1. Water enters a tube at **27°C** with a **flow rate of 450 kg/h**. The heat transfer from the tube wall to the fluid is given as **$q_s'$ (W/m)= ax,** where the **coefficient a** is **20 W/m$^2$** and x (m) is the axial distance from the tube entrance.

1. (a) Beginning with a properly defined differential control volume in the tube, derive an expression for the temperature distribution $T_m(x)$ of the water.

$q[prime] := a \cdot x$

$$q_{prime} := a\,x \quad \textbf{(1)}$$

$mdot := 450$

$$mdot := 450 \quad \textbf{(2)}$$

$Tmi := 27$

$$Tmi := 27 \quad \textbf{(3)}$$

#Energy in + == Energy out -

$mdot \cdot Cp \cdot Tm = a \cdot x\, dx + mdot \cdot Cp \cdot Tm + mdot \cdot Cp \cdot dTm$

$$0\ Cp\ Tm = a\ dx\ x + 450\ Cp\ Tm + 450\ Cp\ dTm \quad \textbf{(4)}$$

$0 = a \cdot x\, dx + mdot \cdot Cp \cdot dTm$

$$0 = a\ dx\ x + 450\ Cp\ dTm \quad \textbf{(5)}$$

$a \cdot x\, dx = mdot \cdot Cp \cdot dTm$

$$a\ x\ dx = 450\ Cp\ dTm \quad \textbf{(6)}$$

$\int_0^x a \cdot x\, dx \int_{Tmi}^{Tmf} Tm\, dx$

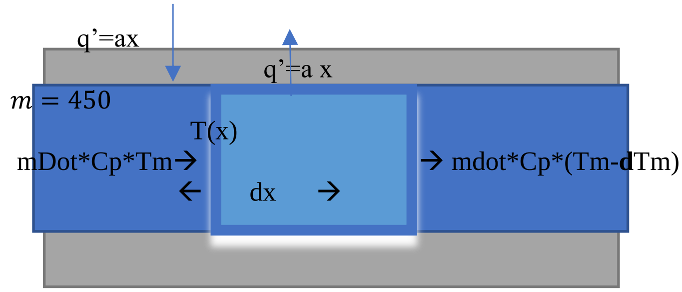
$$\frac{1}{900}\frac{a\,x^2}{Cp} + C = Tm(x) \quad \textbf{(7)}$$

$\frac{1}{900}\frac{a\,x^2}{Cp} + 27 = Tm(0)$

$$\frac{1}{900}\frac{a\,x^2}{Cp} + 27 = Tm(0) \quad \textbf{(8)}$$

#a

$\frac{1}{2 \cdot mDot}\frac{a\,x^2}{Cp} + 27$




(b) What is the mean outlet temperature of the water for a heated section of 30 m long?

$x := 30$

$$x := 30 \quad \textbf{(10)}$$

$Cp := 4181$

$$Cp := 4181 \quad \textbf{(11)}$$

$a := 20$

$$a := 20 \quad \textbf{(12)}$$

$mdot := \frac{mdot}{3600}$

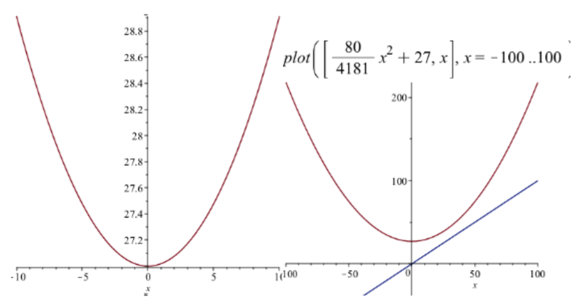
$$mdot := \frac{1}{8} \quad \textbf{(13)}$$

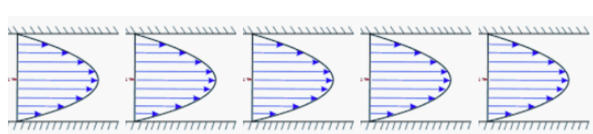
$evalf\left(\frac{1}{2 \cdot mdot}\frac{a\,x^2}{Cp} + 27\right)$

$$44.22076058 \quad \textbf{(14)}$$

**44.22076058 Degrees C**

(c) Sketch the mean fluid temperature, $T_m(x)$, and the tube wall temperature, $T_s(x)$, as a function of distance along the tube for fully developed and developing flow conditions.



(d) What value of a uniform wall heat flux, $q''$ (instead of $q' = ax$), would provide the same fluid ss

outlet temperature as that determined in part (b)? For this type of heating, repeat part (c).

$$qs[dubPrime] := \frac{\left(\frac{mdot}{3600} \cdot Cp \cdot (44.22076058 - 27)\right)}{\mathrm{Pi} \cdot \mathrm{D} \cdot 30}$$

$$qs_{dubPrime} := \frac{95.49296585}{\mathrm{D}}$$

**$q_s'' = 95.4929/D$   KL/m^2**

2. **SAE 30 oil (k = 0.15 W/m-K)** is heated by flowing through a circular tube of diameter **D = 50 mm** and length **L = 25 m** and whose surface is **maintained at 150°C.** If the flow rate and inlet temperature of the oil **are 0.5 kg/s** and **20°C**, what is the outlet temperature $\mathbf{T_{m,o}}$? What is the total heat transfer **rate q for the tube**?

