UTILIZATION OF HONEYCOMB STRUCTURES FOR A FLAT-PLATE SOLAR COLLECTOR BY REDUCTION OF NATURAL CONVECTION HEAT LOSS

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A most common and economical way of utilizing solar energy is to use a flatplate collector to capture incoming solar energy by heating either liquids or gases. Therefore, a solar collector should be the most critical part of the performance necessary for the system, since maximum available heat depends solely on the collector. In the present investigation, considering that most heat loss from solar collectors results from the natural convection between an absorber plate and a coverglass, it has been demonstrated that this natural convection can be suppressed and heat performances of a solar collector are enhanced by placing thin and poorly conducting honeycomb material between an absorber plate and a coverglass. By suppressing natural convection within collector spacing it has been shown experimentally that honeycomb structures effectively raise critical Rayleigh number, since they provide more shear surfaces.

Key Words: Honeycomb Structure, Solar Collector, Heat Use Ratio, Suppression

NOMENCLATURE

A_c : Absorber plate area, m
A_H : Aspect ratio, $A_H = H/L$
A_w : Horizontal aspect ratio, $A_w = W/L$
C_p : Specific heat of air, Kcal/kg °C
C_w : Specific heat of water, Kcal/kg °C
E : Heat use ratio, Q use/Q total
g : Gravity constant, 9.80665m/sec^2
G_r : Grashof number, $G_r = g \cdot \beta (T_p - T_c) L^3/\nu^2$
H : Length of honeycomb cell, m
H_T : Instantaneous intensity of the solar radiation, Kcal/sec
K : Conductivity of air, Kcal/m sec °C
L : Height of honeycomb cell, m
$\dot{m}$: Mass flow rate of water, kg/sec
Nu : Nusselt number, $Nu = U_L \cdot L/K$
Pr : Prandtl number, $Pr = \mu C_p/K$
Q loss : Heat loss quality, Kcal/m sec °C
Q use : Useful heat energy, Kcal/m sec °C
Q total : Total heat energy, Kcal/m sec °C
Ra : Rayleigh number, $Ra = \rho^2 g \beta C_p L^3 \ \Delta T/\mu \cdot K$
T_a : Mean temperature of air, °C
T_i : Mean temperature of the inlet water, °C
T_p : Mean temperature of the absorber plate, °C
t : Thickness of honeycomb cell, m
T_c : Mean temperature of the coverglass, °C
T_o : Mean temperature of the outlet water, °C
U_L : Overall heat transfer coefficient, Kcal/m sec °C
w : Width of honeycomb cell, m

Subscripts

β : Volume coefficient of expansion for air, 1/°C
ΔT : Temperature difference between the T_p and T_c, °C
θ : Solar collector tilt angle, deg
μ : Dynamic viscosity of air, kg/m sec
ν : Kinematic viscosity of air, m/sec
ρ : Density of air, kg/m
α : Absorptivity
τ : Transmissivity

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1. INTRODUCTION

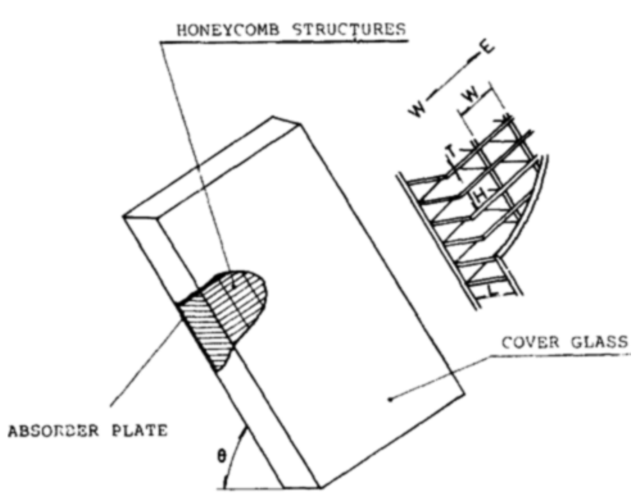
The major heat losses from well-designed flat-plate solar collectors are the result of conductive-convective-radiative heat transfer. The various methods have been investigated in order to reduce the heat losses from the solar collector for many years. Hollands (1965a; 1965b; 1973) presented a simplified analysis of honeycomb solar collectors. Four aspects of honeycomb panels were discussed: natural convection, thermal radiation and conduction heat transfers directly through the honeycomb walls and finally the transmittance of honeycomb to solar radiation. Buchberg, et al. (1971) indicated that a rectangular cellular structure with the long side running east-west was superior to fixed flat-plate solar collector because of higher solar transmittance to the absorber plate. Arnold, et al. (1978) studied on the effects of aspect ratio on liquidfilled rectangular honeycomb. The results showed heat loss Nusselt number was increased with higher tilt angles and higher aspect ratios (W/H) in the range of the Rayleigh numbers from 10^3 to 10^6. Cane, et al. (1977) experimentally obtained Nusselt number-Rayleigh number results for the free convective heat loss rate across honeycomb panels heated from below and inclined with respect to the horizontal. Meyer, et al. (1979) has studied the local and average values of the Nusselt Number in moderate aspect ratio enclosures. The results show that aspect ratios between 1 and 2 results in the highest heat transfer coefficients.

