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Parabolic Trough Solar System Piping Model

Final Report
May 13, 2002 — December 31, 2004

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Subcontract Report
NREL/SR-550-40165
July 2006

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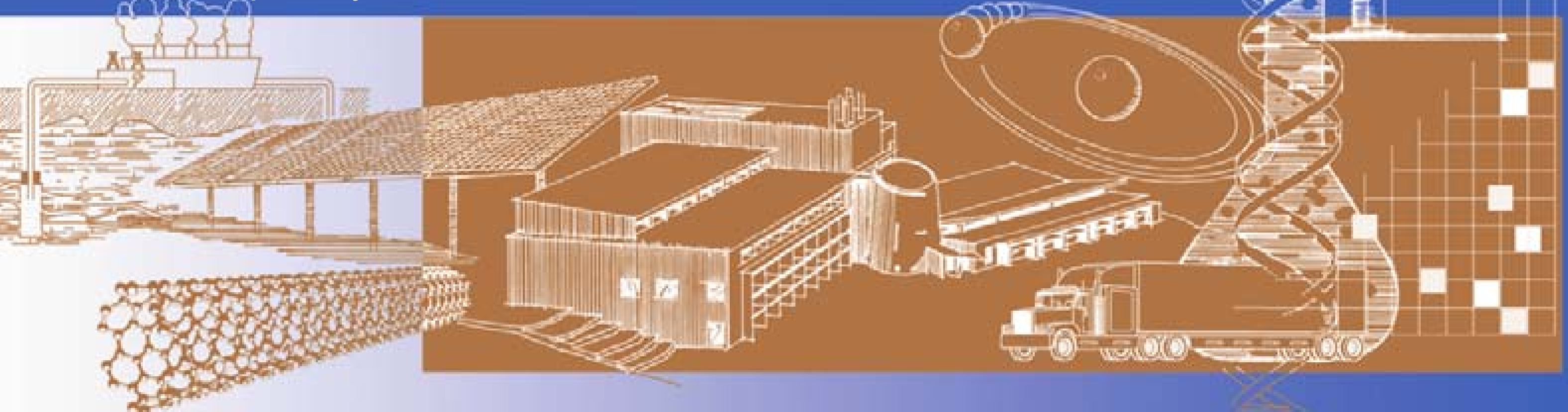

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Parabolic Trough Solar System Piping Model

Final Report

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A. Introduction

One requirement in a conceptual design of a solar power plant is to estimate the cost of the solar steam system. The main elements of that cost estimate are the solar collectors, control system, heat transfer fluid (HTF) piping system, HTF pump system, and solar heat exchangers. The piping system consists of header piping, valves, and fittings. Since the piping system cost can constitute up to 10% of the total solar system cost, it is important to obtain a reasonably accurate estimate.

The piping system design also affects performance. The pumping power required to circulate the HTF through the system is a significant contributor to the plant parasitic power requirement. Further, the piping heat loss reduces the useful heat delivered by the solar field to the power plant.

As part of their performance and cost modeling development for parabolic trough power plant development, Flabeg Solar International (Cologne, Germany) developed an internal solar field piping model – termed SolPipe -- for use in their solar system design work on parabolic trough configurations. The purpose of the model was to estimate, for a solar field size and layout configuration, the piping system parts list, costs, and pumping power for the HTF flow at design capacity. These results can then be utilized to provide input into subsequent performance and investment cost models, with the final criterion being the impact of the solar field piping design on the overall levelized electricity cost.

NREL requires a similar piping model to provide similar input to the *Trough Excelergy* parabolic trough plant performance and cost model. The purpose of the present work is to develop a spreadsheet model to satisfy this need. Flabeg has provided access to SolPipe for purposes of comparison of the methodology and results.

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B. Flabeg Solar System Piping Model

Design Approach

The basic method used by SolPipe is to calculate the HTF header configurations based on an assumed design flow velocity in the piping. This is a key design feature. The design velocity is chosen by the user as part of a process to approximately optimize solar field piping costs, that is, to find the velocity that optimizes the tradeoff between piping size and parasitic pumping power. Generally a values in the range of 2-3 m/s have been assumed based on past experience or results of optimizations. The input parameters to SolPipe basically set the total HTF flow, the flow per loop, the number of loops and the solar field configuration. In the design tradeoff, small header pipes would reduce piping and fitting costs, but increase pumping parasitics, while larger header pipes would have the opposite effect. Setting the design velocity, however, enables calculation of the pipe diameters for subsequent costing evaluations.

Header Piping, Valves and Fittings

In SolPipe, as in a real solar field, header pipe sizes change along the flow path to approximately maintain the design flow velocity. In a typical parabolic trough solar field configuration, the flow in the cold header is incrementally drawn off through a collector loop and passed to the hot header. Therefore the cold header piping diameters can be reduced along the header length, reducing costs and maintaining the appropriate velocity. The SolPipe code does this calculation automatically for the configuration chosen. In doing so, the code selects standard piping sizes that result in a flow velocity close to the desired design velocity.

