Convection of Heat in Fluid Flow through Tubes.

THE convection of heat to or from the walls of a circular tube conveying fluid in turbulent motion has been studied by a long line of investigators, among whom may be mentioned Joule, Reynolds, Stanton, Nüsselt, Soennecken, Jordan, Stender, Heinrich, and Stückle. From dimensional considerations Rayleigh (NATURE, Mar. 18, 1915, p. 66) deduced a formula which, written in non-dimensional form, is equivalent to

$$\frac{ad}{k}=\phi\left(\frac{Vd}{\nu},\ \frac{k}{s\mu}\right), \quad . \quad . \quad . \quad (1)$$

where a = coefficient of transmission of heat.
d = diameter of tube.
V = mean velocity of flow.
k = conductivity of fluid.
μ = viscosity of fluid.
ν = kinematic viscosity of fluid = μ/ρ.
h = diffusivity of fluid = $k/s\rho$.
s = specific heat of fluid.
ρ = density of fluid.

For gases Stanton (Tech. Report Adv. Committee for Aeronautics, 1912–13) gave a formula reducible to

$$\frac{ad}{k}=\text{const.}\left(\frac{Vd}{\nu}\right)^n, \quad . \quad . \quad . \quad (2)$$

in which $n=0{\cdot}75$ approximately for smooth tubes.

Nüsselt (*Z. V. d. I.*, 1909) proposed a formula for gases reducible to his later form :

$$\frac{ad}{k}=\text{const.}\left(\frac{Vd}{h}\right)^n, \quad . \quad . \quad . \quad (3)$$

which is equivalent to (2) ($n=0{\cdot}78$).

Formulæ for water of the form :

$$a \text{ proportional to } V^n, \quad . \quad . \quad . \quad (4)$$

have been proposed by Stanton (*Phil. Trans. Roy. Soc.*, 1897), Soennecken (*Forsch.* Heft 108/109), Stender ("Wärmeubergang an strömendes Wasser," Springer, 1924), and others. These formulæ do not make explicit mention of the conductivity. Stender finds that the index 'n' depends on an equivalent mean temperature $\tau°$ C. $=0{\cdot}9Tm+0{\cdot}1Tw$, where Tm = mean water temperature and Tw wall temperature. Experiments with oil have been carried out by Heinrich and Stückle, but not fully analysed (*Forsch. Arb.* Heft 271).

The object of the present note is to suggest a general formula applicable to all fluids, liquid or gaseous, under conditions of turbulent flow in circular tubes, namely :

$$\frac{ad}{k}=0{\cdot}0260\left(\frac{Vd}{\nu}\right)^{f\left(\frac{k}{\mu s}\right)}, \quad . \quad . \quad . \quad (5)$$

in which $f(k/\mu s)$ is given approximately by the following values :

$h/\nu=k/\mu s$	0·01	0·10	0·40	1·30
$f(h/\nu)=f(k/\mu s)$	0·97	0·895	0·835	0·785

which lie well on a smooth graph.

This formula agrees well with the experiments of Heinrich and Stückle for oil, those of Stanton, Soennecken and Stender for water ($\tau=10°$ C. to $\tau=70°$ C.). It also agrees as well with the results of Jordan, Nüsselt, Pannel, and others for air, as these agree amongst themselves.

A crucial test of the value of formula (5) would be given by experiments with mercury for which the value of $k/\mu s$ lies outside the range of the experiments referred to above.

A complete formula should take account of the ratio of length to diameter of tube, or else the ratio of initial to final excess temperatures, but (5) is put forward as a step towards the correlation of the results of diverse experiments in which the ratio of length to diameter of tube exceeds about 20.

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The Polishing of Surfaces.

MAY I describe one or two surface-polishing experiments ?

1. The first is more easily described than performed. Prepare a polished biprism having a supplementary angle of 4 or 5 seconds. Continue the polishing of one surface. The debris removed will be carried over the edge and deposited in the minute wedged space between the other surface and the tool. When this space is filled, a continuous perfectly polished surface will be produced and only an appearance of interference on the lee side will betray the original biprism character of the specimen. But under the microscope, and by the judicious use of a steel needle, it will be found that the debris is really only compacted ; it can gradually be broken away and removed. The underlying surface upon which the debris has been deposited retains its original optical polish.

This seems to indicate that, once a group of molecules has been torn from the embrace of its associates, it is practically impossible under polishing conditions to force it back within the region of molecular cohesion.

2. A thermometer embedded in the polishing tool as nearly as possible in contact with the surface will record a rise of temperature of disappointingly small amount. If polishing is due to actual fusion of the 'hill-tops,' it might be expected in practice that, in view of the multitude of the 'hill-tops' acted upon simultaneously, a considerable rise in temperature might be anticipated. This particular theory seems to be based on the assumption that the small amount of energy involved is transmitted into the glass through an extremely minute area. That the area is never extremely small can be observed by carrying out the operation of polishing under the microscope, the action being viewed through the specimen. Within a second or two the area can be extended from about 2 per cent. to 5 per cent. ; in about four minutes the area is about 95 per cent. These results are for a hard pitch polisher. It is remarkable how quickly the pool-like areas spring into view, and an observer will certainly be impressed with the perfection of these areas ; there is no appearance of any intermediate stage suggestive of progressive abrasion.

When the whole area is optically polished, can it be contended that the energy is sufficient to maintain in a state of thermol fusion the whole extent of the surface, however thin the layer may be ? It is necessary to assume that the load is at any one moment carried by a small number of very minute elements, but the test plate applied to an optically polished surface does not disclose any irregularities sufficiently great to penetrate the film of whatever it may be that exists between the surfaces.

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Anniesland, Glasgow, Mar. 19.

The Nodes at the Reduction Division in Bivalents of Hyacinthus.

IN the grasshoppers and some other animals, nodes have been demonstrated in the bivalents, at the late prophase, by Sutton, McClung, Robertson, Wenrich, Janssens, etc. One of the Orthoptera, *Chortophaga* sp., has eleven bivalents and one univalent (X chromo-