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HEAT TRANSFER AND NATURAL CONVECTION PATTERNS ON A HORIZONTAL CIRCULAR PLATE

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NOMENCLATURE

A, area of heating surface;
Gr, Grashof number;
h, heat transfer coefficient;
Nu, Nusselt number;
p_{pc}, pseudo-critical pressure;
Pr, Prandtl number;
Ra, Rayleigh number;
t, temperature;
ϕ, heat flow rate.

Subscripts
b, bulk fluid;
c, cooling plate;
h, heating plate.

INTRODUCTION

HUSAR and Sparrow [1] reported on flow patterns adjacent to various planforms. Their experiments were performed in water, and flow patterns are shown for a Rayleigh-number range from $2 \cdot 10^6$ to $5{\cdot}5 \cdot 10^8$. In this report flow patterns can be presented for Rayleigh-numbers from 10^9 to 10^{13}. In order to obtain these high Rayleigh-numbers, the experiments were carried out with carbon-dioxide in the supercritical region close to the critical point (31·04°C; 73·84 bar). Three different pressures were applied: 75·84 bar, 89·63 bar and 103·4 bar. Heat transfer coefficients were determined and comparison with Nusselt-type correlations was attempted.

EXPERIMENTAL SET-UP

The experiments were performed in a pressure vessel which is described in [2]. The test arrangement after adjusting this vessel consisted of a circular borosilicate plate, the heating plate, 3·2 mm thick and 50 mm dia. with an electrically conducting surface. The non-conducting side was bonded to a 6·3 mm thick pyrex-glass disc of the same diameter, the so-called measuring-plate, with a diametric groove 0·8 mm deep on each side. Into these grooves thermocouples were cemented with their junctions in the center of the disc. In order to reduce downward heat-losses, another pyrex disc was glued to the measuring plate.

The resulting glass cylinder was set on the lower glass window of the pressure vessel, which had been turned by 90° compared to its former use [2]. It was kept in place by a micarta tube around it and the window, thus also reducing heat losses to the sides. The tube ended 3 mm below the heating surface, so that there were no constraining walls around it. Cooling was provided from tap water running through copper coils wound around the vessel.

Besides the two thermocouples in the glass cylinder, which indicated the temperature-distribution in the center of the disc, another two thermocouples in the vessel gave the bulk temperature.

The pressure vessel was mounted over an optical bench. The light coming from a carbon arc lamp, after passing through a lens system, was directed through the vessel in such a way that the Schlieren-images on a screen gave the view normal to the heating plate. For better contrast a color Schlieren arrangement was used.

RESULTS

A local heat transfer coefficient was calculated from

$$h = \phi / A(t_h - t_b)$$

with the heat flow rate ϕ, the area of the disc A and the temperature difference between the center of the heating surface and the bulk fluid $t_h - t_b$. Figure 1 gives a plot of this heat transfer coefficient vs. the surface temperature at various pressures. As a second parameter, the bulk temperature t_B has to be given for each curve.

Comparison was made between experimental data and Nusselt-type correlations of the form

$$Nu = \text{const.} \quad (Gr \cdot Pr)^{\frac{1}{3}}.$$

There was no agreement among the data for the three different pressures. It may be assumed that an extra term in the correlation will consider the pecularities in the vicinity of the critical point [3]. For the lack of sufficient data, especially at various bulk temperatures such a correlation was not performed here.

The flow patterns show distinct differences for various

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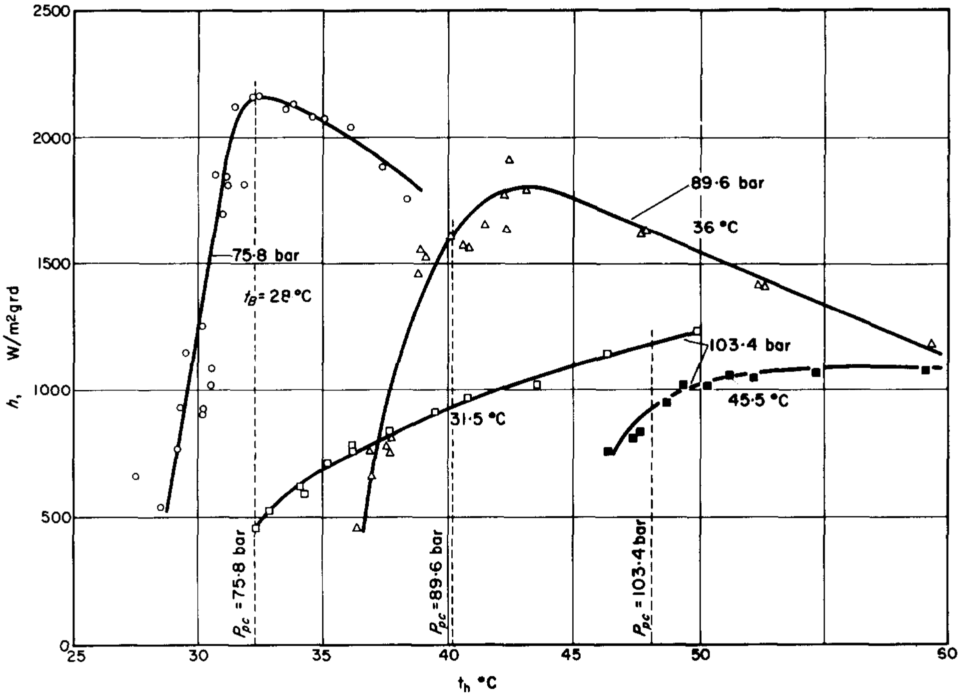

FIG. 1. Local heat transfer coefficient vs. heating plate temperature.

