PERGAMON

International Journal of Heat and Mass Transfer 44 (2001) 3381–3384

International Journal of HEAT and MASS TRANSFER

www.elsevier.com/locate/ijhmt

Technical Note

An experimental investigation into natural convection heat transfer from horizontal isothermal circular disks

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Received 5 May 2000; received in revised form 18 October 2000

Abstract

Experimental heat transfer data are presented and a dimensionless correlation developed for natural convection from heated horizontal stationary isothermal circular disks over a wide range of the Rayleigh numbers. Experiments with air were performed for a variety of disks of different diameters and thickness-to-diameter aspect ratios. The significant volume of data is consistent with the single set of data available in the archival literature, and is correlated with a classical Nusselt–Rayleigh correlation.

1. Introduction

Experimental heat transfer data are presented in this paper and a dimensionless correlation developed for natural convection from heated, stationary, horizontal, isothermal circular disks over a wide range of the Rayleigh number. Experiments with air were performed for disks of different diameters and thickness-to-diameter aspect ratios. This data is compared with the very limited amount of experimental data found in the archival literature, consisting of a single reliable experimental set.

Considerable empirical data exist in the archival literature for natural convection heat transfer involving a variety of geometries, and for various ranges of the Rayleigh number. Many heat transfer textbooks [1,2] present empirical correlations for natural convection for horizontal and inclined flat plates, horizontal and vertical cylinders, spheres, bispheres, oblate and prolate spheroids, horizontal upward and downward facing surfaces, cubes of various orientations, vertical and inclined channels, rotating geometries, as well as geometries within enclosures. A geometry that seems to be missing from all of these lists is that of a thin horizontal circular disk.

There has been some experimental research devoted to natural convection heat transfer from stationary and rotating horizontal circular disk *surfaces*; heated upward facing [3–8] and cooled downward facing [9]. There have also been numerical studies [10–14]. Hassani and Hollands [15] performed experiments measuring the natural convection heat transfer from a *complete* circular disk in both vertical and horizontal configurations. They proposed a characteristic length [1] such that the experimental data obtained could be collapsed with certain other geometrical shapes for a limited range of the Rayleigh number; the goal being a type of 'universal correlation'. Their experimental data was obtained using a single disk heat transfer model with a diameter of 82 mm. The work of Goldstein et al. [19] appears to be the only other experimental data found in the archival literature for a complete horizontal disk. The research data that was reported was for a diameter range of 1.27 cm $< d <$ 20.3 cm. There were two limitations to

[1] Other investigators have strived, with limited success, to attain a characteristic length such that experimental data for a variety of shapes could be collapsed to a single curve. The interested reader should refer to the works of Sparrow and Ansari [16], Sparrow and Stretton [17] and Lienhard [18], as well as Hassani and Hollands [15].

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0017-9310/01/$ - see front matter
PII: S0017-9310(00)00330-6

this data. First, the data was obtained in such a way that the results were clustered together; each cluster appearing to be bunched around a particular Rayleigh number. Secondly, the research was directed at a study of mass transfer; heat transfer data being drawn out later through analogy. This may be a reason that their experimental heat transfer data does not match up with that of Hassani and Hollands [15], or that of the current research.

Adding to the single reliable data set of [15] is a major contribution of this research. Since no empirical correlations appear to exist in the familiar classical form

$$Nu_d = C Ra_d^n \tag{1}$$

for a thin, stationary, horizontal circular disks, and since circular disk geometry is of practical relevance in fields such as electronic component cooling, among other buoyancy-related applications pointed out by Gebhart [20], an empirical correlation such as that of Eq. (1) is another major objective of the current research.

In earlier research [21–23], the present authors developed a novel approach to obtaining accurate experimental heat transfer data by utilizing commercially available thermistors of circular disk geometry. The prior research dealt primarily with *vertical* circular disks and flat plates. Because of the simplicity of the experimental technique, however, it was readily adapted to a horizontal configuration.

2. Experimental apparatus and measurement techniques

The experimental apparatus and measurement techniques used in the present research were similar to those used in previous research [21], the only difference being that a larger diameter test section was needed to accommodate a horizontal disk. Therefore, only a brief summary will be presented here. The circular disks that were used as heat transfer models for the present experimental data were commercially available disk-type *thermistors*. [2] Thermistors were chosen as the heat transfer models because they provided a unique combination for indirectly measuring the surface temperature and the convective heat transfer rate. The thermistor was self-heated by means of Joule heating. Conduction losses through the thermistor lead wires (0.127 mm dia) were minimized (less than 8%) by using constantan wire, which has a low enough thermal conductivity to minimize the ‘fin effect’, and an electrical resistivity low enough to minimize Joule heating in the leads themselves. A one-dimensional analysis was done on the lead wires modeling the fin effect and taking into account the Joule heating. The result of this analysis indicated that the existence of any Joule heating acted to decrease the conduction losses through the lead wires. Even though they were small, corrections were made for lead losses in obtaining the experimental data [19].

