# Comparison SAM & Thermoflow for Linear Fresnel (LF) Plants

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http://www.upm.es/observatorio/vi/index.jsp?pageac=grupo.jsp&idGrupo=221

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# Presentation outline

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-Introduction (Thermoflow and SAM brief descriptions)

- Solar Field (SF) modeling main capabilities

- Balance of plant (BOP) modeling main capabilities

- LF reference power plant

- Design-Point (21st June, Solar Noon)

- Annual performance

-SAM & Thermoflow capabilities summary

-Conclusions and future work

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# THERMOFLOW AND SAM BRIEF DESCRIPTIONS

# Thermoflow

**Thermoflow** (1) is a fully flexible software that allows to model a broad range of mass and heat balances in power plants.

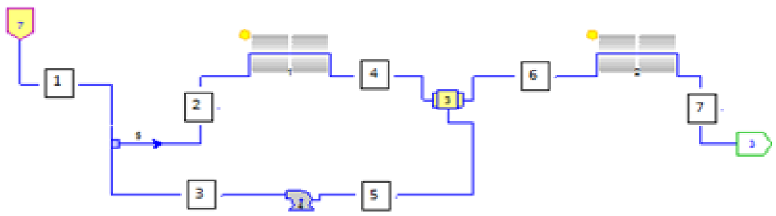


**Figure 1**. LF DSG recirculation loop model in Thermoflow.

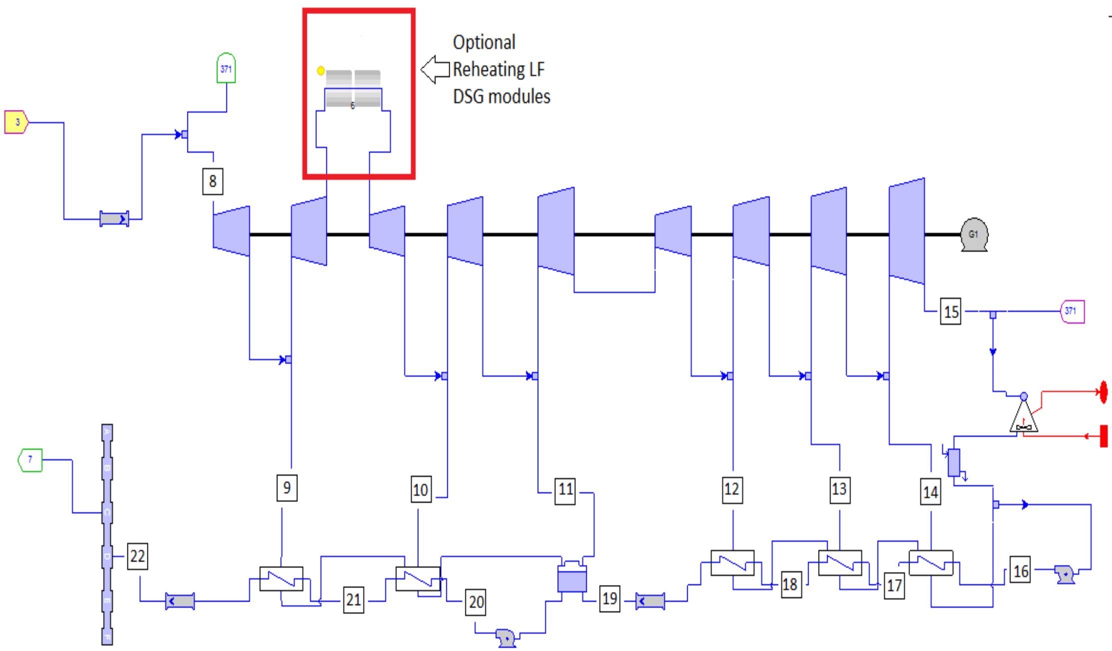


**Figure2**. BOP model in Thermoflow .

| | | |
|---|---|---|
| 1. Number of IAM data points | 91 | |
| 2. Line collector type: 0=parabolic trough, 1=linear fresnel | 1 | |
| 3. Receiver tube outside diameter | 70 | mm |
| 4. Receiver tube wall thickness | 4.191 | mm |
| 5. Aperture width (sum of primary reflector widths) | 12 | m |
| 6. Aperture width / Collector unit width (Fresnel only) | 0.7246 | - |
| 7. Collector unit width (for information Fresnel only) | 16.56 | m |
| 8. Collector focal length | 7.4 | m |
| 9. Number collector rows per flow path | 1 | - |
| 10. Number collector row banks | 1 | - |
| 11. Active reflector length as percent of total length | 95 | % |
| 12. Collector unit row pitch / collector unit width | 1.242 | - |
| 13. Reflector cleanliness factor | 0.95 | |
| 14. Row (tracking axis) rotation from due North | 0 | Degrees |
| 15. Row (tracking axis) tilt from horizontal | 0 | Degrees |
| 16. Coefficient A1 in heat loss per unit length equation | 1 | W/m-C |
| 17. Coefficient A2 in heat loss per unit length equation | 1.963E-8 | W/m-K^4 |
| 18. Overall heat loss correction factor | 1 | - |
| 19. Number of computational segments along receiver | 10 | |

