First Summer School

Part A: Line-focus Solar Thermal Technologies

September 20-24, 2021

Lecture 10:

Design process for Solar Fields with Parabolic Trough Collectors

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Design Process for Solar Fields with PTCs

Content

- The "*Design Point*" parameters
- Number of collectors in series within each row
- Number of parallel rows
- Electrical power of the pumping equipment

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Design Process for Solar Fields with PTCs

Important Remark

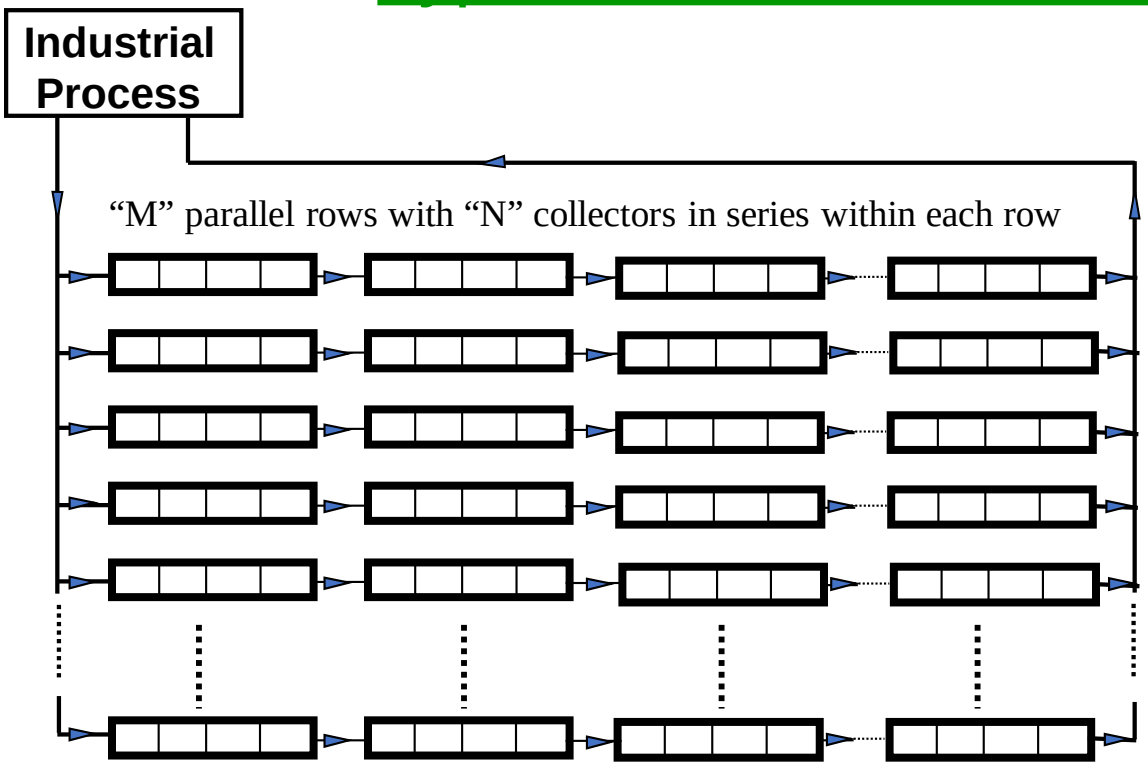
Since the energy source of a solar field is the solar radiation, the output thermal power delivered by the solar field will change as the solar radiation changes along the day during the sunlight hours. However, the term "**Nominal Power**" is used as a reference for the thermal power delivered by the solar field

What is the "Design Point" for a solar field ?

The "*Design Point*" is the set of parameters under which the solar field will deliver its *nominal power. For a set of parameters different from the "Design Point", the solar field will provide less or higher power than its nominal one*

Design Process for Solar Fields with PTCs

Typical solar field with PTCs



The main objective of the design of a solar field with PTCs is the determination of

a) the number of collectors that must be connected in series within each row, and
b) the number of parallel rows needed

Design Process for Solar Fields with PTCs

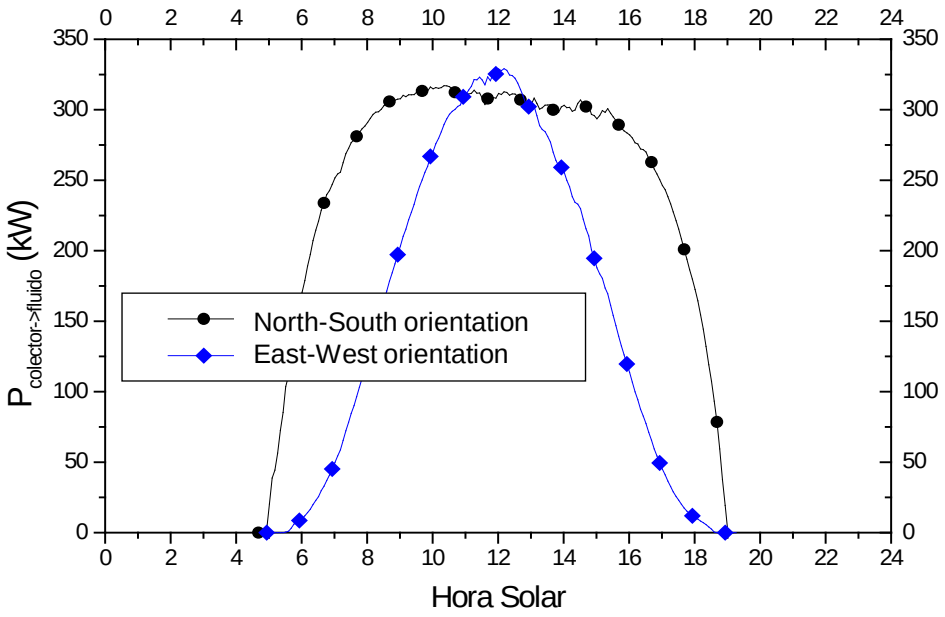
Design procedure (I)