The purpose of honeycomb is to suppress or dampen the free convection currents which would otherwise occur in the air layer and increases the heat performance of solar collector. In the present analysis, the results have been extended to determine optimum honeycomb sizes for a flat plate solar collector by suppressing natural convection heat losses.

2. EXPERIMENTAL METHOD

Heat performances were measured and compared directly from simultaneous installations of two solar collectors (Fig. 1), one with honeycomb structures fabricated from thin polycarbonate sheet and the other without honeycomb structures. Tilt angles of 30, 45 and 60 deg. from the horizontal, and honeycomb sizes($W \times H$) of 10×10mm, 10×20mm and 10×40mm were utilized. Fig. 2 shows honeycomb structures utilized in the present experimentation. Honeycomb cell walls are made of transparent poly-carbonate, with a thermal conductivity, 0.000795kcal/m s °C.

Fig. 1 Photograph of experimental set-up



NO	TYPE	L	H	W	t	A_H=H/L	A_W=W/L
1	SQUARE CELL	28 cm	10 mm	10 mm	0.5 mm	0.357	0.357
2	RECTANGULAR	28	20	10	0.5	0.774	0.357
	CELL	28	40	10	0.5	1.429	0.357

Fig. 2 Honeycomb structures in a solar collector

Two Sam Sung collectors are placed on the top of the Inha Engineering College building in Inchon, Korea (NL 37°35′, L126°30′E).

A Pyranometer is placed on the top of the coverglass, slightly above and paralled to the collector module surface, to measure incoming solar radiation. Forty thermocouples (ϕ = 0.3mm, C type) are placed at various positions in the collector to measure temperatures of the absorber plate, the coverglass, the ambient, and the inlet and the outlet fluid. Signals from sensing devices are sent to Data Logger (FLUKE, 2240C.), which consists of five scanners.

The experiment began each day at about 10A.M. and stopped at about 4P.M. during April-May, 1986. Experimental data for typical days are plotted in Fig. 3~11. Most of the days were cloudless or partly cloudy and the average wind speed 2-3m/s. Mass flow rate supplied the solar collector was set to a constant at 1.2ℓ/m² min.

Total heat loss from the solar collector is broken down as following four areas: (1) Radiant heat loss between the two faces of a honeycomb panel. (2) Conduction heat loss through honeycomb walls. (3) Conduction heat loss through back and side walls of a solar collector. (4) Natural convection heat loss between an absorber plate and a coverglass. However, it has been shown that the most important source of the total heat loss in a flat plate solar collector is due to natural convection (Park, 1986).

