Congreso Nacional del Medio Ambiente (Conama 2012)

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La energía termosolar en el futuro

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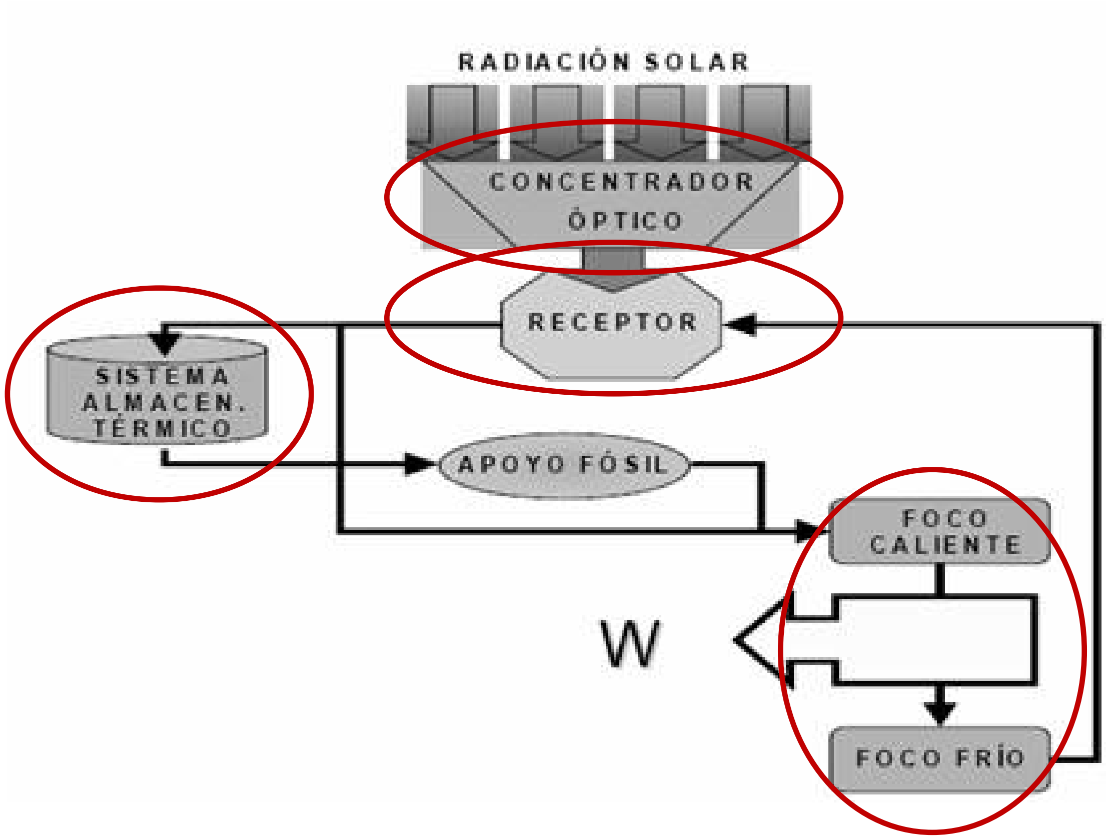
Concentrated Solar Power - CSP

- Energía solar concentrada, concepto de planta para producción de energía



Línea más prometedora en CSP

1. Concentrador: Linear Fresnel Reflectors (LFR)

- **High Concentration Linear Fresnel Reflectors (HCLFR)**
- **Patentes concedidas al GIT/UPM (ideadas para reducir las ineficiencias de la configuración óptica)**

2. Receptor: Multitubo (patentado)

- **Grados de libertad para optimizar prestaciones (exergía)**
- **Selección de fluido; CO2 (+ sales para conexión y BOP)**

3. Ciclos de potencia

- **Rankine agua/vapor (primera fase)**
- **Joule–Brayton peri-crítico, regenerativo (patente en trámite)**

4. Almacenamiento térmico

- **Desde Sales (convencional) a Gas + lechos cerámicos**

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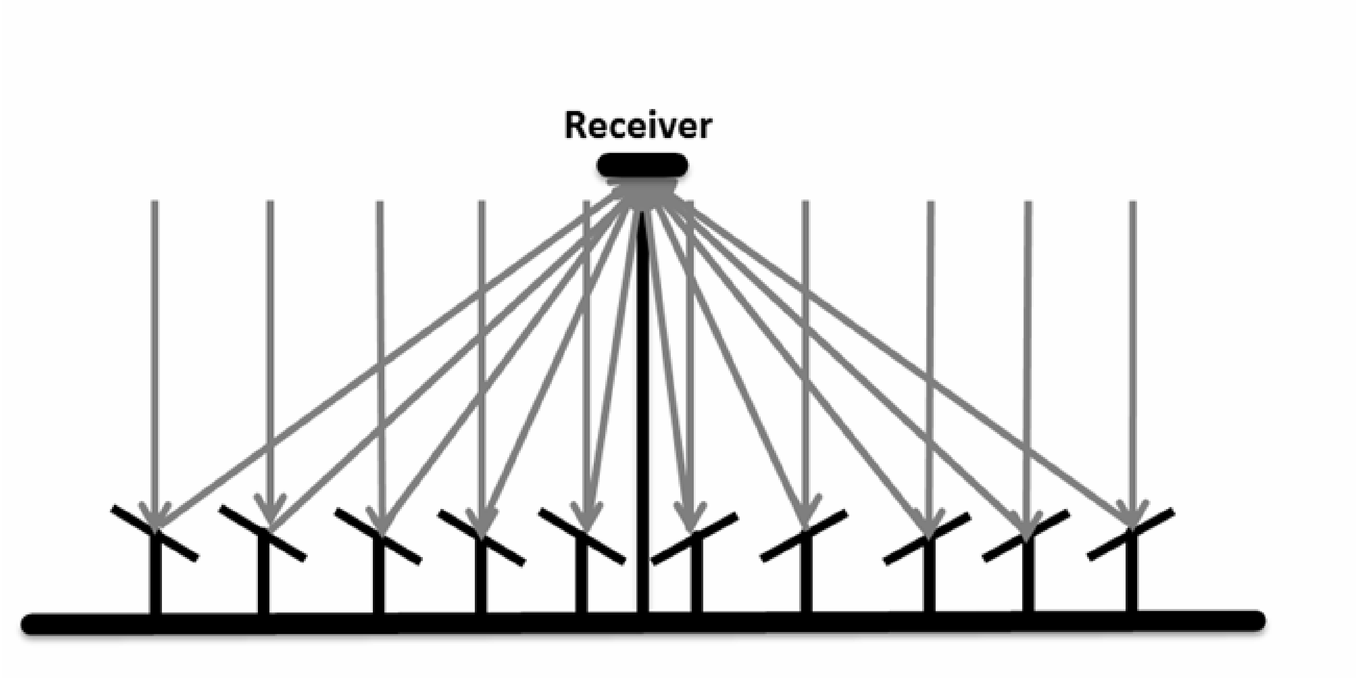
1. Concentrador: Linear Fresnel Reflectors

