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LETTER TO THE EDITOR

COMMENTS ON "AN INVESTIGATION OF HEAT TRANSFER AND FRICTION FOR RIB-ROUGHENED SURFACES"

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MUCH work to develop roughened heat-transfer surfaces has been done in the past. The aim is to obtain general correlations for pressure drop and heat transfer of different types of roughnesses applicable to different channel geometries. In their recent paper Han, Glicksman and Rohsenow [1] present experimental results on rectangular roughness in a parallel plate channel. The results on roughness functions could add new information to that already existing in the literature, provided the roughness functions are evaluated correctly, though the investigations cover a range of very high e/D_h values which is of minor importance for practical applications.

However, the presented results of the roughness functions Re^+ and He^+ evaluated from the friction factors and measured Stanton numbers, and most of the conclusions, are wrong. Equation (6) of [1] is only valid for circular tubes. In the case of parallel plates an analog equation can be found by an integration of the law of the wall {equation (5) [1]} across the cross-section A [2–4]:

$$u^+_{max} - u^+_{av} = \frac{1}{A}\int_0^L 2.5 \ln \frac{L}{y}\, dA, \qquad (1)$$

with L as the length of the velocity profile between the wall and the position of zero shear stress and y as the distance from the wall. The RHS of equation (1) is dependent on the geometry of the channel. For parallel plates this geometry parameter G has the value $G_{pp} = 2.5$ instead of $G_t = 3.75$ as for circular tubes. The non-dimensional maximum velocity is calculated from the law of the wall at $y = L$:

$$u^+_{max} = 2.5 \ln \frac{L}{e} + Re^+. \qquad (2)$$

The non-dimensional average velocity across the channel by definition of the friction factor is

$$u^+_{av} = \left(\frac{2}{f}\right)^{1/2}. \qquad (3)$$

With equations (2) and (3) and $G_{pp} = 2.5$ we get from equation (1)

$$Re^+ = \left(\frac{2}{f}\right)^{1/2} + 2.5 \ln \frac{e}{L} + 2.5. \qquad (4)$$

Since

$$L = \frac{D_h}{4}, \qquad (5)$$

the final equation for parallel plates reads

$$Re^+ = \left(\frac{2}{f}\right)^{1/2} + 2.5 \ln \frac{4e}{D_h} + 2.5. \qquad (6)$$

Therefore, all roughness functions (Re^+ and He^+) evaluated by equation (6) are higher by

$$\Delta R = 2.5 \ln 2 - 1.25 = 0.48,$$

compared with those calculated from equation (6) of [1]. This makes a correction of about 14% for $Re^+ = 3.5$ (an average value for most of the results of [1]).

Therefore, most of the conclusions of [1] are not valid, e.g.:

(1) There is no coincidence of the new data with the data of Webb *et al.* [5] and Dalle Donne and Meerwald [6].

(2) The influence of the rib height to the length of the velocity profile is not doubtful, since there is experimental evidence [4, 7, 8] and the new data evaluated correctly confirm these findings: higher roughness functions Re^+ for higher e/L compared with the data of Webb *et al.* [5] at lower e/L.

(3) The influence of e/L on Re^+ is not caused by the transformation methods as the new data show.

(4) The statement by Dalle Donne and Meyer that Re^+ should fall for $e/L > 0.235$ is based on a volumetric hydraulic diameter. For high e/L the definition of the origin of the velocity profile and thus the hydraulic diameter is very important. Nowhere in the paper [1] can an exact definition of the hydraulic diameter be found.

(5) The wrong definition used for Re^+ also has an influence on the calculated heat-transfer parameter He^+ {see equation (14) of [1]}.

Moreover, the statement "small changes to the rib cross-section from square to rectangular should have negligible effect on the friction factor and the heat transfer" may be valid only for *small* changes. A difference in e/w between 1.0 and 0.67 is not a small change. The correlations published in the literature for rectangular roughness indicate the following differences in the roughness function Re^+. For $p/e = 7.5$ the difference $R(e/w = 0.67) - R(e/w = 1.0)$ is found to be 0.52 [8], 0.60 [4], and 0.55 [7]. Assuming $\Delta R = 0.5$ for $p/e = 7.5$ and the friction factor $f = 0.074$ for high Reynolds numbers (Fig. 10) and $e/w = 0.67$ the friction factor for $e/w = 1.0$ would change to $f' = 0.091$. Therefore, the friction factor for $p/e = 7.5$ would be higher than for $p/e = 10$ with a profile of $e/w = 1.0$. The conclusion that the friction factor assumes its highest value for p/e about 10 is not true. As found in the literature the highest friction factors occur for $e/w = 1.0$ at about $p/e = 7 \div 8$ [4, 7].

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REFERENCES

1. J. C. Han, L. R. Glicksman and W. M. Rohsenow, An investigation of heat transfer and friction for rib-roughened surfaces, *Int. J. Heat Mass Transfer* **21**, 1143–1156 (1978).
2. K. Maubach, Friction laws of turbulent flows, *Chemie-Ingr.-Tech.* **42**(15), 995–1004 (1970) (in German).
3. K. Maubach, Rough annulus pressure drop—

Interpretation of experiments and recalculation for square ribs, *Int. J. Heat Mass Transfer* **15**, 2489–2498 (1972).
4. M. Dalle Donne and L. Meyer, Turbulent convective heat transfer from rough surfaces with two-dimensional rectangular ribs, *Int. J. Heat Mass Transfer* **20**, 583–620 (1977).
5. R. L. Webb, E. R. G. Eckert and R. J. Goldstein, Heat transfer and friction in tubes with repeated-rib roughness, *Int. J. Heat Mass Transfer* **14**, 601–617 (1971).
6. M. Dalle Donne and E. Meerwald, Heat transfer from rough surfaces, latest results, NEA-GCFR Specialist Meeting on Heat Transfer, Windscale, U.K. (1972).
7. R. J. Firth, UKAEA experience of fluid mechanics and heat transfer in gas-cooled reactor fuel elements, Advanced Study Institute on Turbulent Forced Convection in Channels and Rod Bundles, Istanbul, Turkey (1978).
8. W. Baumann and K. Rehme, Friction correlations for rectangular roughnesses, *Int. J. Heat Mass Transfer* **18**, 1189–1197 (1975).