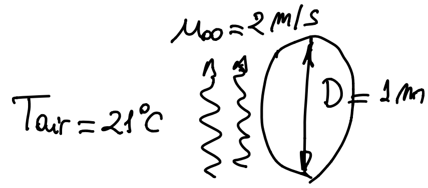
Problem 1



$T_{air} = 21°C = 299K \quad A = 0.84\ m \quad D = L = 1\ m$

We can get the properties of air at 20°C without applying the film temperature

ONLY AN ASSUMPTION IN THIS CASE

$\rho = 1.22\ \frac{Kg}{m^3} \quad K = 25.5 \times 10^{-3}\ \frac{W}{m.K} \quad \mu = 1.80 \times 10^{-5}\ \frac{Kg}{m.s} \quad Pr = 0.71$

The heat loss through the two ears (heat is transferred from both sides

$$q = 4A\,h\,(T_s - T_{air})$$

The value of h needs to be determined

$$Re = \frac{\rho u_\infty D}{\mu} = \frac{1.22 \times 2 \times 1}{1.80 \times 10^{-5}} = 1.35 \times 10^5$$

Since I use consistent units the Reynolds number is dimensionless

Flow is laminar so the equation to estimate the Nusselt Number Nu is:

$$Nu = 0.664\, Re^{1/2}\, Pr^{1/3} = 0.664 \times (1.35 \times 10^5)^{1/2} \times 0.71^{1/3} \cong 218$$

$$Nu = 218 = \frac{hD}{K} \Rightarrow h = \frac{218\,K}{D} = \frac{218 \times 25.5 \times 10^{-3}\ W/m.K}{1\ m} = 5.6\ \frac{W}{m^2K}$$

$$q = 4 \times 0.84 \times 5.6\,(T_s - 20) = 18.82\,(T_s - T_{air})\ \text{Watts}$$

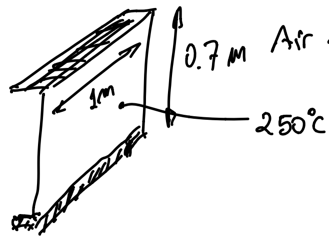
A plot as a function of T_s easily

If the heat production by the elephant is 1650 W and we assume the body temperature 37°C, the heat dissipated by the ears is:

$$\text{percentage} = \frac{18.82\,(37-20)\ W}{1650} \times 100 = 19.4\%$$

About 19.4% of the heat generated is lost through the ears

Problem 2



Air in room is still

$T_{air} = 20°C$

(2)

(a) Because the air is still the type of Convection will be natural Convection. Natural convection is produced by the flow created by a difference in densities

(b) Heat transfer to the room

$q = hA(T_s - T_{air})$ so we need to estimate the value of h

For a vertical surface

$$Nu_L = \left(0.825 + \frac{0.387\, Ra_L^{1/6}}{\left[1+\left(\frac{0.492}{Pr}\right)^{9/16}\right]^{8/27}}\right)^2 \quad (1)$$

This time I remember using the film temperature!!

$$T_f = \frac{250+20}{2} = 135°C \cong 408K$$

I will use T = 400K to get the properties of air so interpolation is avoided

From Table for air at 400K

$\rho = 0.882 \frac{Kg}{m^3}$ / $\mu = 2.286 \times 10^{-5} \frac{Kg}{m.s}$ $K = 0.03365 \frac{W}{m.K}$

$Pr = 0.689$ $\beta = \frac{1}{T_f} = \frac{1}{408} = 2.451 \times 10^{-3} \frac{1}{K}$

$$Gr = \frac{2.451 \times 10^{-3} \times 9.81 \times 0.8822^2 \times 0.689^3 \times (250-20)}{(2.286 \times 10^{-5})^2} = 2.83 \times 10^9$$

$$Ra_L = Gr \times Pr = 2.83 \times 10^9 \times 0.689 = 1.95 \times 10^9$$

Substituting values into Eq.(1)

$$Nu_L = \left(0.825 + \frac{0.387 \times (1.95 \times 10^9)^{1/6}}{\left(1+\left(\frac{0.492}{0.689}\right)^{9/16}\right)^{9/27}}\right)^2$$