**Figure 3**. LF DSG parameters definition.

(**1**) Patrick Griffin, Karsten Huschka, Gabriel Morin. Software for design, simulation, and cost estimation of solar Thermal power and heat cycles. SolarPaces 2009.

# SAM

**SAM** (System Advisor Model). A quasi-steady-state model to estimate LF plants annual performance. Main advantages : reduced computing time, very reliable tool, open source fortran code. Main disadvantages: not graphical environment, not fully-flexible, not energy and mass flows details between equipments.

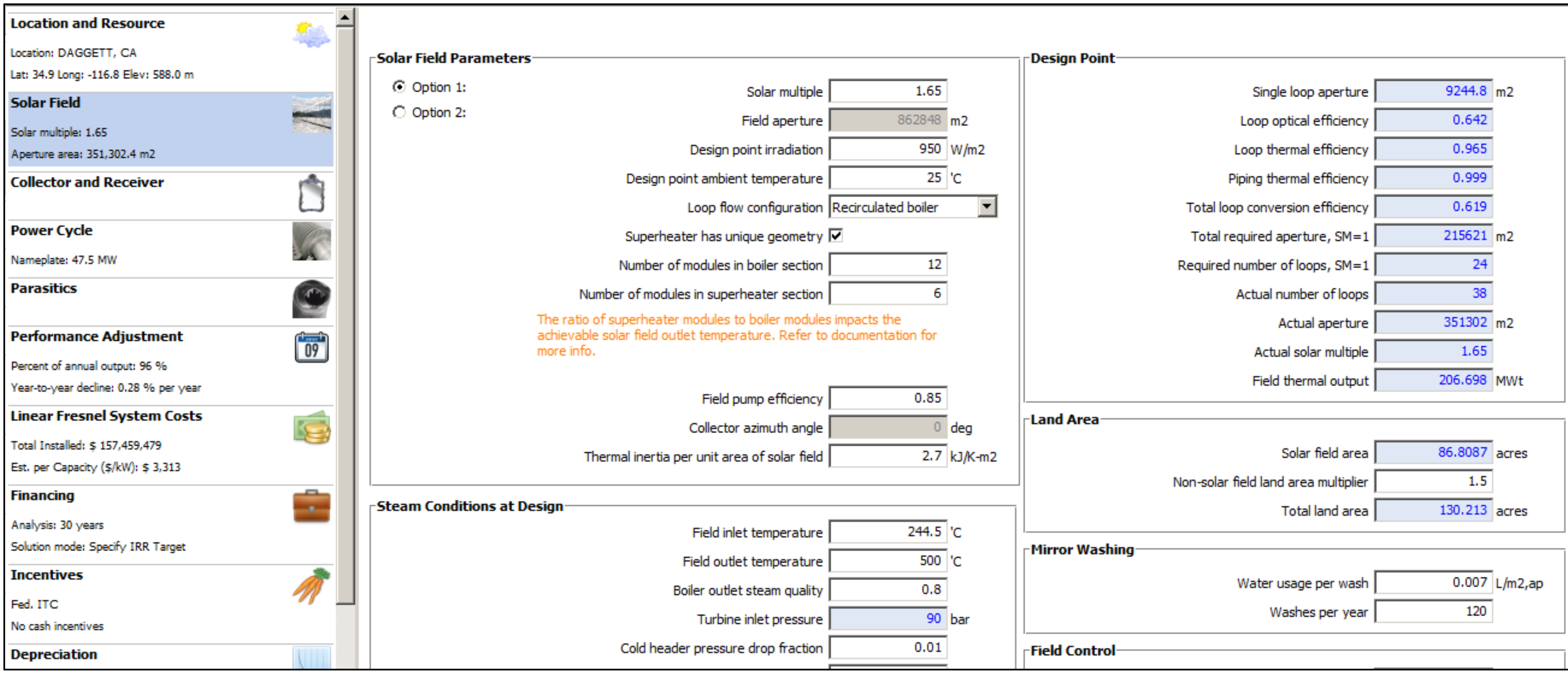


**Figure 4**. SAM user interface overview .

# SOLAR FIELD MODELING CAPABILITIES

# Solar Field (SF) modeling main capabilities

1. **Meteorological data loaded from weather files** (TMY2, TMY3, etc).
SAM provides this option, and also hyperlinks to official web pages with different countries weather data information. However, Thermoflow not includes this option, but integrates a model developed by Hottel (**2**) to determine the fraction of extraterrestrial flux reaching the earth at the specified location.

