Int. J. Heat Mass Transfer. Vol. 30, No. 3, pp. 509–515, 1987
Printed in Great Britain

0017-9310/87 $3.00+0.00

Heat transfer correlation for thermally developing laminar flow in a smooth tube with a twisted-tape insert

J. P. DU PLESSIS*† and D. G. KRÖGER‡

* Department of Applied Mathematics, University of Stellenbosch, Stellenbosch, South Africa.
‡ Department of Mechanical Engineering, University of Stellenbosch, Stellenbosch, South Africa

(*Received* 11 *February* 1985 *and in final form* 6 *June* 1986)

Abstract—A new method of correlating heat transfer characteristics is presented for the case of thermally developing laminar flow in a smooth tube with a twisted-tape insert. The tube is considered to be at a constant temperature axially and peripherally and the tape is fully adiabatic. The correlating method is based on numerical results for the case on an infinitely thin tape and the finite tape thickness is incorporated through the definition of effective flow parameters. A complete step-by-step procedure for the implementation of the final correlative equation is presented.

1. INTRODUCTION

THE APPLICATION of a twisted-tape insert to a tubular heat exchanger may lead to significant enhancement of heat transfer. Based on numerical work by Date and Singham [1], Shah and London [2] supplied empirical correlations to quantify this enhancement. Their results cover the case of an axially and peripherally isothermal tube containing an axially and radially isothermal tape at the same temperature as the tube. Experimental work led to empirical correlations by Hong and Bergles [3] for cases of axially uniform heat flux.

In this paper a suggestion by Nazmeev and Nikolaev [4], namely to employ effective flow parameters for the correlations, is elaborated on in the case of thermally developing laminar flow. This method was also used for friction factor correlations and the main features are fully described by du Plessis and Kröger [5]. For the present it will suffice to state that all hydrodynamical and heat transfer variables are based on effective flow parameters. These parameters follow from a purely geometrical consideration of the curved passage formed by the twisted-tape insert and are recapped shortly in Appendix A. In Fig. 1 a diagram is presented to illustrate the tape geometry.

In general the Nusselt number for constant property twisted-tape flow may be considered as a function of six independent variables namely, the Prandtl number Pr, the Reynolds number Re_D, the dimensionless axial distance x/D, the tape twist ratio y, the tape fin parameter c_{fin} and the tape thickness δ. For the present study a fully adiabatic tape ($c_{fin} = 0$) is assumed as a theoretical limiting case. An axially and peripherally

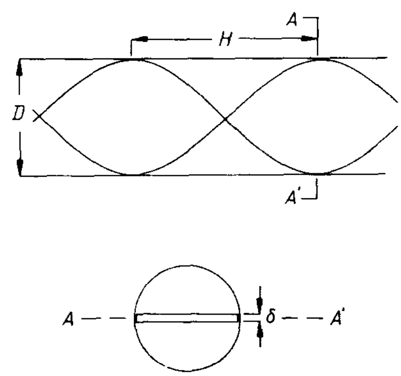

FIG. 1. The tube-and-tape geometry.

constant wall temperature is assumed on either side of an axial step change in wall temperature in accordance with experimental results obtained by du Plessis [6]. No experimental results are available for such a set of boundary conditions together with constant fluid properties. The computer program was, however, extensively tested against experimental results for variable property twisted-tape flow and good agreement was obtained [6].

An extensive parametric numerical investigation was carried out [6] for the independent variables in the following ranges:

$$\begin{aligned} 50 &\leqslant Re_D \leqslant 2000 \\ 3 &\leqslant y \leqslant \infty \\ 50 &\leqslant Pr \leqslant 1000 \\ 10 &\leqslant x/D \leqslant 100. \end{aligned} \quad (1)$$

For any combination of Re_D and y, one computational run was done to obtain the fully developed velocity profile upstream of the step change in wall tempera-

† Present address: Department of Chemical Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2G6.

