TECHNICAL NOTE

Influence of cylindrical screens on free convection heat transfer from a horizontal plate

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Experimental investigations of laminar free convection from horizontal, screened plates to water and glycerine are reported. The screen diameter (D) was equal to the diameter of a heated isothermal plate, while the screen height (H) was varied. The effect of screening on convective heat transfer is determined. Comparison with heat transfer from an unscreened horizontal plate is made.

Keywords: horizontal plate; free convection; cylindrical screens

Introduction

Although investigations of free convection from horizontal plates have already been published,[1–4] only Goldstein and Kei-Shun Lau[5] have given information on heat transfer from horizontal plates with plate-edge extensions. They solved the problem analytically and numerically and pointed out that shielding causes an attenuation of heat transfer.

This technical note reports results of experimental investigations of convective heat transfer from a circular screened horizontal plate to ambient liquid. In contrast to Goldstein and Kei-Shun Lau,[5] under certain conditions, some enhancement of heat transfer has been recorded. This work has been undertaken to examine the influence of heating plate screening on free convection heat transfer.

Results presented in this paper have been used in investigations on heat transfer in devices for solar radiation absorption, such as collectors and solar ponds.[6–8]

Experimental apparatus

The experimental apparatus is shown schematically in Figure 1. The heated copper plate 0.07 m in diameter was placed in glycerine or water in a cylindrical Plexiglas vessel of 0.4 m in diameter and 0.5 m in height. The surface temperature (T_w) was measured by copper-constantan thermocouples welded in small holes. Calibrations were performed at 15°C, 30°C, 45°C, 75°C, 90°C, and 150°C by putting the whole plate in an ultrathermostat. The plate was furnished with an electric heater. The winding was formed of insulated high-resistance wire. The heater was supplied with direct current at a controlled power rate of up to 200 W. The power input to the heater was calculated from the voltage and current, which were measured by digital meters.

Four copper-constantan thermocouples were used to measure the bulk temperature of the fluid T_f at different levels in the vessel. All thermocouple leads were connected to a rotary switch selector. The inaccuracy of the temperature measurement did not exceed ± 0.1 K.

The selection of different steady states was achieved by a cooling system located at the top of the vessel. This system consisted of a copper coil immersed in liquid and connected to a thermostat.

Each screen tested (various heights H and diameter D equal to the diameter of the heating plate) was laid on the flat adiabatic bottom of the experimental vessel. Screen heights were 6.3, 8.9, 21.0, 42.0, 63.0, and 84.0 mm. Screens were made of glass to allow observation of flow.

Experimental procedure

During the experimental runs, the surface temperature of the heating plate, the bulk temperature of the fluid, and the voltage and current of the heater were measured. All these data were recorded during established steady states. Steady state was assumed to have been reached when the emf reading varied by less than 3 μV over a 10-min period. The time to establish steady-state conditions was usually about 1.5 h. A higher temperature level was achieved by increasing the voltage and simultaneously lowering the water temperature circulating in the cooling system. Investigations were carried out alternatively for a screened plate and for a plate without screen.

Experimental investigations were performed in a hermetically closed vessel, using distilled water and glycerine dehydrated by means of a molecular sieve. The density, thermal expansion coefficient, and dynamic viscosity of the liquids were determined for experimental run. The thermal conductivity of the liquids was taken from published data.[9]

The heat losses from the heating plate to the bottom of the experimental vessel (see Figure 1) were eliminated by a counteracting heat flux from a subsidiary or guard heater. By progressive and controlled regulation of the power supply to the subsidiary heater, temperatures of the heating plate and adjacent wall were balanced, and thus any stray heat flux was eliminated.

The experimental apparatus was calibrated by performing a series of experiments with a horizontal, isothermal flat plate without screens. The correlation of the data obtained led to

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Received 2 June 1989; accepted 5 September 1990

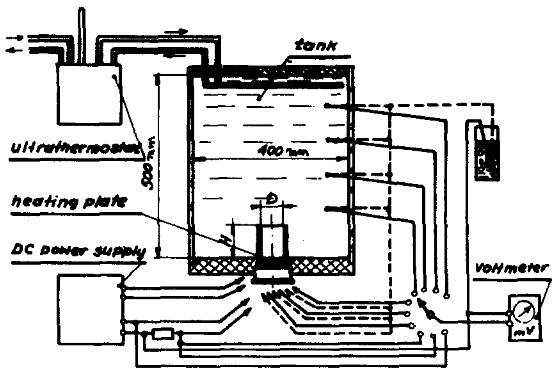

Figure 1 Test section schematic

the formula:

$$Nu = 0.711(Ra)^{1/4}$$

which agrees well with published results ($Nu = 0.70(Ra)^{1/4}$: Al-Arabi;[1] $Nu = 0.71(Ra)^{1/4}$: Bosworth[2]). This provided evidence that the experimental apparatus was sound and that the measurement procedure was valid.

