Special Topics Course ME 5374 "APPLICATIONS OF CONCENTRATING SOLAR THERMAL TECHNOLOGIES"
Spring 2024

Please submit electronic copies of the homework to CANVAS under assignment 5.

Read Chapters 4, 5 and 7 (You should have read chapter 4 and started 5 last week)

5.1 In a receiver tube design similar to Fig. 4.1 pressurized water flows at a mass rate of 0.9 kg/s. The specific heat of water can be considered as constant for this calculation at a value of 6000 J/(kg K). The incident solar radiation on the concentrator is 800 W/m^2 and the area is 4 m^2. Note: The incident solar radiation represents the peak value for this system and the performance will provide the peak power production. The concentration factor for the field is 250 (linear concentrator) and the optical efficiency is 0.92. The tube is made of Inconel with a thermal conductivity of 11.4 W/(m K), outer diameter of 0.080 m, an inner diameter of 0.075 m and a length of 1 m. In this CSP design two tubes are used in series to heat the working fluid. The solar absorptivity of the tube is 0.95 and the long wave emissivity is 0.2.

The convection heat transfer coefficient between the working fluid and the inner tube wall is 550 W/(m^2 K). The heat transfer coefficient on the outer tube surface is 17 W/(m^2 K). For this part of the problem there is no glass envelop surrounding the tube to provide an evacuated space. The tube is exposed to the environment.

For each 1 m section of tube the assumption that the temperature of the working fluid varies linearly with flow distance (Similar to Assignment 2 and the "element" section discussed in Chapter 4) so that an average temperature can be used for the convection and radiation calculations.

The ambient temperature is 24 C and clear sky conditions exist for the time of this calculation. The working fluid enters the first tube at a temperature of 100 C. For this calculation you can assume steady state conditions.

a) Determine the incident area of the solar energy on the tube and the fraction of the tube's diameter that is exposed to the incident solar energy.
b) Determine the working fluid temperature exiting the first, 1 m section of the tube. Assume for this calculation that the working fluid, water, remains as a liquid due to the operating pressure. Also report the average temperature of the tube wall.
c) Determine the working fluid temperature at the exit of the second 1 m section under the same assumed liquid conditions. Also report the average temperature of the tube wall.
d) Calculate the rate of useful energy collected which equals the change in enthalpy of the water as it moves through the system.
e) Using water data, is it possible to operate the system as described? Another way of asking this question is what pressure would have to be used to keep the water in a liquid state through the tubes?

Part 2:

For the same conditions as described above consider that a glass envelop is placed over the tube. The glass envelop has an inner diameter of 0.095 m, an outer diameter of 0.120 m and a thermal conductivity of 0.6 W/(mK). The solar reflectance of the tube is 0.08 and its transmittance is 0.95. The space between the glass envelop and receiver tube contains air at a pressure of 0.1bar (A reduced pressure). The convective heat transfer coefficient between the enclosed air and the surfaces of the receiver tube and glass is 3 W/(m^2 K) and the glass is opaque at long wavelengths with an emissivity of 1.0 (a back body). Repeat the calculations for parts b to e above. Also, include the average temperature of each glass section.

Part 3

i) Does using the glass envelop improve the performance of this collector design? Does it increase the temperature of the working fluid exiting the collector?

ii) Can you use water for this application; that is can a pressure be stated which will maintain the water as a liquid throughout the collector?

iii) Is the assumption of a constant value of the specific heat of the water a good assumption?