For a solar collector, solar absorption rate, Q total, equals the sum of the heat loss rate, Q loss, and the heat use rate for the load, Q use;

$$Q \text{ total} = Q \text{ use} + Q \text{ loss} \tag{1}$$

The solar absorption rate can also be expressed as the product of glazing transmittance, τ, plate absorptance, α, plate area, A_c, and the instantaneous intensity of solar radiation incident on glazing, H_T;

$$Q \text{ total} = A_c H_T \ \tau_A \tag{2}$$

Heat loss rate can be written in terms of an effective overall heat transfer coefficient, U_L, plate area, A_c, and the temperature difference between average absorber plate and ambient $(T_p - T_a)$;

$$Q \text{ loss} = A_c \ U_L(T_p - T_a) \tag{3}$$

The heat use rate for the load can also be written in terms of mass extraction rate, $\dot{m}$, specific heat of water, C_w, and the temperature difference between average outlet water and inlet water $(T_o - T_i)$;

$$Q \text{ use} = \dot{m} C_w (T_o - T_i) \tag{4}$$

Therefore the heat use ratio (E) can be written as follows;

$$E = \frac{Q \text{ use}}{Q \text{ total}} = \frac{\dot{m} C_w (T_o - T_i)}{A_c H_T \ \tau_A} \tag{5}$$

3. RESULTS AND DISCUSSION

Figures 3~11 show experimental results with or without honeycomb structures in the collectors. Measured temperature difference between outlet and inlet of the collector, and

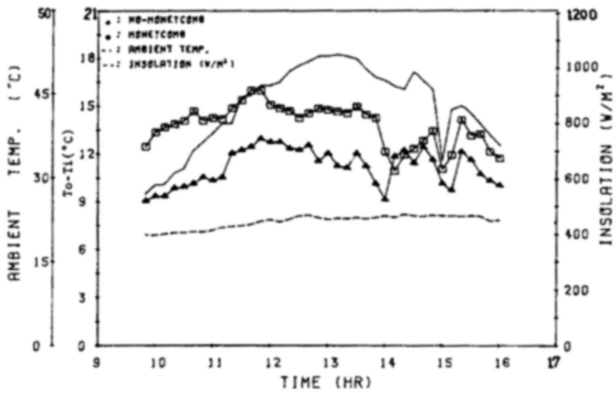


Fig. 3 Temperature difference and insolation 10×10 honeycomb and no-honeycomb at 30 deg

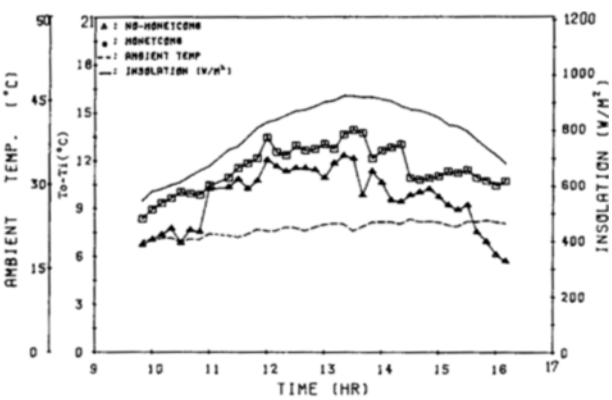


Fig. 4 Temperature difference and insolation 10×10 honeycomb and no-honeycomb at 45 deg

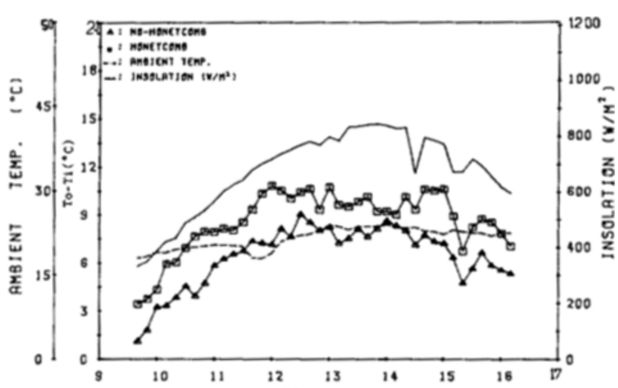


Fig. 5 Temperature difference and insolation 10×10 honeycomb and no-honeycomb at 60 deg

