Homework Assignment Number Ten
Assigned: Wednesday, March 31, 1999
Due: Wednesday, April 7, 1999 BEFORE LECTURE STARTS.

Problem 1. Geankoplis 4.7-6, page 322

$$T_{in} = 25C = 298K\text{, } T_{out} = 10C = 283K$$

$$\overline{T} = 0.5(T_{out} + T_{in}) = 290.5$$

$$\rho = \frac{MW \cdot p}{R\overline{T}} = \frac{0.0288 \cdot 101325}{8.314 \cdot 290.5} = 1.208\frac{kg}{m^3}$$

$$\beta = \frac{1}{\overline{\overline{T}}} = 0.00344K^{-1}$$

$$\mu = 1.78 \cdot 10^{-5}\frac{kg}{m \cdot s}$$

$$\delta = 0.010m\text{, } L = 2.0m\text{, } W = 1.8m$$

$$N_{Gr} = \frac{\delta^3\rho^2 g\beta\Delta T}{\mu^2} = \frac{0.010^3 1.208^2 \cdot 9.8 \cdot 0.00344 \cdot 15}{\left(1.78 \cdot 10^{-5}\right)^2}$$

$$N_{Gr} = 2329$$

$$C_p = 1004.8\frac{J}{kg \cdot K}$$

$$k = 0.026\frac{W}{m \cdot K}$$

$$N_{Pr} = \frac{\mu C_p}{k} = 0.688$$

Check $\frac{L}{\delta} = \frac{2.0}{0.010} = 200.0 > 3$

Check $N_{Gr}N_{Pr} = 1602 < 2000$

Obtain N_{Nu} from equation 4.7-8, Geankoplis, page 258

$$N_{Nu} = 1.0$$

$$h = \frac{kN_{Nu}}{\delta} = 2.6\frac{W}{m^2 \cdot s}$$

Problem 2. Geankoplis 4.8-2, page 323

(Solution not posted.)

Problem 3.

Under the Lecture Notes Section of the Course Website, there is a handout titled "Algorithm for the solution of a shell and tube heat exchanger problem". The algorithm contains 35 steps. Also in the hand-out is a sample MATLAB code which conducts those 35 steps.

(a) Write your own code (probably quite similar to the one in the hand-out to solve the heat exchanger problem). Your code should output six properties.

(i) shell-side film heat transfer coefficient, h_{shell}

(ii) tube-side film heat transfer coefficient, h_{tube}

(iii) over-all heat transfer coefficient (based on outer diameter), U_o

(iv) the heat transfer rate, q

(v) the shell-side outlet temperature, $T_{shell,out}$

(vi) the tube-side outlet temperature, $T_{tube,out}$

For part (a), I want a print-out of the code.

(b) Use your code to solve the following problem:

We will be using cold water to cool hot water in a 1-1 shell and tube heat exchanger. The hot water is inside the tubes. The cold water is in the shell. The flow is counter-current.

The cold water enters the shell at $T_{shell,in} = 250K$. The hot water enters the tubes at $T_{tube,in} = 400K$. The flow-rate of the hot stream is $\dot{m}_{tube} = 0.10\frac{kg}{s}$ and the flow-rate of the cold stream is $\dot{m}_{shell} = 0.20\frac{kg}{s}$.

The heat exchanger is made of stainless steel tubes of outside diameter 1 inch ,BWG 10. The length of the tubes and the length of the shell are $L = 4.0m$; the number of tubes, $N_{tube} = 24$; the diameter of the shell, $D_{shell} = 0.15m$. Use fouling factors for city water.

Determine the six quantities specified in part (a)

(c) Repeat Part (b) with cocurrent flow.

(d) Repeat Part (b) with $L = 1.0m$

(e) Repeat Part (b) with the hot fluid in the shell and the cold fluid in the tube.

solution:

(a) I used the code, hxchnger_v2.m available on the course website.

(b) I iterated until both outlet temperatures were constant within 0.00001 Kelvin.

```
» hxchger_v2
initial guess:  Ttubeout = 370.000000 Tshellout = 281.500000
at j =    1, i =   25:  Ttubeout = 298.569505 Tshellout = 340.750000
at j =    2, i =   25:  Ttubeout = 311.014789 Tshellout = 311.125000
…
at j =   23, i =   24:  Ttubeout = 301.612188 Tshellout = 298.940543
at j =   24, i =   24:  Ttubeout = 301.612182 Tshellout = 298.940536
Tube-side Temp (K)  inlet:  400.000000, outlet 301.612182, avg 350.806088
Shell-side Temp (K)  inlet:  250.000000, outlet 298.940536, avg 274.470271
Wall Temp (K):  Tube-side = 300.771756, Shell-side = 295.300084, avg = 298.035920
Heat Transfer coefficients  shell film, heat film, overall (W/m^2/K):
hshell = 259.205906 htube = 147.361123 Uo = 73.371215
Uo = 73.371215 Ui = 100.195101
Heat Transferred (W): q = 41360.433298 q_tube = 41360.434493 q_shell = 41360.427860
Enthalpy Changes (W): tube = -41374.088821 shell = 41360.436210
```