Configuraciones Fresnel

- **Central Linear Fresnel Reflector (LFR)**
  - **Only one linear absorber in the centre of the solar field (all mirrors of the array aim at a unique receiver)**
  - **The receiver must be horizontal, or slightly tilted for East West configurations**

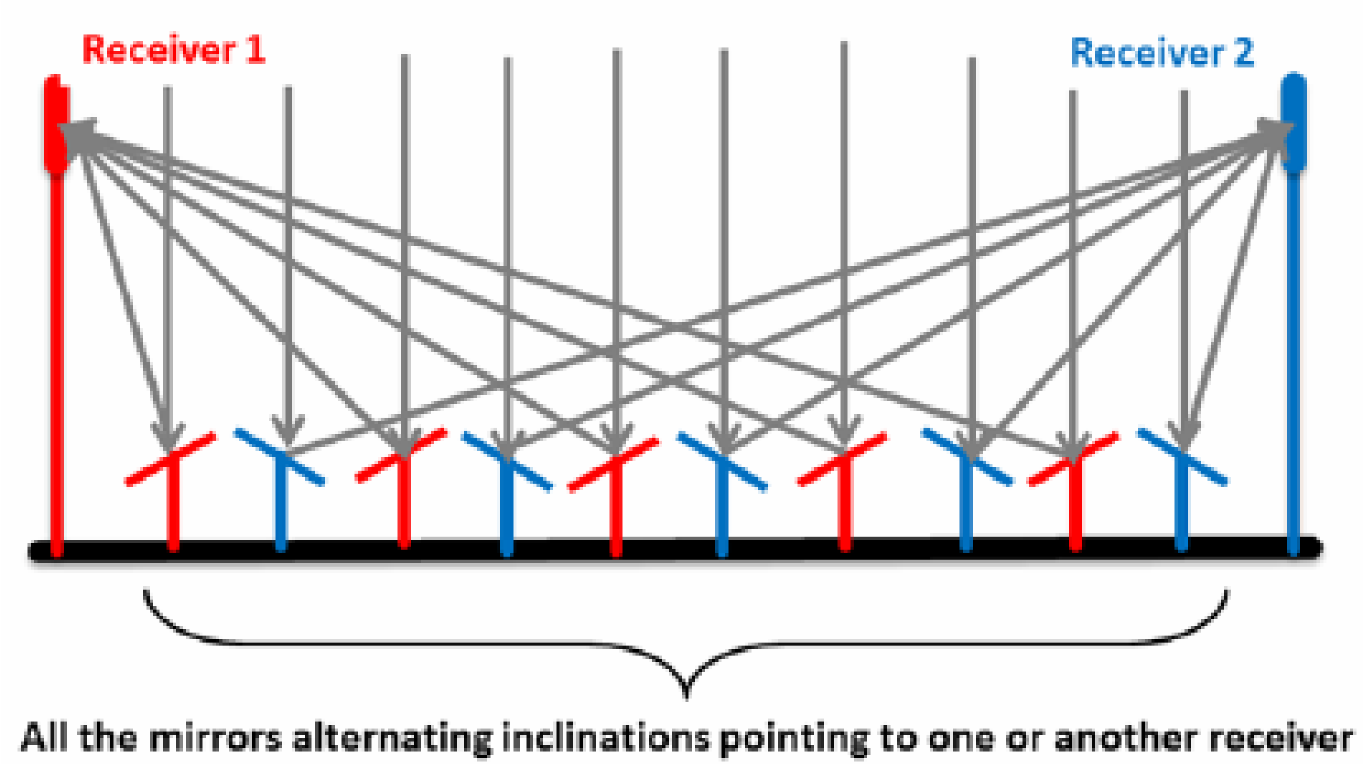


Configuraciones Fresnel

Central Linear Fresnel Reflector (LFR)

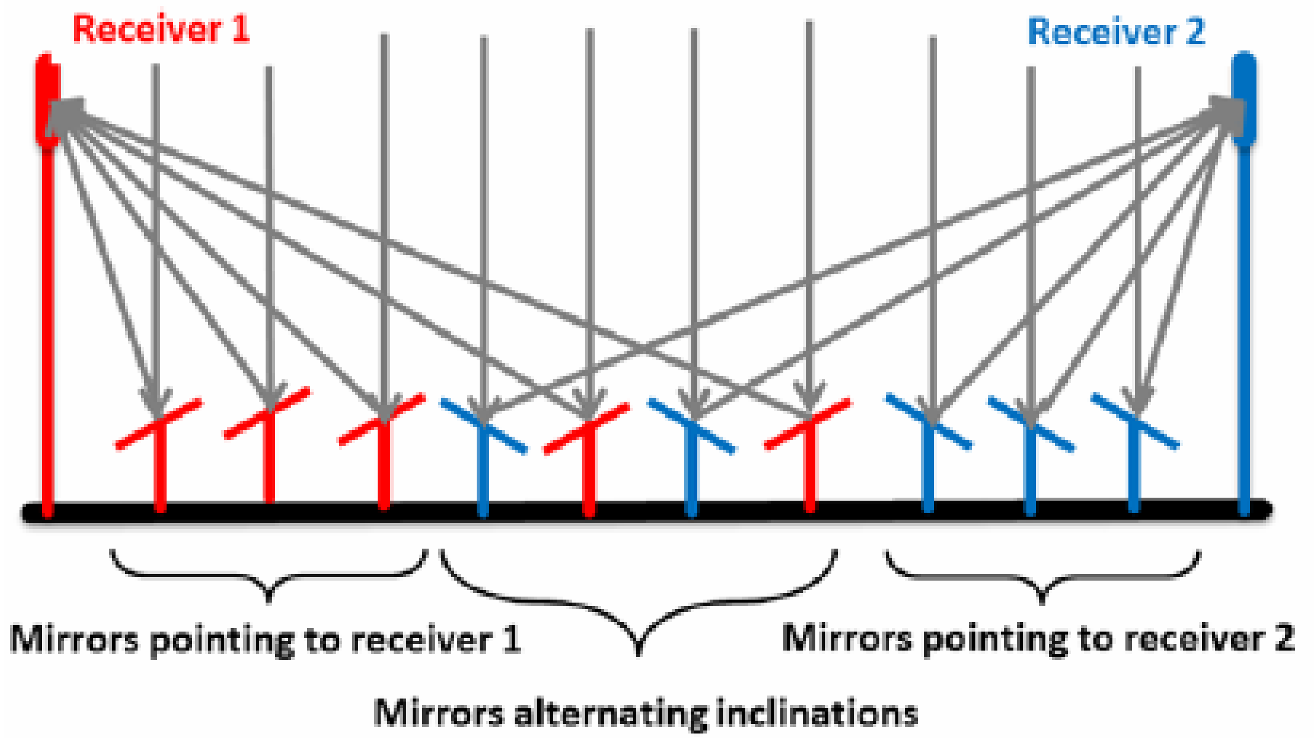
Full CLFR

- All mirrors in the solar field alternate their tilt pointing to one or another receiver, so that they may be placed closer together
- Receivers may be horizontal or vertical