$d := evalf\left(\frac{50}{1000}\right)$

$d := 0.05000000000$ **(1)**

$L := 25$

$L := 25$ **(2)**

$mdot := 0.5$

$mdot := 0.5$ **(3)**

$k = 0.15$ # W/m−K

$\frac{69}{500} = 0.15$ **(4)**

$T[s] := 150$

$T_s := 150$ **(5)**

$T[m] := 20$

$T_m := 20$ **(6)**

$Tm := \frac{T[m] + T[s]}{2} + 273$

$Tm := 358$ **(7)**

# @350 K, find properties for the oil

rho := 852

$\rho := 852$ **(8)**

$Cp := 2130$

$Cp := 2130$ **(9)**

nu := 37

$\nu := 37$ **(10)**

mu := 0.032

$\mu := 0.032$ **(11)**

$k := 138 \cdot 10^{-3}$

$k := \frac{69}{500}$ **(12)**

$Pr := 490$

$Pr := 490$ **(13)**

$Ren[p] := evalf\left(\frac{4 \cdot mdot}{\mathrm{Pi} \cdot d \cdot \mathrm{mu}}\right)$

$Ren_p := 397.8873578$ **(14)**

$x[s] := 0.05 \cdot d \cdot Ren[p] \cdot Pr$

$x_s := 487.4120133$ **(15)**

$0.05 \cdot d \cdot Ren[p]$

$0.9947183945$ **(16)**

$hBar := 2131$

$hBar := 2131$ **(17)**

$T[mo] := T[s] - (T[s] - T[m]) \cdot \exp\left(-\frac{\mathrm{Pi} \cdot d \cdot L}{mdot \cdot Cp} hBar\right)$

$T_{mo} := 149.9497193$ **(18)**

$$Nus := 3.657 + \frac{\left(0.0668 \cdot \left(\frac{d}{L}\right) \cdot Ren[p] \cdot Pr\right)}{\left(1 + 0.04 \cdot \left(\left(\frac{d}{L}\right) \cdot Ren[p] \cdot Pr\right)^{\frac{2}{3}}\right)}$$

$Nus := 11.96572707$ **(19)**

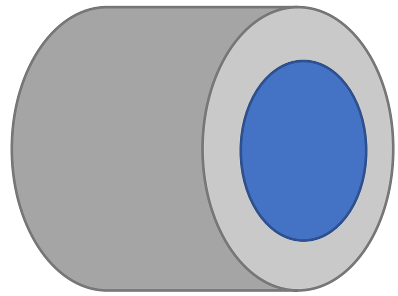
$K[f] := 0.138$

$K_f := 0.138$ **(20)**

$h := \frac{Nus \cdot K[f]}{d}$

$h := 33.02540672$ **(21)**

h:= **33.02540672** ***W /m2K***



#*Find the total Heat Transfer*

$T[mo] := 34.88$

$T_{mo} := 34.88$ **(22)**

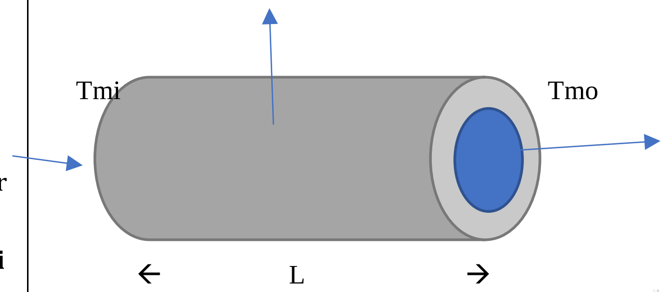
$q := mdot \cdot Cp \cdot (T[mo] - T[m])$

$q := 15847.200$ **(23)**

**15847.200 W**

3. To cool a summer home without using a vapor-compression refrigeration cycle, air is routed through a plastic pipe (**k = 0.15 W/m-K, $D_i$ = 0.15 m, $D_o$ = 0.17 m**) that is submerged in an adjoining body of water. The water temperature is nominally **at $T_\infty$ = 17°C**, and a convection coefficient of **$h_o$ = 1500 W/m$^2$-K** is maintained at the outer surface of the pipe. If air from the home enters the pipe at a temperature of **$T_{m,i}$ = 29°C** and a volumetric flow rate of **$V_i$ = 0.025 m$^3$/s**, what pipe length is needed to provide a discharge temperature of **$T_{m,o}$ = 21°C**?

