FAMU-FSU College of Engineering
Department of Mechanical Engineering
EML4930/5930: Energy Conversion Systems II
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Lab 3: Concentrated Solar Power

Basic Concept

One of the most cost efficient ways of generating electricity from solar radiation is through solar thermal power – turning solar heat in to electricity. Direct solar radiation can be concentrated and collected by Concentrating Solar Power (CSP) technologies to provide medium to high temperature heat. The heat is then used to operate a conventional power cycle, for example, through a steam turbine or Stirling engine. Four main elements are required to produce electricity from solar thermal power: 1) concentrator, 2) receiver, 3) heat exchanger, and 4) storage and power conversion equipment. The small thermal power units which use a parabolic (dish) shaped reflector to concentrate sunlight use heated gas to generate power in a small engine at the focal point of the reflector. This lab is aimed at providing hands on experience with the different elements of a dish-engine system.

The Sun

The sun is the closest star to the earth, with inner temperatures reaching 40 million Kelvin, and a surface temperature of 6000 Kelvin. The origin of the enormous amount of radiant energy that is emitted by the sun is due to the thermo-nuclear processes which take place within the sun. The diameter of the sun is 1.39×10^{9} meters and is located 1.49×10^{11} meters from the earth. At this distance, the earth receives 1.35kW of thermal power for each square meter at the terrestrial orbit level. The solar radiation is thus reduced in the terrestrial atmosphere, thus reaching the earths surface with about 1.1 kW/m^2 of solar radiation. With this amount of solar radiation, solar-thermal flat plate collectors can be used, but can only reach temperatures upwards to 100 deg C. However, for the processes we are looking at, we want to obtain higher temperatures on the order of 250 to 700 deg C.

The Concentrator

The purpose of employing a focusing collector system is to increase the intensity of the solar radiation falling on the collector. By increasing the intensity, it makes it possible to collect the solar energy at a higher temperature with a smaller collector area that that of a simple flat-plate system. These concentrating solar collectors require the use of reflective surfaces with high specular reflectance in the solar spectrum. The reflecting surfaces are usually highly polished metals or metal coatings. In the case of the concentrator used in this lab set up, the substrate is opaque, and thus an aluminized mylar is front-surfaced on the dish.
The concentration of solar radiation is achieved by reflecting or refracting the flux incident on the aperture area, A_a, onto a smaller receiver/absorber area, A_r. An optical concentration ration, CR_o, is defined as the ration of the solar flux, I_r, on the receiver to the flux, I_a, on the aperture. The optical concentration ratio is defined as:

$$CR_o = \frac{I_r}{I_a}$$

The geometric concentration ratio, CR, is based on the areas of the aperture and receiver. It is defined as the ratio between the concentrator opening area and the aperture area that receives all the solar radiation concentrated by the system. The geometric concentration ratio is given by:

$$CR = \frac{A_a}{A_r}$$

The optical concentration ratio gives a ‘true’ concentration ratio because it accounts for the optical losses from the reflecting and refracting elements, however, since it has no relationship to the receiver area, it does not give insight into thermal losses which are proportional to the receiver area.

Receiver

The receiver consists of a stainless steel water drum and coils housed in a stainless steel welded tube. The heat transfer medium is a molten nitrate salt (Draw salt), which has a melting point of 222°C. This salt is used for both heat storage and heat transfer due to its ability to retain heat for a long period of time.

Pre-lab Calculations:

Determine the orientation of the dish and the number of degrees of movement for your specified lab time.

Experiment

Setup / Specifications

- 12-foot parabolic reflector
  - Diameter: 146.75 inches
  - Depth: 25.5 inches
  - Focal Length: 52.75 inches
- Solar tracking system
- Receiver constructed of stainless steel
  - Diameter: 6 inches
  - Height: 7.5 inches
- Receiver contains molten salt heat transfer medium
- Impulse Steam Turbine
- Tachometer
- TC1 – inlet water temperature
- TC2 – exit water temperature
- TC3 – molten salt bath temperature (Thermal bath)

Procedure

1.) Allow the thermal bath to reach 800°F with no water flowing.

2.) Once the thermal bath reaches 800°F, the bad ass lab technician will connect the pump and turn on the water flow.

3.) Measure the inlet, outlet, and thermal bath temperatures and the flow rate of the water. Also note the reaction that is taking place and how it changes with time.

4.) Allow this to continue until the outlet and bath temperatures reach steady state.

5.) Have the lab technician disconnect the pump and record the temperature of the bath in 30-second intervals as the thermal bath is allowed to reach 800 °F.

6.) Repeat steps 1 through 5 for two other flow rates (for a total of 3 different flow rates).

7.) While allowing the thermal bath to reach 800°F, have the talented lab technician connect the steam turbine to outlet side of system.

8.) Once the thermal bath has reached temperature, have the genius lab technician reconnect the pump and set it to the lowest of the three previously measured flow rates.

9.) Measure the power output and outlet temperature at 5 second intervals as the steam passes through the turbine.

Questions

NOTE: These questions represent the minimum amount of information that must be provided in your report!

1.) Calculate the surface areas of the dish and the receiver and use these to determine the geometric concentration ratio.

2.) Assuming 1 kW/m^2, determine the optimal temperature that can be reached in the receiver for the calculated concentration ratio. Also determine the maximum system efficiency by calculating maximum Carnot.

3.) Plot the heat capacitor transient temperature profiles for all three of the cases you did – this is the increasing bath temperature as a function of time. What does this tell you?

4.) Calculate both the transient and steady state heat transferred into the water by way of the concentrator/boiler setup for all three of the flow rates you used. Based on your results, determine the efficiency of the concentrator/boiler setup. Assume 80% reflectivity for the surface of the dish.

5.) For the turbine, did the power change as the steam temperature dropped? What does this mean regarding the quality of the steam? Can the power be presented as a function of pressure (using steam tables)? If so, do it. If not, explain why.

6.) Estimate the flow rate which could provide equilibrium in the boiler? Do you think this amount is useful, or should the dish be run in cycles allowing the boiler to heat to higher temperatures?