Franklin W. Olin College of Engineering
ENGR 3310: Transport Phenomena

Problem Set 10

Assigned: 12/2/04 Fall 2004
Due: 12/9/04 by 5:00 pm

Problem 1 (10.40 from Incropera and DeWitt)

Saturated steam at 0.1 bar condenses with a convection coefficient of 6800 W/m^2K on the outside of a brass tube having inner and outer diameters of 16.5 and 19 mm respectively. The convection coefficient for water flowing inside the tube is 5200 W/m^2K. Estimate the steam condensation rate per unit length of the tube when the mean water temperature is 30 °C. (Hint: You will need to look at the condensation handout, or the book to get the appropriate equations for this problem).

Problem 2 (11.49 from Incropera and DeWitt, 5th edition)
This is the problem that we went over briefly at the end of class on Thursday. Your assignment is to redo the problem from scratch and make sure you are familiar with the use of the ε -Ntu Method. You do not need to turn in this problem.

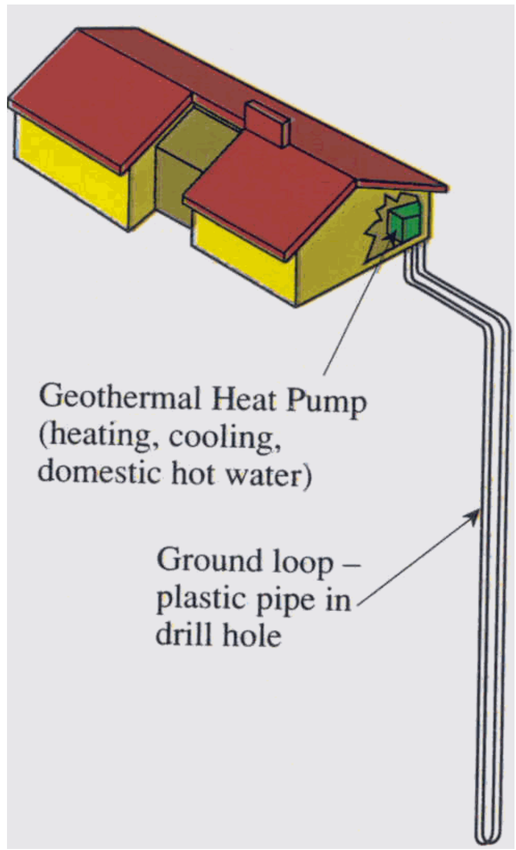
Problem 3

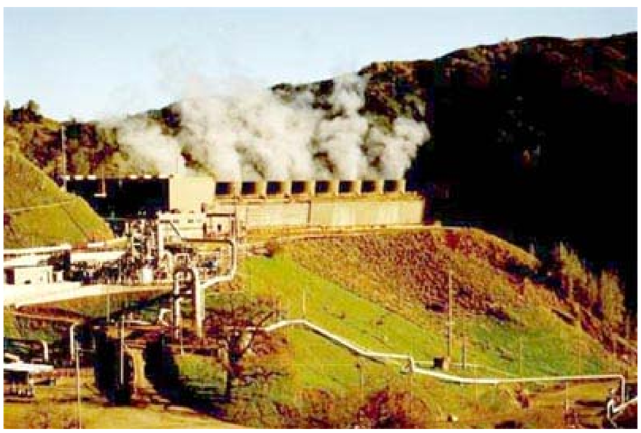
Recovery of Geothermal Energy

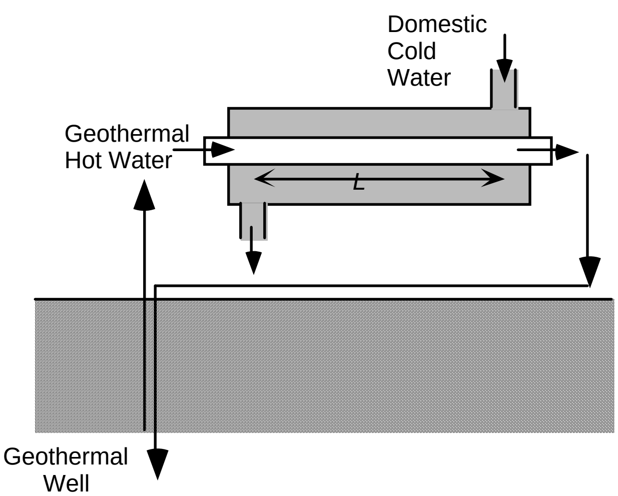
See for example: http://www.nevadageothermal.com/s/Home.asp