- *Definition of the Design Point parameters:*
  - Orientation of the collectors

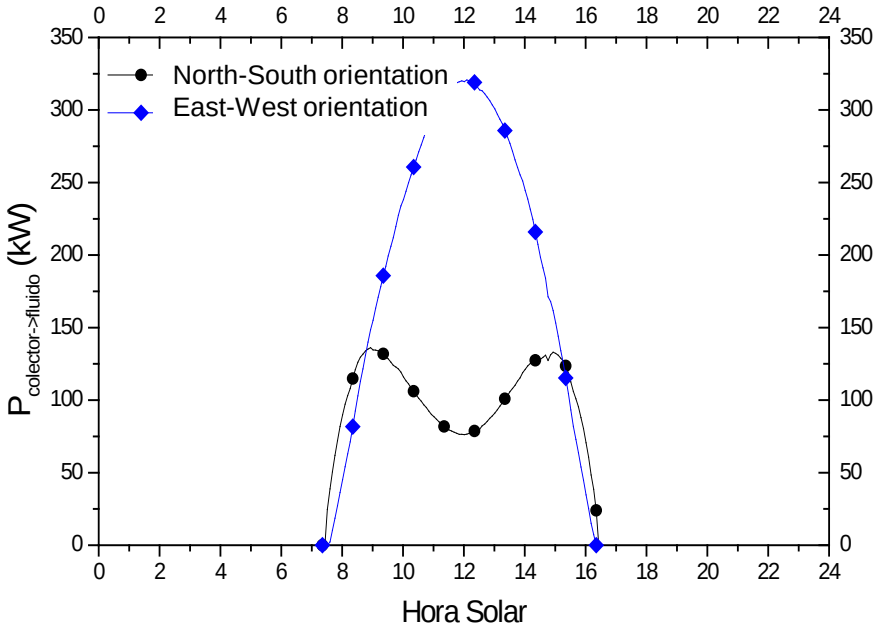
Design Process for Solar Fields with PTCs

Influence of the collector orientation on the seasonal performance

(Simulation of a ET-100 collector installed in Southern Spain)



Performance in a clear day in June



Performance in a clear day in December

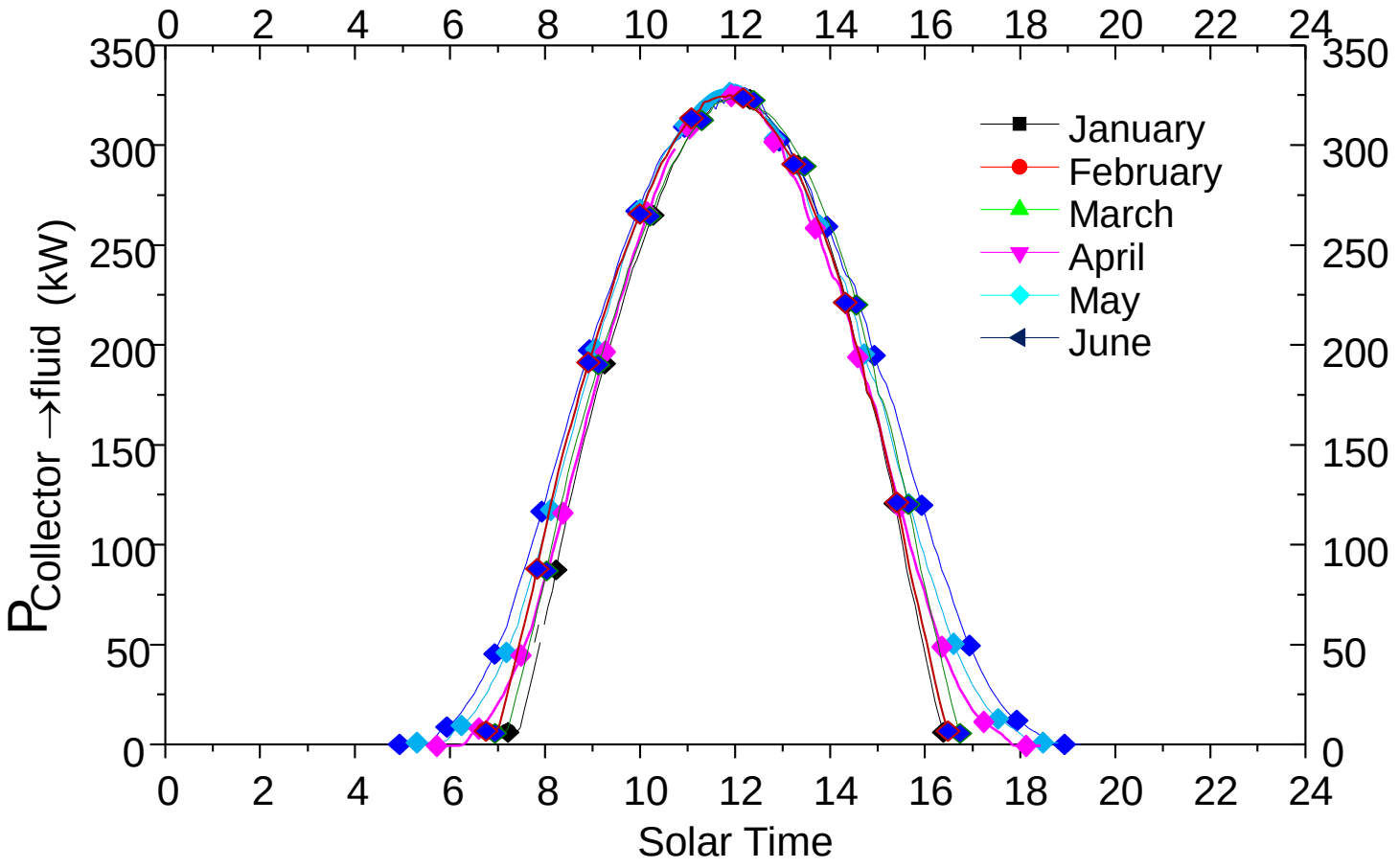
Design Process for Solar Fields with PTCs

