Cankaya University
Faculty of Engineering
Mechanical Engineering Department
ME 313 Heat Transfer

Chapter 8
Internal Flow Examples
Fall 2016

Example -1 Consider the heating of atmospheric air flowing with a velocity of $V = 0.5$ m/s inside a thin-walled tube 2.5 cm in diameter in the hydrodynamically and thermally developed region. Heating can be done either by condensing steam on the outer surface of the tube, thus maintaining a uniform surface temperature, or by electric resistance heating, thus maintaining a uniform surface heat flux. Calculate the heat transfer coefficient for both of these heating conditions by assuming air properties can be evaluated at 350 K.

SOLUTION The air properties at 350 K are

$$\nu = 20.76 \times 10^{-6}\ \mathrm{m^2/s} \qquad k = 0.03\ \mathrm{W/(m \cdot s)}$$

The Reynolds number for the flow is

$$\mathrm{Re} = \frac{VD}{\nu} = \frac{(0.5)(0.025)}{20.76 \times 10^{-6}} = 602$$

Hence the flow is laminar. The Nusselt number for laminar flow inside a circular tube in the hydrodynamically and thermally developed region is given for the constant wall heat flux and constant wall temperature boundary conditions. Therefore, the heat transfer coefficients for these two cases are determined as follows:

Heating by condensing steam:

$$h = 3.66\frac{k}{D} = 3.66\frac{0.03\ \mathrm{W/(m \cdot s)}}{0.025\ \mathrm{m}}$$

$$= 4.39\ \mathrm{W/(m^2 \cdot {}^\circ C)}$$

Electric resistance heating:

$$h = 4.364\frac{k}{D} = 4.364\frac{0.03\ \mathrm{W/(m \cdot s)}}{0.025\ \mathrm{m}}$$

$$= 5.24\ \mathrm{W/(m^2 \cdot {}^\circ C)}$$

Example -2 Air at atmospheric pressure and with a mean velocity of $V =$ 0.5 m/s flows inside thin-walled, square cross-section ducts of sides $b = 2.5$ cm. The air is heated from the walls of the duct, which are maintained at a uniform temperature by condensing steam on the outside surface. Calculate the friction factor and the heat transfer coefficient in the hydrodynamically and thermally developed region. Air properties can be evaluated at 350 K.

SOLUTION The air properties at 350 K are

$$\nu = 20.76 \times 10^{-6}\ \text{m}^2/\text{s} \qquad k = 0.03\ \text{W/(m}\cdot\text{s)}$$

The hydraulic diameter of the duct is

$$D_H = \frac{4b^2}{4b} = b = 2.5\ \text{cm}$$

and the Reynolds number becomes

$$\text{Re} = \frac{V D_h}{\nu} = \frac{(0.5)(0.025)}{20.76 \times 10^{-6}} = 602$$

From Table for a square duct we obtain

$$f\ \text{Re} = 56.91$$

$$f = \frac{56.91}{602} = 9.45 \times 10^{-2}$$

and **for constant wall tempeature**

$$\text{Nu}_T = 2.976$$

$$h = 2.976 \frac{k}{D_h} = 2.976 \frac{0.03\ \text{W/(m}\cdot{}^\circ\text{C)}}{0.025\ \text{m}} = 3.57 \frac{\text{W}}{\text{m}^2\cdot{}^\circ\text{C}}$$

Example 3 Determine the hydrodynamic and the thermal entrance lengths in terms of the tube inside diameter D for flow at a mean temperature T_m = 60°C and Re = 200 inside a circular tube for mercury, air, water, ethylene glycol, and engine oil, under constant wall heat flux boundary condition.

