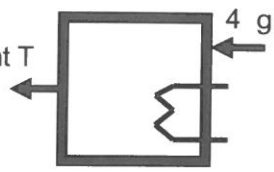
ANSWER SHEETS PROVIDED. Only the answer sheets will be graded, and your name must be on each one. You must turn this test sheet in with your work.

1.(35) A 100 gal well-insulated hot water heater tank is initially filled with water at 150 F. At time t = 0, people start taking showers and extracting water from the tank. At the same time, the tank is kept full by supplying 4 gpm of 50 F water, and a 8.8 kW (500 Btu/min) electric heater coil in the tank comes on. The water in the tank is well mixed and can be considered to be at a uniform temperature T at which the water exits. Use ρ_{water} = 8.3 lb/gal and C_p = 1.0 Btu/lb-F if needed.



a) (3) What is the flow rate of water leaving the tank if it stays full, gpm?
b) (15) Write a differential equation and initial condition that could be solved for the temperature T of the water in the tank as a function of time. Do not solve.
c) (10) What is the eventual steady water exit temperature if the 4 gpm flow to the shower continues, F?
d) (7) Roughly how long until this steady state is reached, min? This can be done without solving the ODE in (a).

2.(30) Recall that the pump power required to pump water through a closed constant diameter piping loop can be written, using Hazen-Williams for head loss, as

$$\text{power} = \frac{\gamma h_L Q}{\eta} = \gamma A \frac{L_{eff} Q^{1.852}}{C^{1.852} D^{4.8704}} \cdot \frac{Q}{\eta}$$

where $L_{eff} = L + L_{eq}$, γ = weight density, and η = pump efficiency.

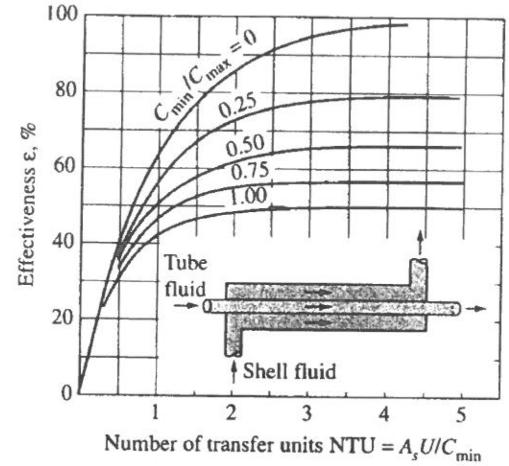
a) (12) What are the normalized sensitivity coefficients for C and L_{eff}?
b) (12) What % total uncertainty in power results from a 20% uncertainty in C and a 10% uncertainty in L_{eff} (due mostly to uncertainty in L_{eq} in valves and fittings).
c) (6) Which uncertainty contributes more to uncertainty in pump power? For credit, you must give a quantitative reason.

3.(35) A crossflow air-handling unit (AHU) is used to cool air at T_{ai} = 25 C using chilled water at T_{wi} = 10 C. The required heat transfer rate is 50 kW. The following additional info is available:

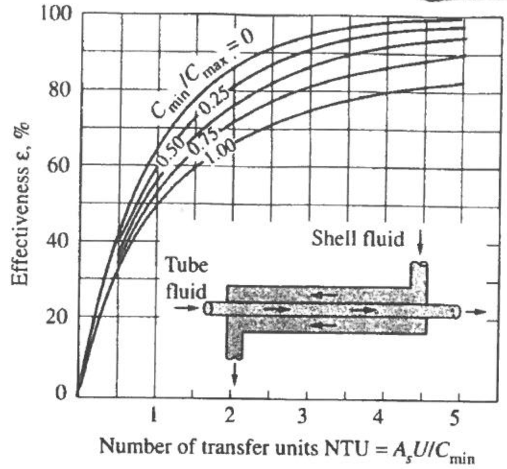
- U value of the AHU is 20 W/m^2-K.
- Heat exchanger area costs \$150/m^2.
- Annual chilled water pumping cost in \$ is $2\dot{m}_w^3$, where $\dot{m}_w$ is in kg/s.
- Annual fan operating cost in \$ is $3\dot{m}_a^3$, where $\dot{m}_a$ is in kg/s.
- Uniform series present worth factor is 8.0.