Results and discussion

Figure 2 shows the variation of the relative Nusselt number ($Nu_{H/D}/Nu_{(H/D)=0}$) versus the H/D ratio for both test liquids. The results are related to heat fluxes $\dot{q}$, which were constant for each experimental run. As Figure 2 shows, the shallowest screen tested has the greatest influence on heat transfer, so the discussion of the results is limited to the screen $H/D = 0.09$ and to the unscreened plate only. The results obtained for other screens are between those two cases.

Depending on the value of $\dot{q}$, the shallowest screen tested causes augmentation or attenuation of heat transfer from the plate. The enhanced heat transfer was recorded for $200\ W/m^2 < \dot{q} < 15{,}000\ W/m^2$. For $\dot{q} < 200\ W/m^2$ or $\dot{q} > 20{,}000\ W/m^2$, an inhibition of heat transfer was indicated.

The variation of the relative Nusselt number ($Nu_{(H/D)=0.09}/Nu_{(H/D)=0}$) versus Rayleigh number calculated for the unscreened plate is shown in Figure 3. Three subranges may be distinguished within the investigated range:

- $Ra < 6 \times 10^5$—primary inhibition;
- $6 \times 10^5 < Ra < 10^9$—augmentation of heat transfer with a maximum of about 17% at $Ra = 4 \times 10^7$;
- $Ra > 10^9$—secondary inhibition.

For practical applications, the results obtained for the shallowest screen may be correlated by the formula (in Figure 3 in brackets):

$$\frac{Nu_{(H/D)=0.09}}{Nu_{(H/D)=0}} = -4.745 + 5.890 \sin[0.141 \log(Ra_{(H/D)=0}) + 13.072]$$

calculated by the least-squares method. This formula is valid for $3.5 < Pr < 1{,}650$ and was obtained at wall temperatures of $21.5°C < T_w < 142.4°C$ and wall-to-liquid temperature differences of $2.88\ K < \Delta T < 104.16\ K$.

Conclusions

The experimental results of laminar free convection heat transfer from an isothermal horizontal circular plate with screens to water and glycerine have been presented.

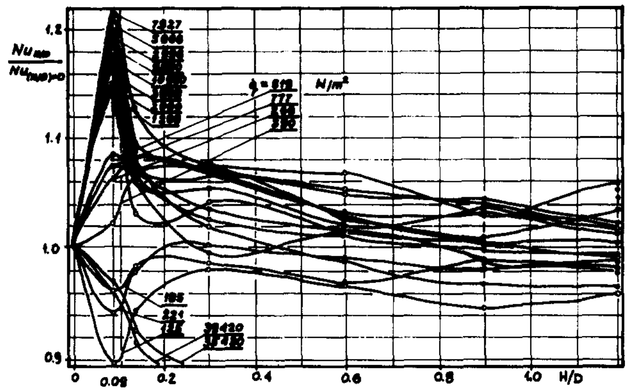

Figure 2 Effect of $\dot{q}$ on variation of ($Nu_{H/D}/Nu_{(H/D)=0}$) versus H/D ratio

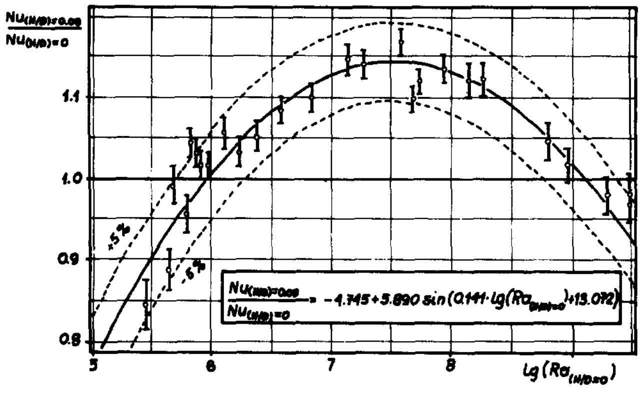

Figure 3 Variation of ($Nu_{H/D}/Nu_{(H/D)=0}$) versus $\log(Ra_{(H/D)=0})$

Notation

a	Thermal diffusivity, m^2/s
D	External diameter of the plate, internal diameter of screens, m
g	Gravitational acceleration, m/s^2
H	Height of screen, m
$Nu = \alpha D/\lambda$	Nusselt number
$Nu_{(H/D)=0}$	Nusselt number for plate without screens
$Nu_{H/D}$	Nusselt number for plate with screen of height H
Ra	Rayleigh number, $g\beta\,\Delta T\,D^3/(\nu a)$
$\dot{q}$	Heat flux density, W/m^2
T_w	Surface temperature of the heating plate, °C
T_f	Bulk temperature of the fluid, °C
ΔT	Wall-to-liquid temperature difference, $T_w - T_f$, K

Greek symbols

α	Heat transfer coefficient, $W/(m^2K)$
β	Coefficient of volumetric expansion, 1/K
ν	Kinematic viscosity, m^2/s
λ	Thermal conductivity, W/(mK)

For all screens examined, except the shallowest screen, an increase of H causes attenuation of heat transfer irrespective of $\dot{q}$. This is in agreement with the theoretical solution by Goldstein and Kei-Shun Lau.[5]

For the shallowest screen tested, enhancement or inhibition of heat transfer, depending on heat flux density, was recorded.

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