2. **SF configuration modeling flexibility.**
SAM integrates two alternatives for SF configurations modeling :recirculation parallel loops RC, or once-through (OT) parallel loops, but without water injections to avoid dryout, see DUKE project reference (**3**). Thermoflow provides a more flexible graphical simulation enviroment for SF configurations design, showing stream properties (mass, pressure, temperatures, enthalpies) between SF components.

3. **Headers and receivers pressure drop models.**
SAM calculates pressure drops by means of fixed coefficients for cold headers, hot headers, boiling sections, etc. Thermoflow includes more accurate models: saturated steam pressure drops are calculated with Friedel (**4**) correlation , Superheated steam and Supercritical water are considered compressible fluids.

4. **Receiver Thermal losses.**
Both software integrate the capability to calculate thermal losses based on empirical polynomials equations provided by manufacturer (Novatec). But Thermoflow also includes a very accurate model with Kandlikar (**5**) (for saturated steam) and Dittus Boelter (**5**) for liquid and superheated steam correlations to calculate Heat Transfer Coefficients (HTC) in receivers pipes.

(**2**) Hottel, H.C., A Simple Model for Estimating the Transmittance of Direct Solar Radiation Through Clear Atmospheres, *Solar Energy*, Vol 18, pp. 129-134, Pergamon Press, 1976
(**3**) "Concept comparison and test facility design for the analysis of Direct Steam Generation in Once-Through mode". Jan Fabian Feldhoff (1), et al. German (DLR),CIEMAT, SolarPACES 2012.
(**4**) Friedel's method described by Whalley, P.B., Boiling, *Condensation and Gas-Liquid Flow*, Oxford University Press, 1987
(**5**) Dittus-Boelter equation from Lienhard, John, H., *A Heat Transfer Textbook, 2nd Edition*, Prentice-Hall, Inc., 1987
Kandlikar, Satish, G., A General Correlation for Saturated Two-Phase Flow Boiling Heat Transfer Inside Horizontal and Vertical Tubes, *Journal of Heat Transfer*, February 1990, Volume 112, p. 219-229

# LF DSG Solar Field (SF) modeling capabilities



## 5. SF operational limits.

SF real behaviour is represented by SAM by means of the following parameters: flow limiting, stow and deploy angles limits, freezing limit , stow wind, etc. These options are not provided in Thermoflow. Most of the listed parameters limits impact widely under low Sun radiation conditions. As a further improvement, stratified flow or annular flow could be predicted by software according to water pressure and entalphy conditions.

## 6. Reflector "end losses" factor.

SAM integrates LF end losses calculations in Incident Angle Modifiers (IAM ), as indicated in Novatec brochure. However, Thermoflow calculates explicitly this factor according with the following equations (**6**):

$$\eta_{opt} = \eta_{nominal} * IAM(\theta_{\perp}, \theta_{//}) * f_{clean} * f_{end\ loss}$$

$$\eta_{end-loss} = 1 - \tan(\theta_i)\frac{D_{pm}}{L_{abs}} ,$$

where $D_{pm}$ is the distance of primary mirrors from the tube absorber, and $L_{abs}$ represents the receiver length.

## 7. SF themal inertia.

Thermoflow doesn't include this capability. SAM, considers a value of 2.7 kJ/K m2 for thermal intertia per unit area of solar field. Thermal inertia depends on receiver material and could be detailed computed by the software tool depending on material selection.

(**6**) A.Giostri, et. al. Comparison of two linear collectors in solar thermal plants: parabolic trough & fresnel. ESFuelCell 2011-54312

# LF DSG Solar Field (SF) modeling capabilities

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**8. Receiver material selection , stress analysis, and wall thickness calculation.**

Thermoflow allows user to select different receiver materials (Carbon steel, or other stainless steels: Super 304H, TP 347 HFG, T91, etc), and also pipes stress analysis and wall thickness for operating pressures are calculated. SAM doesn´t consider stress analysis as a limiting variable in LF SF design.

**9. Incidence Angle Modifiers (IAM).**

Three options are provided by SAM in order to compute IAM values:

a) IAM depending on Sun position angles (zenith and azimuth).
b) IAM based on collector incidence angles (longitudinal and transversal incident angles) .
c) Incidence angle modifiers polynomials approach.
See in the following slide (Table 1 and 2), IAM values for Novatec LF collectors, from SAM and Thermoflow.

