# Force Convection Heat Transfer to Water Flowing Normal to a Cylinder

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Extensive data are available for the flow of gases normal to a single steam-heated or electrically-heated cylinder. The available information on the heat transfer to liquids is not nearly as extensive as that for gases. The experimental data on perimeter mean heat transfer coefficients for the flow of air normal to cylinders are summarized and correlated by McAdams (*1*) and Douglas and Churchill (*2*), by means of the dimensionless equation of the Nussult type:

$$hD/k = a\,(DG/\mu_f)^m\,(C_p\mu/k)^n{}_f$$

Surprisingly the data for liquids flowing normal to a single cylinder covers a range of Reynolds numbers of only 0.1 to 200. For this reason heat transfer data were obtained beyond the range previously reported. Since completion of this work, Roach and Goodgame (*3*) have presented their results and those of others at higher Reynolds numbers. Some of the results reported were for boiling of the liquids.

The main reason for the low Reynolds numbers of previous work with liquids was the use of small diameter wires. In the correlation the diameter used in calculating the Reynolds number is the diameter of the cylinder. In this work (*4*) an attempt was made to use a glass cylinder with a conducting resistive-film (tin oxide) surface as both the heating element and the heat-sensing device. Films have been used for both purposes but apparently not combined.

The major problems with this technique were finding a suitable commercially available coated tube and making a satisfactory electrical contact. The tube chosen for use is a coated pyrex glass tube normally used for heating jackets (*5*). The thin (about sixteen millionths of an inch thick) transparent electrically conductive film is permanently bonded to the outside surface. The tube length required for the experimental work was only 3 in.; consequently new contacts had to be fabricated.

In one technique two holes were made in the specimen with an ultrasonic drill, about 3/16 in. from each end. Number 20 AWG single conductor (and stranded wire in another instance) copper wire was wrapped around the outer surface and pulled through the holes. To ensure electrical contact between the wire and the film the connection was soldered. When this proved unsatisfactory, air-dry silver paint was applied to the contact area; this too proved unsuccessful. The technique finally adopted consisted of wrapping a strip of copper foil around the end of the tube and then securing this tightly with a clamp made from 0.008-in. copper sheet.

Although the method showed considerable promise, a satisfactory solution was not obtained because of the unfavorable film composition and in part because of the difficulty in making electrical contact. At the present time it appears that a tube of electrically stable film composition coupled with a high coefficient of electrical resistivity is not commercially available. Perhaps a chromium film deposited by vacuum evaporation would prove satisfactory. Electrical contact could be made by copper wire soldered to fired-on platinum layers. This technique has been described by Winding, Topper, and Baus (*6*).

To check the order of magnitude of the results from the experimental test an estimate of the heat transfer coefficient was made from friction factor data. The Colburn analogy was selected because of its simplicity and known empirical accuracy:

$$N_{Nu} = (f/2)\,N_{Re}\,(N_{Pr})^{1/3}$$

Sherwood (*7*) has compared the skin friction data over a cylinder with mass transfer data; the agreement was excellent. These same data were used to estimate $N_{Nu}/(N_{Pr})^{0.3}$ from $f/2$ for skin friction only. The results are shown in Figure 1. The analogy gives a line that coincides exactly with the McAdams correlation at a Reynolds number of about 100. The data of other investigators are shown as shaded areas, as well as those of the present investigation. It is not known why the Roach and Goodgame data are low. The low values in the present work can be attributed to the unfavorable film composition, which did not allow an accurate enough measurement of the surface temperature. As can be seen the data are of the correct order of magnitude and show that the technique has promise and if refined could provide a convenient heat transfer research tool.

Until further work can be done to perfect the method, it appears that the extrapolation based on the Colburn analogy will give satisfactory design data.

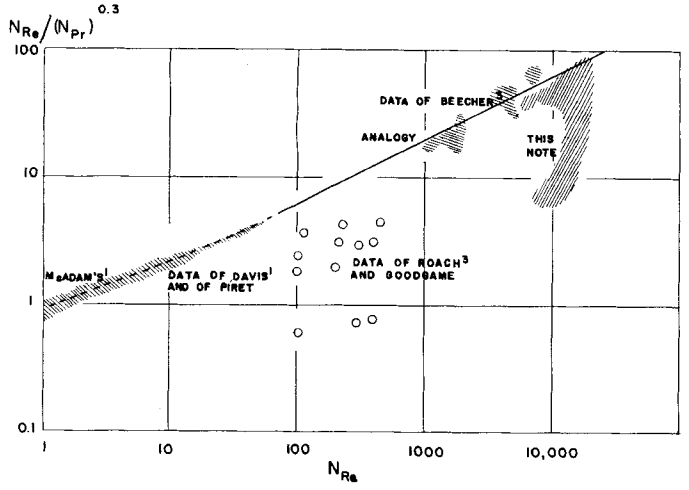


Fig. 1. Comparison of analogy to heat transfer data for water flowing normal to a cylinder.

## LITERATURE CITED

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