Convection heat transfer calculation examples:

1. The convective heat transfer to a plane wall inner surface is 9 W/m^2K, and on the outer wall it is 95 W/m^2K. The wall is 2.3m high and 3.1m wide. Ignoring the conduction of the wall find the thermal resistance for the inside and outside convective conditions, and hence for the overall wall. [0.0171 K/W]

2. What is the heat transfer in question 1 if the inner air is at 18°C and the outer air is at 1°C? Sketch the temperature profile through the wall. [994 W]

3. A high pressure hot water pipe of inner diameter 28mm carries water at 347°C, 160 bar. The inner wall convective heat transfer coefficient is *assumed* to be 940 W/m^2K. The pipe is made of stainless steel (k=15W/mK) and has a wall thickness of 6mm. It is insulated by 100mm of refractory material having k=0.8W/mK. The surrounding air temperature is 25°C and the heat transfer coefficient is 10W/m^2K. What is the heat loss per m length of pipe? What is the external surface temperature? [638 W, 109°C]

4. The pipe in Q3 is part of a heat exchanger and it is useful to know the overall heat transfer coefficient for this insulated part of it to compare with the uninsulated part in the heat exchanger. Starting with the thermal resistance in Q3, calculate the overall heat transfer coefficient based on 1 m lenght of the inner diameter of the pipe to produce the overall heat transfer coefficient, and compare it to the overall heat transfer coefficient in the heat exchanger, which instead of insulation has a convective heat trnasfer coefficient of 90 W/m^2K.

5. Calculate convective heat transfer coefficient for the inner surface in question 3 using the Colburn correlation ($Nu_d=0.023Re_d^{0.8}Pr^{0.4}$). Given the velocity of water in the pipe is 3m/s, the density is 613kg/m^3, the viscosity is 9×10^{-5}kg/ms, the Prandtl number is 0.94 and the conductivity is 0.54W/mK. What effect will this have on the calculation of heat loss in question 3? [17,466 W/m^2K]

6. Calculate the Grashof number for a vertical surface 0.5m high and 1m wide, in a room of still air, if the air temperature is 18°C and the surface temperature is 150°C. Use the Nusselt correlation: $Nu_x = 0.59\,(Gr_L\,Pr)^{0.25}$ if $10^3<GrPr<10^9$ and $Nu_x = 0.13\,(Gr_L\,Pr)^{0.33}$ if $10^9<GrPr<10^{12}$. Use $\beta=1/T_f$, where T_f is the film temperature (the mean value of the surface and the surrounding gas), and take the properties of air from the tables of dry air at low pressure at T_f. What is the heat transfer from the surface to the room by convection? [403 W]

Solutions convection heat transfer:

1. Convective thermal resistance is 1/hA, inside 1/9*2.3*3.1=0.0156K/W and outside 1/95*2.3*3.1=0.0015K/W. Total thermal resistance is now 0.0171K/W. The external resistance is much less, indicating that it transfers heat well into the wall because of the enhanced heat transfer coefficient.
2. For these temperatures, the heat transfer is $q=\Delta T/R_{th}$ = 17/0.0171 = 994W.
3. Use the formula for thermal resistance of axisymmetric pipe wall and insulation and the convection at the inner and outer surfaces to produce:

$$\dot{q}' = \frac{-(347-25)}{\frac{1}{940\ 2\pi 0.014} + \frac{ln\ (0.020/0.014)}{2\pi 15} + \frac{ln\ (0.12/0.020)}{2\pi 0.8} + \frac{1}{10\ 2\pi 0.12}}$$

and the heat transfer is 322/(0.012+0.0038+0.357+0.132)=322/0.505=638W/m. External temperature is given by the convective calculation on the exterior only i.e. q= $\Delta T/R_{th}$, so 638 = -($T_{air} - T_s$) /0.132 so T_s = 109°C.

4. Overall heat transfer coefficient is the thermal resistance for 1 m^2 of the heat exchange surface. The previous question has the thermal resistance for a 1 m length of the pipe. For the thermal resistance in this case based on the area of the inner diameter of the pipe and 1 m length so that it is consistent with the R_{th} calculation in Q3:

$$UA = U(2\pi 0.014) = \frac{1}{\frac{1}{940\ 2\pi 0.014} + \frac{ln\ (0.020/0.014)}{2\pi 15} + \frac{ln\ (0.12/0.020)}{2\pi 0.8} + \frac{1}{10\ 2\pi 0.12}}$$

U = 22.5 $W \cdot m^{-2} \cdot K^{-1}$

For the case with no insulation and convection heat transfer coefficient of 90 $W \cdot m^{-2} \cdot K^{-1}$ on the outer surface of the pipe:

$$U(2\pi 0.014) = \frac{1}{\frac{1}{940\ 2\pi 0.014} + \frac{ln\ \left(\frac{0.020}{0.014}\right)}{2\pi 15} + \frac{1}{90 \times 2\pi 0.02}} = 1/(0.012 + 0.0038 + 0.0884)$$

U = 109 $W \cdot m^{-2} \cdot K^{-1}$

5. Inner surface $Nu_d=0.023Re_d^{0.8}Pr^{0.4}$ where Re=ρUD/μ, Re=613×3×0.028/9×10^{-5} = 572,133. Nu_d=0.023×572,133$^{0.8}$× 0.94$^{0.4}$ = 905. Knowing that h=Nu.k/D, h = 17,466 W/m^2K. The effect of this will be to decrease the convective thermal resistance. So 1/17466.2π.0.014, making it effectively zero. The thermal resistance is decreased by 0.012 out of 0.505 or 2.4%, and hence there will be 2.4% more heat transfer or 653 W/m. Therefore a small effect.
6. Film temperature is average of wall and fluid temp = 291+423)/2 = 357K, take properties at 350K to reasonable accuracy. $Gr = \frac{g\beta l^3 \rho^2 \Delta T}{\mu^2}$ and use ν=μ/ρ, so Gr =

9.81*1/((291+423)/2)*0.5^3*(150-18)/(2.056*10^{-5})^2 = 1 072 601 784 or 1.073*10^9.

Work out the product of GrPr = 1.073*10^9 ×0.697 = 7.48×10^8, where Pr is from p.16 at 350 K.

Therefore the first Nu correlation is appropriate: $Nu = 0.59(GrPr)^{0.25}$

$$Nu = 0.59(7.48 \times 10^8)^{0.25} = 97.6$$

h=Nu_xk/D=97.6*0.03003/0.5 = 5.86 W/m^2K, where k is from p.16 at 350 K. Therefore heat transfer rate is:

Q = hA(T_s-T_{air}) = 5.86*0.5*1*(150-18) = 386.9 W.