Configuraciones Fresnel

- **Central Linear Fresnel Reflector (LFR)**
  - **CLFR – hybrid**
    - **Only the central mirrors of the solar field alternate their tilt pointing to one or another receiver, so that they may be placed together**
    - **Receivers may be horizontal or vertical as well**



Inefficiencies and efficiencies

- **Optical Efficiency**

$$\eta_{optical} = \frac{Rays\ incident\ in\ the\ receiver}{Total\ rays}$$

- **Energy Efficiency**

$$\eta_{energy} = \frac{Incident\ energy\ in\ the\ receiver}{DNI \cdot Primary\ mirrors\ surface}$$

- **Useful Energy Efficiency**

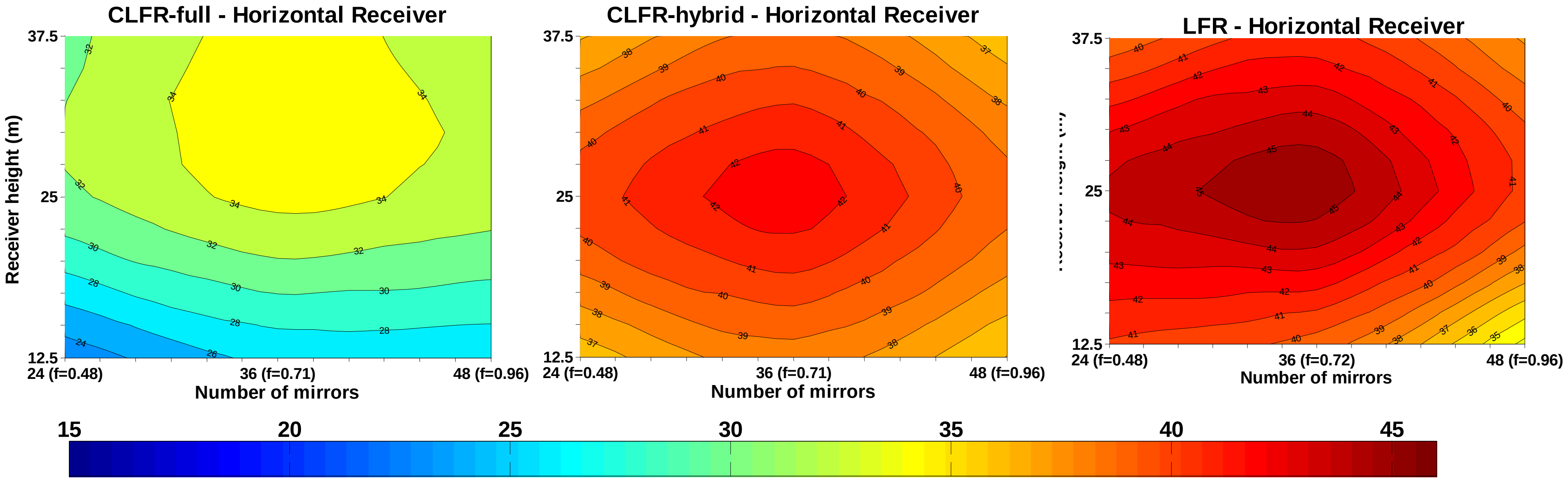
$$\eta_{useful\ energy} = \frac{Incident\ energy\ in\ the\ receiver\ \left(Flux \geq 10\ {}^{kW}\!/_{m^2}\right)}{DNI \cdot Primary\ mirrors\ surface}$$

- **The best efficiency parameter to optimize the configuration is the useful energy efficiency**

Comparative analysis

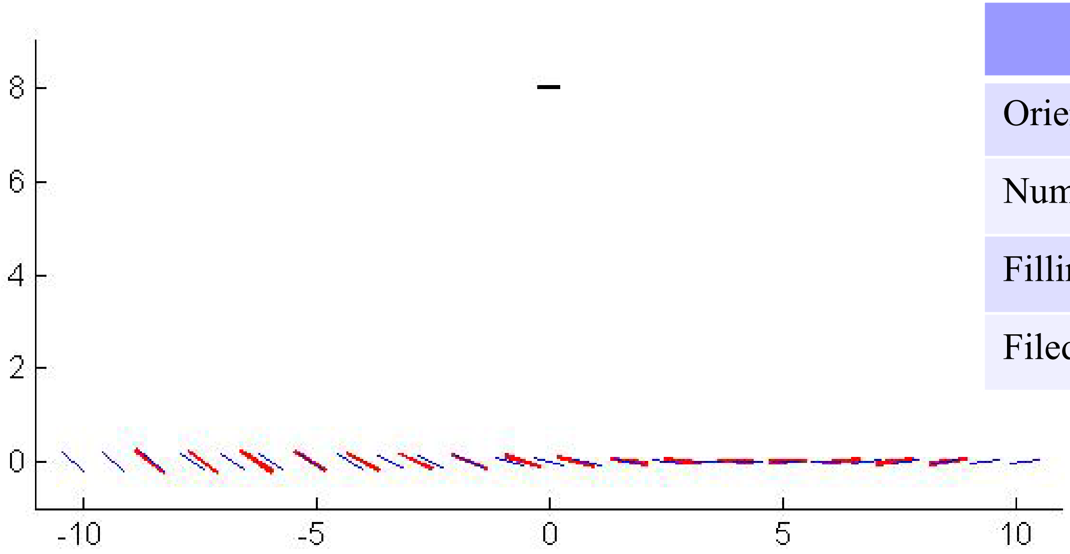
Annual Useful Energy Efficiency:

CLFR-full Horizontal Receiver < CLFR-hybrid Horizontal Receiver < HCLFR Horizontal Receiver



- **Useful energy efficiency is higher for f=0.72**
- **It is an adequate parameter for the selection of the optimum configurations**