(c) For cocurrent flow, I had to change the variable flow from 1 to 0.
Then I reran the code:

```
» hxchger_v2
initial guess:  Ttubeout = 370.000000 Tshellout = 281.500000
at j =    1, i =   25:  Ttubeout = 306.997020 Tshellout = 340.750000
at j =    2, i =   25:  Ttubeout = 343.078103 Tshellout = 311.125000
…
at j =   23, i =   25:  Ttubeout = 312.982627 Tshellout = 293.403824
at j =   24, i =   25:  Ttubeout = 312.982632 Tshellout = 293.403831
Tube-side Temp (K)  inlet:  400.000000, outlet 312.982632, avg 356.491319
Shell-side Temp (K)  inlet:  250.000000, outlet 293.403831, avg 271.701912
Wall Temp (K):  Tube-side = 314.655192, Shell-side = 291.497858, avg = 303.076525
Heat Transfer coefficients  shell film, heat film, overall (W/m^2/K):
hshell = 242.314115 htube = 156.575664 Uo = 74.890121
Uo = 74.890121 Ui = 102.269306
Heat Transferred (W): q = 36745.975914 q_tube = 36745.977922 q_shell = 36745.982630
Enthalpy Changes (W): tube = -36667.588518 shell = 36745.966614
```

Comparing with (b), we see that 11.2% less heat is transferred in the cocurrent case.

(d) For L=1.0, I had to change the variable L from 4.0 to 1.0.
Then I reran the code:

```
» hxchger_v2
initial guess:  Ttubeout = 370.000000 Tshellout = 281.500000
```

at j = 1, i = 25: Ttubeout = 359.549220 Tshellout = 265.750000
at j = 2, i = 25: Ttubeout = 358.154194 Tshellout = 273.625000
…
at j = 21, i = 23: Ttubeout = 358.658962 Tshellout = 270.650952
at j = 22, i = 23: Ttubeout = 358.658972 Tshellout = 270.650944
Tube-side Temp (K) inlet: 400.000000, outlet 358.658972, avg 379.329491
Shell-side Temp (K) inlet: 250.000000, outlet 270.650944, avg 260.325476
Wall Temp (K): Tube-side = 305.801467, Shell-side = 300.862941, avg = 303.332204
Heat Transfer coefficients shell film, heat film, overall (W/m^2/K):
hshell = 226.830379 htube = 170.775546 Uo = 77.462901
Uo = 77.462901 Ui = 105.782671
Heat Transferred (W): q = 17609.727567 q_tube = 17609.726238 q_shell = 17609.729997
Enthalpy Changes (W): tube = -17563.246687 shell = 17609.736286

Comparing with (b), we see that less heat is transferred for a shorter length. In fact, shortening the length by a factor of 0.25, decreased the heat transfer by a factor of 0.426.

(e) For switching fluids, I had to change the inlet temperatures, the mass flows, and the outlet temperature initial guesses.
Then I reran the code:

» hxchger_v2
initial guess: Ttubeout = 281.500000 Tshellout = 370.000000
at j = 1, i = 25: Ttubeout = 316.722003 Tshellout = 310.000000
at j = 2, i = 24: Ttubeout = 295.358789 Tshellout = 280.000000
…
at j = 23, i = 25: Ttubeout = 295.180723 Tshellout = 309.353480
at j = 24, i = 25: Ttubeout = 295.180729 Tshellout = 309.353473
Tube-side Temp (K) inlet: 250.000000, outlet 295.180729, avg 272.590368
Shell-side Temp (K) inlet: 400.000000, outlet 309.353473, avg 354.676740
Wall Temp (K): Tube-side = 335.890171, Shell-side = 340.546931, avg = 338.218551
Heat Transfer coefficients shell film, heat film, overall (W/m^2/K):
hshell = 352.657264 htube = 107.499772 Uo = 62.331582
Uo = 62.331582 Ui = 85.119473
Heat Transferred (W): q = -38171.915570 q_tube = 38171.916184 q_shell = 38171.915613
Enthalpy Changes (W): tube = 38228.697330 shell = -38171.911472

Comparing with (b), we see that we have different outlet temperatures and 9.2% less heat transfer rates when we have the hot fluid in the shell, rather than in the tube.