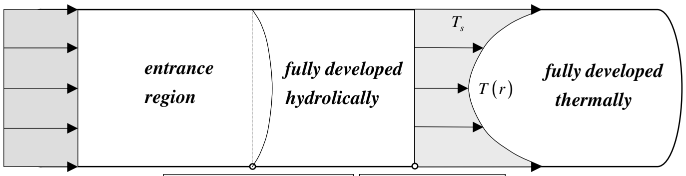
INTERNAL FLOW – THERMAL ANALYSIS

circular tube

all properties at averaged mean temperature $\bar{T}_m = \frac{T_{m,i}+T_{m,o}}{2}$

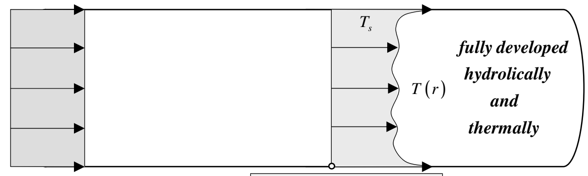
$$Re_D = \frac{u_m D}{\nu} = \frac{\rho u_m D}{\mu} = \frac{4\dot{m}}{\mu \pi D}$$

LAMINAR $Re_D < 2300$

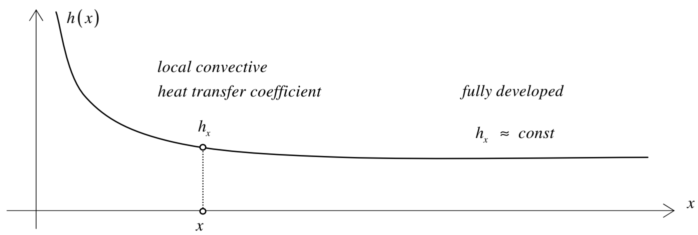


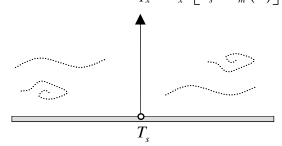
$x_{fd,h} = D \cdot 0.05 \cdot Re_D$ $\quad x_{fd,t} = x_{fd,h} \cdot Pr$

TURBULENT $Re_D > 2300$



$x_{fd,t} = x_{fd,h} = 10 \cdot D$



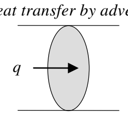


mean temperature

$$q''_x = h_x \cdot \left[T_s - T_m(x)\right] = k_f \left.\frac{\partial T}{\partial r}\right|_{r=r_0}$$

local convective heat flux

heat transfer by advection



$$q = \int_{A_c} \rho c_p T u dA_c = \rho c_p T_m \int_{A_c} u dA_c = \rho c_p T_m A_c \frac{\int_{A_c} u dA_c}{A_c} = \rho c_p T_m A_c u_m = \dot{m} c_p T_m$$

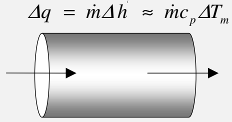
mean temperature

$$T_m = \frac{\int_{A_c} \rho u c_p T dA_c}{\dot{m} c_p} \quad \text{circular pipe} \quad = \frac{2}{u_m r_0^2}\int_0^{r_0} uTr dr$$

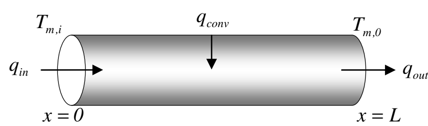
Thermodynamics:

$$\Delta q = \dot{m} \Delta h \approx \dot{m} c_p \Delta T_m$$

(enthalpy)



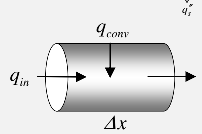
Energy balance for entire pipe



$$q_{conv} = q_{in} - q_{out}$$

$$q_{conv} = \dot{m} c_p \left(T_{m,o} - T_{m,i}\right) \quad (8.34)$$

$$\dot{m} c_p \left[T_m(x+\Delta x) - T_m(x)\right] = \underbrace{h_x \left[T_s - T_m(x)\right]}_{q''_s} \cdot \underbrace{(P \cdot \Delta x)}_{A_s}$$



$$\frac{T_m(x+\Delta x) - T_m(x)}{\Delta x} = h_x \left[T_s - T_m(x)\right] \cdot \frac{P}{\dot{m} c_p}$$