SOLUTION The hydrodynamic entrance length $x_{fd,h}$ for laminar flow inside a circular tube, is obtained as

$$x_{fd,h} = 0.05 \ \mathrm{Re}\, D$$
$$= (0.05)(200)D \cong 10\ D$$

The thermal entrance length, given heat transfer under the constant wall heat flux boundary condition, is given as

$$x_{fd,t} = 0.05 \ \mathrm{Re\,Pr}\, D$$
$$= (0.05)(200)\ \mathrm{Pr}\, D = 10\ \mathrm{Pr}\, D$$

Example -4 Ethylene glycol at 60°C, with a velocity of V= 4 cm/s, enters the 6-m-long, heated section of a thin-walled, 2.5-cm-ID tube, after passing through an isothermal calming section. In the heated part, the tube wall is maintained at a uniform temperature $T_w = 100°C$ by condensing steam on the outer surface of the tube. Calculate the exit temperature of ethylene glycol.

SOLUTION The Reynolds number should be determined to establish whether the flow is laminar or turbulent. The mean fluid temperature inside the tube cannot be calculated yet because the fluid exit temperature is not known. Therefore, we start by evaluating the physical properties of the fluid at the inlet temperature 60°C. We obtain

$$c_p = 2562 \text{ J/(kg} \cdot °\text{C)} \qquad \rho = 1088 \text{ kg/m}^3$$

$$\nu = 4.75 \times 10^{-6} \text{ m}^2\text{/s} \qquad k = 0.26 \text{ W/(m} \cdot °\text{C)} \qquad \text{Pr} = 51$$

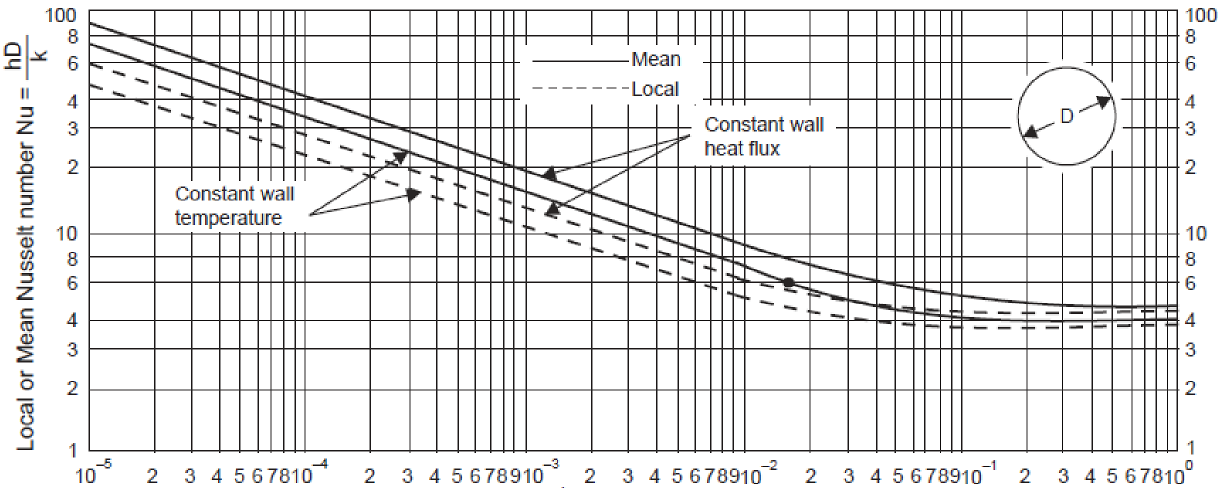
Then

$$\text{Re} = \frac{u_m D}{\nu} = \frac{(0.04)(0.025)}{4.75 \times 10^{-6}} = 210$$

and the flow is laminar. In the heat transfer section, the flow can be regarded as thermally developing but hydrodynamically developed, because there is an isothermal calming section, and for fluids with high Prandtl number the hydrodynamic entrance length is short compared with the thermodynamic entrance length, as illustrated before Therefore, Figure can be used to calculate the mean Nusselt number.