Thermoflow only integrates b) option. This option is validated by information supplied by Novatec.
As a improvement we propose to integrate analytical IAM models (like FirstOptic code) or montecarlo model (SolarTrace) within SAM or import/export IAM values.

**10. SF parasitic looses.**

Tracking power loss and piping thermal loss coefficient are explicity inputed by user in SAM, not in Thermoflow.

**11. Turbine inlet temperature limited by reciver's selective coating materials.**

In Thermoflow is posible to limit superheated steam temperature leaving superheater LF modules. SAM doesn't allow to fix this limit, only field outlet design temperature could be provided by user, but under part-load conditions this temperature limit is superseded.

# LF DSG Solar Field (SF) modeling capabilities

**Table 1**. Incidence Angle Modifiers IAM table (SAM).

| 0 | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0.97894 | 0.95382 | 0.94864 | 0.91162 | 0.86104 | 0.7036 | 0.48456 |
| 10 | 0.97791 | 0.95732 | 0.93275 | 0.92768 | 0.89148 | 0.84202 | 0.68806 | 0.47386 |
| 20 | 0.92189 | 0.90247 | 0.87932 | 0.87454 | 0.84041 | 0.79378 | 0.64864 | 0.44671 |
| 30 | 0.83049 | 0.813 | 0.79214 | 0.78784 | 0.75709 | 0.71509 | 0.58433 | 0.40242 |
| 40 | 0.70119 | 0.68642 | 0.66881 | 0.66518 | 0.63922 | 0.60375 | 0.49336 | 0.33977 |
| 50 | 0.5336 | 0.52236 | 0.50896 | 0.50619 | 0.48644 | 0.45945 | 0.37544 | 0.25856 |
| 60 | 0.32563 | 0.31877 | 0.31059 | 0.30891 | 0.29685 | 0.28038 | 0.22911 | 0.15779 |
| 70 | 0.1173 | 0.11483 | 0.11188 | 0.11128 | 0.10693 | 0.101 | 0.08253 | 0.05684 |
| 80 | 0.01103 | 0.0108 | 0.01052 | 0.01046 | 0.01006 | 0.0095 | 0.00776 | 0.00534 |
| 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Specifying collector incidence angle table: Rows indicate longitudinal incidence angles (deg), columns indicate transversal incidence angles (deg)

**Table 2**. Incidence Angle Modifiers IAM table (THERMOFLOW).

| Angle Degrees | IAM Longitudinal | IAM Transverse |
|---|---|---|
| 0 | 1 | 1 |
| 1 | 0.999 | 0.994 |
| 2 | 0.998 | 0.983 |
| 3 | 0.997 | 0.973 |
| 4 | 0.995 | 0.971 |
| 5 | 0.993 | 0.971 |
| 6 | 0.991 | 0.977 |
| 7 | 0.988 | 0.988 |
| 8 | 0.985 | 0.996 |
| 9 | 0.982 | 0.992 |
| 10 | 0.978 | 0.98 |
| 11 | 0.974 | 0.97 |
| 12 | 0.97 | 0.967 |
| 13 | 0.965 | 0.965 |
| 14 | 0.96 | 0.97 |
| 15 | 0.955 | 0.981 |
| 15 | 0.955 | 0.981 |
| 16 | 0.949 | 0.986 |
| 17 | 0.943 | 0.979 |
| 18 | 0.936 | 0.965 |
| 19 | 0.929 | 0.958 |
| 20 | 0.922 | 0.956 |
| 21 | 0.915 | 0.955 |
| 22 | 0.907 | 0.963 |
| 23 | 0.899 | 0.97 |
| 24 | 0.89 | 0.967 |
| 25 | 0.88 | 0.952 |
| 26 | 0.871 | 0.945 |
| 27 | 0.862 | 0.943 |
| 28 | 0.852 | 0.941 |
| 29 | 0.841 | 0.951 |
| 30 | 0.831 | 0.951 |

# LF DSG Solar Field (SF) modeling capabilities



**12. Number of discretization nodes to compute energy flows in receivers pipes.**

Thermoflow defines a user input parameter to define the number of segments to subdivide the receiver to calculate water properties along receiver length, and heat looses. This parameter is very important to obtain accurate heat transfer coeffients, compresible pressure drops, and energies fluxes in receiver.

SAM identiffies number of boiling and superheating modules with only one node. This model could be improved by means of increasing number of nodes inside each module.

**13. Parallel loops input parameters.**

In Thermoflow is posible to define different parameters for each LF module or loops. For example incident DNI could varies from one loop to the other. Also cleanless factor differences between loops could impact in SF behaviour. All these facts cannot be modeled in SAM.

**14. Collector orientation respect North.**

Thermoflow includes two parameters to define collector azimuth angle respect north and tilt angle. In SAM are not programmed these two orientation options.