Rayleigh-numbers. These Rayleigh-numbers are based on mean temperature properties and the diameter of the disc as characteristic length. In Fig. 2(a) relative long streaks of hot fluid which show as dark lines, move irregularly from the edge to the center of the disc. An increase in Rayleigh-number i.e. an increase in heating plate temperature causes the split-up of the long streaks into shorter structures. These structures become shorter and thinner with higher Rayleigh-numbers, Figs. 2(b) and (c), and move faster and more irregularly. At a Rayleigh-number which corresponds to the so-called pseudo-critical state, the granulation of the structures proved to be extremely fine and the motion was so turbulent that, with the light available, no fully focussed photographs could be obtained, Fig. 2(d).

Also no satisfying black and white pictures could be taken for mean temperatures above the pseudo-critical, where Rayleigh-numbers are decreasing again.

The series presented in Fig. 2 is taken at a pressure of 89·63 bar, the same characteristics appear with other pressures. In general the structures are shorter and thinner when the critical point is approached closer.

A steady, regular pattern is difficult to observe because of eddies, Fig. 2(d), which occur irregularly on the plate, wiping off any developed pattern. A pattern which seems to prevail is an X-shape, formed by the rising plume of hot fluid. The plumes appear where the streaks of hot fluid meet which move along more or less parallel paths inward from the edge of the disc.

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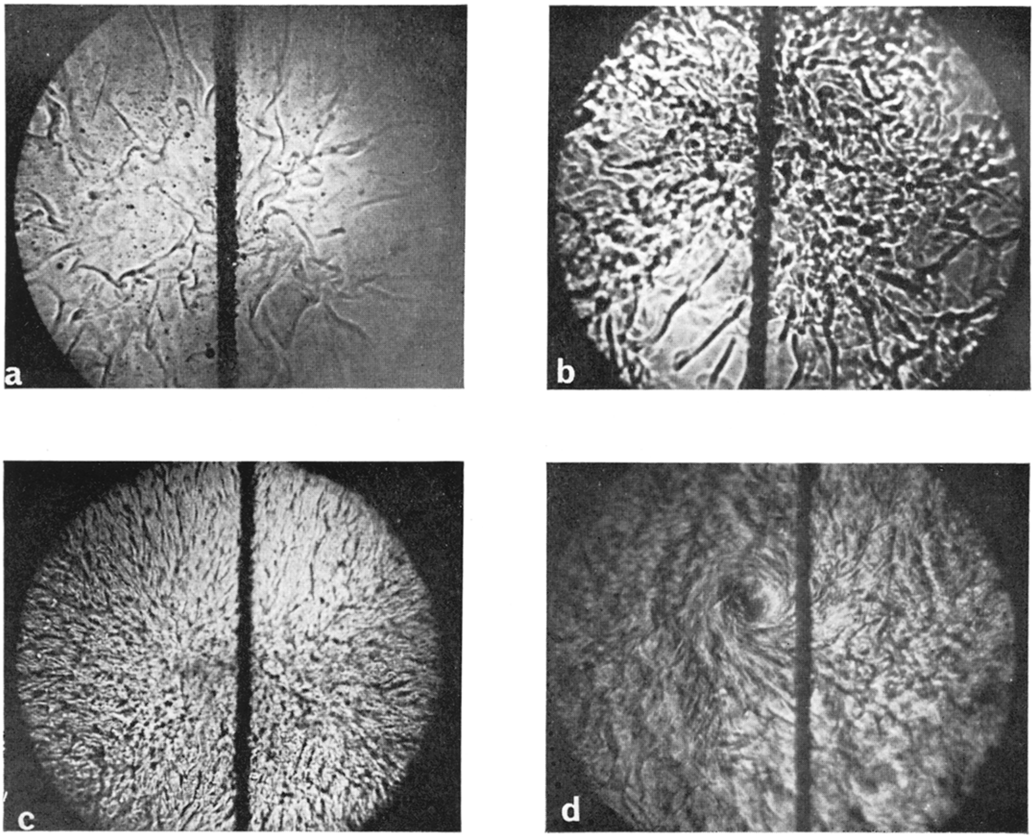

FIG. 2. Flow patterns on a circular disc for various Rayleigh-numbers.
(a) Ra $=1.1 \cdot 10^9$; (b) $5.1 \cdot 10^{10}$; (c) $3.2 \cdot 10^{11}$; (d) $1.6 \cdot 10^{13}$.
Black centre line—thermocouple shadow.