Modeling Solar Concentrating Systems in Thermal Desktop

C&R Thermal Desktop® and SINDA/FLUINT offers best-in-class thermal radiation solutions, which are critically important to both space vehicle and solar power system analyses. This tool suite also uniquely offers single- and two-phase thermohydraulics, which means an entire solar energy system can be modeled from the collectors to the steam power cycle or feedwater heat exchangers.

Solar concentrating systems focus the sun’s energy onto a collection system for conversion into electricity. There are several types of concentrator systems: parabolic dish with Stirling-cycle engine, power tower, linear Fresnel concentrators, and parabolic trough concentrators. Many of these systems collect heat into a heat transfer fluid that is used either to boil water, or to preheat the water before it enters a boiler heated by a conventional fuel source.

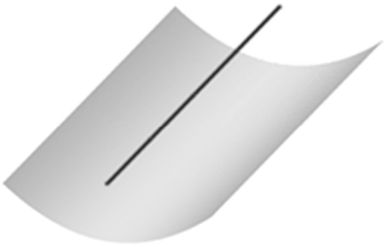
The latter strategy was recently implemented near Grand Junction, Colorado by Xcel Energy. In that system, a parabolic trough system is used to preheat feedwater to a coal burning power plant, thereby reducing the amount of coal required. See Xcel News Release 6/30/2010: First-Ever Solar-Coal Project Is Running.

Figure 1 - Typical parabolic-trough solar field

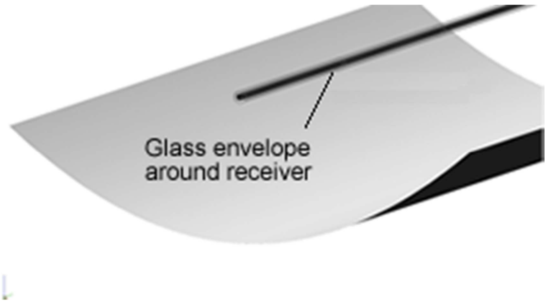
Parabolic trough: The parabolic trough presents a unique problem for modeling. Estimating the shape of a parabola with faceted surfaces (i.e., meshed surfaces) makes it extremely difficult to accurately calculate reflections. Thermal Desktop overcomes this limitation by including mathematically correct surfaces, such as parabolic dishes and parabolic troughs whose shape can be adjusted parametrically. Such native Thermal Desktop surfaces provide accurate shapes *independent of the nodal resolution.*

To emphasize this point, the trough shown in the images below is represented by a single thermal node. More realistic resolution is easily obtained as needed to calculate temperature gradients on the reflector, perhaps as caused by imperfect alignment, convection, etc. False gradients on the collector, which result from a faceted representation of the reflector, are not a concern at any resolution with the Thermal Desktop trough surface.

(Click on images for larger views)



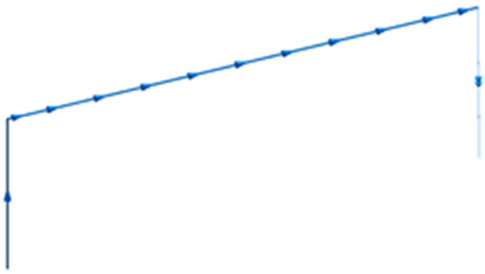
Parabolic trough reflector with heat collector element (HCE) modeled in Thermal Desktop



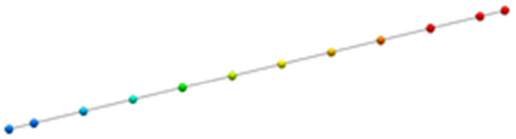
Heat collector element consists of transparent glass envelope, receiver and heat transfer fluid; all of which can be modeled in Thermal Desktop.

Heat Collector Element: At the focus of the parabolic trough is a heat collector element (HCE). The HCE typically consists of (1) an evacuated glass envelope, (2) a steel receiver pipe coated with a high absorptivity and low emissivity coating, and (3) a heat transfer fluid flowing through the pipe. The evacuated envelope prevents heat loss through convection. Occasionally, the vacuum is lost, so parametric modeling in Thermal Desktop can be used to show the effect of heat transfer between the receiver pipe and the envelope. With FloCAD® for creating the thermohydraulic piping network, the analyst can assume the receiver pipe is isothermal about its circumference or can examine the effects of higher resolution about the circumference. Thermoelastic loading, perhaps caused by asymmetric heating of the HCE, could be analyzed by mapping the temperature results to a structural model (independent of the resolution used in the thermal model).

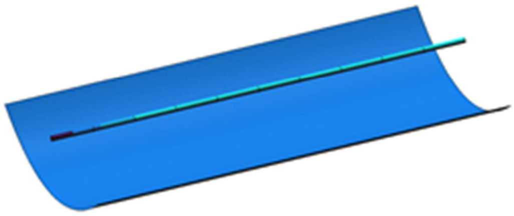
Fluid Flow and Energy Balance: SINDA/FLUINT can calculate the energy transfer through conduction, convection and radiation as well as the fluid flow through the HCE. The solution from SINDA/FLUINT can provide temperatures throughout the system and pressures and flow rates in the flow network. Strengths of the thermohydraulic solutions include two-phase flow and transients (e.g., start-up, shut-down, and control system design).



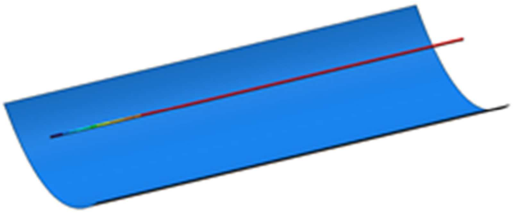
Flow path through receiver pipe including flow rate definition to the right. Flow rate can be defined as a set mass or volumetric flow or with a pump device.



Temperature of heat transfer fluid



Temperature of trough and glass envelope (different scale than the fluid graphic above)



Temperature of trough and receiver (same scale as trough and envelope at left)

Additional Thermal Desktop, RadCAD, FloCAD and SINDA/FLUINT Capabilities for Concentrating Solar Power Systems

- Accurate curved surfaces for radiation calculations
- Transparent surfaces and solids with refraction
- Mapping of thermal results to structural models
  - Receiver pipe
  - HCE supports
- Parameterized analyses
  - External convection to ambient
  - Internal convection between receiver pipe and glass envelope
  - Optical properties of the reflector and receiver
- Free molecular heat transfer for near-vacuum in glass envelope
- Diffuse solar load and diffuse sky IR radiation
- Solar tracking for surfaces or groups of objects
- Psychrometrics for condensing air heat exchangers
- Condenser, evaporator, and boiler sizing and simulation
- Phase change materials for thermal energy storage
- Turbomachine components
  - Cycle-level analysis of power generation cycles
  - Performance map-based descriptions of single- or multi-stage turbomachines
  - Steam turbines
  - Heat transfer fluid pumps

These capabilities may be used separately for component-level analyses or together for plant-level analyses.