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SHORTER COMMUNICATIONS

NATURAL CONVECTION ARISING FROM STRIPWISE HEATING ON A HORIZONTAL SURFACE

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NOMENCLATURE

A_1, total heated strip area;
A_2, total surface area (strip plus spacing);
g, acceleration of gravity;
Gr_i, Grashof number, $(g\beta/v^2)\Delta T_i l_i^3$;
h_i, heat-transfer coefficient, $q_{total}/A_i\Delta T_i$;
i, index (either 1 or 2);
k_f, fluid thermal conductivity;
l_1, heated strip width;
l_2, heated strip plus spacing width;
Nu_i, Nusselt number, $h_i l_i/k_f$;
q_{total}, total power convected from test surface;
ΔT_1, difference between the heated strip temperature and the ambient temperature;
ΔT_2, difference between the average surface temperature and the ambient temperature;
β, average volumetric thermal expansion coefficient;
v, kinematic viscosity.

INTRODUCTION

NATURAL convection flows arising from essentially isothermal, horizontal surfaces have been of interest in engineering applications for many years, e.g. [1, 2]. On the other hand, flows arising from nonisothermal surfaces have apparently been of interest almost entirely in the study of atmospheric phenomena. For example, Rouse *et al.* [3] have reported a study of the flows formed over a surface with two parallel sources of heat as had been used for removing fog from airport runways. Other authors [4, 5] have been concerned with the use of the land-based heat sources to stimulate rainfall. Also of related interest to the present work are the two-dimensional convection cells which can be formed on either isothermal or non-isothermal surfaces [6–8].

It is possible that the transfer of heat from a horizontal surface on which the heating is accomplished in a stripwise arrangement might be more efficient than that associated with isothermal surfaces. It is this hypothesis that is probed in the study reported below.

APPARATUS*

The test section for the present work consisted of electrically heated elements and insulated sections in a flat, horizontal configuration. The heater elements were constructed with various width, long strips which were cut from thin shim stock. The heater strips were mounted between two Bakelite strips, which, in turn, were mounted on a thick base which measured 45·72 cm by 50·8 cm. One of the Bakelite strips was movable and mounted such that the metal ribbons could be held in tension at all times. Between the heater ribbons and below them acrylic strips were positioned such that a smooth heating surface was formed. Small, enclosed, air cavities existed directly below each heater strip for insulative purposes.

In the course of the experiment five ribbon widths were used ranging from 0·635 cm to 3·81 cm. For each of the ribbon widths three spacing arrays were used: even spacing of heated and unheated strips, spacing with the ratio of unheated to heated width of three, and a single heated strip on an otherwise adiabatic surface.

Heat transfer performance of the surface was monitored in two independent ways. A laser-powered 15·24 cm Mach–Zehnder interferometer was used to examine the heating phenomena optically. Temperatures were also monitored for determining the ambient conditions as well as the temperatures at several locations on the heated and unheated

* For more complete information on this topic see [9]

portions of the test section. All tests were performed in a small, almost air tight room to minimize spurious air currents.

RESULTS AND DISCUSSION

Numerical results from the present study are shown in Figs. 1 and 2. Note that the same data are presented in two different ways. There are several lengths and three temperatures associated with the problem. Therefore a single length and temperature difference upon which to base the dimensionless numbers are not uniquely obvious.

When the consideration is given to the single strip cases, the decision pertaining to what should be defined as the characteristic length and temperature difference is somewhat straightforward. By assuming two-dimensional behavior, the ribbon width becomes the characteristic dimension. The difference between the ribbon temperature and the

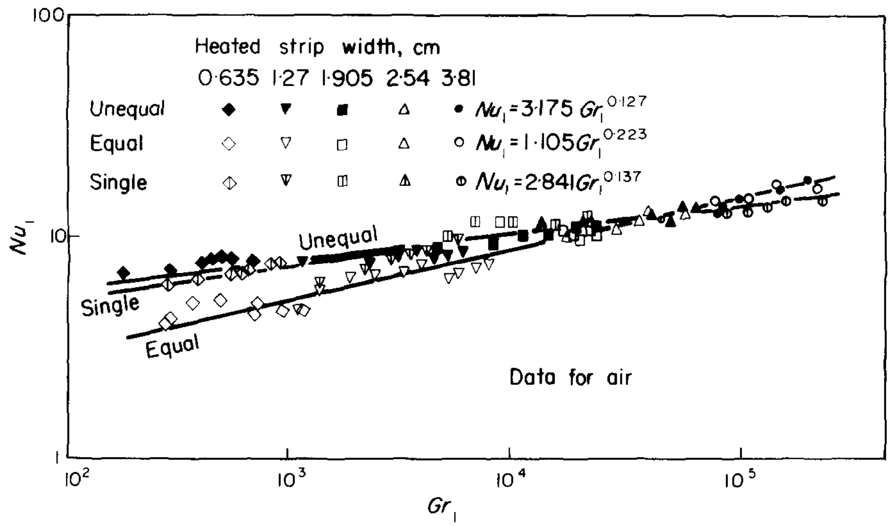

FIG. 1. Data of the study and resultant correlations presented using the strip width and strip temperature.