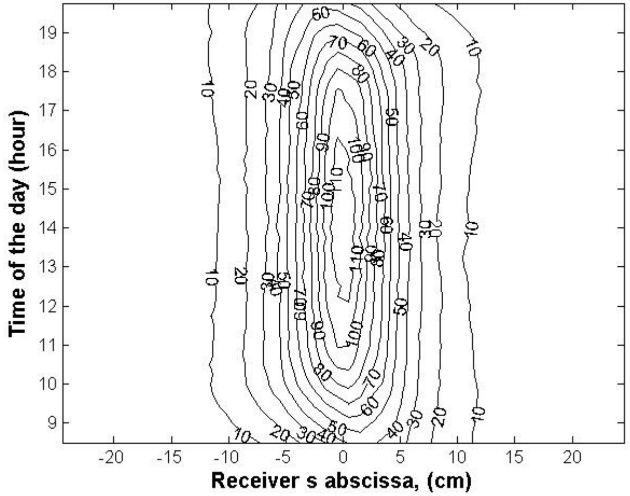
State of the art



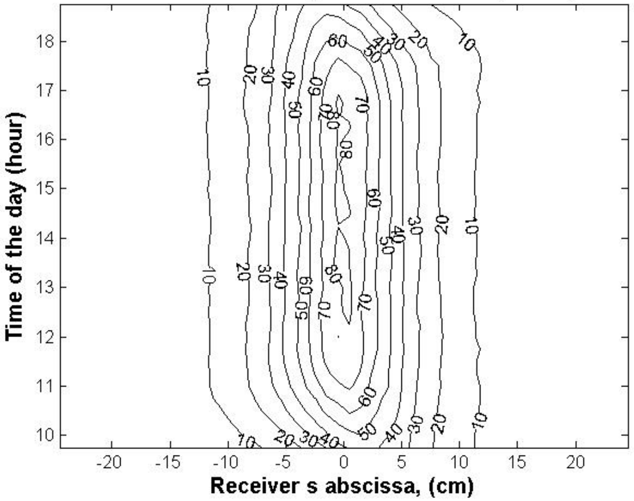
	Fresdemo	Puerto Errado
Orientation	N-S	N-S
Number of mirrors	25	16
Filling factor	71.4%	69.2%
Filed width/receiver heigh	2.63	2.24

- Solar cone: pill box, 4.65 mrad semiangle
- Mirrors shape errors: Gaussian, 2.5 mrad semiangle
- Reflectivity: 0.9

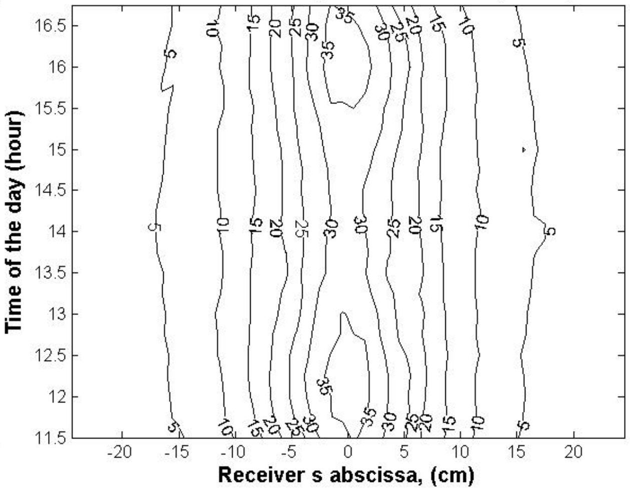
Summer



Spring

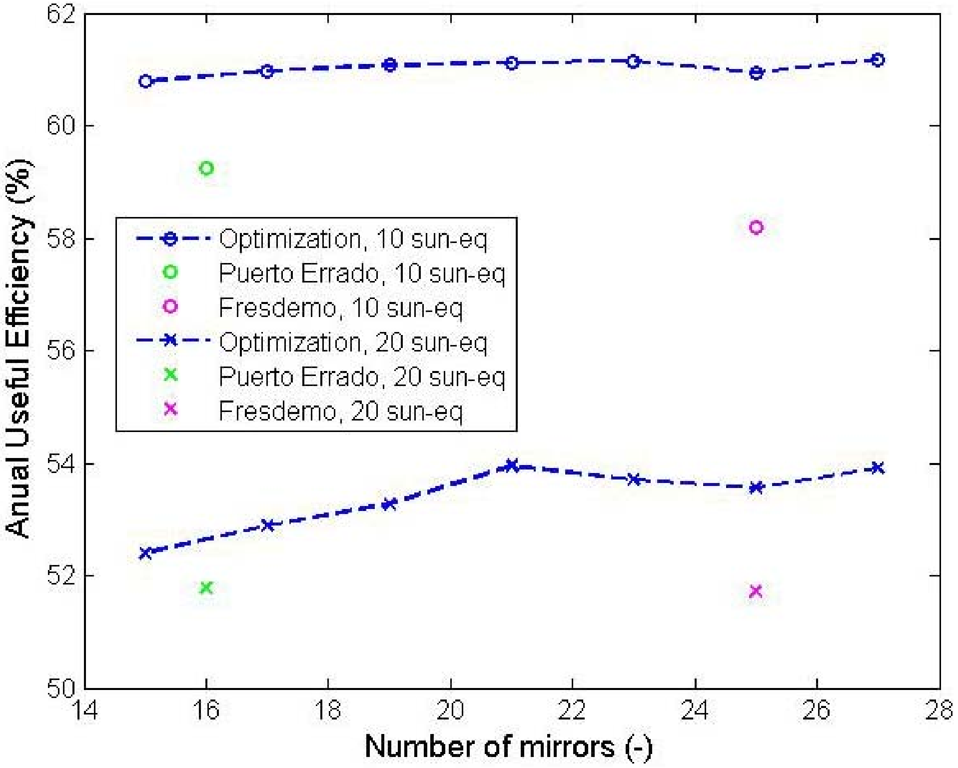


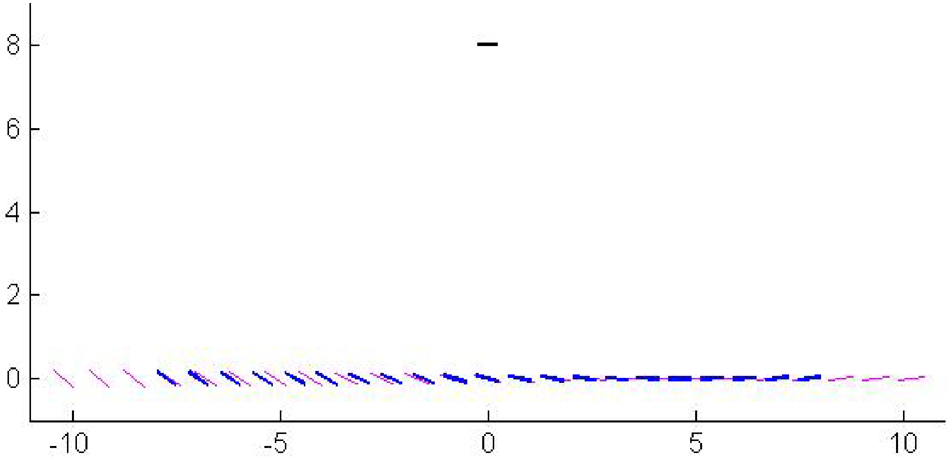
Winter



Optimization of the solar field

- For 20 sun-eq concentration, saturation is achieved at around 21 mirrors
- For 10 sun-eq, it is achieved for fewer mirrors than 15
- Fresdemo and Puerto Errado designs can be improved importantly