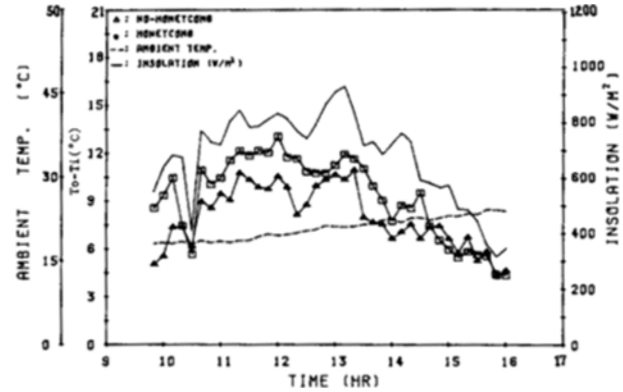


Fig. 6 Temperature difference and insolation 10×20 honeycomb and no-honeycomb at 30 deg

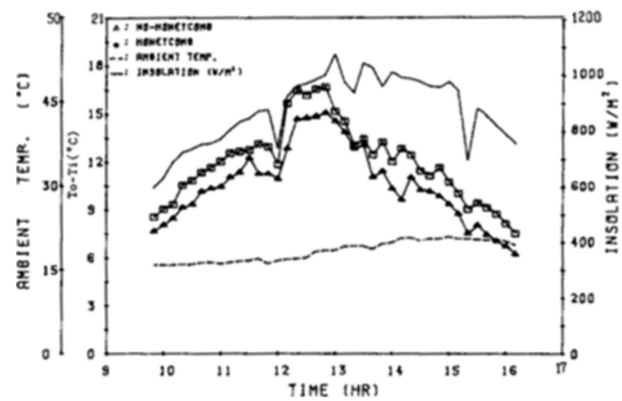


Fig. 7 Temperature difference and insolation 10×20 honeycomb and no-honeycomb at 45 deg

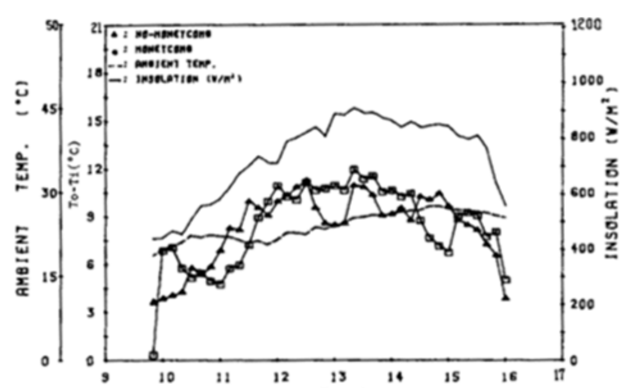


Fig. 8 Temperature difference and insolation 10×20 honeycomb and no-honeycomb at 60 deg

the ambient temperature are plotted with insolation during the day. Various honeycomb sizes and various tilt-angles were utilized for the performance comparisions for these two installations. It is found that the temperature difference of the collector performance is basically proportional to insolation.

The free convection heat loss between the absorber plate and the coverglass may be explained to be due to the loss from the Bernard cell flow pattern expected in the top-heavy type instability driven by the component of gravity normal to the heated bounding surface, and the loss caused by the parallel flow motion driven by the component of gravity along the heated bounding surface of the honeycomb panel.

The third source of the heat loss is believed to be due to the secondary motion from the stratification of the flow in the side wall regions. Each of these flow patterns is expected to interact each other to a greater or less extent with various honeycomb sizes and tilt-angles.

It is shown that the temperature difference between the inlet and outlet water temperatures of the collector with honeycomb structure are generally larger than that without honeycombs. These results show honeycomb structures successfully suppress the natural convection flow pattern in the

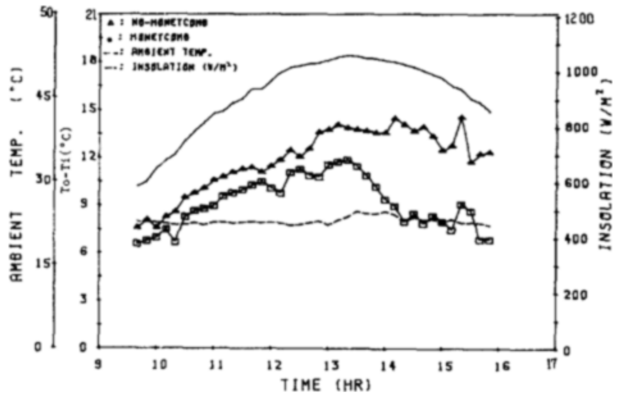


Fig. 9 Temperature difference and insolation
10×40 honeycomb and no-honeycomb at 30 deg

