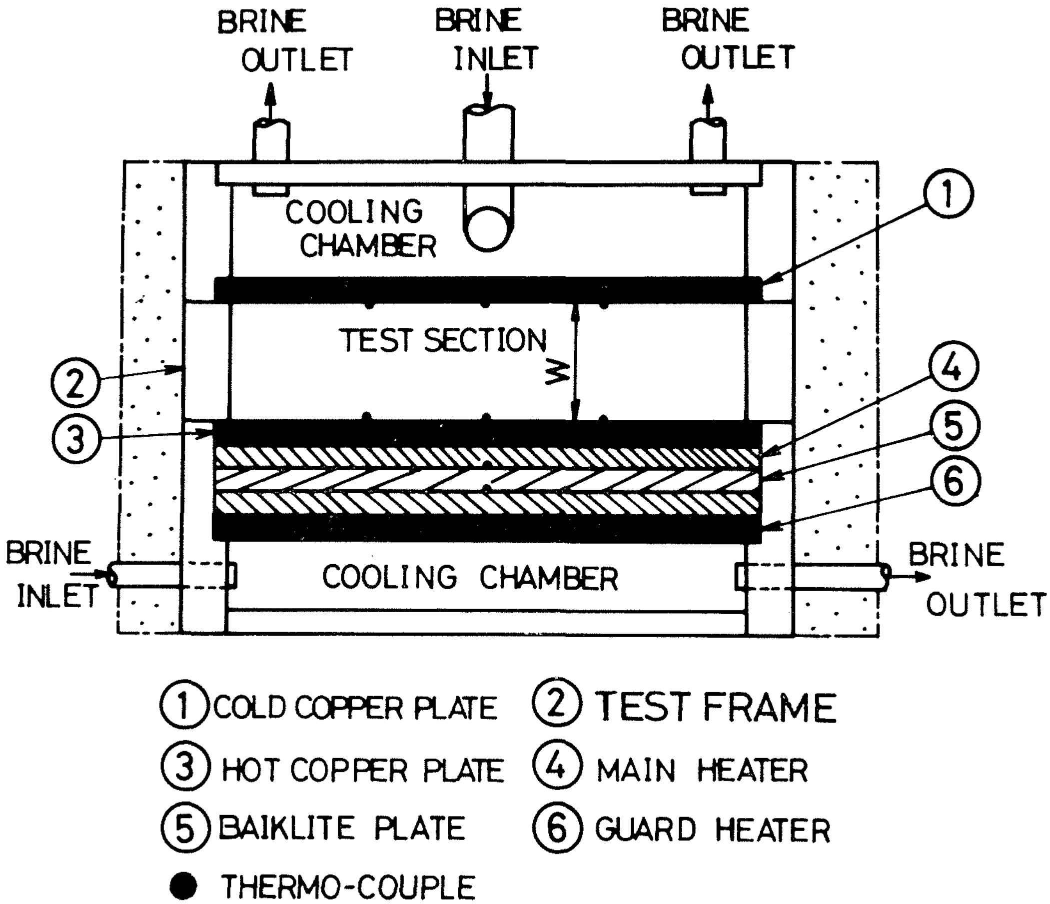

Fig. 1. Schematic diagram of the experimental device.

to minimize the heat loss from the main heaters into the environment. Cooling of the cold wall is conducted with a coolant introduced into the separated cooling chambers. The distance between the hot and the cold walls (W=10, 20 and 50 mm) is changed by using the three adjustable frames. Test samples of glass wool guaranteed by JIS A 9505 standard are used.

To investigate the effect of the cold wall surface temperature T_c on λ_{eff}, the surface temperature of the hot wall T_h is uniformly kept at 20 (°C) and the surface temperature of the cold wall T_c is varied from 10 to -15 (°C). Heat transfer is measured after a seady state in the test section is reached thermally and hydrodynamically. In each of the runs, it takes about 7～10 hrs to reach the steady state.

4. Experimental results and discussion

a) The precision of the experimental device

The precision of the experimental device as shown in Fig. 1 is examined in a horizontal fluid layer whithout glass wool. The obtained results are compared with Silveston's experimental results[5].

The experiments are carried out with water over a wide range of difference of surface temperature under conditions of T_c>4 (°C). The data are plotted in Fig. 2 together with Silveston's data indicated as a solid line.

It is clear from this figure that the precison of the present device is satisfactory.