NOMENCLATURE

A cross-sectional flow area
c_{fin} tape fin parameter
c_p fluid heat capacity
D tube inner diameter
G helical factor defined in equation (A1)
H tape pitch for twist of π radians
k fluid thermal conductivity
Nu Nusselt number
$\dot{m}$ mass flow rate
P wetted perimeter
Pr Prandtl number
Re Reynolds number
x axial distance
x^* dimensionless thermal axial distance
y twist ratio, H/D.

Greek symbols
δ tape thickness
μ fluid dynamic viscosity
π constant, 3.14159
Ψ conversion factor defined in equation (2)
Ω swirl factor.

Subscripts
c tube with tape insert
D tube diameter
fin relating to fin effect of tape
H1 constant heat flux
m mean
T constant temperature
t tapeless tube
ε effective flow parameter
Ω relating to swirl factor
∞ infinite.

ture. Thereupon only the temperature cycle is computed during subsequent runs for different values of the Prandtl number since this study was limited to thermally developed flow. The computer program used for this work was based on the numerical procedure SIMPLE of Patankar and Spalding [7] for parabolic flow.

2. NUSSELT NUMBER ACCORDING TO EFFECTIVE FLOW PARAMETERS

A careful graphical study of the numerical results suggests that the effective flow concept should be introduced at the outset in order to obtain consistency at low Re_D/y values when the Nusselt number is plotted against Reynolds number.

Following the analysis of Shah and London [2], the Nusselt number Nu_D based on the dimensions of a tube without a tape, may therefore be expressed in terms of Nu_ε as follows:

$$Nu_D = (D/D_\varepsilon)^2(A_\varepsilon/A)Nu_\varepsilon \equiv \Psi_\varepsilon Nu_\varepsilon. \quad (2)$$

In the special case of a thin ($\delta = 0$) and flat ($y = \infty$) tape, the conversion factor is fixed analytically by

$$\Psi_\varepsilon = \left(\frac{\pi + 2}{\pi}\right)^2 = 2.685. \quad (3)$$

The multiplying factor Ψ_ε in equation (2) is presented in Table 1 for some values of y with $\delta = 0$.

This result may be seen as a first basic correlation for Nu_D where Nu_ε is to be taken from any correlation valid for corresponding heat transfer in a smooth tube with dimensions similar to the effective flow parameters. Equation (2) is valid for any temperature boundary conditions as well as for axially local or mean Nusselt numbers.

Table 1. Some numerical values of the conversion factor Ψ_ε for cases of zero tape thickness ($\delta = 0$)

y	Ψ_ε	y	Ψ_ε
1.0	1.9712	8.0	2.6425
1.5	2.1561	8.5	2.6465
2.0	2.3001	9.0	2.6499
2.5	2.3995	9.5	2.6527
3.0	2.4674	10.0	2.6552
3.5	2.5145	15.0	2.6680
4.0	2.5481	20.0	2.6726
4.5	2.5727	25.0	2.6747
5.0	2.5911	30.0	2.6759
5.5	2.6052	35.0	2.6766
6.0	2.6162	40.0	2.6770
6.5	2.6250	45.0	2.6773
7.0	2.6320	50.0	2.6776
7.5	2.6378	∞	2.6785

An extensive set of graphical plots, obtained from the numerical results, reveals the power laws as indicated in Table 2 for the independent effective flow variables. According to the numerical work an accuracy of $\pm 2\%$ is expected for these powers. In cases of $Pr > 1000$ or $Re_\varepsilon/y > 350$ the finite-difference grid employed ceases to be able to handle the severe curvature in the temperature profile near the tube wall correctly. Such incorrect values have been omitted.