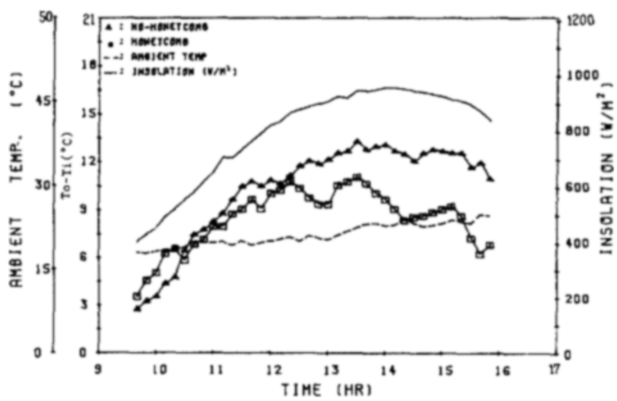


Fig. 10 Temperature difference and insolation
10×40 honeycomb and no-honeycomb at 45 deg

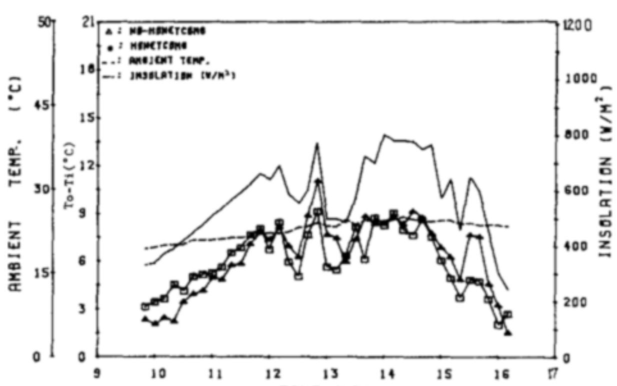


Fig. 11 Temperature difference and insolation
10×40 honeycomb and no-honeycomb at 60 deg

collector spacing, resulting in reduction of heat loss. However, as shown in Fig. 10~Fig. 11, temperature difference of the collector with honeycomb of 10×40mm show smaller values than those without honeycomb.

Figures 12~15 represent the heat use ratio-*Ra* plots for various tilt-angles. The longitudinal motion is expected to play an important role to the heat transfer.

The results of all figures present indirectly that the flow induced by the topheavy instability tends to generate the longitudinal roll and that it is a major factor of heat loss. Therefore, the effect of suppressing the natural convection at

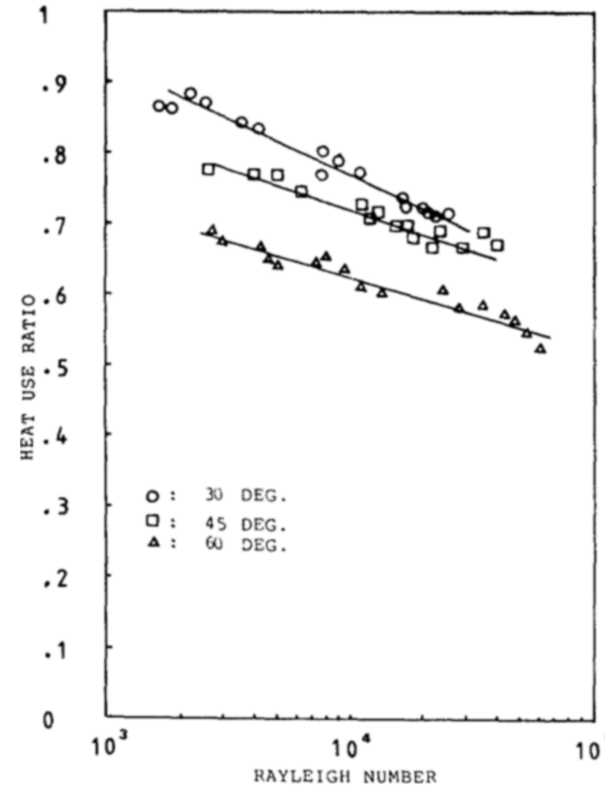


Fig. 12 Experimental results in terms of heat use ratio versus Rayleigh number for 10×10mm honeycomb