**15. Multitubes LF configuration** (**7**).

Neither SAM nor Thermoflow allow to define a physical multitube LF model. Only polynomial equations to define heat losses or pressure drops could be selected to simulated this kind of solar collector.

(**7**) R.Abbas, J.Muñoz, J.M. Martínez-Val. Steady-state thermal analysis of an innovative receiver for linear Fresnel reflectors. Elsevier, Applied Energy 92 (2012) 503-515.

# BOP MODELING CAPABILITIES

# Balance of plant (BOP) modeling capabilities

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**1. Innovative regresion model to estimated plant annual performance.**

SAM integrates an estimative BOP model to reduce computing time for anual plant performance calculations. This model could be programmed in Thermoflow in order to improve the Excel link (E-Link) option available to perform this kind of annual estimations.

**2. BOP operation modes (start up, shut down, stand by, etc).**

SAM Start-Up energy takes into account thermal inertia to heat-up receivers and headers, and also heating energy required during transitory Sun radiation periods. These energy flows are considered in Thermoflow.

**3. BOP Direct Reheating LF modules** (**8**).

SAM doesn't provides this option for LF power plants. Reheating improve power plant efficiency and power output. In Thermoflow Direct Reheating could be modeled, as well as indirect reheating with a heat exchanger.

**4. Condenser part-load levels.**

SAM simulates air condenser real behaviour. User can input number of part load levels. Also a minimum limit vacuum pressure could be fixed. Thermoflow also offers off-line condenser performance but not allow the two mentioned options.

**5. BOP parasitic energy looses.**

Differences in BOP and SF parasitic energy looses definitions in both software are identified. More detail information will be showed in the following slides. Air condenser Fan power calculations differs in both tools. Due to lack of information in air condenser air stream properties not permit to find energy flux differences.

(**8**) L.Coco Enríquez, J.Muñoz-Antón, J.M. Martínez-Val. Innovations on direct steam generation in linear Fresnel collectors. SolarPaces 2013 (pending published).

# Balance of plant (BOP) modeling capabilities

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**6. BOP equipments performance curves for operation under part-load scenarios.**

During part-load conditions BOP equipments performance parameters (turbine stages efficiencies, heat exchanger TTD and DCA, pumps efficiencies,etc) varies respect to nominal power conditions. These variations should be considered for SAM BOP regresion model. Also in Thermoflow is posible to achieve BOP equipments technology improvements analysis because all equipment performance parameters could be adjusted during annual performance calculations.

**7. Thermal Energy Storage (TES) integrated in LF DSG power plant** (**9**).

Thermoflow integrates different equipments to model TES system. This option is not considered in SAM for DSG LF plants.

**8. SF and BOP cost and financing model.**

SAM is the better tool to make an economical estimation approach for LF power plants. Thermoflow cost model doesn't show the level of details available in SAM.

(**9**)Camille Bachelier, Gabriel Morin, et al. Integration of molten salt storage systems into Fresnel collector based CSP plants. Novatec. SolarPaces 2012.