Expansion loops are placed in the cold and hot headers between every two loops in the solar field, following the design of the SEGS plants. Pipe supports for the headers also follow SEGS plant design practice.

Following this calculation scheme, the results produced by SolPipe include:
- number and size of pipe segments and fittings (such as reducers, elbows, and valves) for HTF system, including the headers and several loop piping elements such as the interconnection to the headers, the crossover pipes between rows, and interconnections within the SCA's, i.e., ball joints or flex hoses.
- insulation on pipes and fittings at prescribed thicknesses.
- costs for elements described above.
- pressure drops throughout the complete HTF system, including the SCA's, and the resulting parasitic pumping power requirement.

User Input

Several types of input data are needed from the user:
- number of collectors (to set the size of the solar field)
- basic type of layout to determine the layout configuration, e.g., like the 30 MW or 80 MW SEGS plants, or a straight-through (non-loop) system between parallel hot and cold headers.
- number of collectors/loop (to determine layout configuration)

- sufficient power cycle information to set the HTF flow rate (either in a simplified or more detailed form).
- other various layout parameters, e.g., distance between rows
- unit cost data for piping and fittings by type and size
- detailed assumptions related to pressure drop calculations

The input data sheet is formatted to differentiate between input data that needs to be provided for each new case (like solar field size and power rating), and input data that is required for the calculations but is not often changed by the user (if ever, such as standard pipe sizes and basic solar collector design information). The HTF flow is calculated from power cycle data to be input by the user. Better results are obtained if detailed thermodynamic data is available from a power cycle calculation, but quite reasonable results can also be obtained via an optional method that requires only simplified power cycle data.

Certain data is imbedded in the cost worksheets, such as piping, insulation and fitting costs, fluid properties, and valve arrangements. All these can, of course, be changed within the code if desired.

Solar field layouts that can be modeled in the Flabeg code generally reflect SEGS design practice for 30 MW and 80 MW solar plants, and are specified by the user.

Design Optimization

For a typical solar power plant conceptual design study, an initial design configuration and flow velocity in the headers is chosen by the user. The results of SolPipe for piping cost and pumping power are fed into the Flabeg models for overall cost and performance, and the LEC determined. Variations on the input, such as the design velocity, are then varied to find the optimum value that provides the lowest LEC. For this specific parameter, recent results from the salt HTF study indicated that the LEC variation is relatively flat for a range of 2-4 m/s in flow velocity, with the lowest values at the low end.

C. NREL Solar System Piping Model

Under contract to NREL, Kearney & Associates and Nexant worked together to develop a solar system piping model to develop piping system costs. Bruce Kelly of Nexant devised a new method for this purpose, with particular emphasis on incorporating added features in the model to automate the optimization method. The following description provides detailed information on the approach and construction of the model.

Approach

The coding of the new model differs completely from SolPipe, though the objectives are similar. One key difference is that the new model includes internal optimizations to arrive at a conceptual design. The optimum collector field piping arrangement should be one in which the sum of the following three elements is a minimum: 1) the capital cost of the pipe, insulation, and supports; 2) the equivalent capital cost of the thermal losses through the pipe insulation; and 3) the equivalent capital cost of the electric energy to circulate the fluid through the piping.

A draft optimization model using Excel spreadsheet has been assembled which calculates the pipe capital and operating costs for two representative types of field layouts. The sections below describe how the model was assembled and how it operates.

Generic Collector Field Layouts

In the draft model, two field layouts are available as an option for the user: an ‘H’ field layout for collector field areas greater than 400,000 m^2, and an ‘I’ field layout for areas less than 400,000 m^2.

<u>‘H’ Field Layout</u>

An example of a possible ‘H’ field piping layout for a representative 80 MWe plant has been prepared, as follows:

- The field is divided into 4 header-pair sections, with the power block located at the center of the field. Cold fluid is distributed from the cold header to solar fields on each side of the header, passing through a series of SCAs arranged in a row, crossing over at the end to an adjacent row, and returning to the hot header via a symmetrical set of SCAs. This arrangement is referred to as a “loop”. Hence there are similar loops on each side of the headers along the header length. In the base case, the headers run East-West.

- Each collector loop consists of 6 LS-3 solar collector assemblies, with the flow going out from the cold header through 3 assemblies, reversing direction, and then returning to the hot header through the remaining 3 assemblies. A total of 36 loops is supplied from the two headers. The arrangement is illustrated in Figure 1.

- The pressure loss in the flow to the outermost loop defines the pressure loss in the flows through all of the loops. The pressure loss in the inner loops is set equal to the pressure loss in the outermost loop by the throttling action of either orifices or valves in the inner loops.

