Homework Assignment Number Twelve
Assigned: Wednesday, April 14, 1999
Due: Wednesday, April 21, 1999 BEFORE LECTURE STARTS.

Water flows through the horizontal tube. In order to compute the tube-side film heat transfer coefficient, h_{tube}, we must guess the tube-side outlet temperature, $T_{tube,out}$, and iterate with respect to $T_{tube,out}$. Use and initial guess of $T_{tube,out} = 303K$ and perform one iteration up to the point where you have a new guess for $T_{tube,out}$. Along the way, show me the numerical values you obtain for (a) N_{Pr}, (b) N_{Re}, (c) N_{Nu}, (d) h_{tube}, (e) the rate of heat transfer THROUGH THE WATER FILM, q, and finally (f) $T_{tube,out}$.

Use Table A.2-11 of Geankoplis on page 862 for all physical properties: C_p, k, μ, ρ.

Steam condenses on the shell-side. The steam is at a pressure, $P = 892kPa$ and is saturated. Compute the shell side film heat transfer coefficient, h_{shell}.

Use Table A.2-9 of Geankoplis on page 857-858 for the saturation temperature, $\overline{T}_{shell} = T_{sat}$, and latent heat of vaporization. Use Table A.2-11 of Geankoplis on page 862 for all other physical properties.

In addition to (a) h_{shell}, report the value of (b) N_{Nu}, (c) write the equation used to calculate the Nusselt number, and (d) the rate of heat transfer THROUGH THE STEAM FILM, q.

Solution:

From the steam tables

$$T_{shell} = T_{sat} = 175C = 448.15K$$

$$\Delta H_{vap}(T_{shell}) = (2773.6 - 741.17) * 1000.0 = 2.032 \cdot 10^6 \frac{J}{kg}$$

1. calculate average tube-side bulk temperature $\overline{T}_{tube} = 0.5\left(T_{tube,out} + T_{tube,in}\right)$
2. obtain saturation temperature T_{sat}, and equate $\overline{T}_{shell} = T_{sat}$
3. calculate wall temperature $\overline{T}_w = 0.5\left(\overline{T}_{shell} + \overline{T}_{tube}\right)$
4. calculate tube-side film temperature $T_{tube,f} = 0.5\left(\overline{T}_w + \overline{T}_{tube}\right)$
5. calculate shell-side film temperature $T_{shell,f} = 0.5\left(\overline{T}_w + \overline{T}_{shell}\right)$
6. obtain tube-side fluid properties at tube-side film temperature C_p, k, μ at $T_{tube,f}$
7. obtain shell-side fluid properties at shell-side film temperature C_p, k, μ at $T_{shell,f}$
8. obtain tube-side fluid properties at tube-side average temperature C_p, μ, ρ at $\overline{T}_{tube}$

9. obtain shell-side fluid properties at shell-side average temperature C_p, μ, ρ at $\overline{T}_{shell}$
10. obtain fluid viscosity at tube-side wall temperature, μ at $\overline{T}_{w,tube}$
11. Calculate tube-side Prandtl Number $N_{Pr,tube} = \left(\frac{\mu C_p}{k}\right)_{T_{tube,f}}$
12. Obtain tube-side velocity $\overline{v}_{tube} = \frac{\dot{m}_{tube}}{\rho(\overline{T}_{tube}) \cdot A_{tube,cross}}$
13. Calculate tube-side Reynolds Number $N_{Re,tube} = \frac{D_{tube}\overline{v}_{tube}\rho(\overline{T}_{tube})}{\mu(\overline{T}_{tube})}$
14. Calculate tube-side Nusselt Number, $N_{Nu,tube}$ $N_{Nu} = 0.027 N_{Re}{}^{0.8} N_{Pr}{}^{1/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$
15. Calculate shell-side Nusselt Number, $N_{Nu,shell}$

$$N_{Nu} = 0.72\left[\frac{\rho_{liq}(\rho_{liq} - \rho_{vap})g\Delta H_{vap}D_{pipe,outside}{}^3}{N_{tube}\mu(T_{shell,f})k(T_{shell,f})(\overline{T}_{shell} - T_w)}\right]^{0.25}$$

16. Calculate tube-side heat transfer coefficient $h_{tube} = \frac{k(\overline{T}_{tube,f})N_{Nu,tube}}{D_{tube}}$
17. Calculate shell-side heat transfer coefficient $h_{shell} = \frac{k(\overline{T}_{shell,f})N_{Nu,shell}}{D_{eff}}$
18. Calculate the outside area, inside area, and log mean area
19. Calculate the overall heat transfer coefficient based on the outside area

$$U_o = \frac{1}{\frac{A_{outside}}{A_{inside}h_{tube}} + \frac{A_{outside}\Delta r_{pipe}}{A_{lm}k_{pipe}} + \frac{1}{h_{shell}}}$$

20. Calculate the log mean temperature, which since the shell temperature is constant, is just the arithmetic mean $\Delta T = (\overline{T}_{shell} - \overline{T}_{tube})$
21. Calculate the heat transfer rate $q = U_o A_{outside}(\overline{T}_{shell} - \overline{T}_{tube})$
22. compute new temperature at surface of wall on tube-side, from

$$q = h_{tube}A_{inside}(T_{w,tube} - \overline{T}_{tube})$$

23. compute new temperature at surface of wall on tube-side, from

$$q = h_{shell}A_{outside}(\overline{T}_{shell} - T_{w,shell})$$

24. compute tube-side energy balance on fluid to check initial guess of tube-side temperature $q = \dot{m}_{tube} \cdot C_p\left(\overline{T}_{tube}\right)\left(T_{tube,out} - T_{tube,in}\right)$, Rearrange to solve for

$$T_{tube,out} = T_{tube,in} + \frac{q}{\dot{m}_{tube} \cdot C_p\left(\overline{T}_{tube}\right)}$$

25. Iterate until $T_{tube,out}$ is converged

The program output yielded in five iterations:

Shell-side contains the hot fluid & tube-side the cold.
initial guess: Ttubeout = 303.000000 Tshellout = 448.150000
at j = 1, i = 22: Ttubeout = 371.516009 Tshellout = 448.150000
Tube-side Temp (K) inlet: 273.000000, outlet 371.516009, avg 322.257970
Shell-side Temp (K) inlet: 448.150000, outlet 448.150000, avg 448.150000
Wall Temp (K): Tube-side = 425.686510, Shell-side = 441.083099, avg = 433.384805
Heat Transfer coefficients shell film, heat film, overall (W/m^2/K):
hshell = 2436.852719 htube = 227.372873 Uo = 144.493316
Uo = 144.493316 Ui = 197.318829
Heat Transferred (W): q = -4122.523275 q_tube = 4122.522545 q_shell = 4122.521240
Enthalpy Changes (W): tube = 4122.517560 shell = 4122.522343

dimensionless numbers from the last iteration:

Nprtube = 1.7363

Nretube = 863.1380

Nnushell = 449.1382

Nnutube = 8.4733