3. ASYMPTOTIC VALUE OF THE EFFECTIVE NUSSELT NUMBER

The correlation for Nusselt numbers should include both the developing and the fully developed thermal states of conditions. The only limiting solution not extractable from the numerical data is the fully

Table 2. Nusselt number power law behaviour for the independent variables (absence of a variable indicates a power of zero)

Re_D	x/D	y = 3	y = ∞
50	10	$Pr^{0.35}Re_\varepsilon^{0.35}y^{-0.35}(x/D)_\varepsilon^{-0.34}$	$Pr^{0.35}Re_\varepsilon^{0.35}(x/D)_\varepsilon^{-0.35}$
	100	$Pr^{0.35}Re_\varepsilon^{0.35}y^{-0.44}$	—
2000	10	$Pr^{0.35}Re_\varepsilon^{0.46}y^{-0.35}(x/D)_\varepsilon^{-0.35}$	$Pr^{0.35}Re_\varepsilon^{0.35}(x/D)_\varepsilon^{-0.35}$
	100	$Pr^{0.35}Re_\varepsilon^{0.46}y^{-0.44}$	$Pr^{0.35}Re_\varepsilon^{0.35}$

developed flat tape case when $y = \infty$. An approximate value for $Nu_{\varepsilon,T}$ ($y = \infty$, $x/D \to \infty$) may be deduced as follows from constant heat flux data available in literature.

Hong and Bergles [3] analytically obtained the limiting value $Nu_{D,H1}$ shown in Table 3 where the subscript H1 denotes the axially constant wall heat flux boundary condition. An investigation of the value of the quotient Nu_T/Nu_{H1} for thermally fully developed flow in several different duct geometries, as may be obtained, for example, from Shah and London [2], suggests that this quotient for twisted-tape flow should be about 0.82. This assumption leads to the values of Nu_T presented in Table 3 and should of course be adjusted whenever more accurate values for the Nusselt numbers become known. The effective flow Nusselt numbers presented in Table 3 are calculated from equations (2) and (3). The value of 1.58 is henceforth assumed for the present derivation as an asymptotic lower limit to $Nu_{\varepsilon,T}$ as $x/D \to \infty$ for the flat tape case when $y = \infty$.

The remainder of this paper is strictly limited to cases of the T boundary condition and this subscript will be dropped forthwith. It is also implicitly assumed that the Nusselt numbers refer to the axially mean Nusselt numbers for the thermal entrance region after a step change in wall temperature.

4. INTRODUCTION OF THE THERMAL ENTRANCE LENGTH

As a first correction to the basic effective flow correlation of equation (2), the case when $y = \infty$ will be exploited in this section in order to obtain a lower bound for all $Nu_{m,\varepsilon}$ in both the developing and the fully developed regions of twisted-tape flow. To this effect the asymptotic matching technique of Churchill and Usagi [8] is applied to the oblique asymptote formed by the numerical data for the cases of thermally developing flow and the approximate value of 1.58 for fully developed flow. Taking as independent variable

$$x_\varepsilon^* \equiv \left(\frac{x}{Re\,D\,Pr}\right)_\varepsilon \tag{4}$$

the limiting solutions are

$$\lim_{x_\varepsilon^* \to \infty} Nu_\varepsilon = 1.58 \tag{5}$$

and, according to Table 2,

$$\lim_{x_\varepsilon^* \to 0} Nu_\varepsilon = 0.845\, x_\varepsilon^{-0.35} \tag{6}$$

whence

$$Nu_\varepsilon = 1.58[1 + 0.153(x_\varepsilon^*)^{-1.05}] \tag{7}$$

with the so-called central value of $Nu_\varepsilon = 2.0$ at $x_\varepsilon^* = 0.167$. This result is graphically shown in Fig. 1.