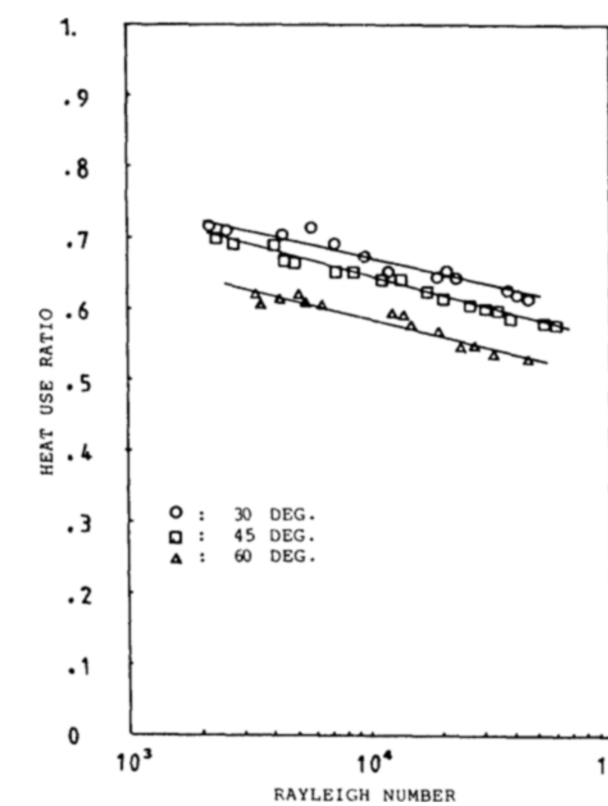


Fig. 13 Experimental results in terms of heat use ratio versus Rayleigh number for 10×20mm honeycomb

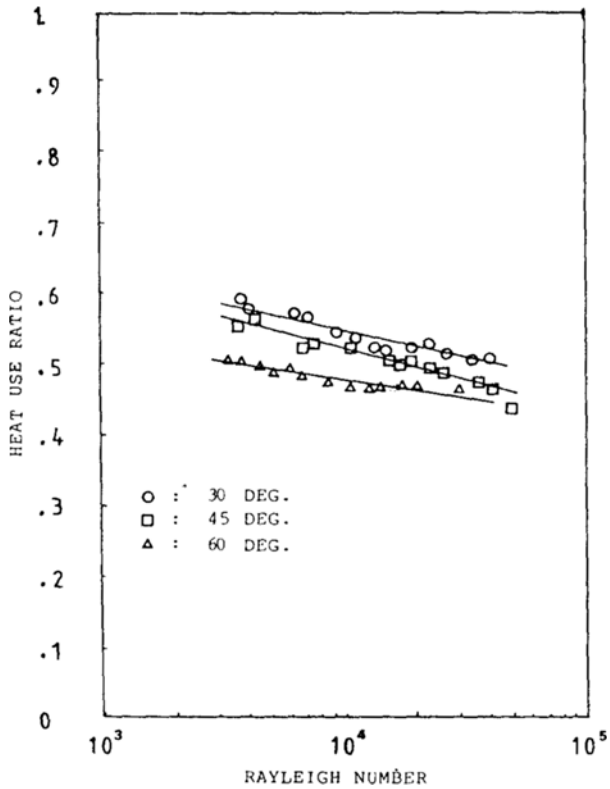


Fig. 14 Experimental results in terms of heat use ratio versus Rayleigh number for 10×40mm honeycomb