Design procedure (I)

- *Definition of the Design Point* parameters :
  - Orientation of the collectors
  - Location (geographic Latitude and Longitude)
  - Day and Hour for the *Design Point*

Design Process for Solar Fields with PTCs

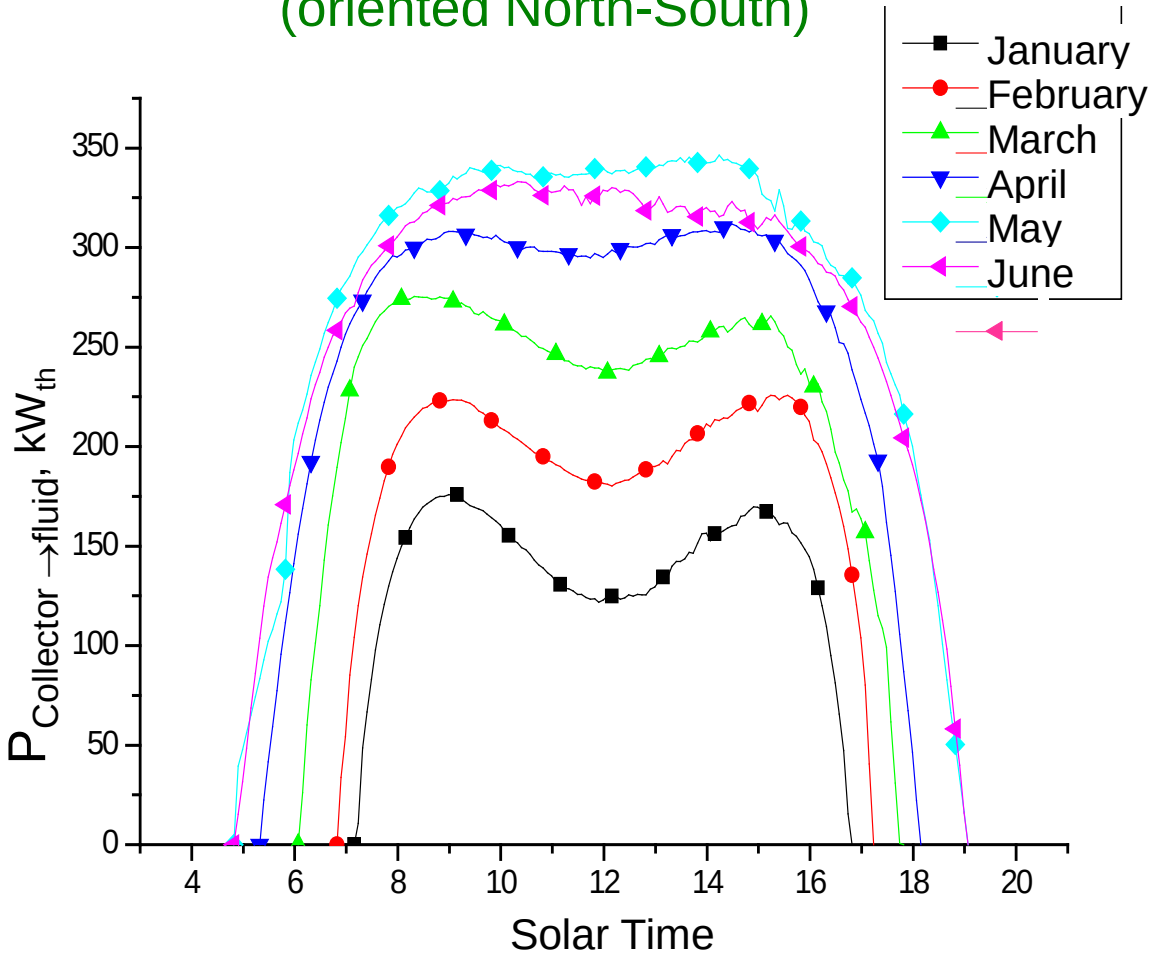
Daily net thermal power delivered by a Parabolic Trough Collector (oriented East-West)



(Simulation of a ET-100 collector installed at the PSA)

