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MECE-497-01
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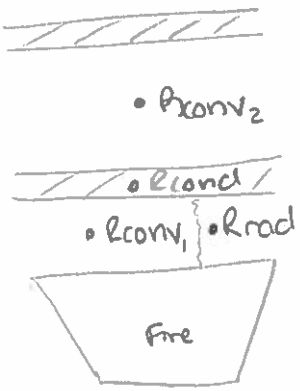
Schematic :



Governing equations :

$R_{cond} = \frac{t}{kA}$ | $h_r = \varepsilon f \sigma (T_s + T_{surf})(T_s^2 + T_{surf}^2)$

$R_{conv} = \frac{1}{hA}$ | $R_{eq,\parallel} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$

$R_{rad} = \frac{1}{h_r A}$ | $R_{eq,-} = R_1 + R_2$

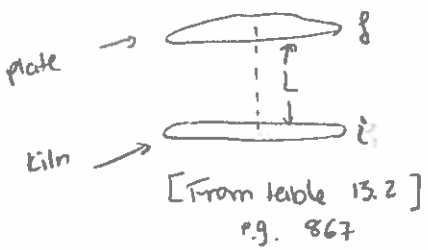
$\overline{Nu}_D = \frac{\bar{h} D}{k} = C Re_D^m Pr^{1/3}$

Constants

$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

$\varepsilon = 0.23$

Analysis :



$R_i = \frac{r_j}{L} = \frac{0.3048}{0.3048m} = 1$

$R_j = \frac{r_i}{L} = \frac{0.5775m}{0.3048m} = 1.894685$

$S = 1 + \left(1 + \frac{R_j^2}{R_i^2}\right) = 1 + \left(\frac{1 + 1.894685^2}{1^2}\right) = 5.5898$

$F_{ij} = \frac{1}{2}\left[S - \left(S^2 - 4\left(\frac{r_j}{r_i}\right)^2\right)^{1/2}\right]$

$= \frac{1}{2}\left[5.59 - \left(5.59^2 - 4 \cdot \left(\frac{0.5775m}{0.3048m}\right)^2\right)^{1/2}\right]$

$= 0.74$

$h_r = (0.23)(0.74)(5.67\times10^{-8} \frac{W}{m^2K^4})[(180+273.15)K + (650+273.15)K][(180+273.15)^2K^2 + (650+273.15)^2K^2] = 14.05 \frac{W}{m^2K}$

$R_{rad} = \frac{1}{(14.05 \frac{W}{m^2K})(0.6096^2 m^2)} = 0.1915 \frac{K}{W}$

$R_{cond} = \frac{0.003429m}{(0.0373 \frac{W}{mK})(0.6096^2 m^2)} = 0.2474 \frac{K}{W}$

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Convection of Air:

$\rho_{bio} = 600 \frac{kg}{m^3} \Rightarrow 3 gal = 0.01135 m^3 = V$

$m = \rho V = (600 \frac{kg}{m^3})(0.01135 m^3) = 6.81 kg$

Assume: Woody material [corn stalk], 1.5hr burn = 5400s.

$\frac{m_{in}}{m_{out}} = \frac{m_{stalk}}{m_{corn}} = 0.20$ hence $m_{stalk} = \frac{6.81 kg}{0.2} = 34.05 kg$

$\dot{m}_{stalk} = \frac{34.05 kg}{5400 s} = 0.0063 \frac{kg}{s}$ $\dot{m}_{bio} = \frac{6.81 kg}{5400 s} = 0.00126 \frac{kg}{s}$

$\dot{m}_{stalk} - \dot{m}_{bio} = \dot{m}_{oxid} \Rightarrow 0.0063 \frac{kg}{s} - 0.00126 \frac{kg}{s} = 0.00504 \frac{kg}{s}$

$\frac{A}{f}$ [mass ratio] $= \frac{(n + \frac{m}{4})(136.44g)}{n(12g) + m(1.008g)}$ $\Rightarrow$ for cornstalks $H:C = 1.5 = m:n$

$\frac{A}{f} = \frac{(5 + \frac{1}{4})(136.44g)}{5(12g) + 1(1.008g)} = 11.74$

$\dot{m}_{exh} = \dot{m}_{oxid}[1 + A/F] = 0.00504 \frac{kg}{s}[1 + 11.74] = 0.06427 \frac{kg}{s}$

$\dot{V} = \frac{\dot{m}_{exh}}{\rho_{exh}} = \frac{0.06427 \frac{kg}{s}}{0.7060 \frac{kg}{m^3}} = 0.091036751 6 \frac{m^3}{s}$

$u_\infty = \frac{\dot{V}}{A_{free}} = \frac{0.09104 \frac{m^3}{s}}{\frac{\pi}{4}(1.155m)^2} = 0.8688886 \frac{m}{s}$

$Re_D = \frac{u_\infty D_h}{\nu} = \frac{0.8688886 \frac{m}{s} \cdot 0.6096m}{3.782 \times 10^{-5} \frac{m^2}{s}} = 14005.10062$

$\overline{Nu_D} = C Re_D^m Pr^{1/3}$; $C = 0.193$ $m = 0.1618$ ← from table 7.2 p.458

$\overline{Nu_D} = 0.193 (14005.10062)^{0.1618} (0.684)^{1/3} = 7762.084$

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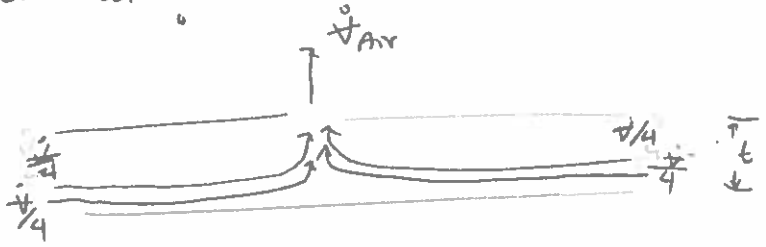
$$h = \frac{\overline{Nu}_D k}{D_h} = \frac{(62.084)(40.7\times10^{-3}\ \frac{W}{mK})}{(0.6096\ m)} = 4.145\ \frac{W}{m^2K}$$

$$R_{conv_1} = \frac{1}{hA} = \frac{1}{(4.145\ \frac{W}{m^2K})(0.6096\ m)^2} = 0.655\ \frac{K}{W}$$

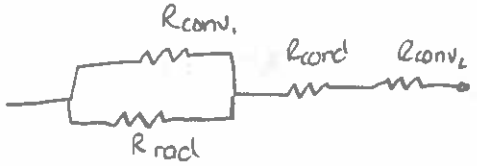
convection in channel:



If assuming fully developed laminar flow:

Using table 8.1, $Nu_D = 8.23$ @ const flux for channel flow

$$h = \frac{\overline{Nu}_D k}{D_h} = \frac{8.23 \cdot 0.14062}{0.09378} = 12.34\ \frac{W}{m^2K} \Rightarrow R_{conv_2} = \frac{1}{(12.34)(0.0619)} = 1.30$$



$$R_1 = \frac{1}{\frac{1}{R_{conv_1}} + \frac{1}{R_{rad}}} = \frac{1}{\frac{1}{0.655} + \frac{1}{0.1915}} = 0.18606\ \frac{K}{W}$$

$$R_{tot} = R_1 + R_{cod} + R_{conv_2} = 0.18606\ \frac{K}{W} + 0.2474\ \frac{K}{W} + 1.308$$

$$\boxed{R_{tot} = 1.741\ \frac{K}{W}}$$