See figure on next page

This means that (a) velocity profile fully developed (b) temperature profile is developing and this a thermal entrance problem.



$$\frac{1}{Gz} = \left(\frac{z}{D}\right)\frac{1}{Re_D\ Pr}$$

First, we calculate the parameter

$$\frac{z\ /D}{\text{Re Pr}} = \frac{600/2.5}{(210)(51)} = 0.0224$$

Second, the mean Nusselt number for constant wall temperature, with $(x/D)/(\text{Re Pr}) = 0.0224$, is determined from figure as

$$\overline{Nu}_D = \frac{\bar{h}\ D}{k} \cong 5.5$$

$$\bar{h} = 5.5\frac{k}{D} = 5.5\frac{0.26}{0.025} = 57.2\ \text{W/(m}^2\cdot{}^\circ\text{C)}$$

To calculate the outlet temperature T_{mo} we consider an overall energy balance for the length L of the tube, stated as

$$\begin{pmatrix}\text{Heat supplied to}\\ \text{fluid from wall}\end{pmatrix} = \begin{pmatrix}\text{energy removed by}\\ \text{fluid by convection}\end{pmatrix}$$

$$\bar{h}\ (\pi DL)\ \Delta T_m = \left(\frac{\pi}{4}D^2\right)(\text{v}\ \rho c_p)(T_{mo} - T_{mi}) \qquad (a)$$

Here $\Delta T_m = \Delta T_{LMTD}$ is the logarithmic mean temperature difference and it becomes

That is, let

$$\Delta T_1 \equiv T_w - T_{mi} = \text{inlet temperature difference}$$

$$\Delta T_2 \equiv T_w - T_{mo} = \text{outlet temperature difference}$$

Then the logarithmic mean temperature difference becomes

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{T_{mo} - T_{mi}}{\ln[(T_w - T_{mi})/(T_w - T_{mo})]} \qquad (b)$$

ar

as ΔT_m is introduced into Eq. (*a*).

$$\bar{h}\,(\pi DL)\frac{T_{mo} - T_{mi}}{\ln[(T_w - T_{mi})/(T_w - T_{mo})]} = \left(\frac{\pi}{4}D^2\right)(\mathrm{V}\,\rho c_p)(T_{mo} - T_{mi})$$

or

$$\ln\frac{T_w - T_{mi}}{T_w - T_{mo}} = \frac{4L\bar{h}}{D\,\mathrm{V}\,\rho c_p}$$

$$\frac{T_w - T_{mi}}{T_w - T_{mo}} = \exp\left(\frac{4L\bar{h}}{D\,\mathrm{V}\,\rho c_p}\right) \qquad (c)$$

The numerical values are substituted:

$$\frac{100 - 60}{100 - T_{out}} = \exp\left(\frac{4 \times 6 \times 57.2}{0.025 \times 0.04 \times 1088 \times 2562}\right)$$

$$\frac{40}{100 - T_{mo}} = 1.636$$

$$T_{mo} = 75.6°\mathrm{C}$$

Next step is to evaluate the fluid properties at the mean temperature $\bar{T}_m = \frac{(T_{mi} + T_{mo})}{2}$ and repeat the calculations and compare the new T_{mo} with the old one.

The results can be improved by computing the physical properties at the bulk fluid temperature $(T_{mi} + T_{mo})/2 = (60 + 75.6)/2 = 68°\mathrm{C}$, but the improvement would be very little, that is, $T_{mo} = 75.4°\mathrm{C}$.

Example 5 Engine oil is cooled from T_{mi}= 120°C to T_{mo} = 80°C while it is flowing with a mean velocity of V= 0.04 m/s through a circular tube of inside diameter 2.5 cm. The tube wall is maintained at a uniform temperature T_w = 40°C. As soon as the enine oil enters the tube, cooling begins. Determine length L.

Solution

From the problem statement that it is clear that this is a combined entrance length problem. That velocity and temperature profile are developing together.