Design Process for Solar Fields with PTCs

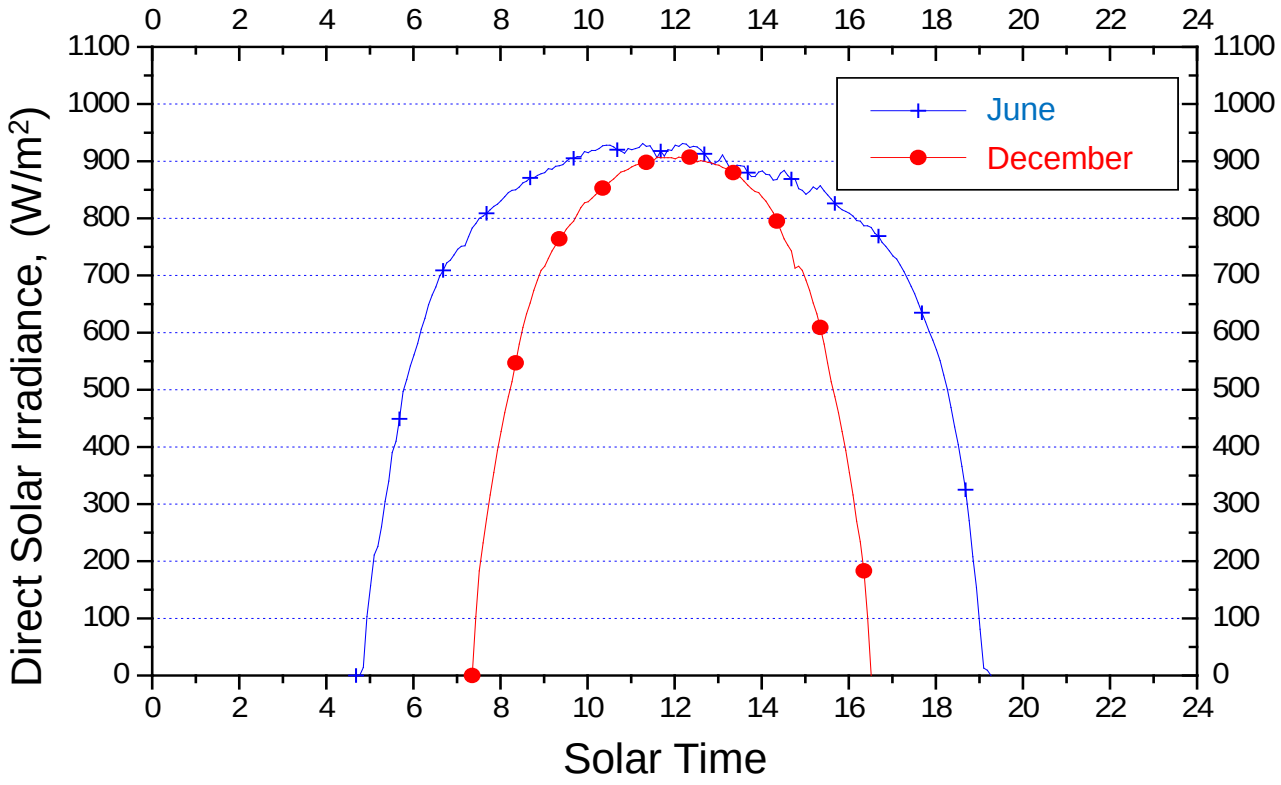
Daily net thermal power delivered by a Parabolic Trough Collector (oriented North-South)



(Simulation of a ET-100 collector installed at the PSA)

Design Process for Solar Fields with PTCs

Selection of the Hour for the *Design Point*



Direct Solar irradiance in a clear day of June and December (at PSA site)

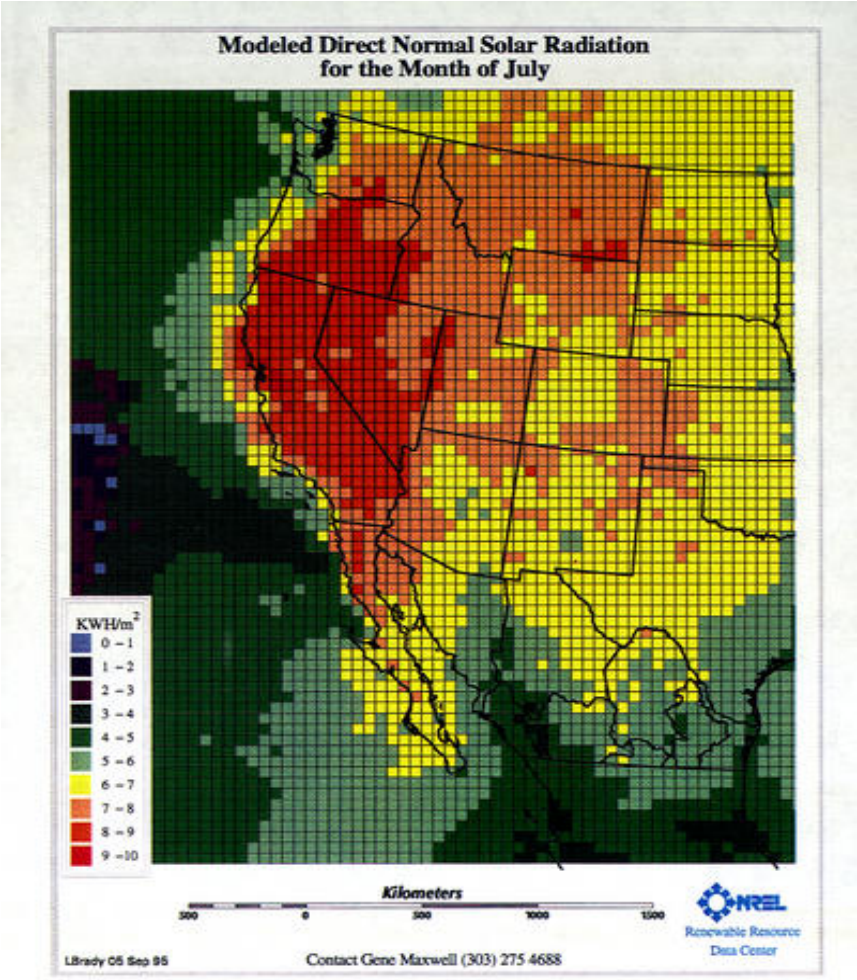
Design Process for Solar Fields with PTCs