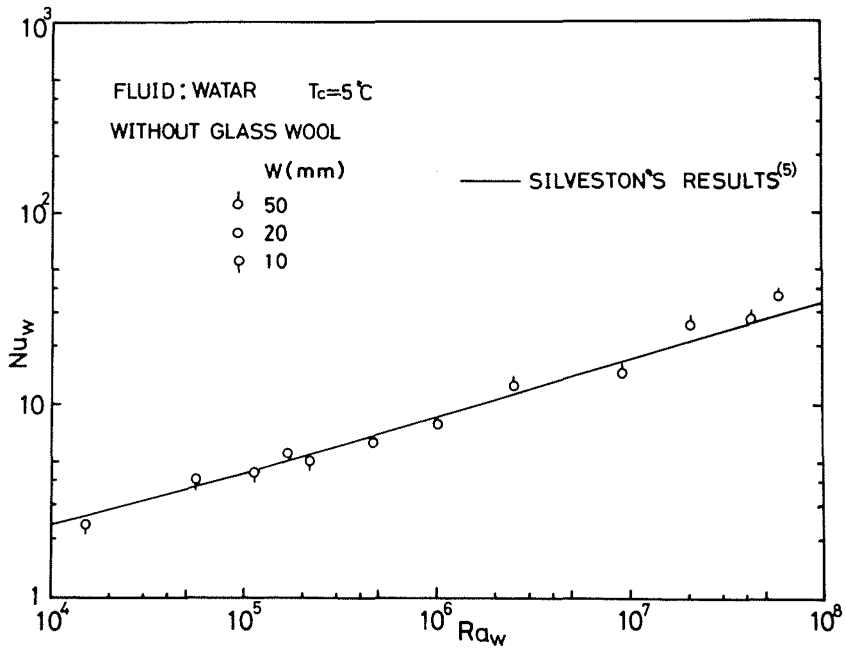

Fig. 2. Relationship between Nu_W and Ra_W for water without glass wool.

b) The effect of the distance between the hot and the cold walls W on λ_{eff}

Fig. 3 shows the relation between W and λ_{eff} with γ as the parameter. Fig. 3-1 for water indicates that the values of λ_{eff} for γ=10 and 30 (kg/m^3) do not vary

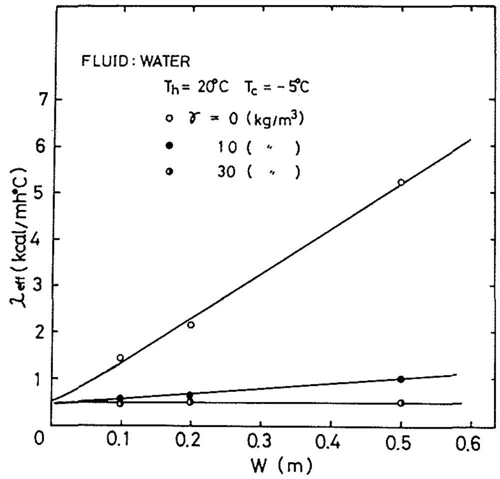

Fig. 3-1

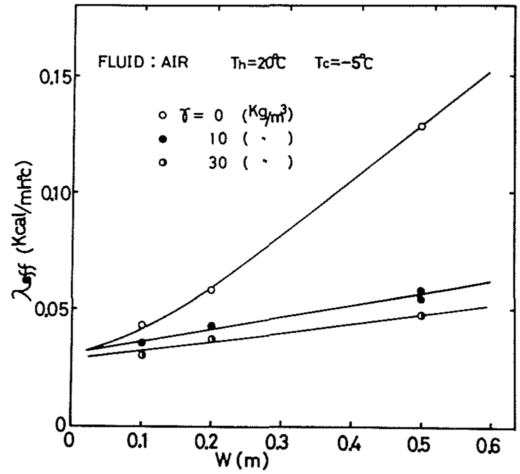

Fig. 3-2

Fig. 3. Effect of W on λ_{eff} with γ as a parameter.

