A flat, very long panel is composed of two layers: a thin film (k_{film} = 0.025 W/mK, thickness = 0.25 mm) and a substrate ($k_{substrate}$ = 0.05 W/mK, thickness = 1 mm). A heat flux q (W/m^2) is applied to the back of the substrate, while the film is subject to cooling by a forced convection air flow. The back of the substrate is maintained at T_1 = 90 °C while the free surface of the film is exposed to air at T_{air} = 20 °C and an average, unknown convection heat transfer coefficient h (W/m^2K). Also, it is required that the temperature T_2 between the film and the substrate must be equal to 60 °C. Determine the heat flux q to be applied to the substrate and the convection heat transfer coefficient of the air flow.

Heat Flux q, Fourier's Law applied to the substrate

$q = k_{substrate}/t_{substrate} * (T1 - T2) = 1500 \ W/m^2$

Temperature T3 of the free surface of the thin film cooled by the forced convection air flow

$q = k_{film}/t_{film} * (T2-T3)$

$T3 = T2 - q*t_{film}/k_{film} = 45$ °C

Convection heat transfer coefficient

$q = h*(T3 - T_{air})$

$h = q/(T3 - T_{air}) = 60$ W/m2K

A shell-and-tube exchanger (two shells, four tube passes) is used to cool down 100 kg/h of pressurized water from 87 to 47 °C with 200 kg/h of methyl alcohol (methanol, $cp_{methanol}$=2672 J/kgK) entering the exchanger at 27 °C. If the overall heat transfer coefficient is 300 W/m^{2}K, determine the outlet temperature of the methanol and the required heat exchanger area.

Mass flow rates and specific heats

m_{water}=0.0278 kg/s
cp_{water}=4189 J/kgK

$m_{methanol}$=0.0556 kg/s
$cp_{methanol}$=2672 J/kgK

Energy balance on the water side

$Q = m_{water}*cp_{water}*(T_{water,in} - T_{water,out}) = 4.6544e+3$ W

Energy Balance on the methanol side

$Q = m_{methanol}*cp_{methanol}*(T_{methanol,out} - T_{methanol,in})$
$T_{methanol,out} = T_{methanol,in} + Q/(m_{methanol}*cp_{methanol}) = 58.4$ °C

Heat Capacities

$C_{water} = 116.36$ W/K $= C_{min}$
$C_{methanol} = 148.4$ W/K $= C_{max}$

$C_{min} / C_{max} = 0.78$

Effectiveness

$\varepsilon = (T_{water,in} - T_{water,out})/(T_{water,in} - T_{methanol,in}) = 0.667$

NTU

$NTU = UA/C_{min} = 1.8$

$A = NTU*C_{min} / U = 0.7$ m^2

Atmospheric air enters a 10-m-long, 150-mm-diameter uninsulated heating duct at 60 °C and 0.04 kg/s. The duct surface temperature is approximately constant at T_{wall} = 15 °C.
What are the outlet air temperature, the heat rate q, and pressure drop p for these conditions?
Also, assuming that the tube wall is thin, an air flow at T_{out} = 0 °C flows over the whole tube with a velocity of 4 m/s. Determine the outer heat transfer coefficient and the overall heat transfer coefficient.

Thermophysical properties (internal flow, T_{film} = 310 K)

rho = 1.139 kg/m3; cp = 1007 J/kgK; ni = 1.659e-5 m2/s;
k = 0.02684 W/mK; Pr = 0.709;

Reynolds number (internal flow)

u = 4*m/(pi*D^2)/rho = 1.99 m/s;
Re = u*D/ni = 1.7968e+04 (turbulent)

Friction factor and pressure drop (internal flow)

f = (.79*log(Re) - 1.64)^-2 = 0.0269;
Dp = f*L/D*rho*(u^2)/2 = 4.03 Pa;

Nusselt Number and heat transfer coefficient (internal flow)

$$\mathrm{Nu}_D = \frac{(f/8)(\mathrm{Re}_D - 1000)\,\mathrm{Pr}}{1 + 12.7\sqrt{f/8}\left(\mathrm{Pr}^{2/3} - 1\right)}$$

for $2300 \le \mathrm{Re}_D \le 5 \times 10^6$.

Nu=47.6;
h=8.52 W/m2K;

Air outlet temperature (internal flow)

$$\frac{T_{b\mathrm{out}} - T_{b\mathrm{in}}}{T_w - T_{b\mathrm{in}}} = 1 - \exp\left(-\frac{\overline{h}PL}{\dot{m}c_p}\right)$$

T_air_out = T_air_in+(T_wall-T_air_in)*(1-exp(-h*pi*D*L/m/cp)) = 31.6 °C;

Heat rate

Q = m*cp*(T_air_out-T_air_in) = -1.1435e3 W;

Thermophysical properties (external flow, T_{film} = 280 K)

rho = 1.261 kg/m3; ni = 1.385e-5 m2/s; k = 0.02473 W/mK; Pr = 0.711;

Reynolds number (external flow)

Re = u*D/ni = 4.3321e+04

Nusselt Number and heat transfer coefficient (external flow)

$$\overline{Nu}_D = 0.3 + \frac{0.62\, Re_D^{1/2}\, Pr^{1/3}}{[1 + (0.4/Pr)^{2/3}]^{1/4}} \left[1 + \left(\frac{Re_D}{282{,}000}\right)^{5/8}\right]^{4/5}$$

Nu=112.3;
h=18.52 W/m2K;

Overall heat transfer coefficient

U=(h^-1 + h_out^-1)^-1 = 5.84 W/m2K;

A long, thin-walled horizontal tube 100 mm in diameter is maintained at uniform temperature T_{tube} = 120 °C by the passage of steam through its interior. The tube is diffuse and it can be considered a gray surface with an emissivity ε = 0.8. The tube is located into a big chamber, which can be considered a blackbody at a temperature T_{wall} = 35 °C for the purpose of the radiative heat exchange. In the chamber, stagnant air is also present at T_{air} = 35 °C. Determine the total heat loss of the tube for unit tube length.

Thermophysical properties (350 K)

rho = 1.008 kg/m3; ni = 2.073e-5 m2/s; alpha = 2.931e-5 m2/s;
k = 0.02984 W/mK; Pr = 0.707;

Rayleigh number

$$\overline{Nu}_D = \left\{0.60 + 0.387\left[\frac{Ra_D}{[1 + (0.559/Pr)^{9/16}]^{16/9}}\right]^{1/6}\right\}^2$$

Ra = 9.81*(1/T_wall_air)*(T_tube-T_wall_air)*(D^3)/ni/alpha = 4.4536e+06;

Nusselt number and heat transfer coefficient

Nu = 22.28;
h = Nu*k/D = 6.65 W/m2K

Heat rates unit tube length

$Q_{radiation}$ = pi*D*e*sigma*((T_tube^4)-(T_wall_air^4)) = 212 W/m;
$Q_{convection}$ = pi*D*h*(T_tube-T_wall_air) = 177.5 W/m;

$Q_{tot} = Q_{radiation} + Q_{convection}$ = 389.5 W/m