Design procedure (I)

- *Definition of the Design Point* parameters :
  - Orientation of the collectors
  - Location (geographic Latitude and Longitude)
  - Day and Hour for the *Design Point*
  - Incidence Angle
  - Direct solar irradiance and ambient temperature

Design Process for Solar Fields with PTCs

Assessment of the Direct Solar Radiation using satellite pictures



Design Process for Solar Fields with PTCs

Design procedure (I)

- *Definition of the Design Point parameters :*
  - Orientation of the collectors
  - Location (geographic Latitude and Longitude)
  - Day and Hour for the *Design Point*
  - Incidence Angle
  - Direct solar irradiance and ambient temperature
  - Solar Field Inlet and Outlet Temperatures
  - Solar field nominal thermal power (or net thermal energy)
- *Selection of the solar collector model*
- *Selection of the working fluid*

Design Process for Solar Fields with PTCs

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Design Process for Solar Fields with PTCs

Design Procedure (II)

- *Number of collectors in each row, N*

$$N = \frac{\Delta T}{\Delta T_c}$$

N = number of collectors to be connected in series in each row
ΔT = Fluid temperature increase in the solar field (To – Ti)
ΔTc = Fluid temperature increase in a collector

- Calculation of the nominal power of a collector

$$P_{Q,\,\text{collector}\rightarrow\text{fluid}} = A_c \cdot G_b \cdot Cos(\theta) \cdot \eta_{opt,0^o} \cdot K(\theta) \cdot F_e - P_{Q,collector\rightarrow ambient}$$

- Calculation of the mass flow to assure a Re ≥ 2×10^5
  - If $G_b \times Cos(\varphi) \geq 800 \rightarrow Re = 4 \times 10^5$.
  - If $500 \leq G_b \times Cos(\varphi) \leq 800 \rightarrow Re = 3 \times 10^5$.
  - If $G_b \times Cos(\varphi) \leq 500 \rightarrow Re = 2 \times 10^5$.

$$(\mathrm{Re} = \rho \cdot v \cdot d / \mu)$$

- Calculation of ΔTc using the energy balance:

$$P_{Q,collector\rightarrow fluid} = q_m \cdot (h_{out} - h_{in}) = q_m \cdot \int_{T_i}^{T_o} C_p \cdot dT$$

being T_i the mean fluid temperature in the solar field

- Calculation of "N" using the equation: $N = \Delta T / \Delta T_c$

Design Process for Solar Fields with PTCs

Design Procedure (III)

- *Calculation of the number of parallel rows*

  - *Option a) System without thermal storage*

    In this case the number of parallel rows is given by the quotient of the solar field nominal power in the Design Point and the nominal power of a single row of collectors in the Design Point.

  - *Option b) System with thermal storage*

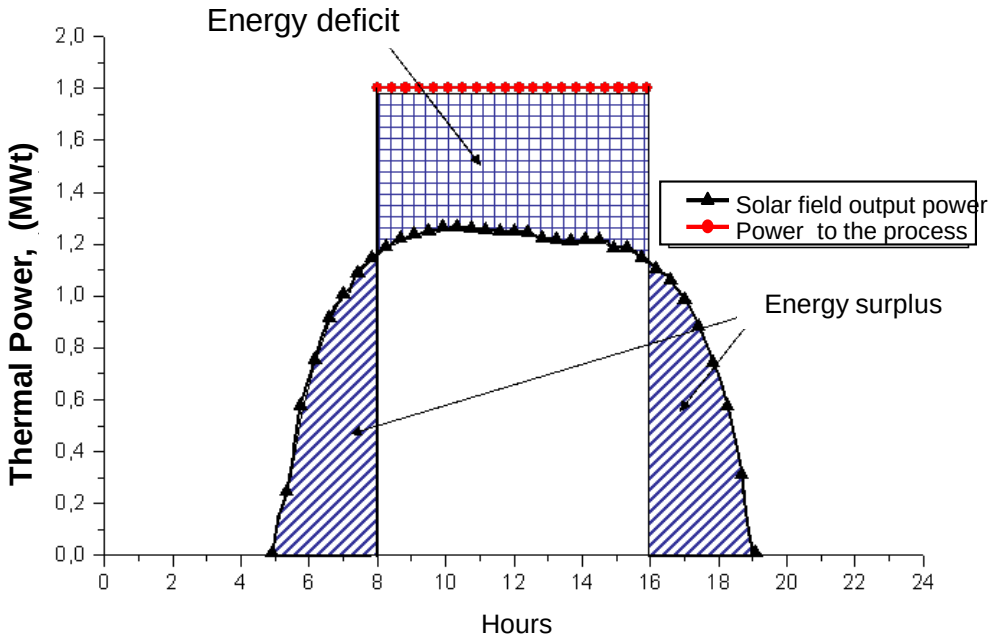
    In this case, the number of parallel rows is given by the quotient of the total thermal energy demanded by the Process in de design day and the thermal energy delivered by a single row in the design day from sunrise to sunset.