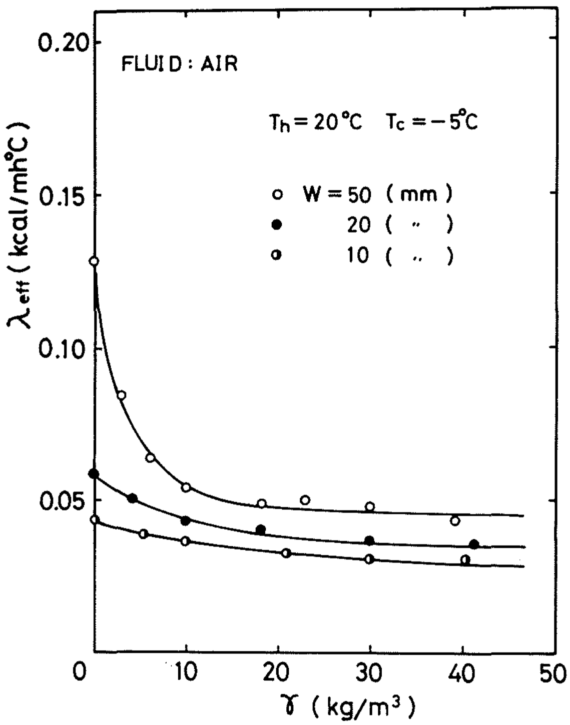

Fig. 4-1

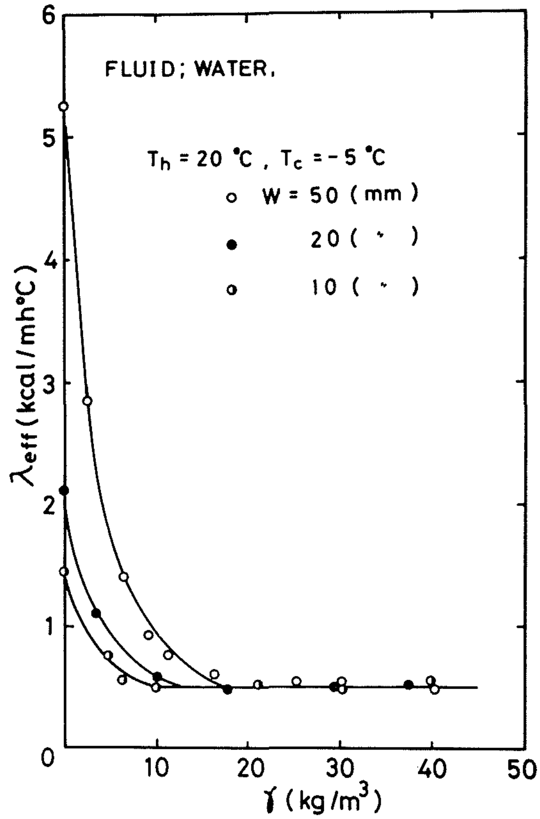

Fig. 4-2

Fig. 4. Effects of the specific

remarkably with the increasing W as compared with those obtained without glass wool. These results indicate that heat transfer through the glass wool layer is carried out almost conductively due to the high viscosity of water. Moreover, the results for air as shown in Fig. 3-2 have a considerable increase of λ_{eff} with the increasing W as compared with those for water in Fig. 3-1.

This fact might explain that the viscosity of fluid used has a strong influence on the natural convection related to λ_{eff}.

c) Effect of the specific weight of glass wool γ on λ_{eff}

Fig. 4 indicates the relation between γ and λ_{eff} or heat transfer coefficient α.

The results shown in Fig. 4-1 for air and Fig. 4-2 for water suggest that the values of λ_{eff} decrease steeply as γ is increased in the range of $\gamma=0\sim12$ (kg/m³) and those of λ_{eff} are constant beyond the range of $\gamma=12$ (kg/m³).

This decrease of λ_{eff} indicates that a strong influence of natural convection is seen in the range of $\gamma=0\sim12$ (kg/m³). It can be understood that the strong natural convective range for γ of horizontal glass wool layer is smaller than that of vertical glass wool layer (in the range of $\gamma=0\sim20$ (kg/m³)).