Table 3. Nusselt numbers for the case of thermally fully developed flow in a straight duct of semi-circular cross section

y	$Nu_{D,H1}$	$Nu_{\varepsilon,H1}$	$Nu_{D,T}$	$Nu_{\varepsilon,T}$
∞	5.172	1.931	4.2	1.58

5. INTRODUCTION OF THE TWIST RATIO

The correlation presented in equation (7) only takes into account the cross-sectional change of the flow channel. A further refinement is necessary to provide for the change in heat transfer due to the deformation of the velocity profile as the fluid is being forced through the curved channel. In Fig. 2 the Nusselt number behaviour according to changes in y and x/D is shown. A decrease in y causes a vertical shift, an increase in axial distance causes a shift to the right towards a lower horizontal asymptote and an increase in $Re_\varepsilon Pr$ shifts the Nusselt number obliquely to the left, parallel to the asymptote for $y = \infty$. A marked deviation from the oblique asymptote is present in all cases of rather high Re/y, but this effect is the consequence of a high swirl factor and will be discussed at a later stage.

A schematic representation of the influence of the flow swirl on the Nusselt number is reconstructed in Appendix B to clarify the situation at this point. The geometrical analysis presented in Appendix B then

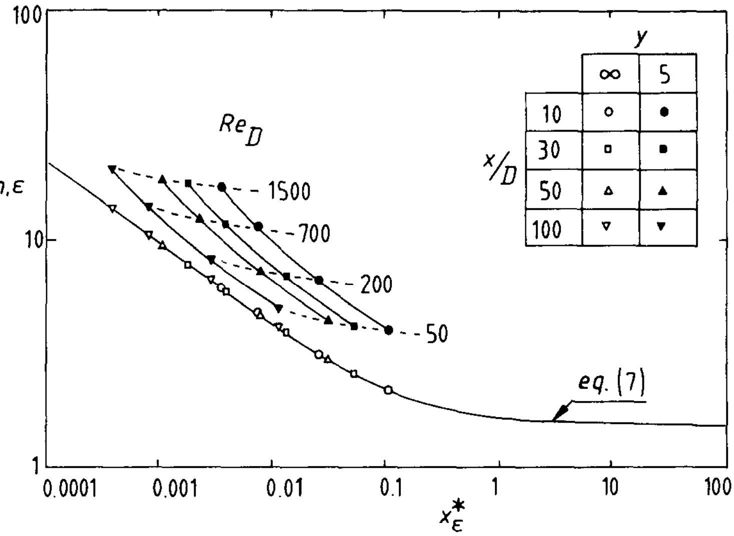

FIG. 2. Nusselt number behaviour with respect to changes in Re_D, x/D and y for $Pr = 50$.

leads to the following expression for the Nusselt number according to equations (2), (7) and (B5):

$$\begin{aligned} Nu_D &= \Psi_\varepsilon Nu_E \\ &= 1.58\Psi_\varepsilon[1 + 0.153(x^*_\infty)^{-1.05}]^{1/3} \\ &\quad \times \left[1 + 0.000064\left(\frac{Re_\varepsilon Pr}{y}\right)^3\right]^{0.117} \end{aligned} \qquad (8)$$

with

$$x^*_\infty = x^*_\varepsilon\left[1 + 0.000064\left(\frac{Re_\varepsilon Pr}{y}\right)^3\right]^{1/3}. \qquad (9)$$

Although this correlation seems accurate to within 10% yet another asymptotic-type correction is introduced in the next section in order to account for the effect of strong secondary flow normal to the helical coordinates.

6. CORRECTION IN CASES OF HIGH SWIRL FACTOR

An increase in the swirl factor

$$\Omega_\varepsilon = Re_\varepsilon/y \qquad (10)$$

leads to an increase in the deviation of the Nusselt number Nu_Ω from the oblique asymptote as was found in the previous section. At the lower limit when the swirl factor is zero the Nusselt number Nu_Ω is correctly predicted so that

$$\lim_{\Omega_\varepsilon \to 0} Nu_\Omega/Nu_E = 1. \qquad (11)$$

At the other extreme, when the swirl is high, a hypothetical asymptote has to be found. According to the numerical data it may be assumed that

$$\lim_{\Omega_\varepsilon \to \infty} Nu_\Omega/Nu_E = 0.35\,\Omega^{0.2}. \qquad (12)$$

This asymptote is then applicable for Ω values up to 700.

