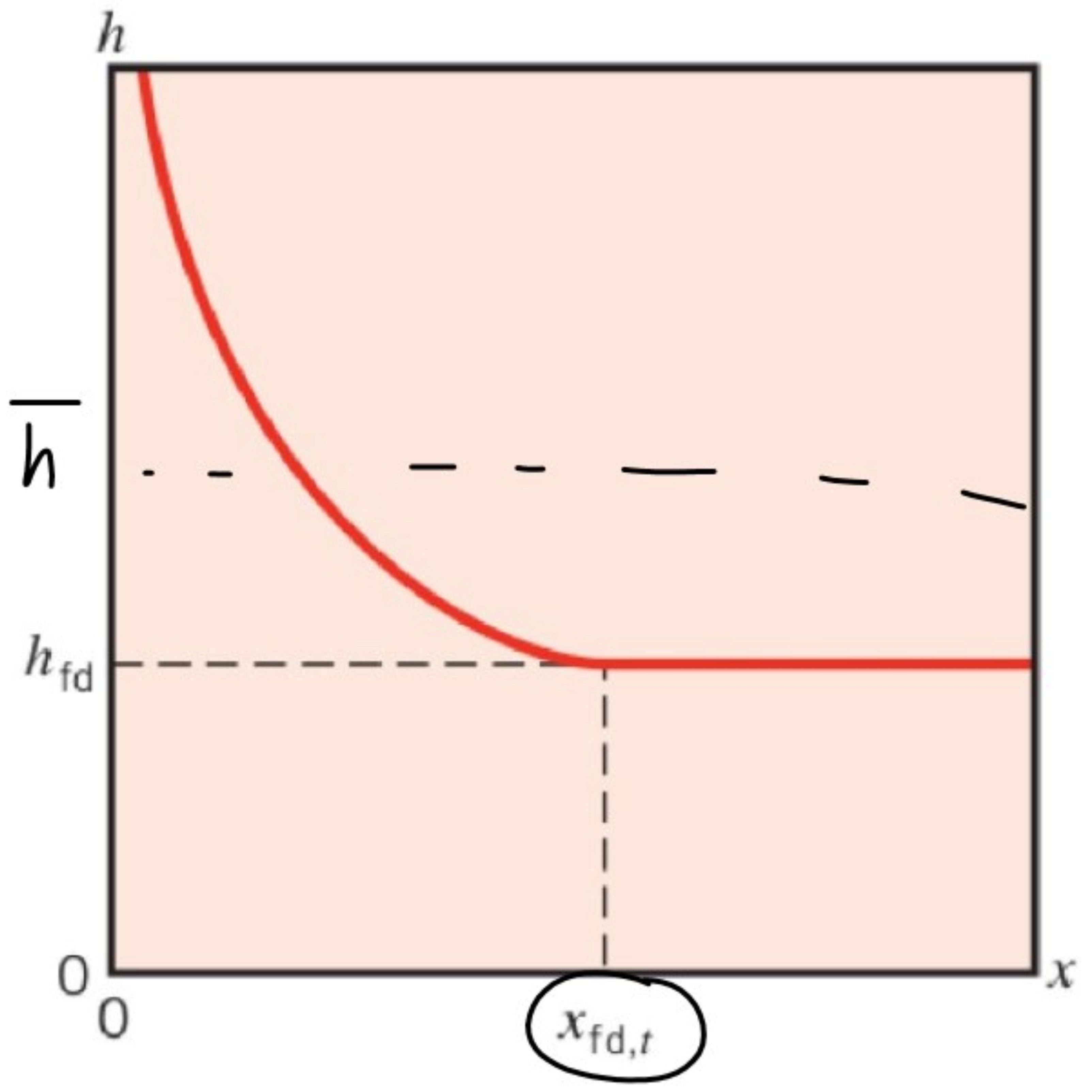


h
$\overline{h}$
h_{fd}
0
0
$x_{fd,t}$
x

$$\frac{T_s - T_m(x)}{T_s - T_{m,i}} = \exp\left(-\frac{Px}{\dot{m} c_p} \bar{h}(x)\right)$$

$$\frac{\Delta T_o}{\Delta T_i} = \frac{T_s - T_{m,o}}{T_s - T_{m,i}} = \exp\left(-\frac{PL}{\dot{m} c_p} \bar{h}\right)$$