- The diameter of the cold header steps down as the distance from the power block increases to provide a roughly uniform fluid velocity in the header. Similarly, the diameter of the hot header increases as the distance to the power block decreases.

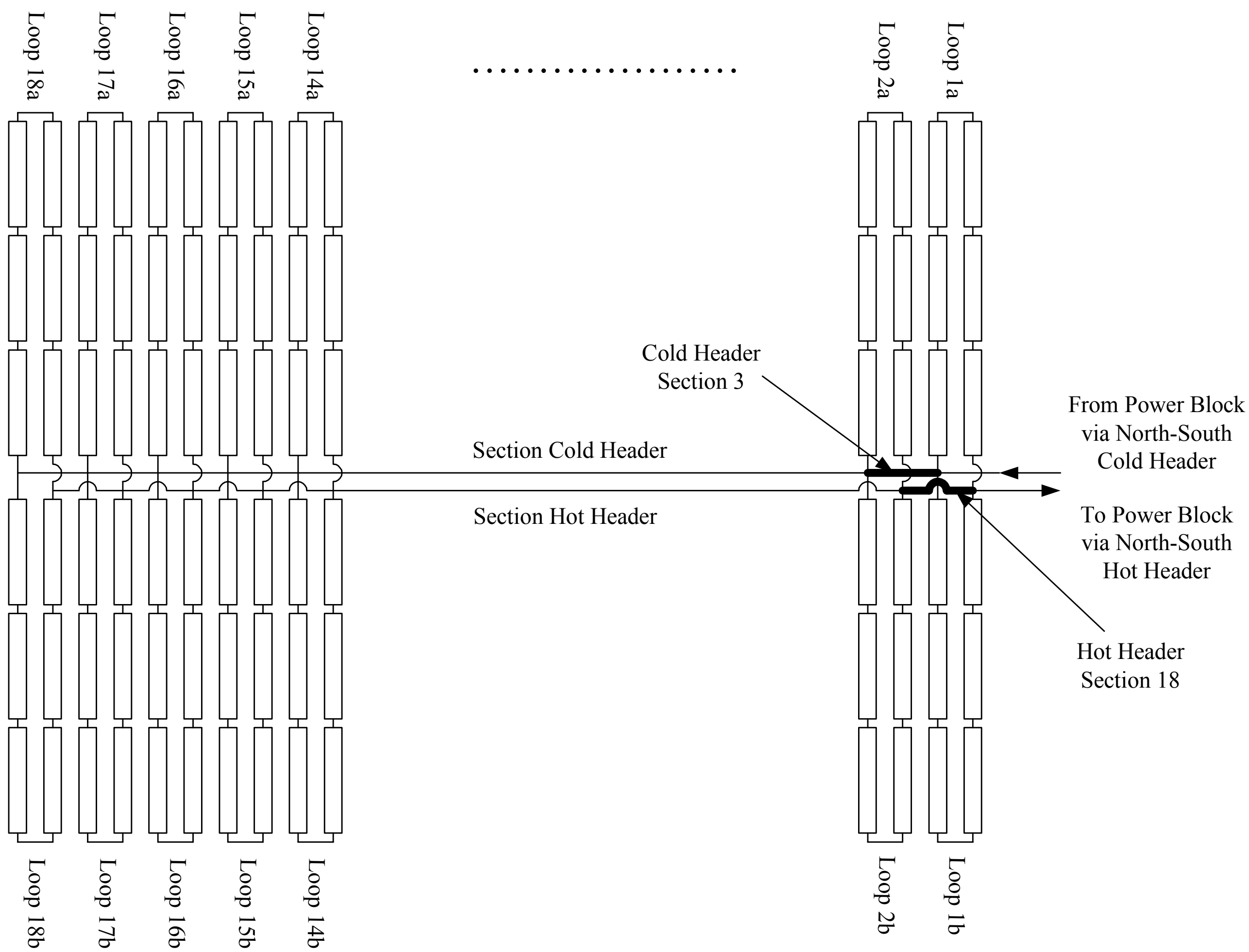

Figure 1. One Section of the Collector Field Layout for a Representative 80 MWe Plant

The flow rate in the East-West cold header for this example is 229 kg/sec, and is calculated as follows:

$$\frac{234{,}700{,}000\ \frac{J}{sec}}{(H\_Therminol_{393\,C} - H\_Therminol_{288\,C},\ J/kg)\,(4)} \qquad [1]$$

where 234,700,000 J/sec is the thermal rating of the collector field, and the '4' represents one-fourth of the collector field. The flow rate in the standard collector loop is 6.4 kg/sec, or 1/36th of the flow in the section header. The flow rate in the third header section is 217 kg/sec [229 kg/sec - (2)(6.4 kg/sec) for the two standard collector loops fed by this section]. The balance of the cold header and hot header section flow rates are calculated in a similar fashion.