The optimum design is achieved when the solar field width is double than the receiver height (20sun-eq)

Conclusions on mirror field design

- Optimum design variables depend more on the concentration required than on the orientation and other factors

Optimization	For 10 sun-eq	For 20 sun-eq
Filling factor	58-66%	66-72%
Field width/receiver height	1.6-1.8	1.9-2.1
Number of mirrors	<15	~21

- A final design should be done coupling optical and thermal processes

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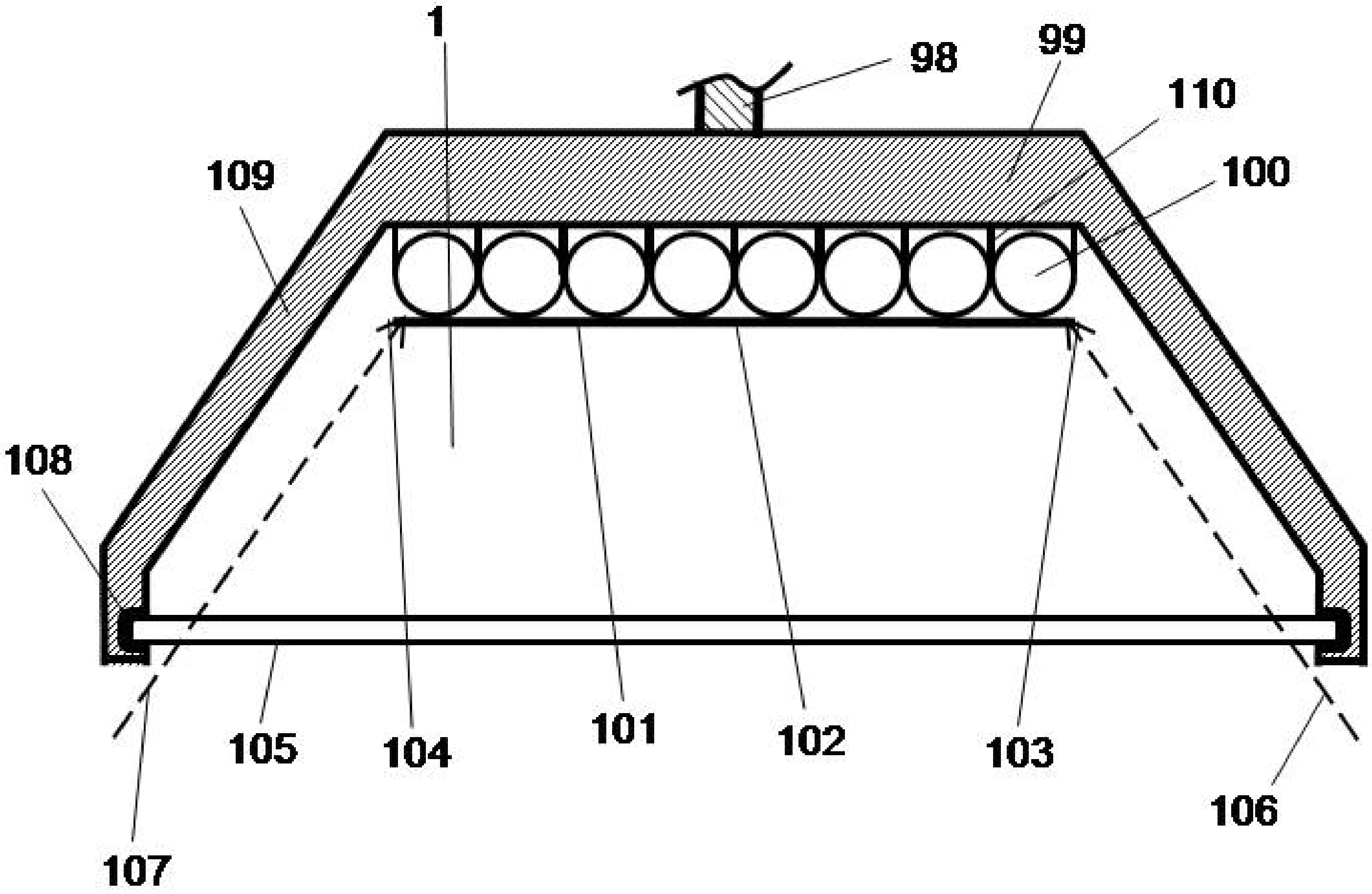
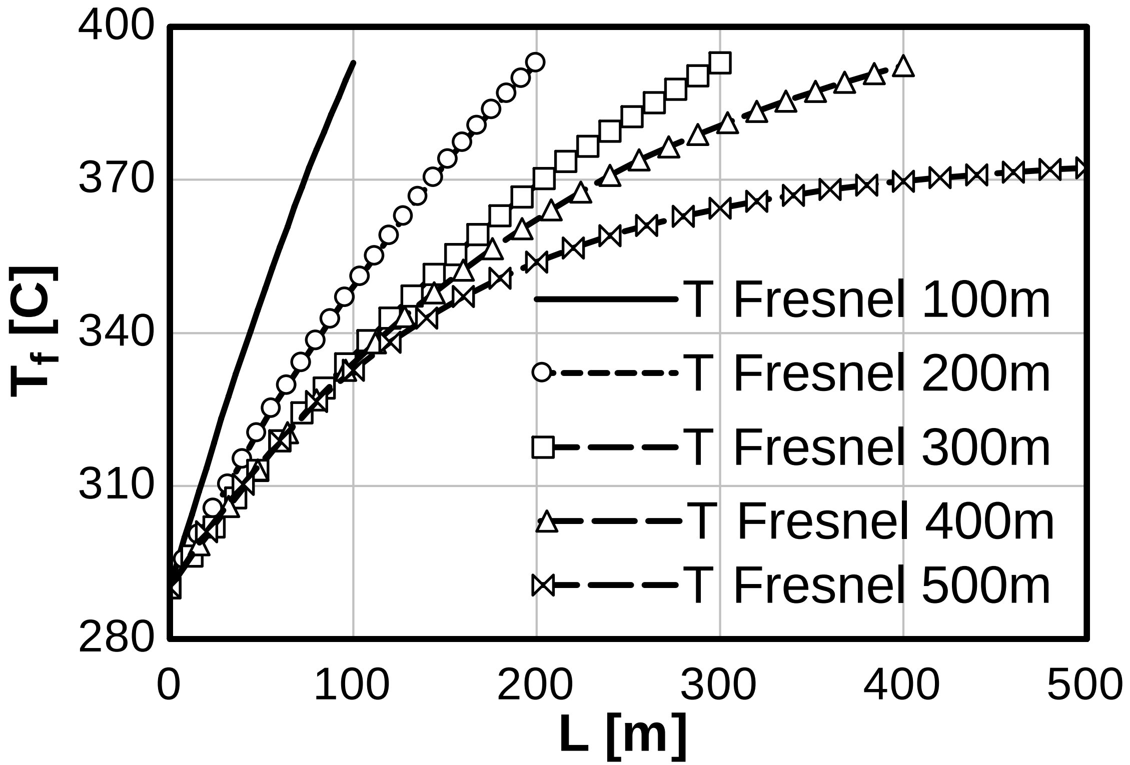
2. Receptor: Multitubo