Heat Transfer Equation for T_m (8.37)

$$\frac{dT_m}{dx} = q''_s \frac{P}{\dot{m} c_p} \quad \text{if } q''_s \text{ is specified}$$

$$\frac{dT_m}{dx} = \frac{h_x P}{\dot{m} c_p}\left[T_s - T_m(x)\right] \quad \text{if } T_s \text{ is specified}$$

Initial condition $T_m(0) = T_{m,i}$

$q''_s = const$

$$\frac{dT_m}{dx} = \frac{q''_s P}{\dot{m} c_p} \qquad T_m(0) = T_{m,i}$$

Mean temperature distribution of fluid in a pipe:

$$T_m(x) = T_{m,i} + \frac{q''_s P}{\dot{m} c_p} x \quad (8.40)$$

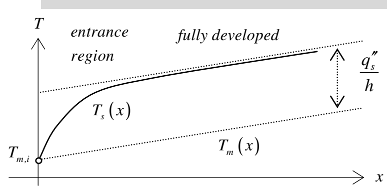
Rate of heat transfer:

$$q_{conv} = q''_s \cdot (P \cdot L) \quad (8.38)$$

$q''_s = h_x \cdot \left[T_s(x) - T_m(x)\right]$

Surface temperature:

$$T_s(x) = T_m(x) + \frac{q''_s}{h_x} = T_{m,i} + \frac{P q''_s}{\dot{m} c_p} x + \frac{q''_s}{h_x}$$



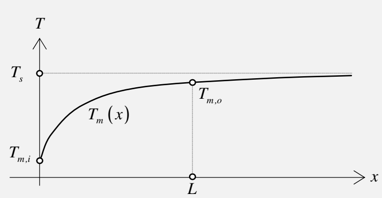
$T_s = const$

$$\frac{dT_m}{dx} = \frac{h_x P}{\dot{m} c_p}\left[T_s - T_m(x)\right]$$

$$T_m(x) = T_s + \left(T_{m,i} - T_s\right) e^{-\frac{\bar{h}_x P}{\dot{m} c_p} x} \quad (8.42)$$

$$q_{conv} = \bar{h} \cdot (P \cdot L) \Delta T_{lm} \quad (8.43)$$

$$\Delta T_{lm} = \frac{\Delta T_0 - \Delta T_i}{ln \frac{\Delta T_o}{\Delta T_i}} \qquad \Delta T_o = T_s - T_{m,o} \qquad \Delta T_i = T_s - T_{m,i}$$

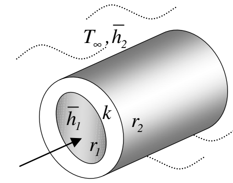


$T_\infty = const$

$$\frac{dT_m}{dx} = \frac{U_1(x) P_1}{\dot{m} c_p}\left[T_s - T_m(x)\right]$$

$$T_m(x) = T_\infty + \left(T_{m,i} - T_\infty\right) e^{-\frac{\bar{U}_1(x) P_1}{\dot{m} c_p} x} \quad (8.45)$$

$$q_{conv} = \bar{U}_1 \cdot (P_1 \cdot L) \Delta T_{lm} \qquad \Delta T_o = T_\infty - T_{m,o} \qquad \Delta T_i = T_\infty - T_{m,i}$$



T_∞ is given instead of T_s in (8.42)
replace $\bar{h}$ by $\bar{U}_1$
replace T_s by T_∞

overall convective coefficient

$$\bar{U}_1 = \frac{1}{\frac{1}{\bar{h}_1} + \frac{r_1}{k} ln \frac{r_2}{r_1} + \frac{r_1}{r_2}\frac{1}{\bar{h}_2}} \approx \frac{1}{\frac{1}{\bar{h}_1} + \frac{1}{\bar{h}_2}}$$

thin wall $r_1 \approx r_2$