The combination of heat exchanger area A, air mass flow rate $\dot{m}_a$, and chilled water mass flow rate $\dot{m}_w$ that will minimize the present value of the purchase and operating cost is sought.

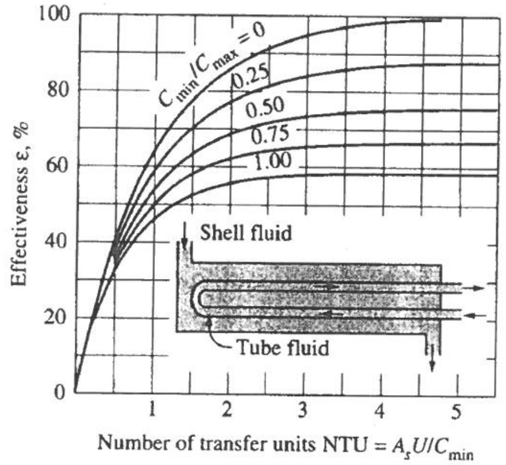
a) (8) What is the objective function?
b) (10) What are the constraint(s)?
c) (17) For A = 280 m^2, $\dot{m}_a$ = 5 kg/s, and $\dot{m}_w$ = 2.5 kg/s
   - What is the present cost,\$?
   - Are the constraint(s) satisfied? If needed, use C_{Pw} = 4.2 kJ/kg-K and C_{Pa} = 1.2 kJ/kg-K. If needed, ε-Ntu plots are attached.



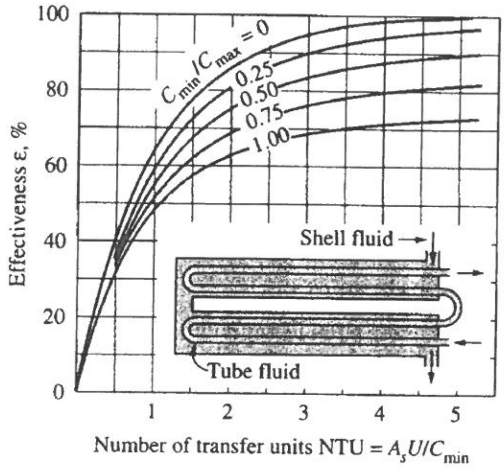
(*a*) Parallel-flow



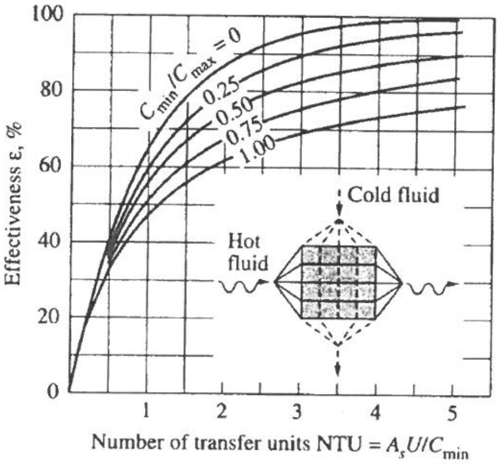
(*b*) Counter-flow



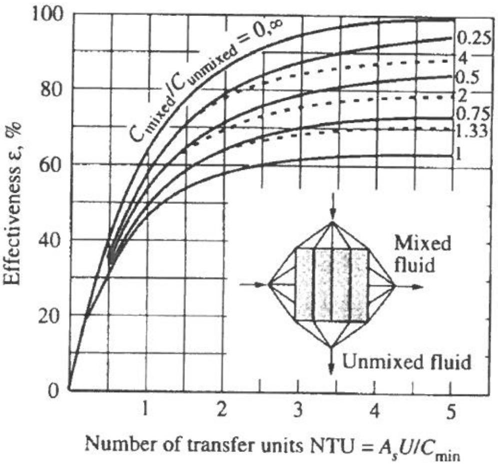
(*c*) One-shell pass and 2, 4, 6, ... tube passes



(*d*) Two-shell passes and 4, 8, 12, ... tube passes



(*e*) Cross-flow with both fluids unmixed



(*f*) Cross-flow with one fluid mixed and the other unmixed

Heat Exchanger Effectiveness for Various Geometries (From Cengel and Turner, *Fundamentals of Thermal-Fluid Sciences*, 2nd Ed., McGraw-Hill, 2005.)