Tube-bundle receiver capturing beam



Linear receiver thermal performance



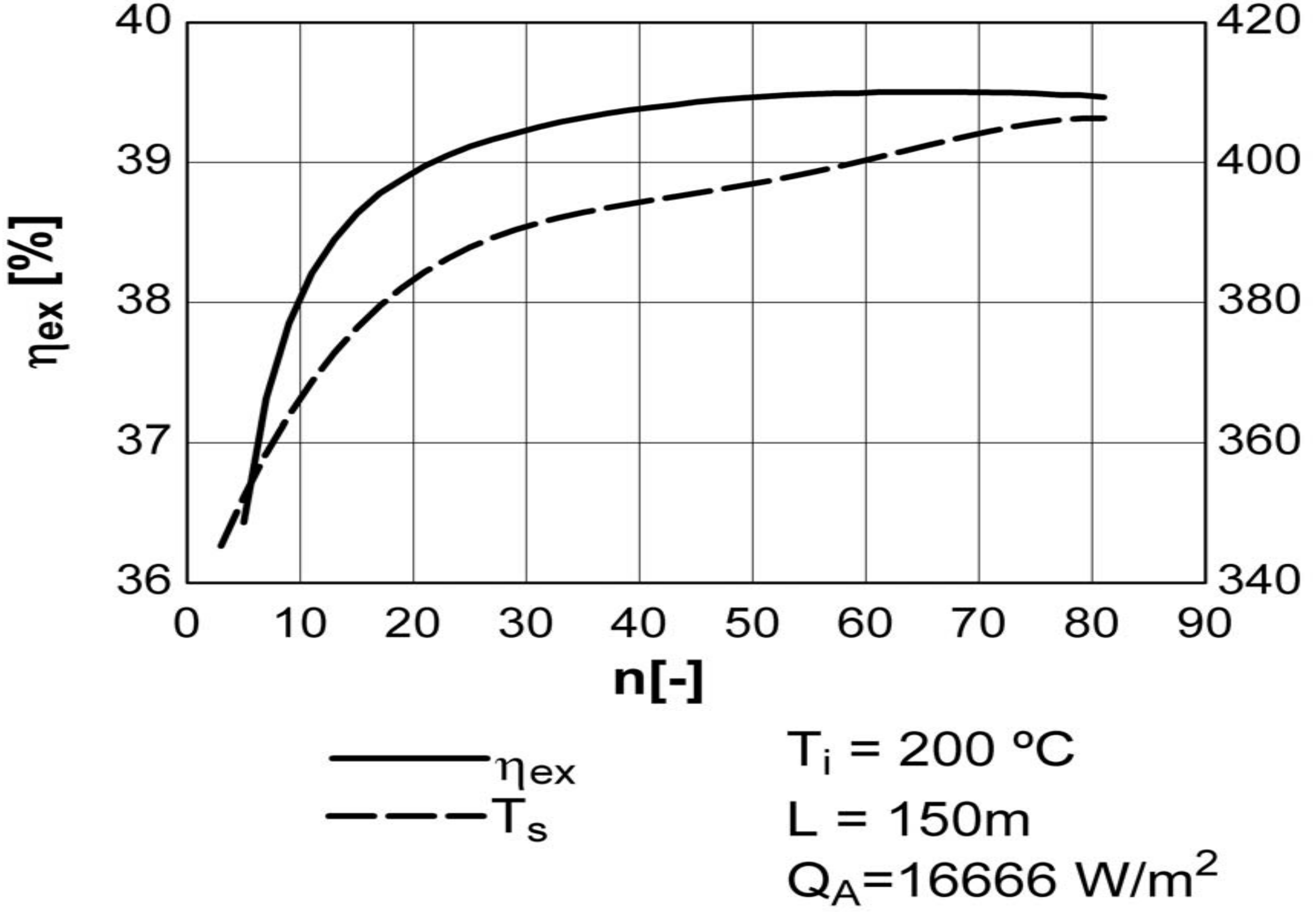
Efficiency

70 %
55 %
40%
22%
9%

Evolution of the fluid temperature (Therminol VP1) along the collector length for a set of linear collectors receiving the same total power, with different radiation intensities and lengths. Intensity goes from 5 to 25 kW/m², corresponding to lengths varying from 500 m from the former to 100 m for the latter