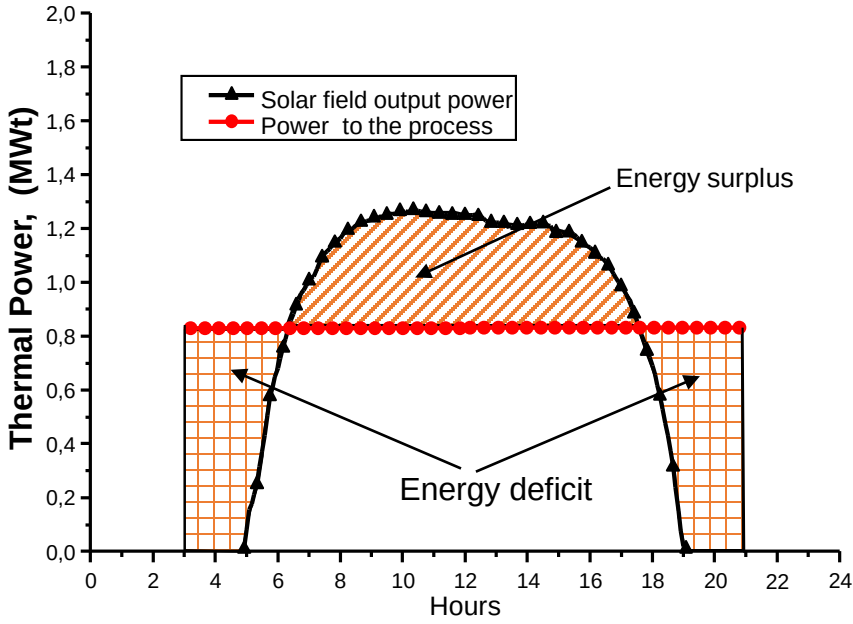
Design Process for Solar Fields with PTCs

Thermal Storage System

A thermal storage system is needed when:

