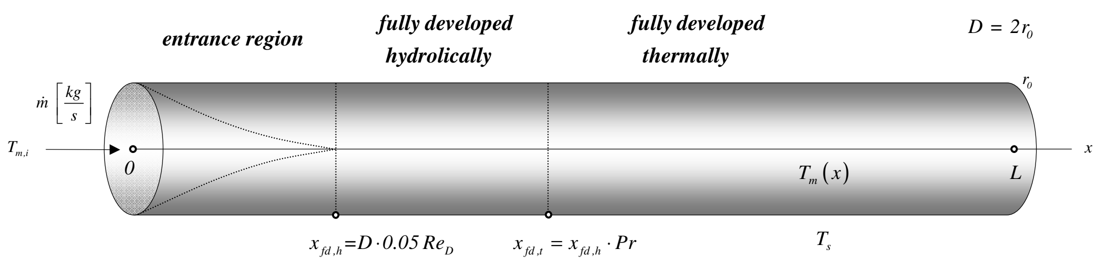
INTERNAL FLOW – CORRELATIONS – LAMINAR

circular tube

LAMINAR $Re_D < 2300$



averaged mean temperature of the fluid

properies at $\bar{T}_m = \frac{T_{m,i} + T_{m,o}}{2}$

μ_s **at** T_s

criterium for fully developed conditions

$$S = \left[\frac{Re_D \cdot Pr}{L/D}\right]^{1/3} \cdot \left[\frac{\mu}{\mu_s}\right]^{0.14}$$

$$Re_D = \frac{\rho u_m D}{\mu} = \frac{4\dot{m}}{\pi \mu D}$$

$$Nu_D = \frac{hD}{k}$$

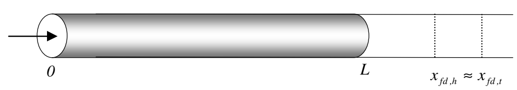
$$h = \frac{k \cdot Nu_D}{D}$$

Developing Flow $S \geq 2$

combined entry length

velocity and temperature profiles are deloping simulteneously

$x_{fd,h} \approx x_{fd,t} \geq L$



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

for $T_s = const$

$0.48 < Pr < 16{,}700$

$0.0044 < \frac{\mu}{\mu_s} < 9.75$

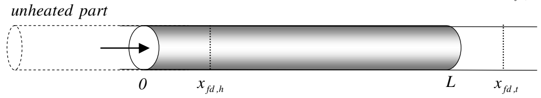
thermal entry length

velocity profile is developed
temperature profile is developing

$x_{fd,h} < L$

$x_{fd,t} \geq L$

unheated part



(8.56) $$\overline{Nu}_D = 3.66 + \frac{0.0668 \cdot \frac{Re_D \cdot Pr}{L/D}}{1 + 0.04\left[\frac{Re_D \cdot Pr}{L/D}\right]^{2/3}}$$

for $T_s = const$

also good gor large Pr > 5 (oils)

Fully Developed Flow $S < 2$

$$\bar{h} = h_x = const$$

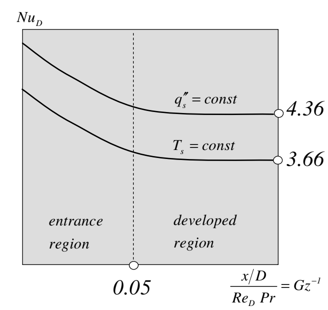
$$\overline{Nu}_D = Nu_D = const$$

$q_s'' = const$

(8.53) $$Nu_D = 4.36$$

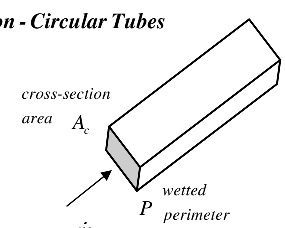
$T_s = const$

(8.55) $$Nu_D = 3.66$$



$$h = \frac{k \cdot Nu_D}{D}$$

Non - Circular Tubes



$$u_m = \frac{\dot{m}}{\rho A_c}$$

Hydrolic Diameter:

$$D_h = \frac{4 A_c}{P}$$

$$Re_{D_h} = \frac{\rho u_m D_h}{\mu} = \frac{4\dot{m}}{\mu P}$$

$Re_{D_h} < 2300$ laminar $\Rightarrow$ Table 8.1

$Re_{D_h} > 2300$ turbulent $\Rightarrow$ Use (8.61) with $Pr \geq 0.7$

TABLE 8.1 Nusselt numbers and friction factors for fully developed laminar flow in tubes of differing cross section

Cross Section	$\frac{b}{a}$	$Nu_D = \frac{hD_h}{k}$ (Uniform q_s'')	(Uniform T_s)	$f\,Re_{D_h}$
	—	4.36	3.66	64
a, b	1.0	3.61	2.98	57
a, b	1.43	3.73	3.08	59
a, b	2.0	4.12	3.39	62
a, b	3.0	4.79	3.96	69
a, b	4.0	5.33	4.44	73
b	8.0	6.49	5.60	82
	∞	8.23	7.54	96
Heated / Insulated	∞	5.39	4.86	96
	—	3.11	2.49	53

Used with permission from W. M. Kays and M. E. Crawford, *Convection Heat and Mass Transfer,* 3rd ed. McGraw-Hill, New York, 1993.