$$Nu_L = 150.5 \Rightarrow h = \frac{K Nu_L}{L} = \frac{0.03365 \times 150.5}{0.7} \frac{W}{m^2K} = 7.24 \frac{W}{m^2K} \quad (3)$$

$$h = 7.24 \frac{W}{m^2K}$$

$$q = 7.24 \frac{W}{\cancel{m^2}\cancel{K}} \times 1 \times 0.7 \cancel{m^2} [250-20] \cancel{K} = 1,165\,W$$

$$\boxed{q = 1.16\,KW}$$

Problem 3

$$q_{w,ev} = 0.001\,Kg/s$$

$$q_{w,ev} = h_m A (\rho_{w,sat} - \rho_{w,air}) \quad (1)$$

$$\frac{\bar{h}}{\bar{h}_m} = \rho C \left(\frac{\alpha}{D_{w,air}}\right)^{2/3} \qquad D_{w,air} = 26 \times 10^{-6} \frac{m^2}{s}$$

$$T_{air} = 290K \qquad T_{pool} = 310K \qquad T_{film} = \frac{290+310}{2} = 300$$

$$RH = 30\%$$

Let's assume that the water vapor behaves as an ideal gas, thus

$$PV = nRT = \frac{m}{M_w} RT \Rightarrow \frac{PM_w}{RT} = \frac{m}{V} = \rho_w$$

Thus

$$\rho_{w,air} = \frac{P_w M_w}{RT} \qquad \rho_w|_{sat} = \frac{P_{sat} M_w}{RT} \quad \text{but } RH = \frac{P_w}{P_{sat}} \quad (2)$$

Substituting Eq.(2) into Eq.(1) we get:

$$q_{w,ev} = h_m A \left[\frac{P_{sat} M_w}{RT} - \frac{P_w M_w}{RT}\right] = h_m A \left[\frac{P_{sat} M_w - P_{sat} RH\, M_w}{RT}\right]$$

$$q_{w,ev} = h_m A \frac{P_{sat} M_w}{RT} [1 - RH] \quad (3)$$

at 310K for water

$$P_{sat} = 0.0622\,bar \times \frac{101.3\,KPa}{1\,bar} = 6.3\,KPa$$

Substituting values into Eq.(3)

$$h_m A = \frac{0.001\,Kg/s}{\frac{P_{sat} M_w}{RT} [1 - RH]}$$

$$h_m A = \frac{0.001\ \cancel{Kg}/s}{\frac{6.3\,KPa \times 18\,\cancel{Kg}/\cancel{Kmol}}{8.31\,\frac{KJ}{\cancel{Kmol}\,\cancel{K}} \times 310\,\cancel{K}}} = \frac{0.001\ 1/s}{0.044\ \frac{KPa}{KJ}} = 0.023\ \frac{KJ}{KPa.s}$$

$$\frac{KJ}{KPa} = m^3 \quad \text{So} \quad h_m A = 0.023\ \frac{m^3}{s} \quad \text{and} \quad A\bar{h} = h_m A \times \rho c \left(\frac{\alpha}{D_{w,air}}\right)^{2/3} \quad (4)$$

at 300K for air $\quad C = 1.0063\ \frac{KJ}{Kg\,K} \quad K = 0.0262\ \frac{W}{m.K} \quad \rho = 1.177\ \frac{Kg}{m^3} \quad \alpha = \frac{0.0262}{1\times10^3 \times 1.177}$

$\alpha = 2.23\times10^{-5}\ m^2/s$

Substituting into Eq.(4)

$$A\bar{h} = 0.023\ \frac{m^3}{s} \times 1.177 \times 1\times10^3 \left(\frac{2.23\times10^{-5}}{26\times10^{-6}}\right)^{2/3} \cong 24.4\ \frac{W}{W}$$

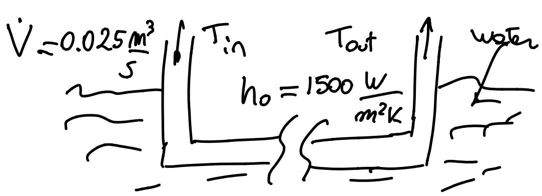
$$q = A\bar{h}\,(310-290) = 24.4\ \frac{W}{\cancel{K}} \times 20\,\cancel{K} = 488\ W$$

the energy lost due to evaporation is

$$q_{w,ev} \times \Delta H_{vap} = 0.001\ \frac{Kg}{s}\,(2568.14 - 155)\ \frac{KJ}{\cancel{Kg}} = \underline{2.41\ KWatts}$$

