EFFECTS OF VARIABLE PHYSICAL PROPERTIES ON HEAT TRANSFER
IN FREE CONVECTION AROUND A HORIZONTAL CYLINDER

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Theoretical and experimental studies have been made on the effects of variable viscosity and compressibility on the average heat-transfer coefficient.

General formulas have been recommended [2, 3] in [1] for calculating heat transfer by free convection from a horizontal cylinder; the purpose was to obtain a single formula applicable over wide ranges in the Rayleigh and Prandtl numbers. The variability in the physical properties was incorporated by taking the mean boundary-layer temperature $T_v = 0.5(T_0 + T_c)$ as the definitive quantity. Here we determine the ranges in the physical parameters in which these formulas apply. An approximate method is proposed for incorporating the property variation more precisely.

There are comparatively few papers dealing with the effects of variability in physical properties on heat transfer from horizontal cylinders.

Akagi [4] derived an approximate self-modeling solution and showed that the variability can be incorporated by solving a self-modeling equation system analogous to that for a vertical plate. The solution was derived numerically for an exponential temperature dependence of the dynamic viscosity. The average Nusselt number was derived [4] as

$$Nu = 0.515 (Gr_\theta Pr_\theta)^{0.26} \left(\frac{\mu_\theta}{\mu_c}\right)^{0.21},$$

where $Nu = \alpha D/\lambda$, $Gr_\theta = g\beta_\theta D^3(T_c - T_0)/\nu_\theta^2$, which applies for $Pr_\theta = 100$ to 10000; $\mu_\theta/\mu_c = 1$ to 140. The correction factor $(\mu_\theta/\mu_c)^{0.21}$ can be discarded if one calculates the physical properties from the defining temperature $T_e = T_0 + 0.75(T_c - T_0)$. Formula (1) is close to the experimental one derived in [5].

In [6], measurements for the range $10^2 < \nu_\theta/\nu_c < 10^4$ gave

$$Nu = 0.70 (Gr_\theta Pr_\theta)^{0.26} (\nu_\theta/\nu_c)^{0.14}. \tag{2}$$

Studies have been made [7, 8] on the effects of simultaneous temperature dependence for the bulk expansion coefficient and kinematic viscosity.
Fig. 1. Comparisons of measured $\text{Nu}_{\text{exp}}$ with calculated values $\text{Nu}_i$, $i = 1, 2, 3$; $\text{Nu}_1 = [2]$, $\text{Nu}_2 = [3]$, $\text{Nu}_3 = [5]$ as functions of $\nu_0/\nu_c$; experimental values, water: 1) [11]; 2) [15]; 3) $T_0 = 30^\circ\text{C}$; 4) $T_0 = 40^\circ\text{C}$ [10]; 5) $D = 6 \, \text{mm}$; 6) 8; 7) 10, 8) 12, 9) 16 [9]; air: 10) [5], 11) [12]; 12) MS-20 oil [5]; 13) No. 2 transformer oil [5]; 14) Cs-20 oil; 15) Cs-100; 16) Cs-350 [11].

Fig. 2. Dependence on $\beta_c/\beta_0$, symbols as in Fig. 1.

Here a comparison with experiment is used to estimate the errors of certain formulas associated with inadequate incorporation of the property variation. An approximate method is used to derive the analytic form for the correction for simultaneous variation in viscosity and compressibility. The method has been checked by comparison with the exact solution and with published data.

We estimated the accuracy of certain general formulas from papers containing primary experimental data: for water [5, 9, 10, 11], air [12], and oils [5, 11]. Measurements in the laminar range were used: $7.1 \cdot 10^4 \leq \text{Ra}_v \leq 2 \cdot 10^8$. Figures 1 and 2 show the results. The