$$q_{conv} = \bar{h} A_s \Delta T_{lm}$$

$$\Delta T_{lm} = \frac{\Delta T_o - \Delta T_i}{\ln(\Delta T_o / \Delta T_i)}$$

T_s surface temp constant

$T_{m,i}$ mean fluid input temp

$T_m(x)$ mean fluid temp at x

$T_{m,o}$ mean fluid output temp

ΔT_{lm} log mean temperature difference

For fully developed thermal boundary layer

$Nu_D = 4.36$ $\qquad q_s'' = const$

$Nu_D = \frac{hD}{k} = 3.66$ $\qquad T_s = const$

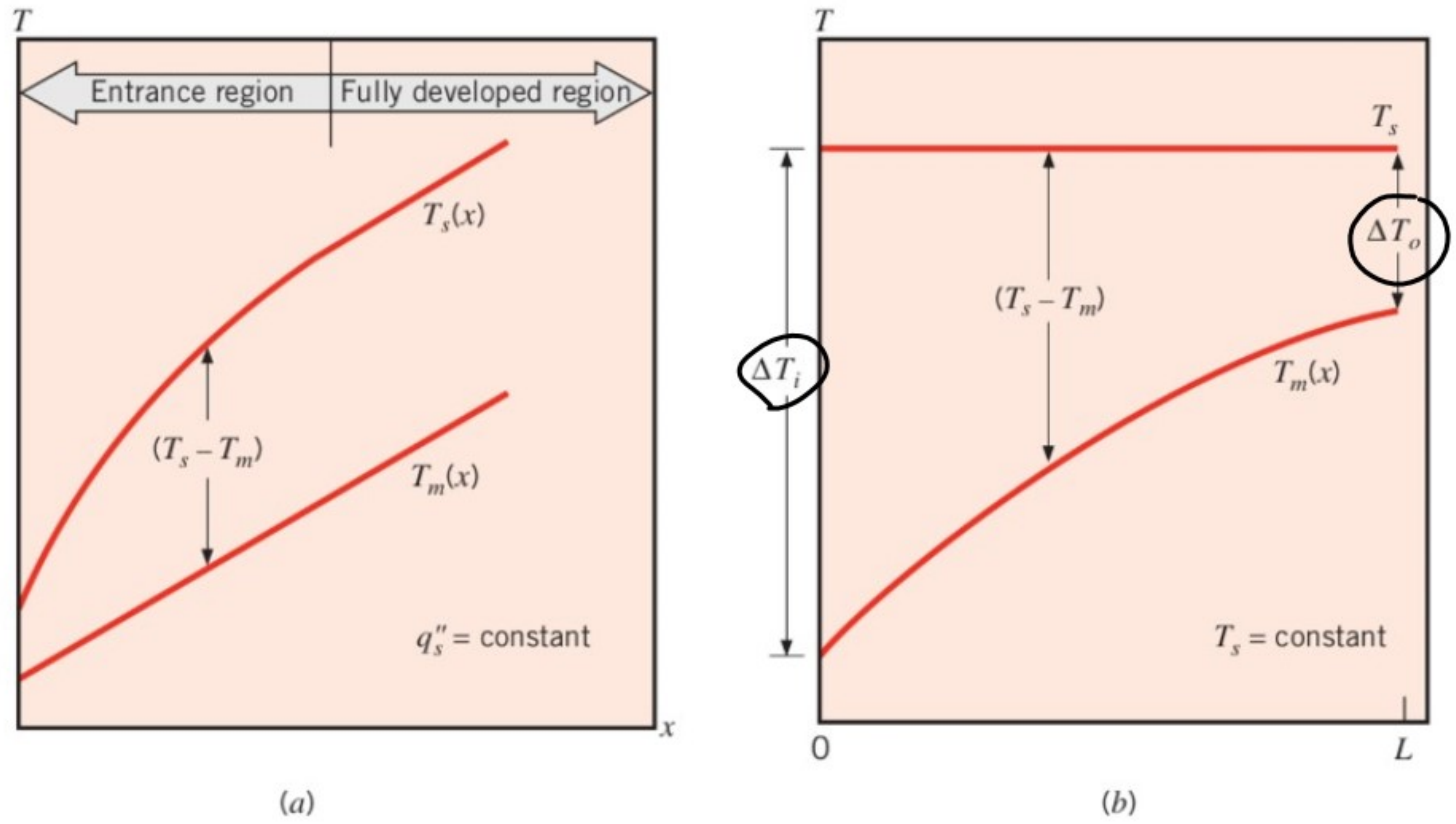
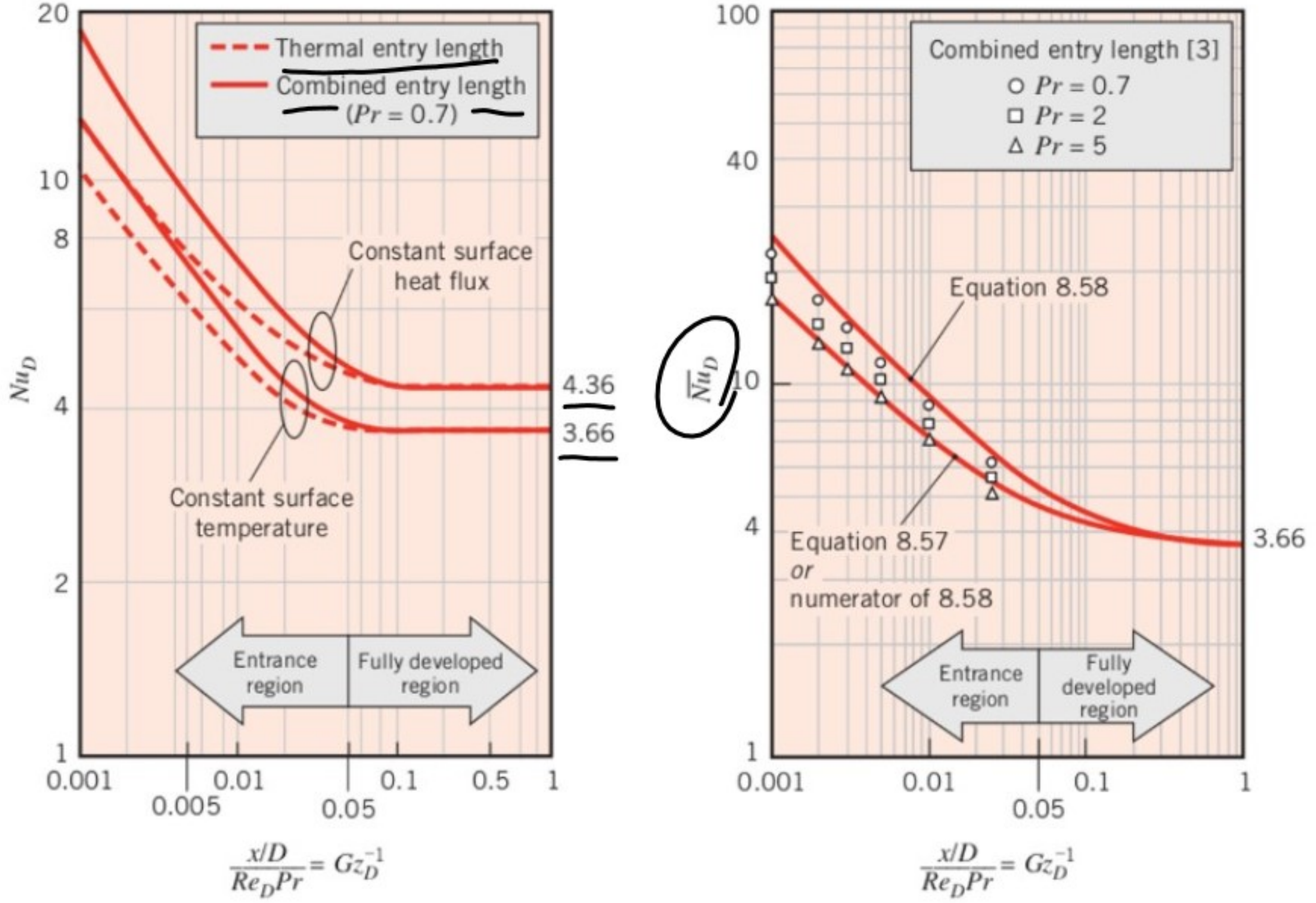