Considerable experimental data was obtained in the present research. Six different circular disk models were tested, ranging in diameter, $5.2 \leqslant d \leqslant 19.97$ mm, and in thickness-to-diameter aspect ratio, $0.063 \leqslant (t/d) \leqslant 0.163$. The experimental results are depicted in dimensionless form in Fig. 1, where the Nusselt number, Nu_d, is plotted as a function of the Rayleigh number, $Ra_d (Ra_d = Pr\, Gr_d)$. The experimental data of Hassani

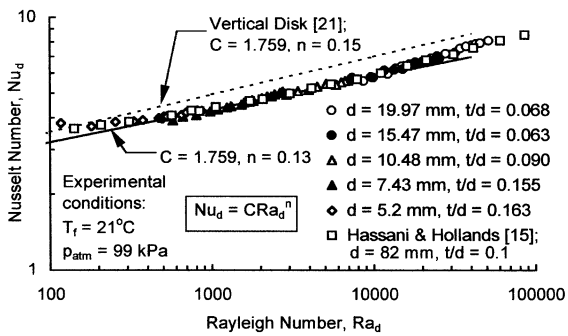

Fig. 1. Natural convection heat transfer for stationary horizontal circular disks; comparison with vertical configuration.

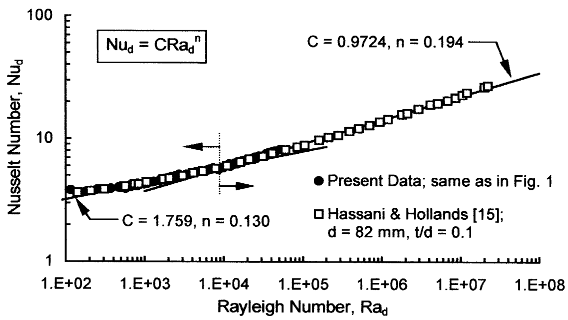

Fig. 2. Natural convection heat transfer for stationary horizontal circular disks; comparison with other data.

Table 1
Empirically determined coefficients and exponents for Eq. (1)

Rayleigh number Ra_d	C	n
3×10^2–10^4	1.759	0.130
$10^4 - 3 \times 10^7$	0.9724	0.194

[2] Thermistors are semiconductors of ceramic material made by sintering mixtures of metallic oxides such as manganese, nickel, cobalt, copper, iron, and uranium. Disks are made by pressing thermistor material under high pressure in a round die to produce flat coin-like pieces. These pieces are then coated with silver on the two flat surfaces. Reference: Thermistor Manual; Fenwal Electronics, Framington, MA 01701.

and Hollands [15] is also included on the graph. As was indicated earlier, their investigation was limited to a single disk model of diameter, $d = 82$ mm, and a thickness-to-diameter aspect ratio, $t/d = 0.1$. Fig. 1 illustrates excellent agreement between the present experimental data and that of Hassani and Hollands [15] for $10^2 \leqslant Ra_d \leqslant 10^5$. Superimposed on the graph is an empirical correlation that best fits the data for $2 \times 10^2 \leqslant Ra_d \leqslant 10^4$. Also superimposed is the empirical correlation developed by the present authors in earlier research [21] for thin *vertical* circular disks. A comparison indicates that heat transfer coefficients are generally higher for disks in a vertical configuration than for disks in a horizontal configuration, except at low Rayleigh numbers where it appears the current horizontal data intersects with the earlier vertical disk data.

Fig. 2 includes the same experimental data as Fig. 1, but also includes the additional single set of experimental data given by Hassani and Hollands [15] for a higher range of the Rayleigh number, $10^5 \leqslant Ra_d \leqslant 10^8$. Two different empirical correlations are seen to be necessary to obtain good accuracy. The empirically determined values for C and n in Eq. (1) that "best" fit all of the experimental data are given in Table 1. The correlation coefficients for the low-end and high-end Rayleigh numbers are 0.992 and 0.998, respectively, with a maximum deviation of less than 10%. [3]

3. Summary and conclusions

Experimental heat transfer data have been presented and dimensionless correlations are proposed for natural convection from heated, stationary, isothermal, *horizontal* circular disks over a wide range of the Rayleigh number. All of the data showed a good fit to the two correlations. Since only air was tested, the correlation is recommended for Prandtl numbers near unity, which includes most common gases. The correlation may be valid for Prandtl numbers outside this range, however, experimental verification of this is unavailable at this time, but should be the subject of future research. Also of interest is the similarity in the coefficients for the vertical and horizontal empirical correlations. Referring to these correlations depicted in Fig. 1, it appears that only the exponent, n, is different. This interesting find lends encouragement for a possible combination of the vertical and horizontal disk correlations with additional data obtained at arbitrary inclination angles. This should be the subject of future research as well.

[3] The results of an analysis of the experimental uncertainty is given by Kobus and Wedekind [21], with a *maximum* uncertainty of less than 10%, albeit experimental uncertainties would normally be expected to be below the maximum.

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