'I' Field Layout

An example of a possible 'I' field piping layout for a representative 30 MWe plant has been developed, as follows:

- The field is divided into 2 header-pair sections, with the power block located at the center of the field.
- A cold oil header, in parallel with a hot oil header, runs East-West through the center of the section.
- Each collector loop consists of 16 LS-2 solar collector assemblies, with the flow going out from the cold header through 8 assemblies, reversing direction, and then returning to the hot header through the remaining 8 assemblies. A total of 22 loops is supplied from the two headers. The arrangement is illustrated in Figure 2.

The flow rate in the cold header for this example is 172 kg/sec, and is calculated as follows:

$$\frac{88{,}000{,}000\ \frac{J}{sec}}{(H\_Therminol_{393\,C} - H\_Therminol_{288\,C},\ J/kg)\,(2)} \qquad [2]$$

where 88,000,000 J/sec is the collector field thermal rating, and the '2' represents one-half of the collector field. The flow rate in the standard collector loop is 7.8 kg/sec, or 1/22nd of the flow in the quadrant header. The flow rate in the third header section is 156 kg/sec [172 kg/sec - (2)(7.8 kg/sec) for the two standard collector loops fed by this section]. The balance of the cold header and hot header section flow rates are calculated in a similar manner.

Heat Transport Fluid Properties

The user can select among the following heat transport fluids: Therminol VP-1; Caloria HT-43; Hitec, a eutectic mixture of sodium nitrite, sodium nitrate, and potassium nitrate; Hitec XL, a eutectic mixture of calcium nitrate, sodium nitrate, and potassium nitrate; and a binary nitrate salt mixture of sodium nitrate and potassium nitrate, or Solar Salt. The model contains the following thermodynamic properties for the five fluids, each as a function of temperature: density; specific heat; enthalpy; and absolute viscosity.