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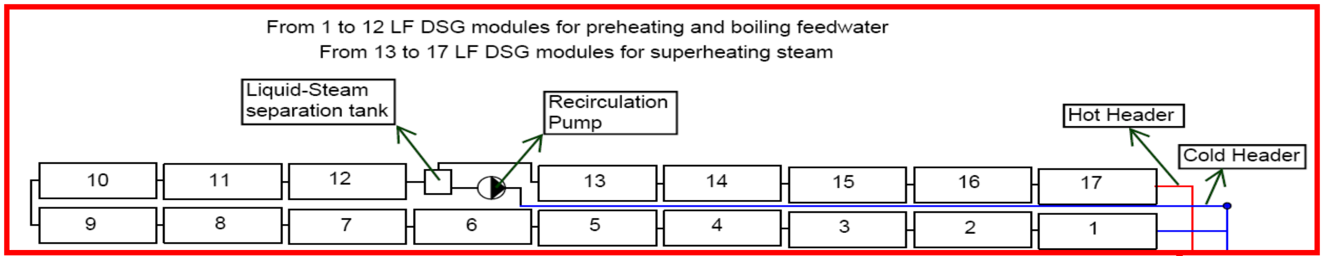
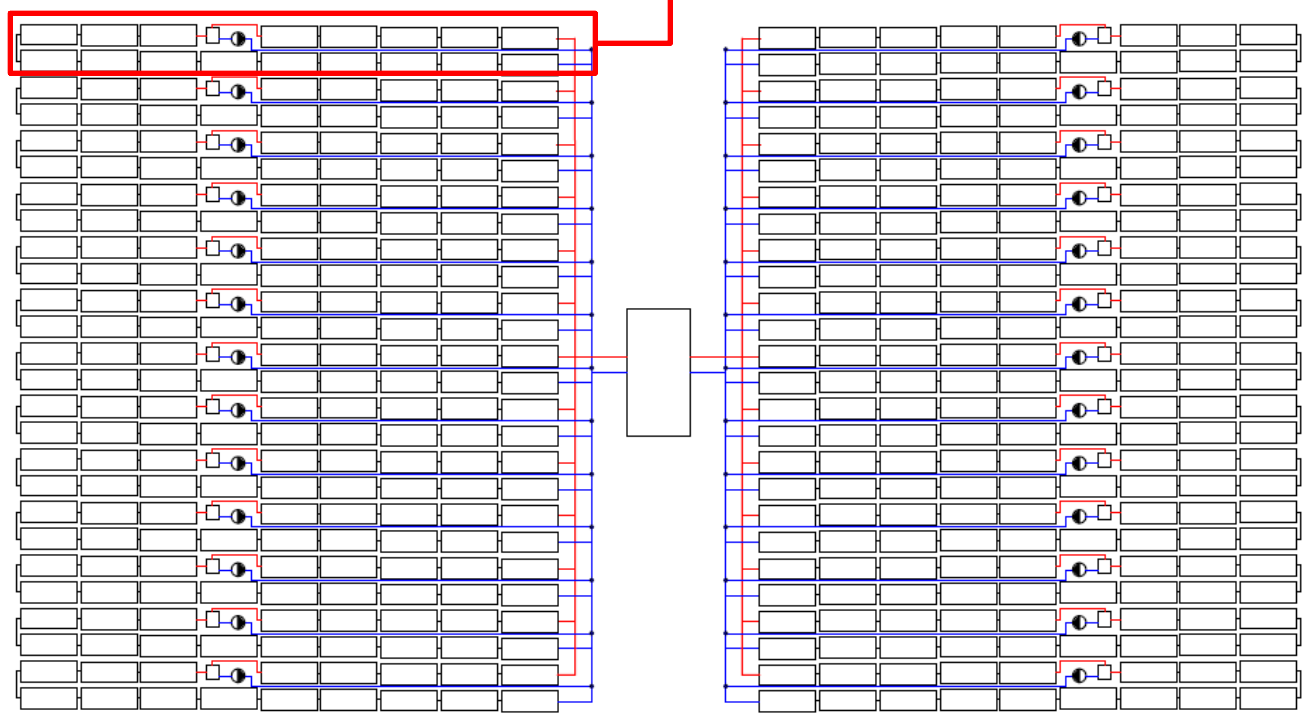
# REFERENCE LF POWER PLANT

(26 recirculation parallel loops)

# Reference LF power plant (26 parallel recirculation loops)



Location: Dagget, CA, USA

Gross Power: 50 Mwe
Net Power: 47,5 Mwe

Solar collector: LF DSG Novatec

Solar Field effective apperture area: 227.100 m2

Superheated steam at turbine inlet:
- Pressure : 90 bar
- Temperature: 500 ºC

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# DESIGN-POINT PERFORMANCE

(21st June, Solar Noon)

# Design-Point (21st June, Solar Noon)

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**1. OPTICAL PERFORMANCE.**

SAM defines a variable called **MidTrack** (time at midpoint of operation). Thermoflow doesn´t consider this variable, and for comparison between both software tools, max. DNI at solar Noon was considered 986 W/m2 at 11:30 am. Also SF stow and deploy limiting angles were not defined. In the following Table Solar Noon conditions are listed.

| | |
|---|---|
| Time | 11:30 am |
| DNI | 986 W/m2 |
| Relative humidity | 18 % |
| Dry bulb temperature | 31.95 ºC |
| Wet bulb temperature | 16 ºC |
| Site Altitude | 588 m |

**Table 3**. Solar Noon conditions.

**Sun and incident angles** calculation in both software shows the same values. These values are calculated for 11:30 am (MidTrack). See Table 2 .

| | Thermoflex | SAM |
|---|---|---|
| Elevation | 77.88 deg | 77.91 deg |
| Zenith angle | 12.12 deg | 12.092 deg |
| Azimuth angle | 159.1 deg | 159.12 deg |
| Long. incident angle | 11.31 deg | 11.31 deg |
| Transv. Incident angle | 4.372 deg | 4.372 deg |

**Table 4**. Solar Noon Sun angles. Results validated with SolPos (NREL) algorithm :http://www.nrel.gov/midc/solpos/solpos.html

# Design-Point (21st June, Solar Noon)

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**Real optical efficiency** (Thermoflow) = Nominal optical efficiency x cleanless factor x end losses factor x IAM

**Real optical efficiency** (SAM) = Nominal optical efficiency x cleanless factor x tracking error factor x geometry effects factor x mirror reflectivity factor x mirror soiling factor

Thermoflow not consider the following factors in real optical efficiency: tracking error factor, geomety effects factor, mirror reflectivity factor, mirror soiling factor.