The physical properties of oil at the bulk mean temperature

$$\bar{T}_m = \frac{T_{mi} + T_{mo}}{2} = \frac{120 + 80}{2} = 100°C$$

are taken as

$$c_p = 2200 \text{ J/(kg} \cdot °\text{C)} \qquad \rho = 840 \text{ kg/m}^3 \qquad \text{Pr} = 276$$

$$\nu = 0.2 \times 10^{-4} \text{ m}^2/\text{s} \qquad k = 0.137 \text{ W/(m} \cdot °\text{C)}$$

Then the Reynolds number becomes

$$\text{Re} = \frac{V D}{\nu} = \frac{(0.04)(0.025)}{0.2 \times 10^{-4}} = 50$$

hence the flow is laminar since Re< 2300 .

We treat this problem as an entrance region heat transfer problem of simultaneously developing flow.

Determine the Nusselt number. However, to perform these calculations, we need the Gratz number

$$\text{Gz} = \frac{\text{Re} \cdot \text{Pr}}{L/D} = \frac{(50)(276)}{L/D} = \frac{13{,}800}{L/D} \qquad (a)$$

Here, since the tube length L is unknown, Gz cannot be determined.

Another relation is obtained by writing an overall energy balance for L as

$$\left(\frac{\pi}{4}D^2\right)(\rho \, V \, c_p)(T_{mi} - T_{mo}) = \bar{h}\,(\pi DL)\,\Delta T_m \qquad (b)$$

We take ΔT_m as the logarithmic means of $T_{mi} - T_w$ and $T_{mo} - T_w$; that is,

$$\Delta T_m = \frac{(T_{mi} - T_w) - (T_{mo} - T_w)}{\ln[(T_{mi} - T_w)/(T_{mo} - T_w)]} = \frac{T_{mi} - T_{mo}}{\ln[(T_{mi} - T_w)/(T_{mo} - T_w)]} \qquad (c)$$

Equation (b) is rearranged in terms of dimensionless parameters:

$$\text{Re Pr}(\tfrac{1}{4})(T_{mi} - T_{mo}) = \overline{\text{Nu}}_D\left(\frac{L}{D}\right)\Delta T_m \qquad (d)$$

The numerical values are

$$(50)(276)(\tfrac{1}{4})(120 - 80) = \overline{\text{Nu}}_D\left(\frac{L}{D}\right)\Delta T_m$$

where

$$\Delta T_m = \frac{120 - 80}{\ln[(120 - 40)/(80 - 40)]} = 57.71$$

Or, solving for $\overline{\text{Nu}}_D$ we obtain

$$\overline{\text{Nu}}_D = \frac{2391.3}{L/D} \qquad (e)$$

At this point we need another equation. This can be

1) Hausen Correlation

This relation can also be used for combined entry length problem

$$\overline{\text{Nu}}_D = 3.66 + \frac{0.00668\text{Gz}_D}{1 + 0.04\text{Gz}_D^{2/3}}$$

$T_w =$ **constant**

$$Gz_D = \frac{L / D}{Re_D \, Pr}$$

$$Pr \geq 5$$

$$\overline{Nu}_D = \frac{\bar{h} D}{k}$$

2) Sider and Tate

$$\overline{Nu}_D = 1.86 \left[\left(\frac{D}{L} \right) Re_D \, Pr \right]^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

$$\left[\left(\frac{D}{L} \right) Re_D \, Pr \right]^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14} > 0.2 \quad \text{or} \quad \left(\frac{D}{L} \right) Re_D \, Pr > 10$$

$$0.5 < Pr < 16\,700$$

$$0.0044 < \left(\frac{\mu}{\mu_w} \right) < 9.75$$

3)

$$\overline{Nu}_D = \frac{\left[\dfrac{3.66}{\tanh\left[2.264g \, Gz_D^{-1/3} + 1.7 Gz_D^{-2/3} \right]} + 0.0499 Gz_D \tanh\left(Gz_D^{-1} \right) \right]}{\tanh\left(2.432 \, Pr^{1/6} \, Gz_D^{-1/6} \right)}$$