Maximum exergetic efficiency

An example: receiver Width= 50 cm. Fluid : Therminol VP1



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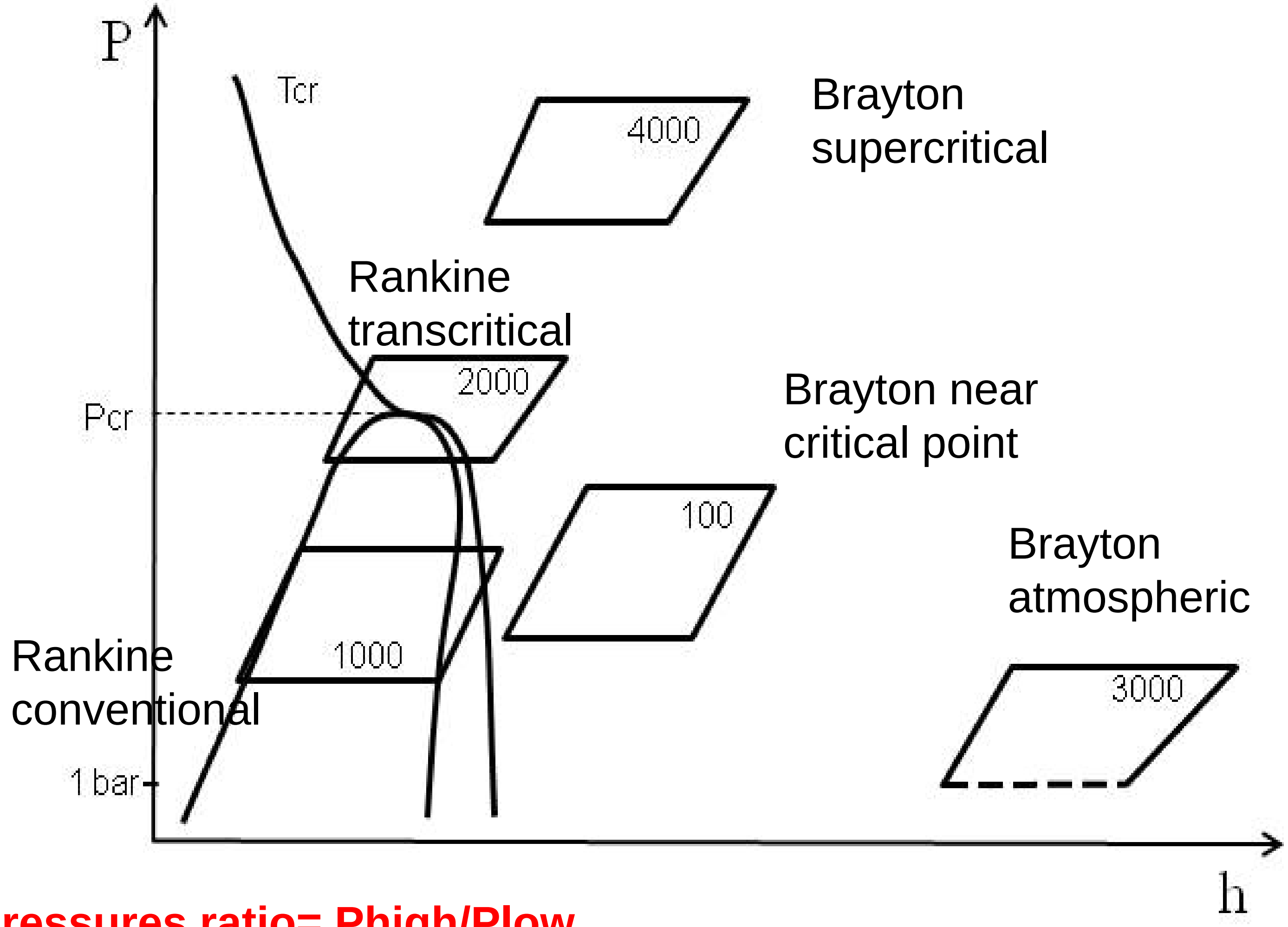
3. Ciclo de potencia: Brayton – Joule