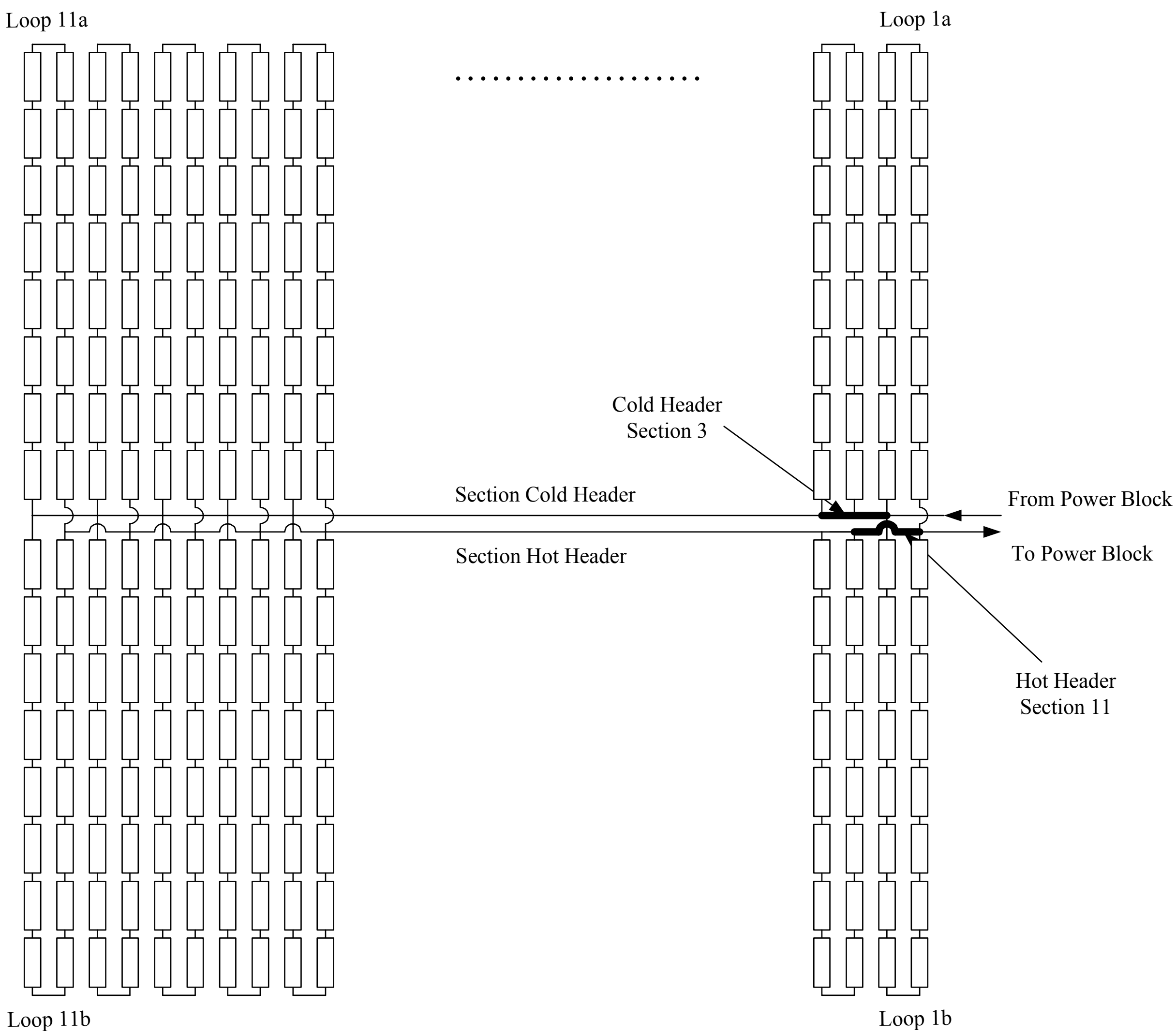

Figure 2. One Section of the Collector Field Layout for a Representative 30 MWe Plant

Optimization Process

The procedures for calculating the pipe diameters, wall thicknesses, and insulation thicknesses for each header section are outlined below. The only constraint on the design is the fluid pressure at the exit from the hot header must be equal to a minimum value set by the user. This feature is principally used with a synthetic oil heat transport fluid to ensure the fluid pressure always remains above the vapor pressure.

<u>Hydraulic and Thermal Development</u>

1. Basic pipe dimension data, such as nominal diameter, wall thickness, and unit weight, for commercial pipe sizes between 2.5 and 48 inches are shown in the worksheet labeled “PipeData”.

2. Allowable pipe stresses as a function of temperature are shown in the worksheet labeled “SvsT”. For fluid temperatures below 399 °C, the data are applicable for ASTM A106, Grade B, seamless carbon steel pipe. For fluid temperatures between 400 °C and 510 °C, the data are applicable for ASTM A335, Grade P91, low alloy steel.

3. For a given nominal pipe diameter, the required wall thickness is calculated using the familiar equation:

$$Wall\ thickness, mm = \frac{(Pressure, bar-1)(Outside\ diameter, mm)(100{,}000\frac{Pa}{bar})}{(2)(Allowable\ stress, MPa)(1{,}000{,}000\frac{Pa}{MPa})+(0.4)(Pressure, bar-1)(100{,}000\frac{Pa}{bar})} \quad [3]$$

The allowable stress is a function of the pipe temperature, and is calculated through a curve fit of the data in “SvsT”.

4. The actual wall thickness is calculated from the minimum wall thickness through the Excel function ActualWall(Dia, MinWall), where ‘Dia’ is the nominal pipe diameter in inches, and ‘MinWall’ is the calculated wall thickness from above. ActualWall is, in essence, a lookup table, which searches for the wall thickness that is the greater of the following: the first commercial pipe wall thickness greater than ‘MinWall’, or a minimum wall thickness of ‘STD’.

5. Friction losses through the header sections, the heat collection elements, and the crossover piping, per meter of length, are calculated using the standard Darcy-Weisbach equation:

$$h_f, m = (f)\left[\frac{1\,m}{Pipe\ inside\ diameter, m}\right]\left[\frac{(Velocity, \frac{m}{sec})^2}{(2)(g_c, \frac{m}{\sec^2})}\right] \quad [4]$$

where f is the friction factor, and g_c is the acceleration due to gravity. The friction factor is calculated using the FricFactor(Rough, Reynold) function in Excel, where ‘Rough’ is the relative pipe roughness, and 'Reynold' is the Reynolds number. The relative roughness is:

$$\frac{0.0457 \text{ mm absolute roughness for commercial steel pipe}}{\text{Pipe inside diameter, mm}} \qquad [5]$$

The Reynolds number is calculated using internal Excel Functions for the absolute viscosity and density of the selected heat transport fluid.

6. Friction losses through the pipe fittings are calculated using:

$$L_e = K\left[\frac{\text{Pipe inside diameter, m}}{\text{Friction factor}}\right] \qquad [6]$$

and

$$\text{Fitting head loss, m} = (L_e)(\text{Unit pipe head loss, m}) \qquad [7]$$

where L_e is the pipe length which gives the same pressure loss as the fitting, and K is the fitting factor.

The types of fittings in the model include reducers (both expansion and contraction losses); short-, medium-, and long-radius elbows; check valves; gate valves; tees; and ball joints. The number of each type of fitting in the cold header sections is set in Rows 10 through 20 of the worksheet labeled "PressureLosses". The number and type of fittings for the hot header sections are set in Rows 133 through 143.