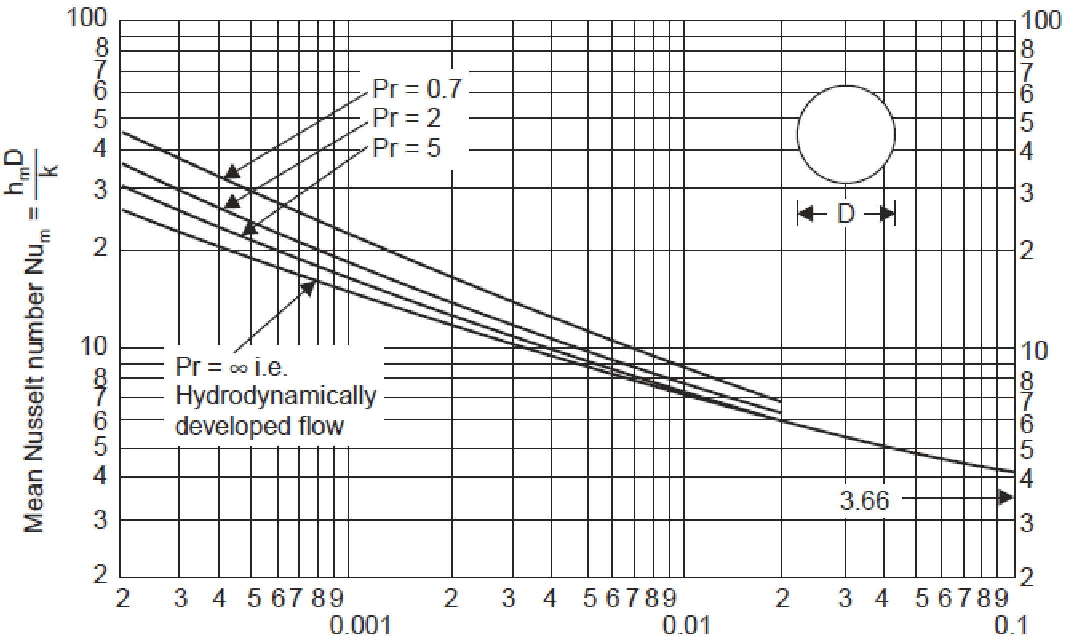
$$T_w = \text{const}$$

combined entry length

$$\mathbf{Pr \gg 0.1}$$

$$\mathbf{Gz}_D = \frac{D}{z} Re_D \, Pr$$

4)



$$\frac{1}{Gz} = \left(\frac{z}{D}\right)\frac{1}{Re_D\,Pr} \qquad T_w = \text{const}$$

Equations (*a*) and (*e*) can be used in conjunction with the appropriate correlation for the Nusselt number, and the two unknowns L/D and $\overline{Nu}_D$ can be found.

We use the Sieder and Tate equations for this purpose. Introducing Eqs. (*a*) and (*e*) into **Sieder Tate equation** **we obtain**

$$\frac{2391.3}{L/D} = 1.86\left(\frac{13{,}800}{L/D}\right)^{1/3}\left(\frac{0.17}{0.21}\right)^{0.14}$$

where $\mu = 0.17$ and $\mu_w = 0.21$ are the viscosities evaluated at the fluid bulk mean and the wall temperatures, respectively.

Solving for L/D, we obtain

$$\frac{L}{D} = 410.2 \qquad \text{or} \qquad L = (410.2)(0.025) = 10.3\text{ m}$$

An iterative solution is needed if **figure for combined entrance problem is used.**

Example 6:

Water enters a tube with fully developed velocity and uniform temperature $T_{mi} = 25\,^{0}C$ .The inside diameter of the tube is 1.5 cm and its length is 80 cm. The mass flow rate is 0.002 kg/s.It is desired to heat the water to $75\,^{0}C$ by maintaining the surface at uniform temperature by condensing steam on pipe surface. Determine the pipe surface temperature.