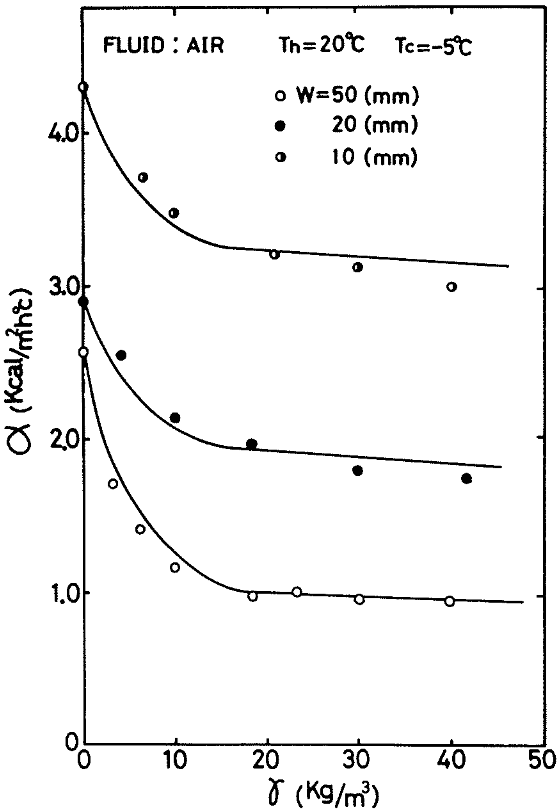

Fig. 4-3

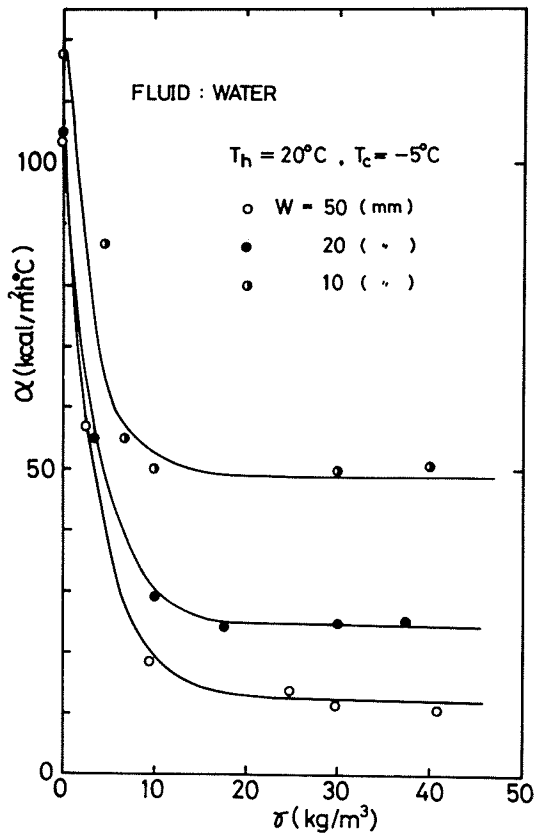

Fig. 4-4

weiget γ on λ_{eff} and α.

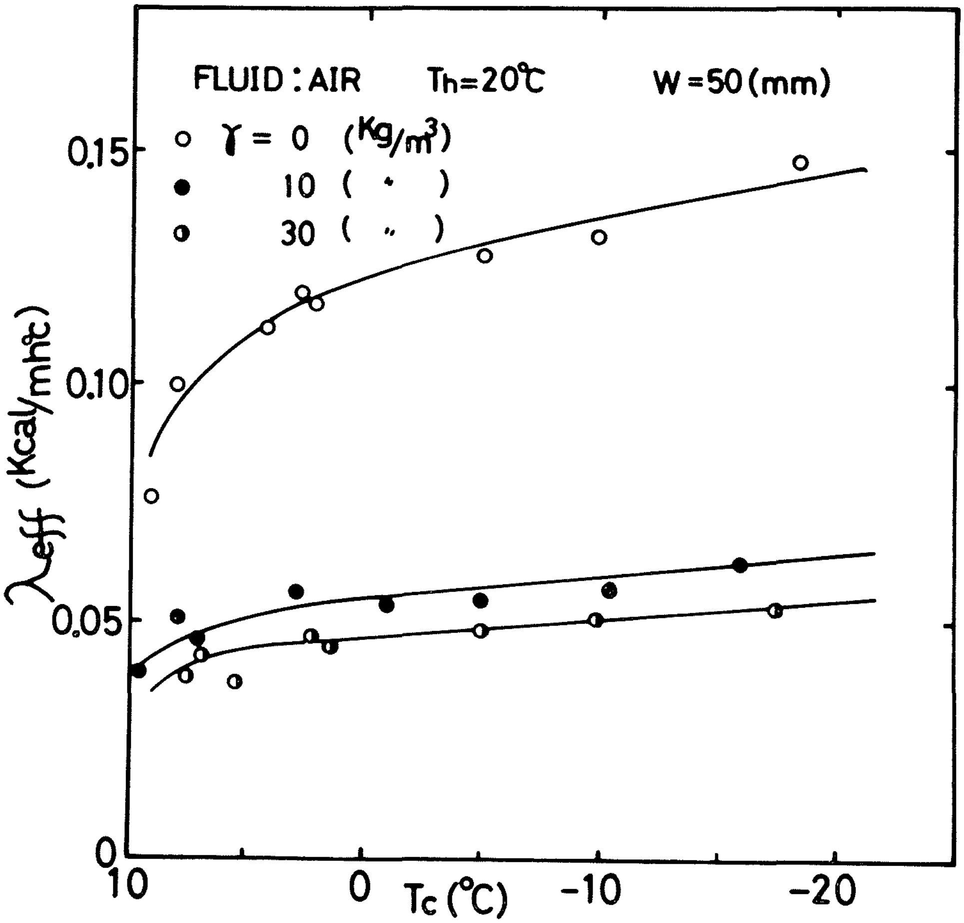

Fig. 5-1

Fig. 5. Effect of T_c on λ_{eff}

This can be explained because the strength of natural convection produces only a weak disturbance compared with that of the vertical glass wool layer.