And the following report from the World Energy Council:
http://www.worldenergy.org/wec-geis/publications/reports/ser/geo/geo.asp

One possible alternative energy source that has been considered repeatedly over the years is the use of geothermal energy – i.e. very hot water recovered from deep underground (an example of a complete geothermal power plant is shown below) A well is sunk deep into the earth and then the hot mineral water is brought to the surface and its thermal energy is extracted. This energy can either be used for a power plant (as shown below) or, in the case we wish to consider today, to directly heat domestic water; for example for hot water in a house or dormitory etc (as shown opposite). To accomplish this energy exchange one needs to use a heat exchanger.







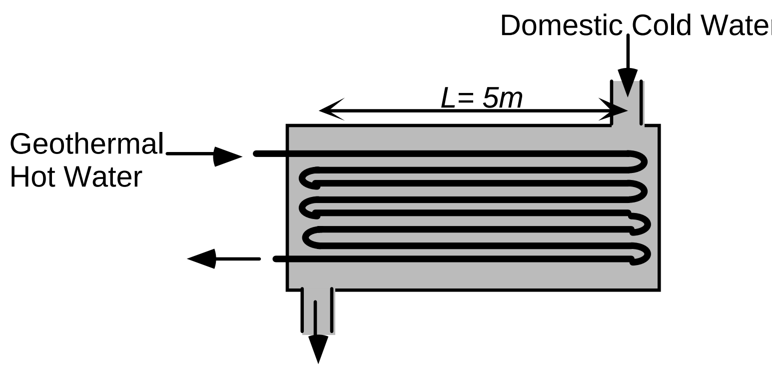
In the present example, hot mineral water at a temperature of 160˚C exits the ground at a mass flow rate of 2 kg/s. We wish to use this to provide domestic hot water for showers/baths etc in a house, at a specified design temperature of 80˚C. The mass flow rate of water required in the house is 1.2 kg/s, and the domestic water is initially at an ambient temperature of 20˚C.

The specific heat of the underground mineral water is 4.3 kJ/kgK and the specific heat capacity of the domestic water is 4.2 kJ/kgK.

We start by constructing a single pass, concentric tube, counter-flow heat exchanger which is very well insulated. The inner tube is constructed from a thin-walled copper pipe with diameter D = 2.5 cm. For the flow rates and fluids specified, design calculations show that the overall heat transfer coefficient is U = 640 W/m^{2}K.

a) Assuming the heat exchanger is sized to exactly meet its design goal, determine the heat transfer rate and the exit temperature of the geothermal water as it is exits the heat exchanger.

b) Using this information, find the overall heat transfer area required, and the length L of copper tube required to achieve the design goal.



The answer obtained in part (b) is obviously unfeasibly long, so we need to use a different design of heat exchanger. We thus select a cross-flow shell-tube heat exchanger consisting of a single shell pass and eight tube passes. Each tube pass consists of a tube of diameter D = 2.5 cm and of length L = 5m. The overall heat transfer coefficient of this heat exchanger remains U = 640 W/m^{2}K.

c) Determine the overall effectiveness ε of this heat exchanger, using the same input temperatures, heat capacities and mass flow rates as given above.

d) Hence find the exit temperatures of the cold stream and hot stream. Does this design satisfy our original design constraint of providing hot water to the building at 80˚C?

For a shell and tube heat exchanger with 1 shell pass and n = 2, 4, 6,… tube passes, we have the following relationships:

$$\varepsilon = 2\left\{1 + C_r + \sqrt{1+C_r^{\,2}}\,\frac{1+\exp\left[-Ntu\sqrt{1+C_r^{\,2}}\right]}{1-C_r\exp\left[-Ntu\sqrt{1+C_r^{\,2}}\right]}\right\}^{-1} \qquad (1)$$

$$Ntu = -\frac{1}{\sqrt{1+{C_r}^2}} \ln\left[\frac{2/\varepsilon - 1 - C_r - \sqrt{1+{C_r}^2}}{2/\varepsilon - 1 - C_r + \sqrt{1+{C_r}^2}}\right] \tag{2}$$