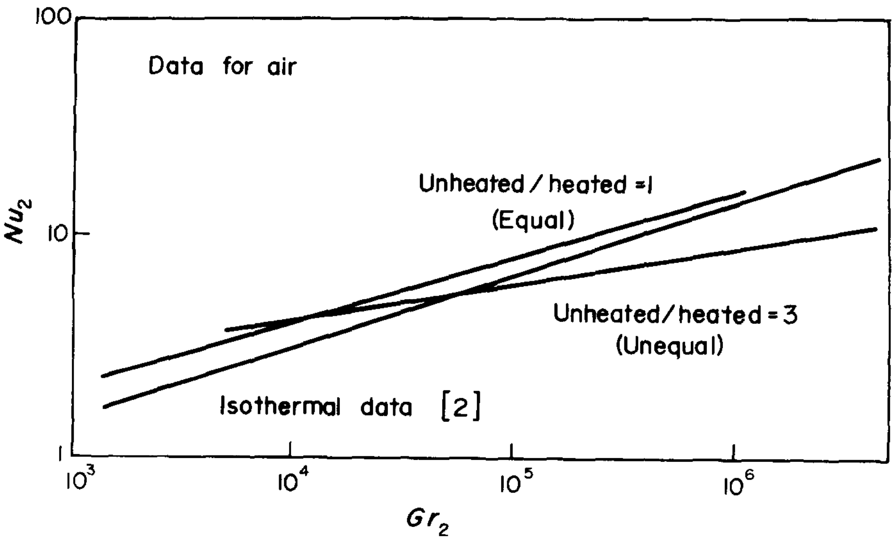

FIG. 2. Correlations of the study presented using the strip plus spacing width and average temperature.

ambient air temperature is the driving potential for heat flow and is thus the characteristic temperature difference. These same definitions were used in processing the data from the multiple strip cases. Dimensionless numbers defined this way are denoted by a subscript of unity. Comparison on this basis allows an evaluation on the heat transfer performance of the geometrical arrangement.

The data, which are shown in Fig. 1, correlate very well with the following equations:

Single strip $Nu_1 = 2{\cdot}841\ Gr_1^{0{\cdot}137}$

Uneven multiple $Nu_1 = 3.175\ Gr_1^{0{\cdot}127}$

Even multiple $Nu_1 = 1{\cdot}105\ Gr_1^{0{\cdot}223}$.

There are several other definitions of characteristic dimensions that could be made for the multiple strip geometries. Rather than present plots using all possible definitions, only one more combination is shown here. In this situation the characteristic length is taken to be the width of the ribbon and an adjacent space. The characteristic temperature difference is taken to be the average surface temperature (considering both the ribbon and adjacent space temperature) minus the ambient air temperature. Note that these definitions are somewhat like the definitions used for heat transfer from an isothermal, horizontal plate facing upwards [2], except the Nusselt number will be smaller here by a factor of n^{-1} (n being the number of ribbons) and the Grashof number will be smaller here by a factor of n^{-3}. The dimensionless groups defined using these quantities will be denoted by a subscript 2. For the two classes of spacing, the following two correlations were found:

Uneven multiple $Nu_2 = 0{\cdot}871\ Gr_2^{0{\cdot}168}$

Even multiple $Nu_2 = 0{\cdot}241\ Gr_2^{0{\cdot}303}$.

These are shown in Fig. 2, where the actual data points have been omitted for clarity.

Also shown on Fig. 2 is the correlation of Fujii and Imura for essentially isothermal plate facing upward [2]. An interesting effect of stripwise heating is indicated.

Imperfections in the present experiments are: (a) There were some losses through the bottom of the test section. Attempts to measure this component of the heat transfer indicated that it amounted to about 3 per cent of the total transfer at the very most, and it was usually much less than this. (b) The flow field was not truly two dimensional. Lateral views with the interferometer, as well as thermocouple measurements indicated that conditions were uniform across the center 90 per cent (approximately) of the test section, but they did vary significantly near the ends. The uniform conditions were used in the data presentation. All results have been corrected for a small radiation loss.

In conclusion, there does definitely appear to be notable differences between uniform and stripwise heating on a horizontal surface. More work will have to be performed before sweeping generalizations can be made, however.

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