Several of the types and locations of the fittings were set automatically by the program, as follows:

- A header reducer was located at each change in the header diameter.
- An isolation gate valve was located at the inlet to, and outlet from, each loop.
- A globe valve was located in each loop for flow rate control.
- A Weldolet was located at the inlet to, and outlet from, each loop for connecting the loop piping to the header.
- Each crossover pipe had two standard elbows, and each collector loop had 10 standard elbows.
- The number of ball joint assemblies in a loop was equal to [2 + Number of solar collector assemblies in the loop].
- The header between every other loop had an expansion loop, with 4 long radius elbows in the loop.
- A gate valve was located at the inlet to, and outlet from, the hot and cold headers for each field section; i.e., there were 4 gate valves for an 'I' field configuration, and 8 gate valves for an 'H' configuration.

7. The pressure distribution through the cold and the hot headers is a function of the local fluid velocities, pipe diameters, and wall thicknesses. However, the wall thickness is also a function of the pressure distribution. The button labeled "Adjust pressure" recalculates both the pressure at the inlet to the cold header and the local pipe

wall thicknesses such that pressure at the outlet of the hot header is equal to the minimum value set by the user.

8. Unit thermal losses through the pipe insulation are calculated as follows:

$$Heat\ loss,\ J/sec\text{-}m = \left[\frac{(2)(\pi)(k,\ \frac{J}{sec\text{-}m\text{-}^{o}C})(1\ m)(T_{inside},\ ^{o}C - T_{ambient},\ ^{o}C)}{ln\left(\frac{r_o}{r_i}\right)} \right] \qquad [8]$$

where k is the thermal conductivity of the insulation, r_o is the outside radius of the insulation, and r_i is the inside radius of the insulation. The thermal conductivity is evaluated at the average of the inside and the ambient temperatures. The conductivity values are derived from a curve fit of the data on the worksheet labeled "Insulation k vs T". For the purposes of the model, the thermal resistances of both the inside and the outside convection coefficients are assumed to small compared to the conduction resistance, and, for simplicity, are ignored.

Annual Losses Development

1. The annual pumping energy for each segment of pipe is assumed to follow a "cube root mean cubed" function; i.e., the pressure loss is proportional to the square of the velocity, and the pumping power is proportional to the flow rate times the pressure loss. The equations are as follows:

$$Average\ flow\ fraction = \frac{\sqrt[3]{\dfrac{\sum_{1}^{Annual\ collector\ field\ operating\ time,\ hours}(Power\ to\ working\ fluid,\ MWt)^3}{Annual\ collector\ field\ operating\ time,\ hours}}}{Design\ power\ to\ working\ fluid,\ MWt} \qquad [9]$$

and

$$Annual\ pump\ energy\ demand,\ kWhe = \frac{(Annual\ collector\ field\ operating\ time,\ hours)(Design\ flow\ rate,\ kg/sec)(Average\ head\ loss,\ m)(g_c,\ \frac{m}{sec2})(3600\ \frac{sec}{hr})}{(1000\ \frac{J}{kW-sec})(3600\ \frac{sec}{hr})(0.75\ annual\ pump\ efficiency)}$$

[10]

where Average head loss, m = (Design head loss, m)(Average flow fraction)

The hourly values for the power to the working fluid, shown on the worksheet labeled "HourOutput", were taken from an Trough Excelergy output file and a weather file for Barstow, California. The annual collector field operating time is 3,436 hours.

2. The annual thermal losses through the insulation are calculated as follows:

$$\begin{aligned}&\textit{(Annual collector field operating time, hours)(Thermal losses at design temperature, J/sec)(3,600 sec/hr)} + \\ &\textit{(8,760 - Annual collector field operating time, hours)(Thermal losses at overnight temperature, J/sec)(3,600 sec/hr)}\end{aligned} \qquad [11]$$

where the average fluid temperature during the overnight circulation periods is assumed to be 200 °C. This value can be adjusted in the future based on analysis of the annual average using Excelergy.

Capital Cost Development

1. The capital cost of the pipe and fittings is estimated as follows:

$$\textit{Unit cost, \$/m} = \textit{(Unit weight, kg/m)(Unit cost, \$/kg)} \qquad [12]$$

where the unit cost, in $/kg, is a function of the pipe diameter and material.

2. The installed cost for the pipe fittings and valves were estimated from the number of fittings and valves, specified by the user, and cost data from vendor quotes[1].

3. The installation labor costs for the pipe, supports, and hangers include the following elements: material handling; erection, lineup, and tack welds; production welds; inspections; and hydraulic tests. The labor hours are a function of the pipe diameter and wall thickness, and were derived from historical Bechtel cost data.

4. The installed costs for the pipe insulation are estimated from a three-dimensional surface fit of cost as a function of pipe diameter and insulation thickness. The cost data were derived from parametric vendor cost information on the Solar Two project, and from project cost data identical to the Flabeg model.

