Analysis of Superheater Tubes with Mutual Irradiation As Applied to a Solar Receiver Steam Generator

Norberto Lemcoff[1], Stewart Wyatt[2]

[1]Rensselaer Polytechnic Institute, Hartford, CT, USA
[2]Alstom Power, Windsor, CT, USA

Abstract

Central solar receiver steam generators consist of dual axis tracking heliostats to concentrate solar radiation onto a tower mounted central receiver [1]. The radiant energy is used to heat the working fluid, high pressure superheated steam, to a high temperature. The working fluid is for use in a turbo generator, as is typical in conventional electricity generating plants. Membrane panels of tangent tubes may be applied to the central receiver of the solar power system as the heat transfer medium between the concentrated solar irradiation and the working fluid. The tube panels are typically flat but arranged to form an approximate cylindrical surface. With the aim of maximizing the use of existing technology, an ideal solar steam generator used for electricity production utilizes the same equipment as a fossil fuel fired electric utility, including high temperature materials and steam turbines. The objective of this paper is to analyze the circumferential temperature variations within a superheater tube of a solar receiver steam generator. The tubes of the solar steam generator are heated by the concentrated collimated solar flux from the array of heliostats. As well as the intended heat transfer from the tube to the steam, the tube is also cooled by conduction (axially and circumferentially), external convection and thermal radiation exchange with the surroundings, consisting of the ambient and adjacent tubes. The various modes of heat loss are considered in this paper, with a focus on the influence of the radiation interchange between a tube and its surroundings. The influence of external convection, heat loss by radiation and conduction within the tube on the temperature distribution are analyzed. Practical models that may be applied to solar receiver steam generator designs were developed for an isolated tube, and the significance of mutual irradiation of adjacent tubes was studied using COMSOL Multiphysics. The model [2] was used to determine the temperature distribution within a thick shell exposed to collimated irradiation (Figure 1). The combined effects of solar irradiation, internal convection and the two dimensional conductivity of the thick walled tube were considered. The temperature variation within the tube wall was shown to be influenced by the material conductivity, wall thickness and internal convection coefficient [3]. However, this model does not take into account the thermal radiation exchange between the surfaces of adjacent tubes. A model was setup using COMSOL Multiphysics to include the heat transfer by mutual irradiation of adjacent tubes. The effects of surface emissivity (e), thermal conductivity (k), and heat transfer (h) were studied. The results for e = 0.09, k = 44.5 W/m.K and h = 4720 W/m2.K are shown in Figure 2and Figure 3. It can be seen that, in the bottom half of the tube, the temperature is quite uniform and the heat flux is relatively low. Both increase significantly in the upper half of the tube.

Reference

1. Anderson, R., and F. Kreith, "Natural Convection in Active and Passive Solar Thermal Systems." Advances in Heat Transfer, Vol. 18, 1-86, 1987.
2. Mackowski, D. W., Conduction Heat Transfer: Notes for MECH 7210, Mechanical Engineering Department, Auburn University, 2011.
3. Wyatt, S., Circumferential Temperature Variation in Superheater Tubes with Mutual Irradiation as Applied to a Solar Receiver Steam Generator, Master's Project, Rensselaer Polytechnic Institute, 2012.

Figures used in the abstract

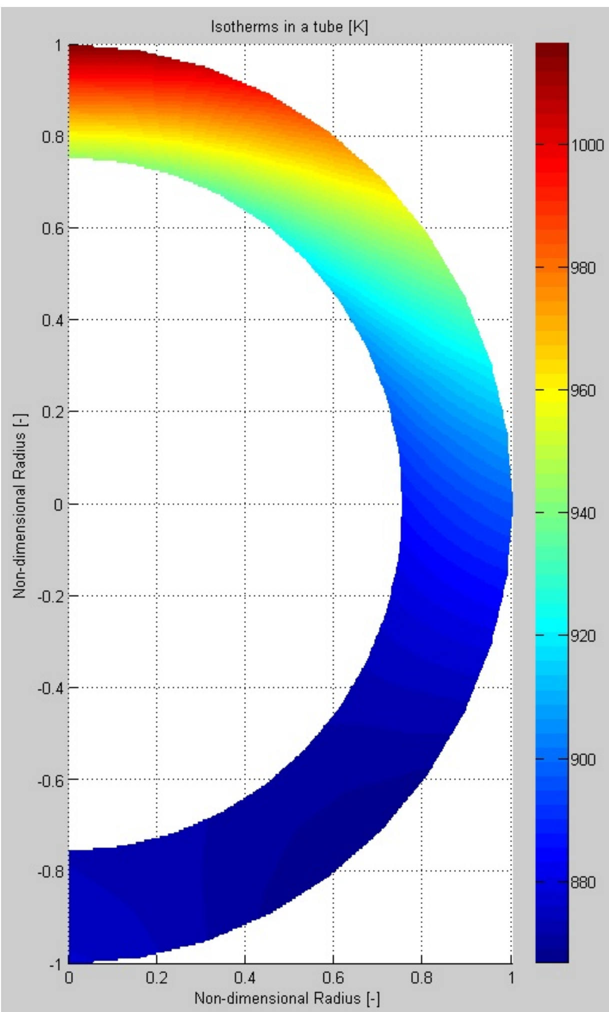

Figure 1: [2] Isotherms at design conditions.

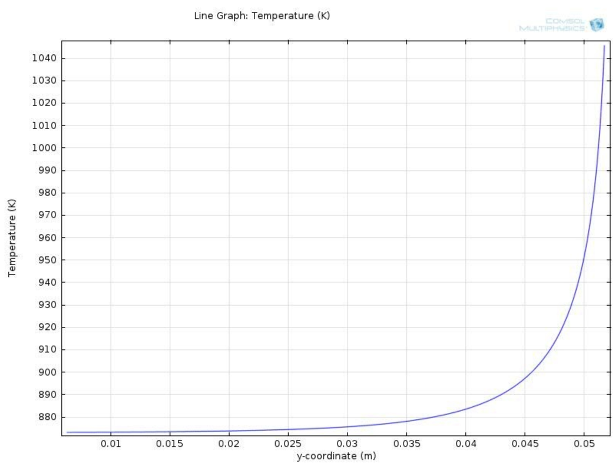

Figure 2: Temperature distribution at the inner surface of a 6.3mm thick tube.

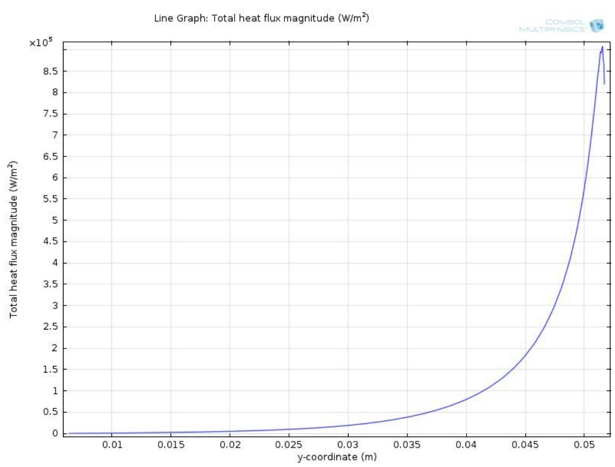

Figure 3: Heat flux distribution at the inner surface of a 6.3mm thick tube.