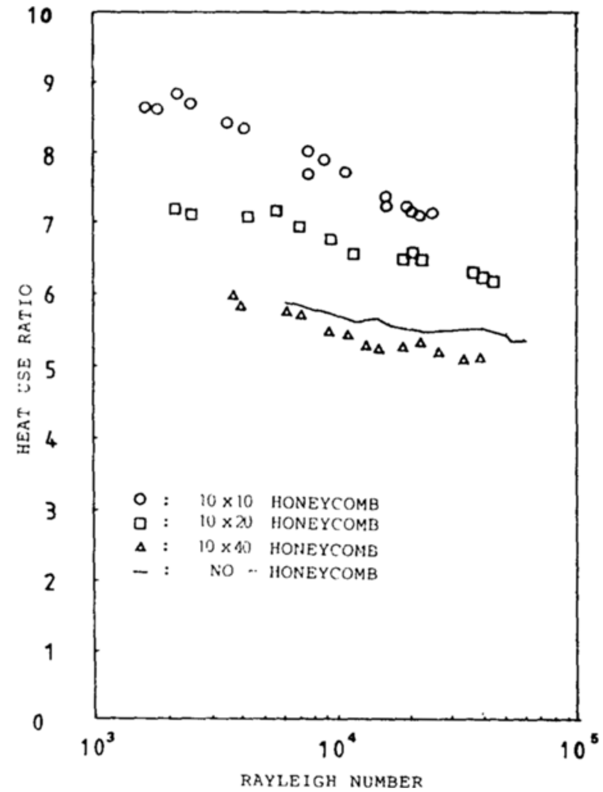


Fig. 16 Experimental results in terms of heat use ratio versus Rayleigh number at 30°

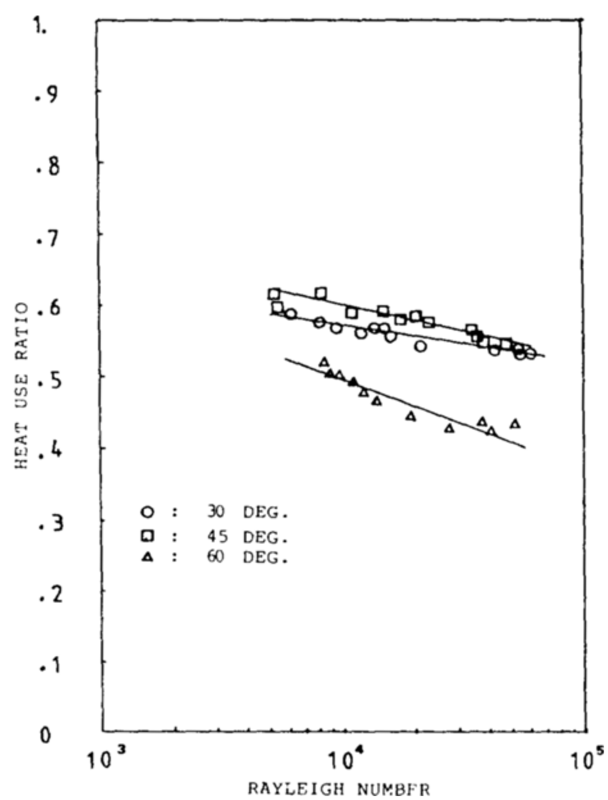


Fig. 15 Experimental results in terms of heat use ratio versus Rayleigh number for no-honeycomb

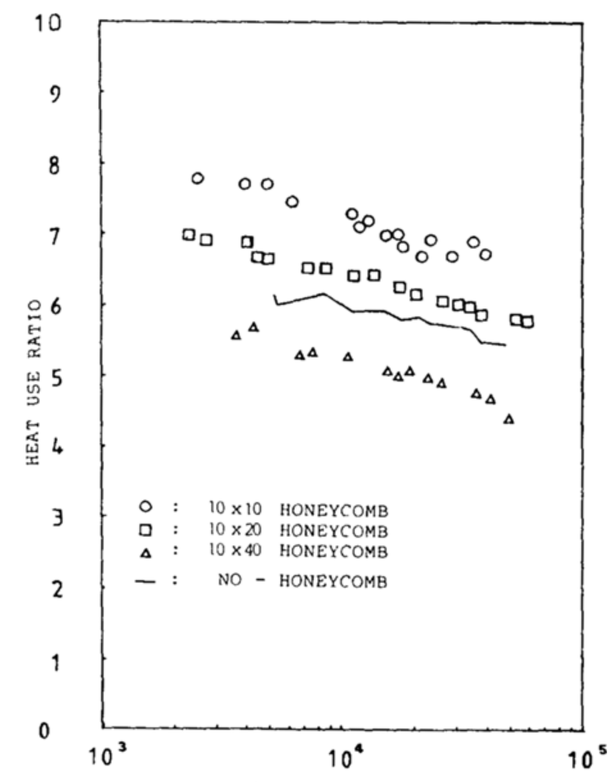


Fig. 17 Experimental results in terms of heat use ratio versus Rayleigh number at 45°