5. In the absence of a pipe stress analysis, pipe supports and anchors were assumed to be located every 8 m. The installed costs for the supports were estimated from cost data from the Flabeg model.

Equivalent Capital Cost of Losses

1. The equivalent capital cost of the heat loss through the insulation is calculated as follows:

$$\textit{Equivalent capital cost} = \frac{\textit{(Annual thermal losses, kWht)(Cost of thermal energy, \$/kWht)}}{\textit{Fixed charge rate}} \qquad [13]$$

where

[1] Currently this cost data is identical to that used in the Flabeg model, with the original source being data obtained from a vendor to Kramer Junction.

$$\text{Cost of thermal energy, \$/kWht} = \frac{\text{(Fixed charge rate)(Unit collector cost, \$/m}^2\text{)}}{\text{(Annual collector efficiency)(Annual radiation, kWht/m}^2\text{)}} \quad [14]$$

where the fixed charge rate is an economic factor for converting a capital investment into an equivalent annual expense. The model uses a unit collector cost specified by the user (for example, \$200/m^2), an annual collector efficiency of 0.50, and an annual direct normal radiation of 2,714 kWh/m^2. The value for the fixed charge rate is arbitrary.

2. The equivalent capital cost of the pressure loss in each header section and the standard collector loop is calculated using the following equations:

$$\text{Equivalent capital cost} = \frac{\text{(Annual pump energy demand, kWhe)(Cost of electric energy, \$/kWhe)}}{\text{Fixed charge rate}} \quad [15]$$

and

$$\text{Annual pump energy demand, kWhe} = \frac{\text{(3,436 hours/year)(Design flow rate, kg/sec)(Average head loss, m)}(g_c, \frac{m}{sec2})(3600\frac{sec}{hr})}{(1000\frac{J}{kW-sec})(3600\frac{sec}{hr})\text{(0.75 annual pump efficiency)}} \quad [16]$$

and

$$\text{Cost of electric energy, \$/kWhe} = \frac{\text{(Fixed charge rate)(Unit plant cost, \$/m}^2\text{)}}{\text{(Annual plant efficiency)(Annual radiation, kWht/m}^2\text{)}} \quad [17]$$

The model uses a unit plant cost specified by the user (for example, \$450/m^2), an annual plant efficiency of 0.135, and an annual direct normal radiation of 2,714 kWh/m^2.

Header Section Diameter Optimization

The optimization process assumes 1) the optimization procedure for each header section can be conducted independently from the balance of the header sections, and 2) the combination of the optimum header designs is the optimum piping configuration for the collector field.

The calculation is started by pushing the button labeled “Optimum header diameters”, and proceeds as follows:

1. The number of loops, and the hydraulic characteristics of each loop, are set automatically, based on the field configuration, the fluid number, the cold fluid temperature, the hot fluid temperature, and the collector field power rating.

2. A trial diameter is selected for each header section. The capital cost, and the equivalent capital cost of the insulation heat loss and pump energy, are calculated.

3. New costs are calculated for the following pipe sizes: two standard sizes below the trial diameter; one standard size below; one standard size above; and two standard sizes above. The costs are stored in a temporary matrix, and the size that provided the lowest cost is selected. During the calculation of the new costs, 1) the pressure distribution is recalculated to provide a pressure at the outlet of the hot header equal to the minimum value set by the user, and 2) the thickness of the thermal insulation is adjusted such that the sum of the capital cost and the equivalent capital cost of the heat loss is a minimum. (The calculation to optimize the insulation thickness can also be run independently of the header optimization by pushing the button labeled 'Optimum insulation thickness'.)

4. The process is repeated for each header section.

5. The process is repeated again for all of the cold and hot header sections to ensure local cost minima were not selected in preference to an overall cost minimum.

The optimum cold header section diameters were shown in Row 7, and the optimum hot header section diameters were shown in Row 130.

Piping and Valves for the Steam Generator and the Heat Transport Fluid Pumps

Cost estimates are also developed for the piping system in and around the steam generator and the heat transport fluid pumps. Line sizes are calculated for the 8 lines summarized in Table 1.