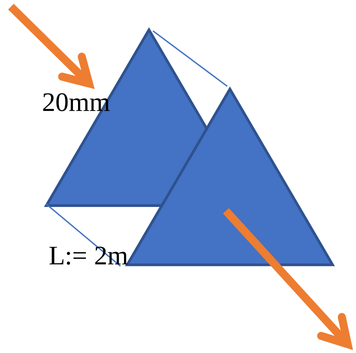
#prob 3
$Di := 0.15$
$$Di := 0.15 \quad (1)$$
$Do := 1.7$
$$Do := 1.7 \quad (2)$$
$Tmi := 29$
$$Tmi := 29 \quad (3)$$
$Vi := 0.025 \# \frac{m^3}{s}$
$$Vi := 0.025 \quad (4)$$
$h := 1500$
$$h := 1500 \quad (5)$$
$T[oo] := 17$
$$T_{oo} := 17 \quad (6)$$
$Tmo := 21$
$$Tmo := 21 \quad (7)$$
$k := 0.15$
$$k := 0.15 \quad (8)$$
#using page 730
rho := 1.177
$$\rho := 1.177 \quad (9)$$
$Cp := 1007$
$$Cp := 1007 \quad (10)$$
mu := $1.857 \cdot 10^{-5}$
$$\mu := 0.00001857000000 \quad (11)$$
nu := 1.578
$$\nu := 1.578 \quad (12)$$
$K := 0.02623$
$$K := 0.02623 \quad (13)$$
$apha := 2.213$
$$apha := 2.213 \quad (14)$$
$Pr := 0.713$
$$Pr := 0.713 \quad (15)$$
$mdot := \text{rho} \cdot Vi$
$$mdot := 0.029425 \quad (16)$$




$Ren[d] := \frac{4 \cdot mdot}{\text{Pi} \cdot Di \cdot \text{mu}}$
$$Ren_d := 13450.03540 \quad (17)$$
$R[tot] := \frac{1}{h \cdot \text{Pi} \cdot A \cdot L} + \frac{\ln\left(\frac{Do}{Di}\right)}{2 \cdot \text{Pi} \cdot L \cdot K} + \frac{1}{ho \cdot \text{Pi} \cdot Do \cdot L}$
$$R_{tot} := \frac{1}{1500\,\pi\,A\,L} + \frac{14.73077134}{L} + \frac{0.1872411095}{ho\,L} \quad (18)$$
$hi := \frac{K}{Di} \cdot 0.073 \cdot Ren[d]^{\frac{4}{5}} \cdot Pr^{0.3}$
$$hi := 23.17050464 \quad (19)$$
$(Uas)^{-1} = \frac{1}{h \cdot \text{Pi} \cdot A \cdot L} + \frac{\ln\left(\frac{Do}{Di}\right)}{2 \cdot \text{Pi} \cdot L \cdot K} + \frac{1}{h \cdot \text{Pi} \cdot Do \cdot L}$
$$\frac{1}{Uas} = 2.174\,L \quad (20)$$
$solve\left(\frac{(T[oo] - Tmo)}{T[oo] - Tmi} = \frac{1}{3} \cdot \exp\left(-\frac{2.174\,L}{0.0289 \cdot 1007}\right), L\right)$
$$L := 14.73 \quad (21)$$

**14.73 m**

4. **Air at $4 \times 10^{-4}$ kg/s and 27°C** enters a triangular duct that is **20 mm** on a side and **2 m long.** The duct surface is maintained at **100°C**. Assuming fully developed flow throughout the duct, determine the air **outlet temperature.**




*#prob4*

$Ti := 27$

$$Ti := 27 \quad (1)$$

$Tmean := \frac{(27+100)}{2}$

$$Tmean := \frac{127}{2} \quad (2)$$

$k := 0.02833$

$$k := 0.02833 \quad (3)$$

$\mathrm{nu} := 1.93 \cdot 10^{-5}$

$$\nu := 0.00001930000000 \quad (4)$$

$Pr := 0.712$

$$Pr := 0.712 \quad (5)$$

$\mathrm{rho} := 1.05$

$$\rho := 1.05 \quad (6)$$

$Di := evalf\left(\frac{\left(4 \cdot \frac{\mathrm{sqrt}(3)}{4}\left(20 \cdot 10^{-3}\right)^2\right)}{3 \cdot 20 \cdot 10^{-3}}\right)$

$$Di := 0.01154700539 \quad (7)$$

$V := 2.2$

$$V := 2.2 \quad (8)$$

$Ren := \frac{V \cdot Di}{\mathrm{nu}}$ *# Laminor*

$$Ren := 1316.238956 \quad (9)$$

$mdot := evalf\left(1.05 \cdot \frac{\mathrm{sqrt}(3)}{4}\left(20 \cdot 10^{-3}\right)^2 \cdot \mathrm{nu}\right)$

$$mdot := 3.510000962\ 10^{-9} \quad (10)$$

$Nus := 0.664 \cdot Ren^{\frac{1}{2}} \cdot Pr^{\frac{1}{3}}$

$$Nus := 21.51107497 \quad (11)$$

$solve\left(Nus = \frac{h \cdot \mathrm{rho}}{k}, h\right)$

$$0.5803892895 \quad (12)$$

$solve(Q := mdot \cdot Cp \cdot (To - Ti), To)$

$$Q := 462 \quad (13)$$

$To := 1175.11$

$$To := 1175.11 \quad (14)$$

**1175.11 degrees C**