Once again the Churchill–Usagi matching technique is applied to the numerical results and it leads to the following corrective measure for the Nusselt number:

$$Nu_\Omega = Nu_E\,[1 + 0.002\,\Omega_\varepsilon^{1.4}]^{1/7}. \qquad (13)$$

According to equations (8) and (13) the final Nusselt number correlation for thermally developing twisted-tape flow is thus given by

$$\begin{aligned} Nu_D = 1.58\,\Psi_\varepsilon&[1 + 0.153(x^*_\infty)^{-1.05}]^{1/3} \\ &\times [1 + 0.000064(\Omega_\varepsilon Pr)^3]^{0.117} \\ &\times [1 + 0.002\Omega_\varepsilon^{1.4}]^{1/7} \end{aligned} \qquad (14)$$

with x^*_∞ being given by equation (9). A complete step sequence of the procedure to be followed to obtain a correlation according to this equation is presented in Table 4. The results obtained when this correlation is applied to the numerical data of this study is presented in Fig. 3 where Nu_C is plotted against x^*_∞.

7. CONCLUSIONS

The method of effective flow parameters is successfully employed in the development of an empirical correlation procedure for thermally developing laminar flow in a smooth tube at a constant temperature and fitted with an adiabatic twisted tape. The thermally developing flow takes place after a step change

Table 4. Step sequence for the calculation of the correlative equation [14] for the Nusselt number of thermally developing twisted-tape flow

Physical entity input data: $H, D, \delta, m, \mu, c_p, k$

Computational step sequence:

$$y = H/D$$
$$G = [1 + (\pi/2y)^2]^{1/2}$$
$$A_t = \pi D^2/4$$
$$A_c = A_t - D\delta$$
$$P_\varepsilon = 2D - 2\delta + \pi D/G$$
$$A_\varepsilon = 2H^2(G-1)/\pi - D\delta$$
$$D_\varepsilon = 4A_\varepsilon/P_\varepsilon$$
$$x_\varepsilon = xA_c/A_\varepsilon$$
$$Re_D = \dot{m}D/(\mu A_t)$$
$$Pr = \mu c_p/k$$
$$Re_\varepsilon = Re_D(A_t/A_\varepsilon)(D_\varepsilon/D)$$
$$\Omega_\varepsilon = Re_\varepsilon/y$$
$$\Psi_\varepsilon = (D/D_\varepsilon)^2(A_\varepsilon/A_t)$$
$$x_\varepsilon^* = x_\varepsilon/(Re_\varepsilon Pr D_\varepsilon)$$
$$x_\infty^* = x_\varepsilon^*[1 + 0.04(\Omega_\varepsilon Pr)^3]^{1/3}$$

Final Nusselt number correlating equation:

$$Nu_{m,D} = 1.58\,\Psi_\varepsilon[1 + 0.153(x_\infty^*)^{-1.05}]^{1/3} \times [1 + 0.000064(\Omega_\varepsilon Pr)^3]^{0.117} \times [1 + 0.002\,\Omega_\varepsilon^{1.4}]^{1/7}$$

in wall temperature. Hydrodynamically the flow is considered to be fully developed throughout the whole length of the tube. The finite tape thickness is also taken into account analytically. The results are promising although more numerical and experimental results are needed for confirmation of the general applicability of the procedure. Nevertheless, the complicated features of twisted-tape flow have in a way been analysed according to some predominant trends and this may help to elucidate future work in this field. It also forms a basis for analyses of thermally and hydrodynamically developing flows as well as the generalization to variable physical properties. Research is presently being directed towards the other limiting case of the entire tape being at the tube temperature. The results obtained in practice for constant property flow will then lie between these limits.

It should be noted that the results presented in this paper are based on a parabolic numeric procedure. Since pronounced secondary flow is present in cases of even mild swirl it is to be expected that a partially parabolic procedure or in the extreme case a fully elliptic procedure may lead to more accurate determination of the fictitious asymptotes.