Table 1 Steam Generator and Heat Transport Fluid Pump Line Designation

Line	From	To
1	Expansion vessel or thermal storage tank	Pump suction header
2	Pump suction header	Individual pump inlet
3	Individual pump discharge	Pump discharge header
4	Pump discharge header	Collector field section headers
5	Collector field section outlet headers	Expansion vessel or thermal storage tank
6	Steam generator supply header	Steam generator supply header
7	Inter steam generator piping	Inter steam generator piping
8	Steam generator outlet header	Expansion vessel or thermal storage tank

The bases for the calculations are as follows:

- Economic optimizations of the line diameters are not performed; rather, the line sizes are based on a fluid velocity specified by the user to meet the system hydraulic requirements, such as uniform fluid distribution or maximum allowable pressure loss. The velocity is specified in Cell B17 on the worksheet labeled ‘Pump-SGS’.
- The number and capacity of the heat transport fluid pumps are specified by the user in Cell B18 and Cell B19, respectively, on the worksheet labeled ‘Pump-SGS’.
- The fluid flow rates in Lines 1 through 4 are calculated based on the following: the collector field thermal power rating in ‘Model Inputs’!Cell B3; the fluid number in Cell B16; the cold fluid temperature in Cell B25; and the hot fluid temperature in Cell B26.
- The fluid flow rates in Lines 5 through 8 are calculated based on the following: the steam generator thermal power rating in ‘Model Inputs’!Cell B4; the fluid number in Cell B16; the cold fluid temperature in Cell B25; and the hot fluid temperature in Cell B26. (The model allows separate values for Cell B3 and Cell B4; thus, the ratio of Cell B3 to Cell B4 is effectively the solar multiple for the plant.)
- One gate valve is located in each of Lines 1, 2, and 3, and one check valve is located in each Line 3.
- Long radius elbows are located in Line 1, and in Lines 2 through 8, for thermal expansion loops. (The number of elbows is currently an allowance; the actual number would be an input to the model following a stress analysis of the piping system. Similarly, the pipe lengths shown for Lines 1 through 8 are also currently an allowance, and must be revised following the development of the piping arrangement.)

The pipe, valve, fitting, support, and insulation costs for the 8 lines are summarized on the Model Inputs worksheet. The cost for Line 2 and the cost for Line 3 were multiplied by the number of heat transport fluid pumps in the calculation of the total system piping cost.

D. General Comparison of Results

Model Comparison

The following table compares the features of the Flabeg and NREL models:

Table 2. Comparison of features in the SolPipe and NREL models

Feature	SolPipe	NREL
Overall layout	H (80MW) or I (30MW) with loops; also straight no-loop layout	Presently H and I configurations
Pipe sizing	Sized based on design velocity set by user	Optimizes each piping section (defined as header piping between loop connections). See below.
Pipe wall thickness	Uses Sked 40 piping	Wall thickness is no thicker than needed for required pressure
Piping/fitting capital costs	Table lookup from vendor data	Table lookup from vendor data
Piping/fitting labor costs	Table lookup from vendor data	Based on Bechtel experience
Insulation costs	Table lookup from vendor data	Table lookup from Solar Two data based on both ID and thickness of insulation
Pumping power cost	Not used	Calculated for typical year
Heat loss	Not used	Calculated for typical year
Optimization for pipe size	Not done	Per section: pipe D assumed→model calculates wall thickness, then capital costs, equiv. heat loss cost, equiv. pumping cost. Then increases D to next std size and recalculates cost for comparison. Within this process, thickness of insulation is optimized.
Expansion loops	Based on SEGS design; between every 2 loops	Same
Loops	Design based on SEGS	Same
Valves/fittings	Specified	Same
Calculation method	Simple arithmetic within cells	Uses macros
Input data	Entered in Input worksheet	Entered in Input worksheet

A case was run for a 30MW plant using the I configuration, similar to the SEGS VI solar plant, for comparison of the NREL and SolPipe codes. The cost results compare satisfactorily for the headers as a whole -- NREL: $\$16.6/m^2$ vs. SolPipe: $\$16.5/m^2$ -- but differ in several specific cost elements due to understandable differences in the model. The header piping sizes are not identical due to the different methods used to select the appropriate diameters. Costs for installed pipe of the same size and type are higher in the NREL model because the labor hours per unit length based on Bechtel historical data base are higher than those assumed in SolPipe. Different pipe sizes lead to variations in fitting and insulation costs, causing a further deviation in the overall cost.

Further, the philosophies differ to a modest degree on the numbers of fittings such as valves and the placement of pipe supports.

[It should be noted that the SolPipe value of $16.5/m^2 is considerably higher than reported in earlier Flabeg studies. This is because the interconnection piping in the loops (the ball joint assemblies) are included here, whereas in the previous Flabeg cost estimates that cost is included in the solar field category, not in the piping category. For comparison, the SolPipe result for this 30MW case is $9.2/m^2 if the ball joint costs are removed.]

With respect to the HTF pressure drop for solar steam system, the NREL code is more inclusive in that it includes all elements of the system (i.e., header piping, solar field loops, and solar heat exchangers). SolPipe contains a less sophisticated pressure drop calculation that is partially scaled from early SEGS VI information.

Use in Trough Excelergy

It is expected that the NREL piping code would be run upfront within Excelergy for each plant configuration, and the results for piping costs and design point solar system parasitics would then be fed into the appropriate part of Trough Excelergy for use.

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