Fig. 4-3 and Fig. 4-4 for air and water respectively indicate the relation between γ and α. It can be seen from these figures that the effect of W on α is shown distinctly.

d) Effect of the cold surface temperature T_c on λ_{eff}

Fig. 5 shows the relation between T_c and λ_{eff}.

The λ_{eff} for air decreases as indicated in Fig. 5-1 because the effect of temperature difference between the hot and the cold walls on natural convection becomes weak with the increasing T_c under constant T_h. Such a decrease is not so much in the cavity packed with glass wool, in other words the value of λ_{eff} is constant in the range of $T_c = -20 \sim 8$ (°C). However, beyond the range of $T_c = 8$ (°C) the values of λ_{eff} decrease steeply and the conductive heat transfer is predominant in the glass wool layer.

The results for water are shown in Fig. 5-2. It can be understood from this figure that the values of λ_{eff} decrease due to the decelerated natural convection resulting

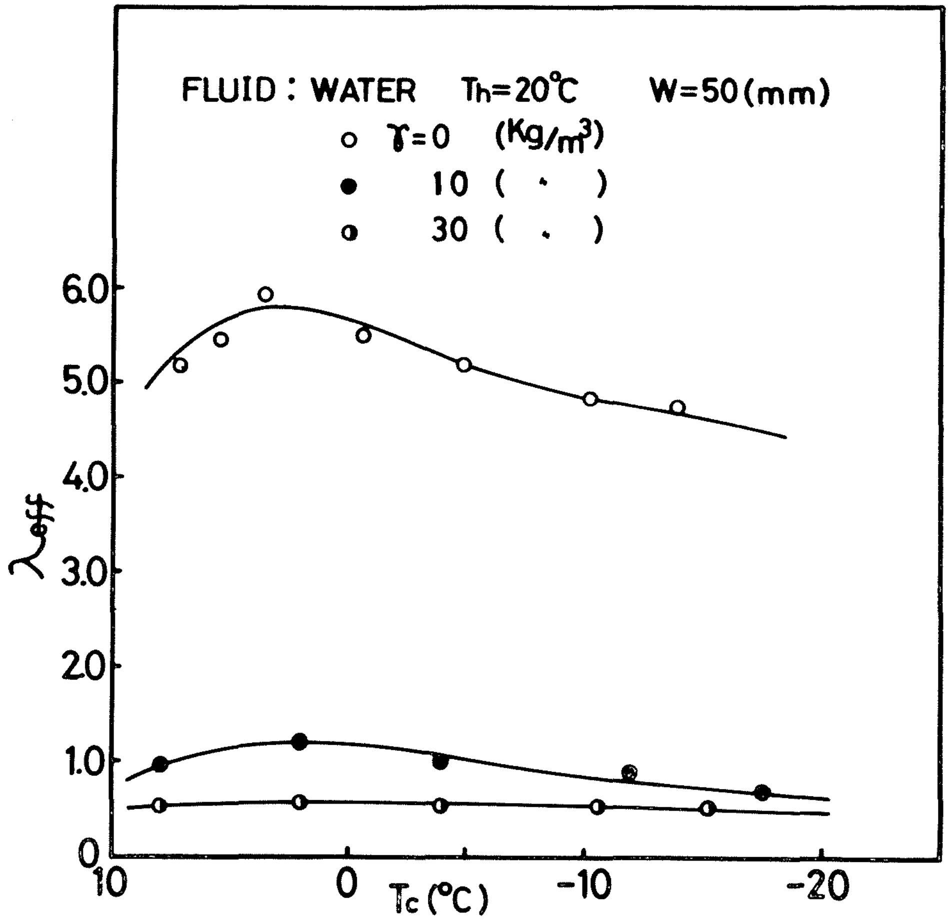

Fig. 5-2

under $T_h=20$ (°C).

from the ice formation and the density inversion effect of water for $T_c<4$ (°C) and λ_{eff} reaches its maximum value at about 5 (°C).

5. Conclusion

It is clarified that the λ_{eff} connecting with a strong influence of natural convection exists in the range of $\gamma=0\sim12$ (kg/m³) for horizontal glass wool layer which is narrower than that for vertical glass wool layer.

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