The synopsis of the results as given in Table 4 may be of great help to the engineer designing to enhance heat transfer by means of twisted-tape inserts. Together with the friction factor correlation presented in a former paper [5] augmentation of heat transfer by a lower twist ratio may be considered against the consequent extra pumping power needed to overcome the adverse increase in pressure drop. In this type of analysis it should be borne in mind that variable physical properties of the fluid may influence the results dramatically.

Acknowledgement—Financial assistance towards this project by the South African CSIR Foundation for Research Development is thankfully acknowledged.

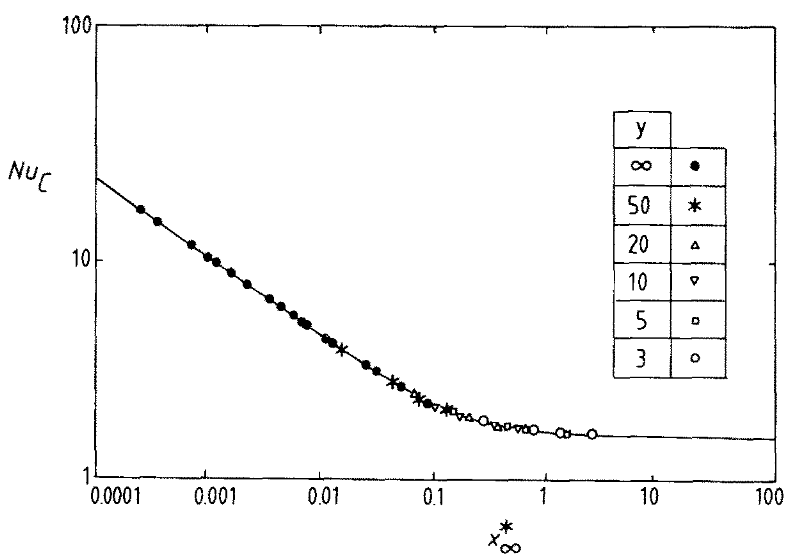

FIG. 3. Correlation of numerically obtained Nusselt number data for thermally developing twisted-tape flow. The data points include random values of Re_D, Pr and x/D within the ranges indicated in equation (1).

REFERENCES

1. A. W. Date and J. R. Singham, Numerical prediction of friction and heat transfer characteristics of fully developed laminar flow in tubes containing twisted tapes, ASME Paper 12-HT-17 (1972).
2. R. K. Shah and A. H. London, Laminar flow forced convection in ducts, *Advances in Heat Transfer*, Supplement 1 (Edited by F. I. Thomas and J. P. Hartnett). Academic Press, London (1979).
3. S. W. Hong and A. E. Bergles, Augmentation of laminar flow heat transfer in tubes by means of twisted-tape inserts, Technical Report HTL5, ISU-ERI-Ames75011, Engineering Research Inst., Iowa State University, Ames (1974).
4. Yu. G. Nazmeev and N. A. Nikolaev, Correlation of experimental data on heat transfer in tubes with twisted-tape turbulence promotors, *Thermal Engng U.S.S.R.* **27**, 151–152 (1980).
5. J. P. du Plessis and D. G. Kröger, Friction factor prediction for fully developed laminar twisted-tape flow, *Int. J. Heat Mass Transfer* **27**, 2095–2100 (1984).
6. J. P. du Plessis, Laminar flow and heat transfer in a smooth tube with a twisted-tape insert. Ph.D. thesis, University of Stellenbosch, Stellenbosch, South Africa (1982).
7. S. V. Patankar and D. B. Spalding, A calculation procedure for heat, mass and momentum transfer in three-dimensional parabolic flows, *Int. J. Heat Mass Transfer* **15**, 1787–1805 (1972).
8. S. W. Churchill and R. Usagi, A general expression for the correlation of rates of transfer and other phenomena, *A.I.Ch.E. Jl* **18**, 1121–1128 (1972).