Solution

$$\frac{T_w - T_{mo}(L)}{T_w - T_{mi}} = \exp\left[-\frac{PL}{\dot{m}c_p}\bar{h}\right] \qquad T_w = \text{const}$$

or

$$T_w = \frac{T_{mi} - T_{mo}\exp\left[-\frac{PL}{\dot{m}c_p}\bar{h}\right]}{1-\exp\left[-\frac{PL}{\dot{m}c_p}\bar{h}\right]}$$

We need $\bar{h}$ to find T_w .

$$\bar{T}_m = \frac{(20+80)(^{\circ}C)}{2} = 50^{\circ}C$$

Properties of water at this temperature are

$c_p = 4182$ J/kg-°C
$k = 0.6405$ W/m-°C
$Pr = 3.57$
$\nu = 0.5537\times10^{-6}$ m²/s
$\rho = 988$ kg/m³

$$V = \frac{4\dot{m}}{\rho\pi D^2} = 0.01146\,m/s$$

$$Re_D = \frac{VD}{\nu} = 310.5$$

Hydrodynamic entrance length:

$$z_{fd,h} = 0.05\,Re_D\,D = 0.232\,m$$

Thermal entry length

$z_{fd,t} = 0.05\,Re_D\,D\,Pr = 0.831\,m$

$z_{fd,h} \ll L$ and flow can be treated fully developed hydrodynamically (fully developed velocity profile).Since $z_{fd,t}$ is comparable to tube length, thermal entrance length must be taken into account.

$$\frac{(z/D)}{Re_D\,Pr} = \frac{(0.8/0.015)}{(310.5)(3.57)} = 0.0481$$

From the table we have

$\frac{1}{Gz} = \frac{z/D}{Re_D Pr}$		$\overline{Nu}(\xi)$
0.04		4.86
0.05		4.64

So we compute average Nusselt number $\overline{Nu}_D$ by interpolation

$\overline{Nu}_D$ =4.681

$$\bar{h} = \frac{k}{D}\overline{Nu}_D \simeq 199.87\,W/m^2K$$

$T_w = \mathbf{109.2\,^0C}$

Turbulent Flow

Example 7 Water flows with a mean velocity of $V = 2$ m/s inside a circular pipe of inside diameter $D = 5$ cm. The pipe is of commercial steel, and its wall is maintained at a uniform temperature $T_w = 100°C$ by condensing steam on its outer surface. At a location where the fluid is hydrodynamically and thermally developed, the bulk mean temperature of water is $T_b = 60°C$. Calculate the heat transfer coefficient h.

SOLUTION Various properties for water at $T_b = 60°C$ are taken as

$$\rho = 985 \text{ kg/m}^3 \qquad \mu_b = 4.71 \times 10^{-4} \text{ kg/(m}\cdot\text{s)}$$

$$k = 0.651 \text{ W/(m}\cdot°\text{C)} \qquad \text{Pr} = 3.02$$

and the viscosity at the tube wall temperature $T_w = 100°C$ is

$$\mu_w = 2.82 \times 10^{-4} \text{ kg/(m}\cdot s)$$

Then

$$\text{Re} = \frac{\rho u_m D}{\mu} = \frac{(985)(2)(0.05)}{4.71 \times 10^{-4}} = 2.04 \times 10^5$$

Flow is fully turbulent since $\text{Re}_D > 10000$. Let us use Gnielinski equation

$$\overline{\text{Nu}}_D = \frac{\left[\left(\frac{f}{8}\right)(\text{Re}_D - 1000)\,\text{Pr}\right]}{1 + 12.7\left[\left(\sqrt{\frac{f}{8}}\right)\left(\text{Pr}^{2/3} - 1\right)\right]}$$

$$0.5 \ll \text{Pr} \ll 2000$$

$$3000 \ll \text{Re}_D \ll 5\times10^6$$

Since the pipe is not a smooth pipe we need the relative roughness of the tube we can use Colebrook equation.This equation can be solved using Matlab 2016b command fzero or we can use fsolve in Maple 2016. Colebrook equation is given as

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{\text{Re}_D\sqrt{f}}\right)$$

Note that logarithm in this equation is a base 10!!