a) a constant thermal power has to be delivered to the process

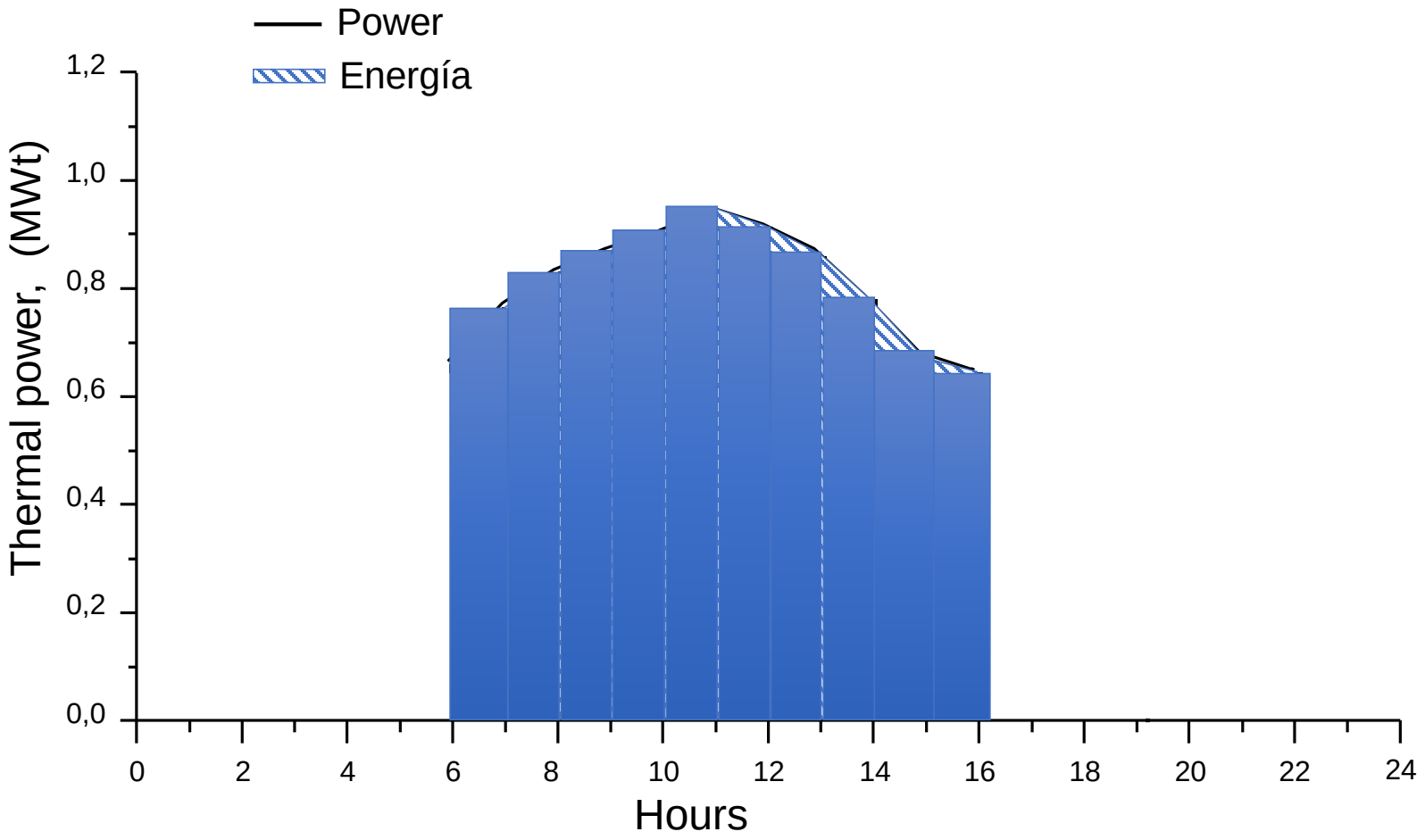




b) thermal energy has to be delivered when sunlight is not available

Design Process for Solar Fields with PTCs

Calculation of the thermal energy on the basis of the thermal power



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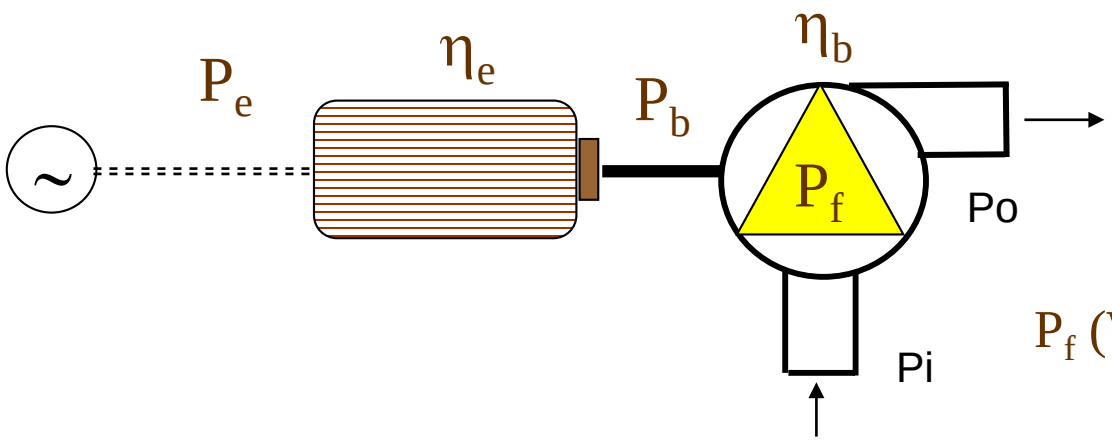
Design of the Feed Pump for a Solar Field with PTC

Electrical pumping power, P_e, for the solar field



$$\Delta P = Po - Pi$$

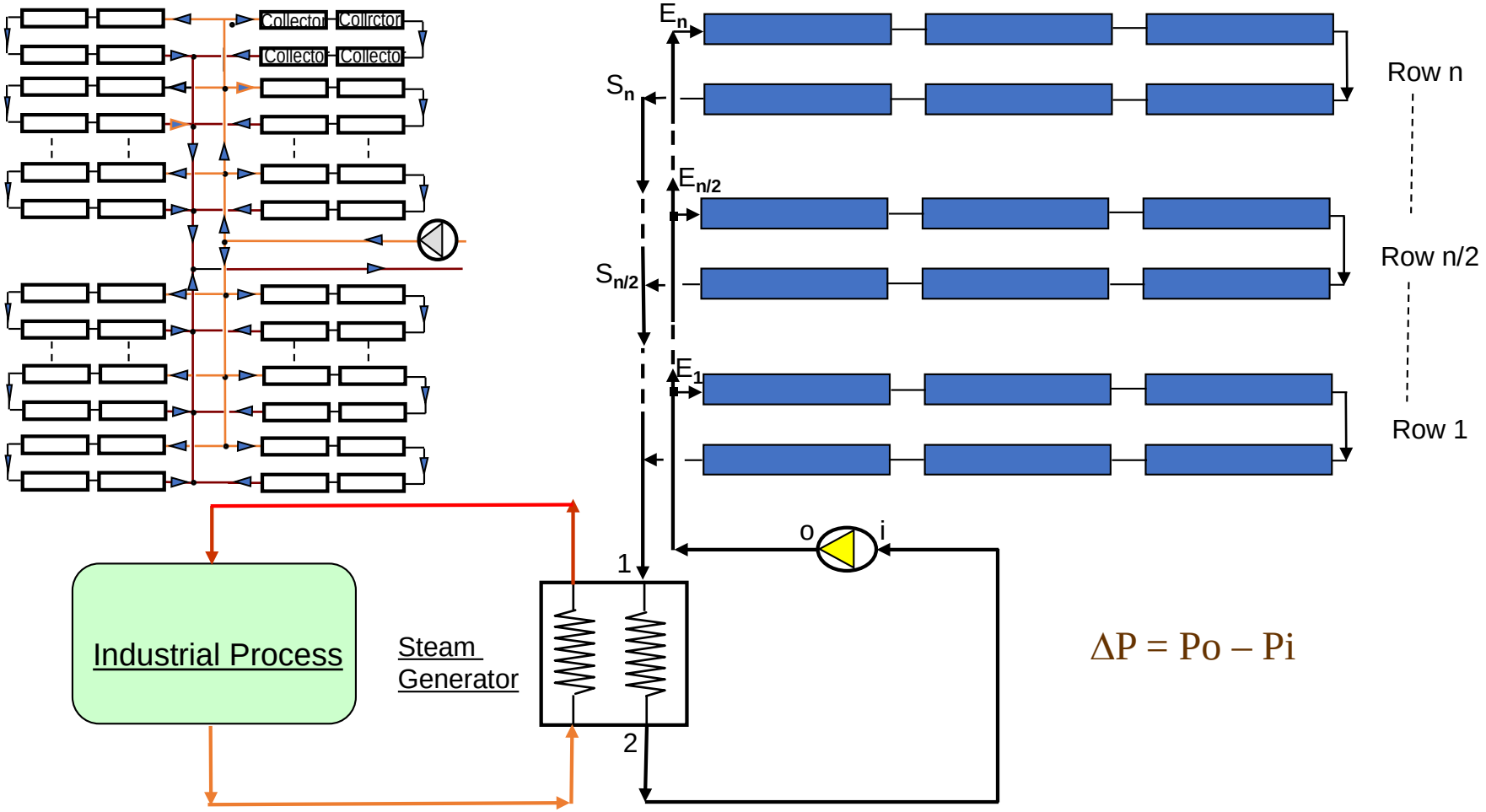
$$P_f\,(W) = \Delta P(Pa) \cdot \text{Flowrate}\,(m^3/s)$$

$$P_e = P_b/\eta_e = P_f / \eta_b \cdot \eta_e = V_{Total} \cdot \Delta P/\eta_e \,.\eta_b = N.\, V_{1row} \cdot \Delta P /\eta_e \,.\eta_b$$