APPENDIX A: EFFECTIVE FLOW PARAMETERS

Through the concept of effective flow parameters one utilizes an effective measure for the physical dimensions of the curved duct formed by a tube which is supplemented by a tight fitting twisted tape. If a helical factor is defined as

$$G \equiv \sqrt{1 + \frac{\pi^2 D^2}{4H^2}} \tag{A1}$$

the effective cross-sectional flow area is

$$A_\varepsilon = \frac{2H^2}{\pi}(G-1) - D\delta \tag{A2}$$

with a wetted perimeter of

$$P_\varepsilon = 2\left(D - \delta + \frac{\pi D}{2G}\right). \tag{A3}$$

An effective hydraulic diameter is then given by

$$D_\varepsilon = 4A_\varepsilon/P_\varepsilon \tag{A4}$$

and the effective mean length of the flow channel is defined in the following way to preserve volumetric dimensions

$$x_\varepsilon \equiv \left(\frac{\pi D^2}{4} - D\delta\right)x/A_\varepsilon. \tag{A5}$$

An effective Reynolds number will thus be

$$Re_\varepsilon = Re_D(A_t/A_\varepsilon)(D_\varepsilon/D) \tag{A6}$$

with

$$Re_D = \dot{m}D/(\mu A_t) \tag{A7}$$

a Reynolds number based on the same volumetric flow rate in a tapeless tube.

APPENDIX B: GEOMETRICAL ANALYSIS OF NUSSELT NUMBER BEHAVIOUR

The dependence of the Nusselt number $Nu_{m,\varepsilon}$ on the various parameters as indicated in Fig. 1, is schematically represented in Fig. B1. Let x_ε^* be the effective dimensionless distance (point A in Fig. B1) according to equation (4) where the Nusselt number is to be predicted. Numerical calculations

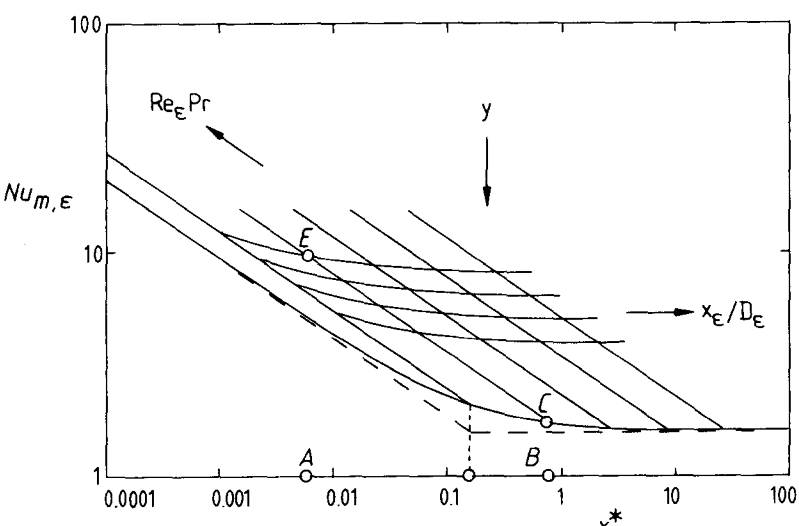

FIG. B1. Schematic representation of the computational procedure for $y < \infty$ Nusselt numbers relative to the correlation obtained for $y = \infty$.

[6] suggest that the variation in Nusselt number $Nu_{m,\varepsilon}$ according to a shift alongside the oblique asymptote, is proportional to some power of $RePr/y$. To the right, alongside the horizontal asymptote, the oblique line traversed meets the $y = \infty$ line (point C in Fig. B1) and thus defines a new axial distance x^*_∞ (point B in Fig. B1). The definition of x^*_∞ allows the horizontal asymptotic behaviour of Nu_ε to be brought into alignment with that of the $y = \infty$ case.