Relative roughness is

$$\frac{\varepsilon}{D} = \frac{0.0045}{5} = 0.0009$$

Le us use Maple 2016

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> restart;
>
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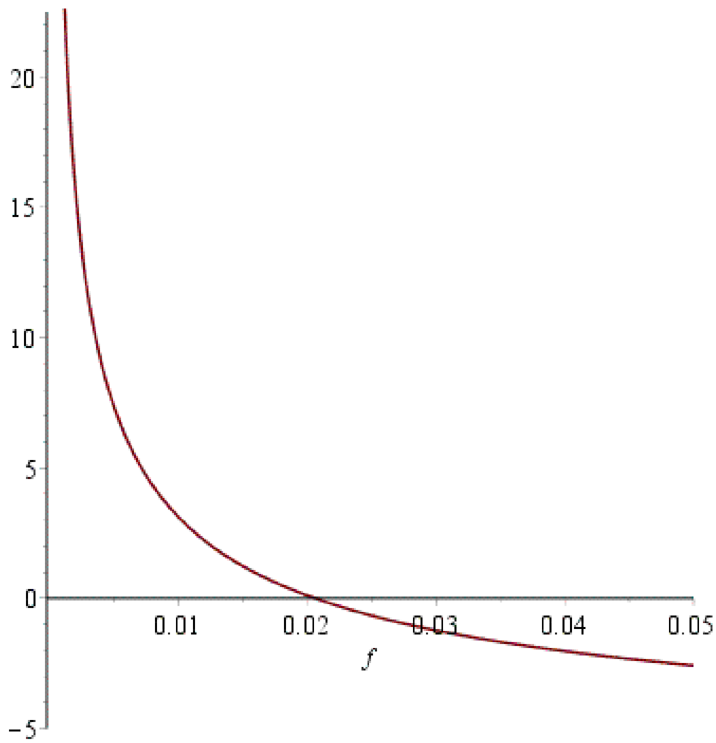
$$> \ eq := \frac{1}{\sqrt{f}} + 2.0 \cdot \log 10\left(\frac{0.0009}{3.7} + \frac{2.51}{2.04 \cdot 10^{5} \cdot \sqrt{f}}\right);$$

$$eq := \frac{1}{\sqrt{f}} + \frac{2.0 \ln\left(0.0002432432432 + \frac{0.00001230392157}{\sqrt{f}}\right)}{\ln(10)}$$

$$> \ plot(eq, f = 0.0001 ..0.05);$$



$$> \ fsolve(eq, f = 0.01 ..0.03);$$

$$0.02060939230$$

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>
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$$\overline{Nu}_D = \frac{\left[\left(\frac{f}{8}\right)(Re_D - 1000)\,Pr\right]}{1+12.7\left[\left(\sqrt{\frac{f}{8}}\right)\left(Pr^{2/3}-1\right)\right]} = \frac{\left[\left(\frac{0.0206}{8}\right)\left(2.04\times10^5 - 1000\right)(3.02)\right]}{1+12.7\left[\left(\sqrt{\frac{0.0206}{8}}\right)\left(3.02^{2/3}-1\right)\right]} = 943.8$$

$$\bar{h} = Nu_D \frac{k}{D} = (943.8)\left(\frac{0.651}{0.05}\right) = 12\,288\ W/m^2K$$

Example 8: Water flows with a mean velocity of V=2 m/s inside a circular pipe of inside diameter D=5 cm. The pipe is smooth pipe and its wall is maintained at a uniform temperature $T_w = 100\,^0C$ by condensing steam on its outer surface. At a location where fluid is hydrodynamically and thermally fully developed, the bulk temperature of water is $T_m = 60\,^0C$ .Calculate the heat transfer coefficient.