**IAM** calculations (Thermoflow):

Long. Incident angle 11.31 deg. : IAM long. =0.974

Transv. Incident angle 4.372 deg. : IAM transv. =0.971

IAM long. X IAM transv. = 0.974 x 0.971 = 0.945

**IAM** calculations (SAM):

Long. Incident angle 11.31 deg. (table rows)

Transv. Incident angle 4.372 deg. (table columns)

IAM = 0.96

**Table 5**. Boiling modules real optical efficiency.

| | Thermoflex | SAM |
|---|---|---|
| Optical Efficiency | 67 % | 67 % |
| Cleanliness factor | 96 % | 96 % |
| End Losses Factor | 99.45 % | n/a |
| IAM | 94.45 % | 96 %(deducted) |
| Real optical efficiency (%) | 60.42 % | 61.74 % |

**Table 6**. Superheating modules real optical efficiency.

| | Thermoflex | SAM |
|---|---|---|
| Optical Efficiency | 65 % | 65 % |
| Cleanliness factor | 96 % | 96 % |
| End Losses Factor | 98.71 % | n/a |
| IAM | 94.45 % | 96% (deducted) |
| Real optical efficiency (%) | 58.18 % | 59.9% |

# Design-Point (21st June, Solar Noon)

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**2. THERMAL PERFORMANCE.**

**Incident Energy** is very similar values in both tools.
Qinc. = DNI x Effective aperture area = 227.100 m2 x 986 W/m2 =
Qinc.= 223.92 MWth

**Received energy** differs in both software due to endlosses factor:
Qrec. (SAM) = Qinc. x nominal optical efficiency x IAM x fcleanless
x ftrack x f geom effects x f mirror reflectivity x f mirror soiling=
Qrec. (SAM) = (166000 m2 x 986 W/m2 x 0.67 x 0.96 x 0.96 x 1 x 1 x 1 x 1 ) (boiling modules) +
(61000 m2 x 986 W/m2 x 0.65 x 0.96 x 0.96 x 1 x 1 x 1 x 1 ) (superheating modules)= 137.1 MWth
Qrec. (Thremoflow) = Qinc. X nominal optical efficiency x IAM x fcleanless x fendlosses =
Qrec. (Thermoflow) = (986 W/m2 x 161644 m2 x 0.6042) (boiling modules) +
(986 W/m2 x 65674 m2 x 0.5818) (superheating modules) = 133.9 MWth

**SF Thermal power** = SF Received Energy – SF Thermal Looses
SF Thermal power (SAM) = 137.18 MWth – 6.71 MWth = 129.78 MWth (see Note)
SF Thermal power (Thermoflow) = 133.92 MWth – 6.6 MWth = 127.3 MWth

| | Thermoflex | SAM |
|---|---|---|
| SF Incident energy | 224.07 MWth | 223.83 MWth |
| SF Received energy | 133.92 MWth | 137.18 MWth |
| SF Thermal losses | 6.6 MWth | 6.71 MWth (see Note) |
| SF Thermal power | 127.32 MWth | 129.78 MWth |

**Table 7**. SF energy flows.

Note: SF piping heat losses are also included in SF Thermal losses and Start-up Energy.

# **Design-Point** (21st June, Solar Noon)

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**Gross Power** (SAM) = SF Thermal Power x Gross Efficiency = 129.78 MWth x 0.3972 = 51.54 Mwe
**Gross Power** (Thermoflow) = SF Thermal Power x Gross Efficiency = 127.32 MWth x 0.395 = 50.29 Mwe

**Net Power** (SAM) = Gross Power – Cooling system parasitic load- Parasitic pumping power-Fixed parasitic power-Collector field parasitic power-Load dependent parasitic power- Aux boiler parasitic power
**Net Power** (SAM)= 51564 kWe – 2708.25 kWe – 131.93 kWe– 283.25 kWe – 45.4 kWe -0-0= 48395 kWe

Net Power (Thermoflow) = Gross Power – Fan Power – Condenser Pump power – Feedwater pump power- SF parasitics – Fixed BOP parasitics (1% Gross power)
Net Power (Thermoflow) = 50284 kWe – 1599.7 kWe – 61.76 kWe – 718.1 kWe – 15.11 kWe – 502.84 kWe = 47386.5 kWe