Problem 4

Pipe $\begin{cases} D_i = 0.15m \\ D_o = 0.17m \\ K = 0.15\ W/m.K \end{cases}$



Since the temperature of the water is constant we can use the equation for a surface temperature constant. We know h_o but we need to estimate the heat transfer coefficient within the tube, h_i

$$Re = \frac{D\,u_\infty\,\rho}{\mu} \qquad u_\infty = \frac{\dot{V}}{\frac{\pi D_i^2}{4}} = \frac{0.025\ m^3/s}{\frac{\pi \times 0.15^2}{4}\ m^2} = 1.415\ \frac{m}{s}$$

The properties of the air, let's assume a $T_{avg} \cong 300K$, are: $\rho = 1.18\ \frac{Kg}{m^3}$ $\quad \mu = 1.85\times10^{-5}\ \frac{Kg}{m.s}$ $\quad Pr = 0.708$ $\quad k = 0.02624\ \frac{W}{mK}$

$$Re = \frac{0.15 \times 1.415 \times 1.18}{1.85\times10^{-5}} = 13540 \quad \text{Turbulent flow}$$

For cooling $n \cong 0.3$ (5)

$$Nu = 0.023 \times 13540^{4/5} \times 0.708^{0.3} = 41.9$$

$$Nu = 41.9 \Longrightarrow h_i = \frac{K_{air} Nu}{D} = \frac{0.02624 \times 41.9}{0.15} = 7.3 \frac{W}{m^2 K}$$

Let's consider all resistances in the system

$$\text{Resistance inside} = \frac{1}{2\pi L \times \frac{0.15}{2} \times 7.3} = \frac{0.29}{L} \frac{K\,m}{W}$$

$$\text{Resistance outside} = \frac{1}{2\pi L \times \frac{0.17}{2} \times 1500} = \frac{1.25 \times 10^{-3}}{L} \frac{Km}{W}$$

$$\text{Resistance wall} = \frac{\ln 0.17/0.15}{2\pi L \times 0.15\, W/m.K} = \frac{0.132}{L} \frac{Km}{W}$$

Obviously the resistance outside can be neglected

$$\frac{1}{U} = \text{Resistance inside} + \text{Resistance wall} = \frac{0.29 + 0.132}{L} = \frac{0.422}{L} \frac{Km}{W}$$

$$\boxed{U = 2.4L \frac{W}{mK}}$$

$$\frac{T_w - T_{out}}{T_w - T_{in}} = \exp\left(-\frac{P \times L \times U}{\dot{m} c}\right)$$

Taking logaritm in both sides of the above equation and by rearranging:

$$\frac{P \times 2.4 L^2}{\dot{m} c} = -\ln \frac{T_w - T_{in}}{T_w - T_{out}}$$

$$L = \sqrt{-\frac{\dot{m} c}{2.4 P} \ln\left(\frac{T_w - T_{in}}{T_w - T_{out}}\right)}$$

$$\dot{m} = \dot{V} \times \rho = 0.025 \frac{m^3}{s} \times 1.18 \frac{Kg}{m^3} \cong 0.03 \frac{Kg}{s}$$

$c \cong 1\, KJ/Kg$ $\quad P = \pi D = \pi \times 0.15 m = 0.47 m$

Substituting above:

$$L = \sqrt{-\frac{0.03 \times 1000}{0.47 \times 2.4} \ln\left(\frac{17 - 21}{17 - 30}\right)} = 5.6 m \qquad L = 5.6 m$$

(b) Substituting in the resistances the value of L, we have: (6)

$$\text{Resistance inside} = \frac{0.29}{5.6} = 5.2\times10^{-2}\,\frac{K}{W}$$

$$\text{Resistance outside} = \frac{1.25\times10^{-3}}{5.6} = 2.23\times10^{-4}\,\frac{K}{W}$$

$$\text{Resistance wall} = \frac{0.132}{5.6} = 2.4\times10^{-2}\,\frac{K}{W}$$