Solution The physical properties at $T_b = 60°C$ are taken as

$$k = 0.651\ W/(m \cdot °C) \qquad Pr = 3.02 \qquad Re = 2.04 \times 10^5$$

$$\mu_b = 4.71 \times 10^{-4}\ kg/(m \cdot s) \qquad \mu_w = 2.82 \times 10^{-4}\ kg/(m \cdot s)$$

The friction factor for smooth pipe at $Re = 2.04 \times 10^5$ is obtained from

$$f = \frac{1}{\left[0.79 \ln(Re_D) - 1.64\right]^2}$$

$$3000 \le Re_D \le 5\times10^6$$

$$f = \frac{1}{\left[0.79 \ln(Re_D) - 1.64\right]^2} = \frac{1}{\left[0.79 \ln(2.04\times10^5) - 1.64\right]^2} = 0.0152$$

1) Gnielnski correlation

$$\overline{Nu}_D = \frac{\left[\left(\frac{f}{8}\right)(Re_D - 1000)\,Pr\right]}{1 + 12.7\left[\left(\sqrt{\frac{f}{8}}\right)(Pr^{2/3} - 1)\right]} = \frac{\left[\left(\frac{0.0152}{8}\right)(2.04\times10^5 - 1000)\,Pr\right]}{1 + 12.7\left[\left(\sqrt{\frac{0.0152}{8}}\right)(3.02^{2/3} - 1)\right]} = 740.3$$

$$\bar{h} = \frac{k}{D}\overline{Nu}_D = \left(\frac{0.651}{0.05}\right)(743.4) = 9638.7\ W/m^2K$$

b) Sider Tate Equation

$$\overline{Nu}_D = 0.027\,Re_D^{4/5}\,Pr^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$0.7 \geq Pr \geq 16\,700$$

$$Re_D \geq 10\,000$$

$$\frac{L}{D} \geq 10$$

$$\mathbf{Nu = 0.027(2.04 \times 10^5)^{0.8}(3.02)^{1/3}\left(\frac{4.71}{2.82}\right)^{0.14}}$$

Then $\quad \mathbf{Nu = 704}$

$$\boldsymbol{h = 704\,\frac{0.651}{0.05} = 9166\ W/(m^2 \cdot {}^\circ C)}$$

c) the Notter and Sleicher

For hydrodynamically and thermally fully developed turbulent flow

$$\overline{Nu}_D = 5 + 0.016\,Re_D^a\,Pr^b$$

$$a = 0.88 - \frac{0.24}{4 + Pr}$$

$$b = 0.33 + 0.5\exp(-0.6\,Pr)$$

$$0.1 \ll Pr \ll 10^4$$

$$10^4 \ll Re_D \ll 10^6$$

$$\frac{L}{D} > 25$$

All fluid properties are evaluated at mean temperature $\overline{T}_m = \frac{1}{2}(T_{mi} + T_{mo})$

$$a = 0.88 - \frac{0.24}{4 + \mathrm{Pr}} = 0.88 - \frac{0.24}{4 + 3.02} = 0.846$$

$$b = 0.33 + 0.5e^{-0.6\,\mathrm{Pr}} = 0.412$$

$$\mathrm{Nu} = 5 + 0.016(2.04 \times 10^5)^{0.846}(3.02)^{0.412}$$

$$= 788$$

$$h = 788\,\frac{0.651}{0.05} = 10{,}267\ \mathrm{W/(m^2 \cdot {}^\circ C)}$$

c) **Dittus-Boelter equation**

For hydodynamically and thermally fully developed turbulent flow in a circular smooth tube, the Nusselt number is given by Dittus-Boelter equation

$$\overline{\mathrm{Nu}}_D = 0.023\,\mathrm{Re}_D^{0.8}\,\mathrm{Pr}^n$$

$$0.6 \geq \mathrm{Pr} \geq 160$$

$$\mathrm{Re}_D \geq 10\,000$$

$$\frac{L}{D} \geq 10$$

$$\mathrm{Nu} = 0.023(2.04 \times 10^5)^{0.8}(3.02)^{0.4}$$

$$= 633$$

$$h = 633\,\frac{0.651}{0.05} = 8242\ \mathrm{W/(m^2 \cdot {}^\circ C)}$$