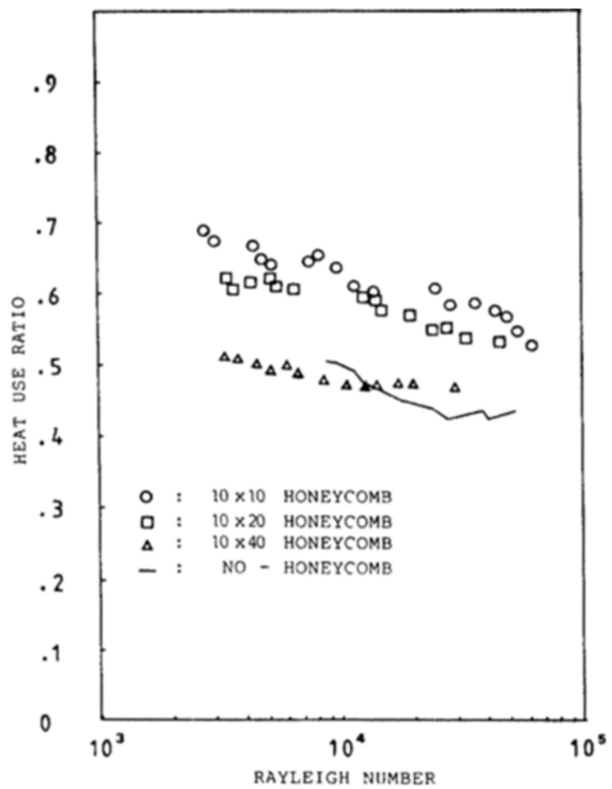


Fig. 18 Experimental Results in terms of Heat Use Ratio versus Rayleigh number at 60°

$\theta=30°$ is superior to that of $\theta=45°$ and $\theta=60°$. For the collector without honeycombs, the heat-use-ratio is found to be superior at $\theta=45°$ compared with the values of $\theta=30°$ and $\theta=60°$.

Figures 16 and Fig. 18 show the heat use ratio as a function of *Ra*.

Figures 16 shows the effects of the suppression from free convection currents with various honeycomb sizes at $\theta=30°$. The suppression employing honeycomb cells is found to be effective means to increase collector heat efficiencies. With honeycomb sizes of 10×10mm and 10×20mm, the results give considerable improvement on the performance of the collectors.

4. CONCLUSIONS

The heat loss in a solar collector results mainly from the natural convection between an absorber plate and a coverglass. Therefore, it is important to suppress this free convection heat loss in order to increase heat performances of a collector.

In the present investigation, it has been successfully demonstrated that the suppression of this free convection is possible by installing honeycomb structures in the collector spacing. Employing two collectors (one with honeycombs and the other without), the results were compared simultaneously for their performances. The heat use ratio for the collector with 10×10mm honeycomb increased approximately 29.5% at the collector tilt angle $\theta=30°$, 18.5% at $\theta=45°$, and 25.3% at $\theta=60°$ compared with that of the collector without honeycombs. The honeycomb structures are appeared to be more effective at low tilt angles. At a fixed tilt angle $\theta=30°$, the heat use ratio increased approximately 29.5% in 10×10mm honeycomb, 17.1% in 10×20mm, but decreased 0.7% in 10×40mm honeycomb.

The results of the present investigation may be limited to Inchon, Korea (NL 37°35′, L126°30′E). However, the data show consistency with various incoming solar radiations and different tilt angles. Therefore, introducing honeycomb structures into collector spacings can be effective means to improve heat performances of flat-plate solar collectors. Especially, at tilt angle of 30°, it is noted that the heat utilization rate of the solar collector for 10×10mm honeycomb has been improved approximately 30% which is significant in any practical application.

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