the shape variable τ is defined by

$$\tau = \int_0^t q_s(\xi)\,d\xi/q_s(t). \tag{13}$$

Equation (12) will be available for many practical cases. Then the time-dependent characteristic length l will necessarily be nearly proportional to $\sqrt{(\alpha\tau)}$ even if it is defined in other ways instead of equation (1). The characteristic length defined by equation (1) is identical, in an approximate sense, with such the thermal boundary-layer thickness as $\theta(t, l)/\theta_s(t) = 1/e^2$.

KOICHI MIZUKAMI
SADAO TANAKA

Kobe University of Mercantile Marine
Higashinada-ku
Kobe
658 *Japan*

REFERENCES

1. I. F. Davenport and C. J. King, The onset of natural convection from time-dependent profiles, *Int. J. Heat Mass Transfer* **17**, 69–76 (1974).
2. A. Sakurai, K. Mizukami and M. Shiotsu, Experimental studies on transient boiling heat transfer and burnout, *Heat Transfer 1970*, Vol. V, B3.4. Elsevier, Amsterdam (1970).
3. A. Sakurai and K. Mizukami, An approximate expression of heat transfer coefficient by transient heat conduction, Tech. Rep. Inst. Atom. Energy Kyoto Univ., No. 155 (1972).
4. A. Sakurai and K. Mizukami, Application of the reduced time to transient conduction problems (II)—an approximate expression of temperature profile, Japan Atomic Energy Society 1971 Fall Meeting on Reactor Physics and Engineering, D39 (in Japanese).

Int. J. Heat Mass Transfer. Vol. 19, p. 126. Pergamon Press 1976. Printed in Great Britain

CORRELATIONS FOR HEAT TRANSFER TO VARIABLE PROPERTY FLUIDS IN TURBULENT PIPE FLOW

(*Received* 18 *June* 1975)

THE PAPER by Sleicher and Rouse [1] presents the most recent of many surveys of heat-transfer correlations for variable-property fluids in smooth pipes. After a review of previous correlations, and careful selection of the most reliable experimental data for comparison, the following equation was proposed:

$$Nu_b = 5 + 0{\cdot}015 Re_f^a Pr_w^b \quad \text{for} \quad \begin{array}{c} 0{\cdot}1 < Pr < 10^5 \\ 10^4 < Re < 10^6 \end{array}$$

where

$$a = 0{\cdot}88 - 0{\cdot}24/(4 + Pr_w)$$

and

$$b = 1/3 + 0{\cdot}5\,e^{-0{\cdot}6Pr_w}.$$

Our first query concerns the meaning of the suffix in Re_f. Does the suffix apply to ρ and μ or only to μ? This is always a dilemma. There is a natural reluctance to base Re upon a produce $\rho_f V$ which is not equal to the average mass velocity; on the other hand, to retain the average mass velocity is to introduce the unwarranted assumption that density variations across the pipe have no effect.

Consider the application of the above correlation to a fluid for which the thermal conductivity increases with temperature, the other properties being constant. As the wall-to-bulk temperature difference is increased, for a fixed bulk temperature, k_w increases but according to the correlation, the heat-transfer coefficient decreases. To illustrate this characteristic of the correlation: at $Pr_b = 1{\cdot}0$, if a thermal conductivity variation was introduced such that $k_w/k_b = 10$, the calculated heat-transfer coefficient would *decrease* by a factor 6·3. It is physically unreasonable that the injection of a higher conductivity into the wall region should reduce the heat-transfer coefficient.

The answer may come back that the correlation is a reasonable fit to the best experimental data, which do not include a fluid for which the conductivity variation predominates. In fitting the experimental data perhaps the anomolous dependence of the correlation on thermal conductivity variation is compensated by an over-allowance for the variation of some other property. This indeed is our principal point: that such a correlation can be regarded only as a summary of a particular set of experimental data, and not, despite the generality of its appearance, as possessing any fundamental basis that would enable it to be used with confidence for predictive purposes outside the conditions of the experiments on which it has been based.

From first principles one may write

$$Nu_b = F\left(Re_b, Pr_b, \frac{\rho_w}{\rho_b}, \frac{\mu_w}{\mu_b}, \frac{C_{pw}}{C_{pb}}, \frac{k_w}{k_b}\right)$$

recognising also that the form of the variation of the properties with temperature is significant. Even for fluids whose properties vary with temperature in a monotomic and "regular" manner (i.e. excluding near-critical fluids in particular) it is certain that any realisation of such a correlation which must include interactions between the different physical property ratios, would be forbiddingly complicated. Fundamental objections to some of the simpler forms of correlation which have been tried for many years have been discussed in [2] and we do not believe that these simpler forms can be regarded as other than convenient summaries of particular sets of data.

As a more positive proposal we believe it would be a useful step forward to shed some light on the influence of variations of the four physical properties, separately and in combination. We are presently engaged upon this task.

School of Mechanical Engineering M. B. IBRAHIM
University of Bradford
Bradford V. WALKER
U.K.

REFERENCES

1. C. A. Sleicher and M. W. Rouse, A convenient correlation for heat transfer to constant and variable property fluids in turbulent pipe flow, *Int. J. Heat Mass Transfer* **18**, 677–683 (1975).
2. V. Walker and L. White, The effect of physical property variations on heat transfer from roughened surfaces, 4th International Heat Transfer Conference, Paper FC. 5.4 (1970).