

would preclude the existence of a fully developed region. There may also exist surface roughness effects, circumferential heat flux or temperature variations, widely varying fluid properties, or transition flow conditions. For a complete discussion of these effects, the literature should be consulted [12, 13, 18, 20, 27].

TABLE 8.4 Summary of convection correlations for flow in a circular tube^{a,d}

Correlation	Conditions
$f = 64/Re_D$	(8.19) Laminar, fully developed
$Nu_D = 4.36$	(8.53) Laminar, fully developed, uniform q_s''
$Nu_D = 3.66$	(8.55) Laminar, fully developed, uniform T_s
$\overline{Nu}_D = 3.66 + \frac{0.0668 Gz_D}{1 + 0.04 Gz_D^{2/3}}$	(8.57) Laminar, thermal entry (or combined entry with $Pr \geq 5$), uniform T_s , $Gz_D = (D/x) Re_D Pr$
$\overline{Nu}_D = \frac{3.66}{\tanh[2.264 Gz_D^{-1/3} + 1.7 Gz_D^{-2/3}]} + 0.0499 Gz_D \tanh(Gz_D^{-1})$ $\tanh(2.432 Pr^{1/6} Gz_D^{-1/6})$	(8.58) Laminar, combined entry, $Pr \geq 0.1$, uniform T_s , $Gz_D = (D/x) Re_D Pr$
$\frac{1}{\sqrt{f}} = -2.0 \log \left[\frac{e/D}{3.7} + \frac{2.51}{Re_D \sqrt{f}} \right]$	(8.20) ^b Turbulent, fully developed <i>This is mostly reverse relation</i>
$f = (0.790 \ln Re_D - 1.64)^{-2}$	(8.21) ^b Turbulent, fully developed, smooth walls, $3000 \leq Re_D \leq 5 \times 10^6$
$Nu_D = 0.023 Re_D^{4/5} Pr^n$	(8.60) ^c Turbulent, fully developed, $0.6 \leq Pr \leq 160$, $Re_D \geq 10,000$, $(L/D) \geq 10$, $n = 0.4$ for $T_s > T_m$ and $n = 0.3$ for $T_s < T_m$
$Nu_D = 0.027 Re_D^{4/5} Pr^{1/3} \left(\frac{\mu}{\mu_s} \right)^{0.14}$	(8.61) ^c Turbulent, fully developed, $0.7 \leq Pr \leq 16,700$, $Re_D \geq 10,000$, $L/D \geq 10$
$Nu_D = \frac{(f/8)(Re_D - 1000) Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)}$	(8.62) ^c Turbulent, fully developed, $0.5 \leq Pr \leq 2000$, $3000 \leq Re_D \leq 5 \times 10^6$, $(L/D) \geq 10$
$Nu_D = 4.82 + 0.0185(Re_D Pr)^{0.827}$	(8.64) Liquid metals, turbulent, fully developed, uniform q_s'' , $3.6 \times 10^2 \leq Re_D \leq 9.05 \times 10^5$, $3 \times 10^{-3} \leq Pr \leq 5 \times 10^{-2}$, $10^2 \leq Re_D Pr \leq 10^4$
$Nu_D = 5.0 + 0.025(Re_D Pr)^{0.8}$	(8.65) Liquid metals, turbulent, fully developed, uniform T_s , $Re_D Pr \geq 100$

^aProperties in Equations 8.53, 8.55, 8.60, 8.61, 8.62, 8.64, and 8.65 are based on T_m ; properties in Equations 8.19, 8.20, and 8.21 are based on $T_f = (T_s + T_m)/2$; properties in Equations 8.57 and 8.58 are based on $\bar{T}_m = (T_{m,i} + T_{m,o})/2$.

^bEquation 8.20 pertains to smooth or rough tubes. Equation 8.21 pertains to smooth tubes.

^cAs a first approximation, Equations 8.60, 8.61, or 8.62 may be used to evaluate the average Nusselt number \overline{Nu}_D over the entire tube length, if $(L/D) \geq 10$. The properties should then be evaluated at the average of the mean temperature, $\bar{T}_m = (T_{m,i} + T_{m,o})/2$.

^dFor tubes of noncircular cross section, $Re_D \equiv D_h \mu_m / \nu$, $D_h \equiv 4A_c/P$, and $\mu_m = \mu / \rho A_c$. Results for fully developed laminar flow are provided in Table 8.1. For turbulent flow, Equation 8.60 may be used as a first approximation.