FIGURE 8.7 Axial temperature variations for heat transfer in a tube. (*a*) Constant surface heat flux. (*b*) Constant surface temperature.



Thermal entry length
Combined entry length
(Pr = 0.7)
Constant surface heat flux
Constant surface temperature
4.36
3.66
Entrance region
Fully developed region
Nu_D
20
10
8
4
2
1
0.001
0.005
0.01
0.05
0.1
0.5
1
x/D / Re_D Pr = Gz_D^-1
Combined entry length [3]
Pr = 0.7
Pr = 2
Pr = 5
Equation 8.58
Equation 8.57
or
numerator of 8.58
3.66
Nu_D
100
40
10
4
1
Entrance region
Fully developed region
0.001
0.01
0.05
0.1
1
x/D / Re_D Pr = Gz_D^-1

$$Gz_D = \frac{D}{x} Re_D Pr$$

$$\overline{Nu_D} = 3.66 + \frac{0.0668\, Gz_D}{1 + 0.04\, Gz_D^{2/3}}$$

T_s const

if combined entry $Pr > 5$

$$\overline{Nu_D} = \frac{\dfrac{3.66}{\tanh(2.264\, Gz_D^{-1/3} + 1.7\, Gz_D^{-2/3})} + 0.0499\, Gz_D \tanh(Gz_D^{-1})}{\tanh(2.432\, Pr^{1/6}\, Gz_D^{-1/6})}$$

T_s const

if combined entry

$Pr > 0.1$

So far all for laminar flow