**Total parasitic power** (SAM) = 51564 kWe – 48395 kWe = 3168.83 kWe
**Total parasitic power** (Thermoflow) = 50284 kWe – 47386.5 kWe= 2897.51 kWe

| BOP | Thermoflex | SAM |
|---|---|---|
| Gross Power | 50284 kWe | 51564 kWe |
| Gross Efficiency | 39.5 % | 39.72 % |
| Net Power | 47387 kWe | 48395.1 kWe |
| Net Efficiency | 37.23 % | 37.3% |
| Fan Power | 1599.7 kWe | 2708.25 kWe |
| Condenser Pump | 61.76 kWe | 131.93 kWe |
| Feedwater Pump | 718.1 kWe | 45.4 kWe |
| SF parasitics | 15.11 kWe | 283.25 kWe |
| Fixed parasitics | 502.84 kWe | |

**Table 8**. BOP energy flows.

## ANNUAL PLANT PERFORMANCE

# Annual plant performance

2% deviation in Gross Power
4% deviation in Net Power

Main differences: collector end losses, thermal inertia (start-up energy) and parasitic looses.

**Table 9**. LF plant annual performance.

| | Thermoflex Gross Power (MWh) | SAM Gross Power (MWh) | Thermoflex Gross Power (MWh) * | Thermoflex Net Power (MWh) | SAM Net Power (MWh) | Thermoflex Net Power (MWh) * |
|---|---|---|---|---|---|---|
| January | 2438 | 2336 | 2294 | 2330 | 2205 | 2189 |
| February | 3649 | 3577 | 3498 | 3482 | 3389 | 3334 |
| March | 6053 | 5871 | 5881 | 5769 | 5546 | 5600 |
| April | 8132 | 8009 | 7982 | 7721 | 7495 | 7573 |
| May | 10396 | 10282 | 10263 | 9838 | 9531 | 9705 |
| June | 11650 | 11539 | 11529 | 10930 | 10613 | 10807 |
| July | 11001 | 10772 | 10848 | 10273 | 9903 | 10119 |
| August | 10973 | 10848 | 10858 | 10282 | 9985 | 10166 |
| September | 8420 | 8324 | 8272 | 7933 | 7651 | 7786 |
| October | 5651 | 5404 | 5481 | 5363 | 4969 | 5197 |
| November | 3324 | 3024 | 3193 | 3173 | 2850 | 3045 |
| December | 2290 | 2275 | 2164 | 2187 | 2124 | 2063 |
| **TOTAL** | **83977** | **82260** | **82263** | **79281** | **76262** | **77584** |

(*) Bypass in last Low Pressure LP turbine stage, to avoid negative power.

# SAM & THERMOFLOW CAPABILITIES SUMMARY

# SAM & Thermoflow capabilities summary

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Comparison of capabilities for LF DSG power plant design.

| | Thermoflex | SAM |
|---|---|---|
| Graphical simulation environment showing energy streams properties | Yes | No |
| SF configuration modeling flexibility | Yes | No |
| Meteorological data directly loaded from weather files (TMY2, TMY3, EPW) | No | Yes |
| SF thermal inertia consumed during start up, shut down and radiationtransitory | No | Yes |
| SF pressure drop accurate models (saturated steam Friedel correlation, compressible superheated steam, etc) | Yes | No |
| SF control parameters (flow limit, stow and deploy limit, freezing limit, stow wind, etc) | No | Yes |
| Receiver heat losses accurate model (Kandlikar, Dittus-Boelter HTC correlations) | Yes | No |
| Receiver tubes thickness calculation and stress limit. | Yes | No |
| BOP Off-Line annual performance innovative regression model capability | Yes | No |
| BOP operational modes (start up, shut down, stand by, etc) | No | Yes |
| SF and BOP parasitic energy looses detail (tracking power, etc) | No | Yes |
| Supercritical water SF and BOP simulation | Yes | No |
| BOP reheating LF DSG modules | Yes | No |
| Condenser part load levels | No | Yes |
| Financial, incentives, depreciation models | No | Yes |

# CONCLUSIONS AND FUTURE WORK

# Conclusions and future work

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Synergies between both software tools development would be a chance to improve SAM and Thermoflow capabilities.

SF and BOP control and operation limits should be included in LF DSG software design tools.

Simulation tools should consider low Sun radiation days with different SF and BOP configuration requirements.

Reduced-Order Power Block Performance Models for CSP Applications (Michael J. Wagner) was validated for DSG LF power plants.

LF Optical performance simulation with analytical or Montecarlo methods, like FirstOptic or SolarTrace, could be integrated in Thermal Balance software tools like SAM and Thermoflow.

Stress analysis limits should be impossed in Thermal Balances simulation software to obtain an optimised and feasible LF DSG power plant design.