The present findings are now employed to predict the Nusselt number according to the schematic lay-out of Fig. B1. Starting from E at x^*_E, the new effective distance x^*_C has to be found. At flat tape conditions when $y = \infty$ the two axial distances must coincide since the Nusselt number is correctly predicted by equation (7). In cases of high twist the solution is unknown. An approximate solution may, however, be calculated from the numerical computations, so that two asymptotic conditions can again be connected by the Churchill–Usagi method, namely

$$\lim_{RePr/y \to 0} x^*_C/x^*_E = 1 \qquad \text{(B1)}$$

and

$$\lim_{RePr/y \to \infty} x^*_C/x^*_E = 0.04\left(\frac{RePr}{y}\right)_\varepsilon. \qquad \text{(B2)}$$

From the central value of 1.26 at $Re_\varepsilon Pr/y = 25$, as is obtained from the numerical data, it then follows that

$$\frac{x^*_C}{x^*_E} = [1 + 0.000064(Re_\varepsilon Pr/y)^3]^{1/3}. \qquad \text{(B3)}$$

This equation defines the point C in Fig. B1 at which the Nusselt number Nu_C is calculated. Geometrically it then follows that

$$\frac{\ln Nu_E - \ln Nu_C}{\ln x^*_C - \ln x^*_E} = 0.35 \qquad \text{(B4)}$$

and together with equation (B3) this leads to

$$Nu_E = Nu_C[1 + 0.000064(Re_\varepsilon Pr/y)^3]^{0.117}. \qquad \text{(B5)}$$

CORRELATION THERMIQUE POUR UN ECOULEMENT LAMINAIRE THERMIQUEMENT ETABLI DANS UN TUBE LISSE AVEC INSERTION DE RUBAN TORSADE

Résumé—On présente une nouvelle méthode de formulation des caractéristiques du transfert thermique pour un écoulement laminaire thermiquement établi dans un tube lisse avec insertion de ruban torsadé. Le tube est à température constante et le ruban est adaibatique. La méthode est basée sur des résultats numériques pour un ruban infiniment mince et l'épaisseur finie du ruban est incluse dans la définition des paramètres effectifs de l'écoulement. Une procédure complète de pas-à-pas est présentée pour l'équation finale.

KORRELATION DES WÄRMEÜBERGANGES IN EINER THERMISCH NICHTENTWICKELTEN LAMINAREN STRÖMUNG IN EINEM GLATTEN ROHR MIT EINEM EINGEBAUTEN VERDRILLTEN BAND

Zusammenfassung—Es wird eine neue Methode zur Korrelation des Wärmeüberganges im Falle einer thermisch nicht-entwickelten laminaren Strömung in einem glatten Rohr mit einem eingebauten verdrillten Band vorgestellt. Das Rohr wird als isotherm, das Band als adiabat betrachter. Die Korrelationsmethode stützt sich auf numerische Ergebnisse für den Fall eines unendlich dünnen Bandes; die endliche Dicke des Bandes wird durch Einführen effektiver Strömungs-Parameter berücksightigt. Es wird ein Schrittverfahren für die Aufstellung der endgültigen Korrelationsgleichung vorgeführt.

ОБОБЩЕНИЕ ДАННЫХ ПО ТЕПЛООБМЕНУ ПРИ ТЕРМИЧЕСКИ НЕУСТАНОВИВШЕМСЯ ЛАМИНАРНОМ ТЕЧЕНИИ В ГЛАДКОЙ ТРУБЕ СО ВСТАВКОЙ В ВИДЕ СПИРАЛЬНОЙ ЛЕНТЫ

Аннотация—Предложен новый метод обобщения характеристик теплопереноса при термически неустановившемся ламинарном течении в гладкой трубе со вставкой в виде спиральной ленты. Предполагается, что температура постоянна по оси и окружности, а лента является полностью адиабатической. Метод обобщения основан на численных результатах, полученных для бесконечно тонкой ленты, а данные для ленты конечной толщины используются для определения эффективных параметров потока. Дано подробное описание методики применения полученного обобщающего соотношения.