P_e in Watts, W
V_1 , V in m^3/s
ΔP_1 ,ΔP in Pascals, Pa (1 bar = 10^5 Pa)

Design of the Feed Pump for a Solar Field with PTC

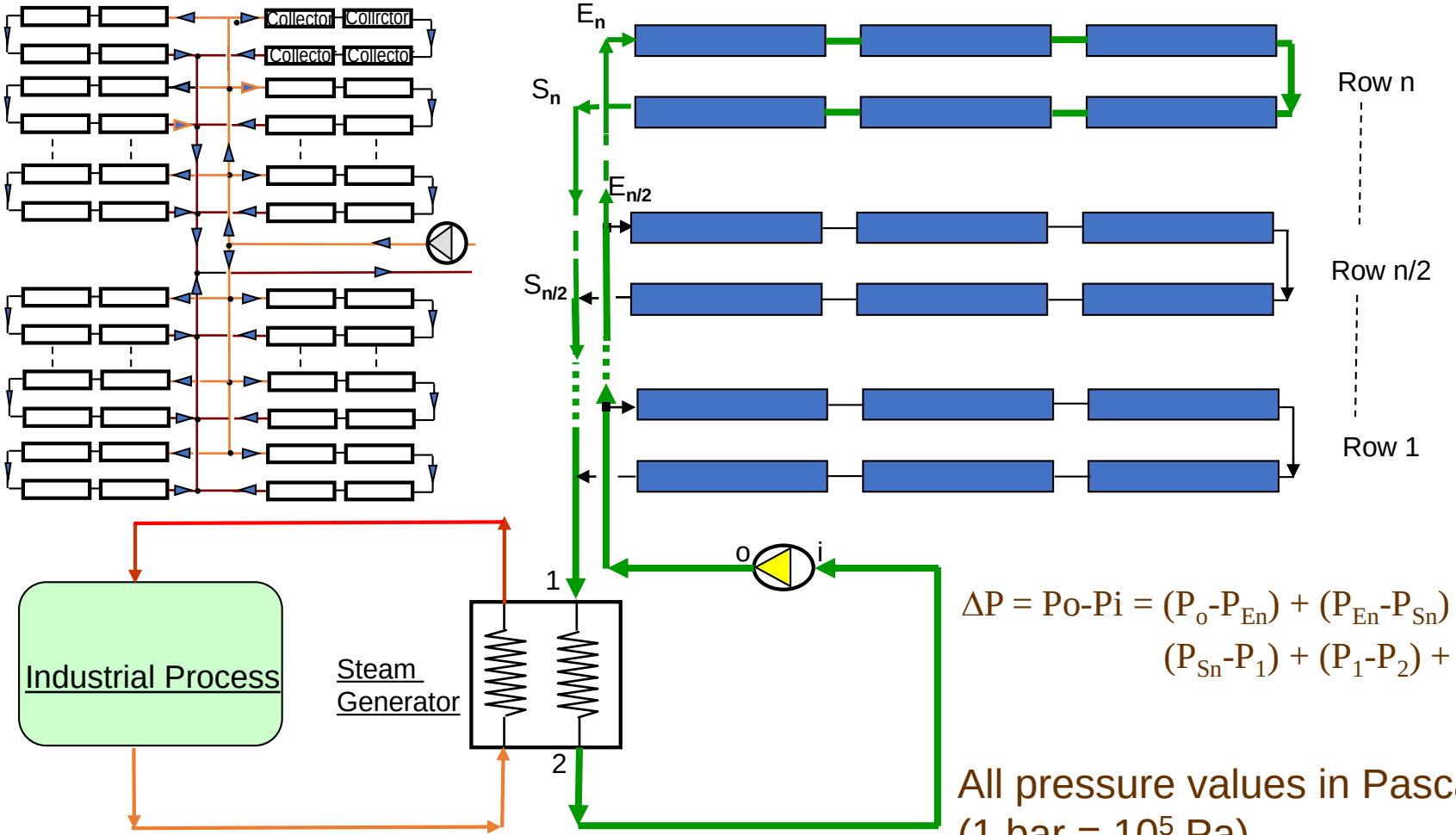
Calculation of the pressure drop ΔP in a multi-row solar field



$$\Delta P = Po - Pi$$

Design of the Feed Pump for a Solar Field with PTC

Calculation of the pressure drop ΔP in a multi-row solar field



$$\Delta P = Po\text{-}Pi = (P_o\text{-}P_{En}) + (P_{En}\text{-}P_{Sn}) + (P_{Sn}\text{-}P_1) + (P_1\text{-}P_2) + (P_2\text{-}P_i)$$

All pressure values in Pascals, Pa
(1 bar = 10^5 Pa)

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- Thank you very much for your attention

- Questions?

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