Families of cycles



Brayton supercritical

Rankine transcritical

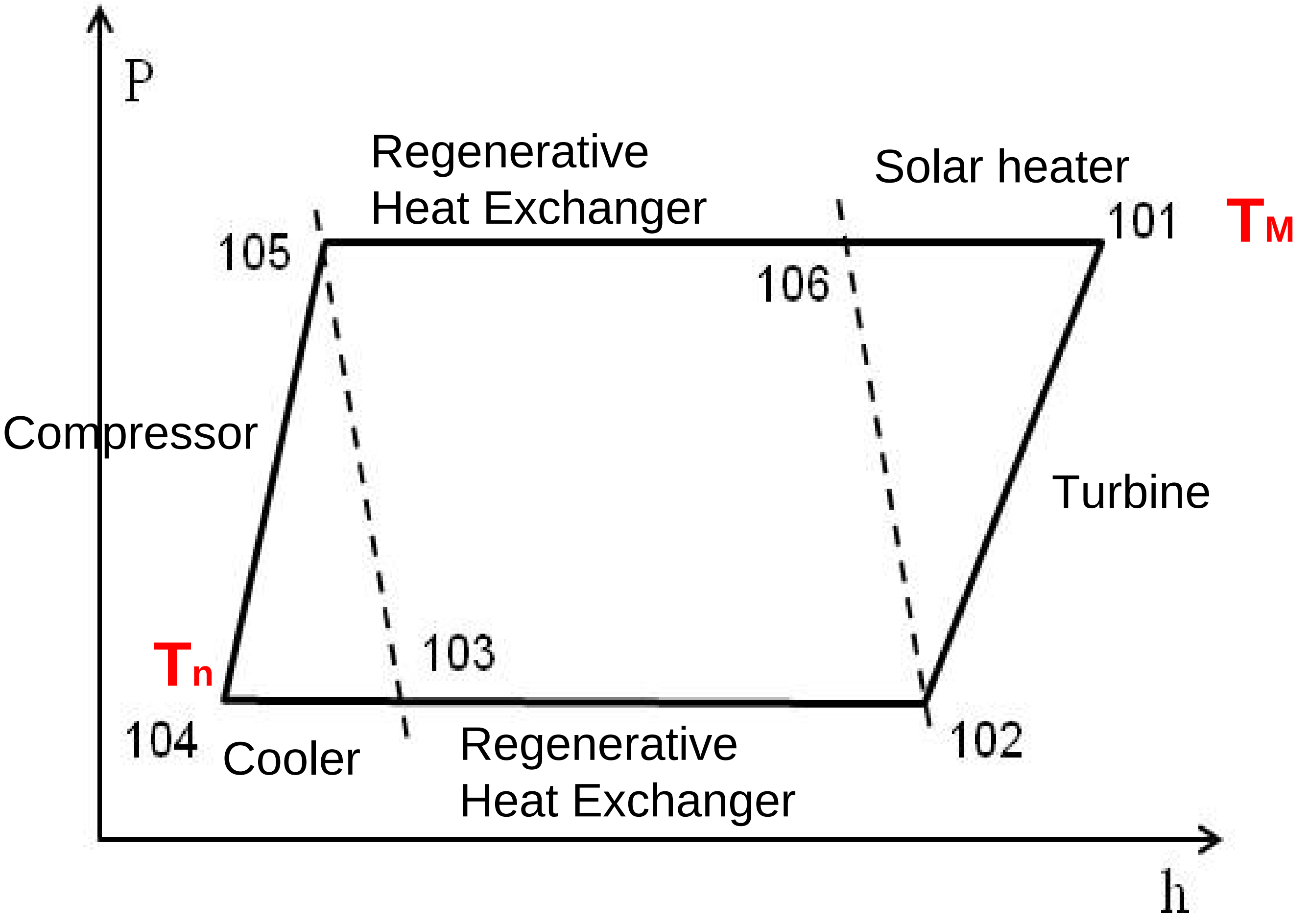
Brayton near critical point

Brayton atmospheric

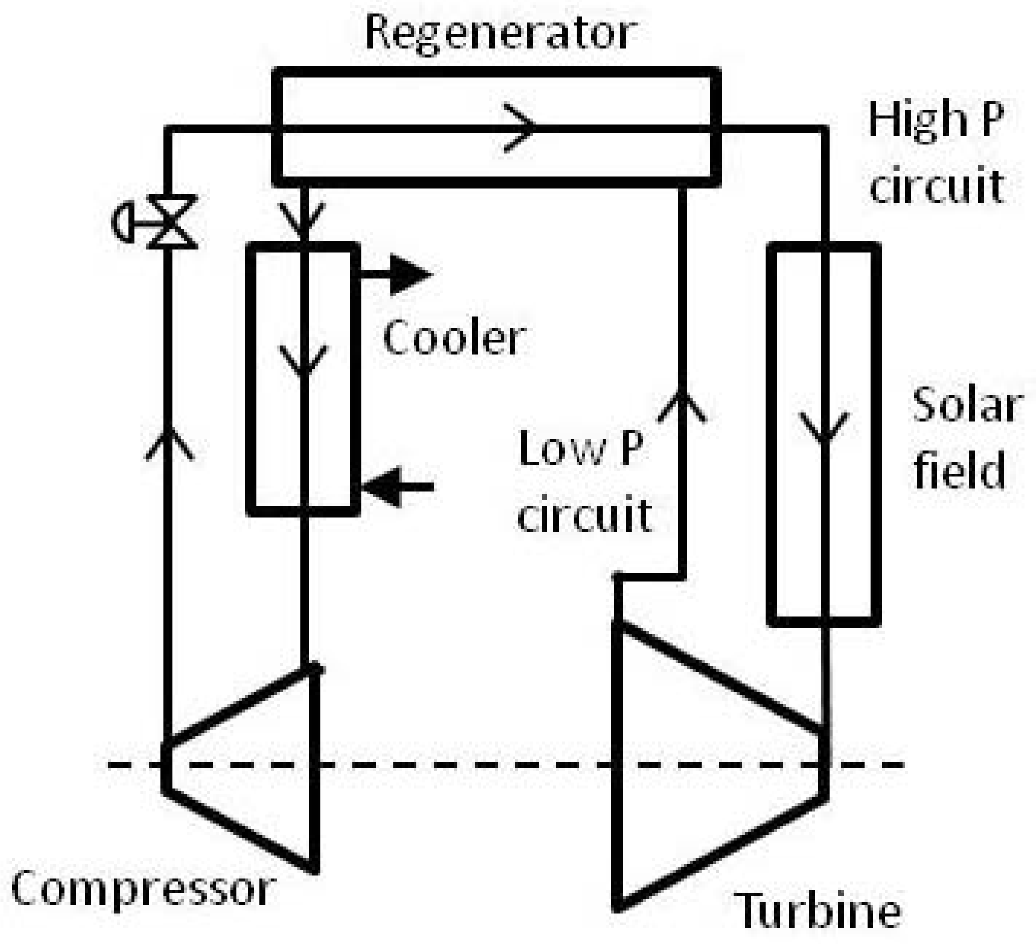
Rankine conventional

c = pressures ratio= Phigh/Plow

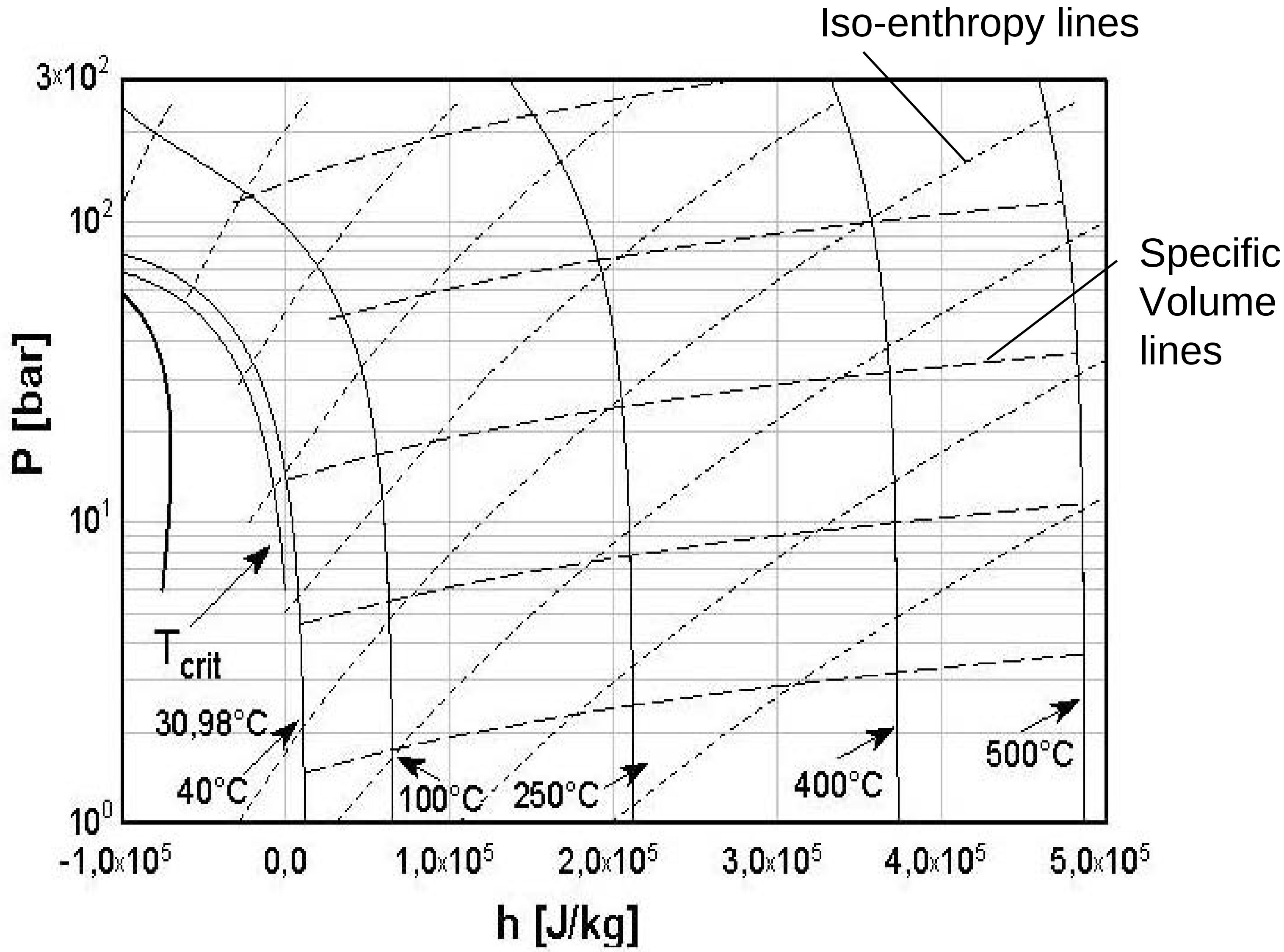
Regenerative Brayton cycle



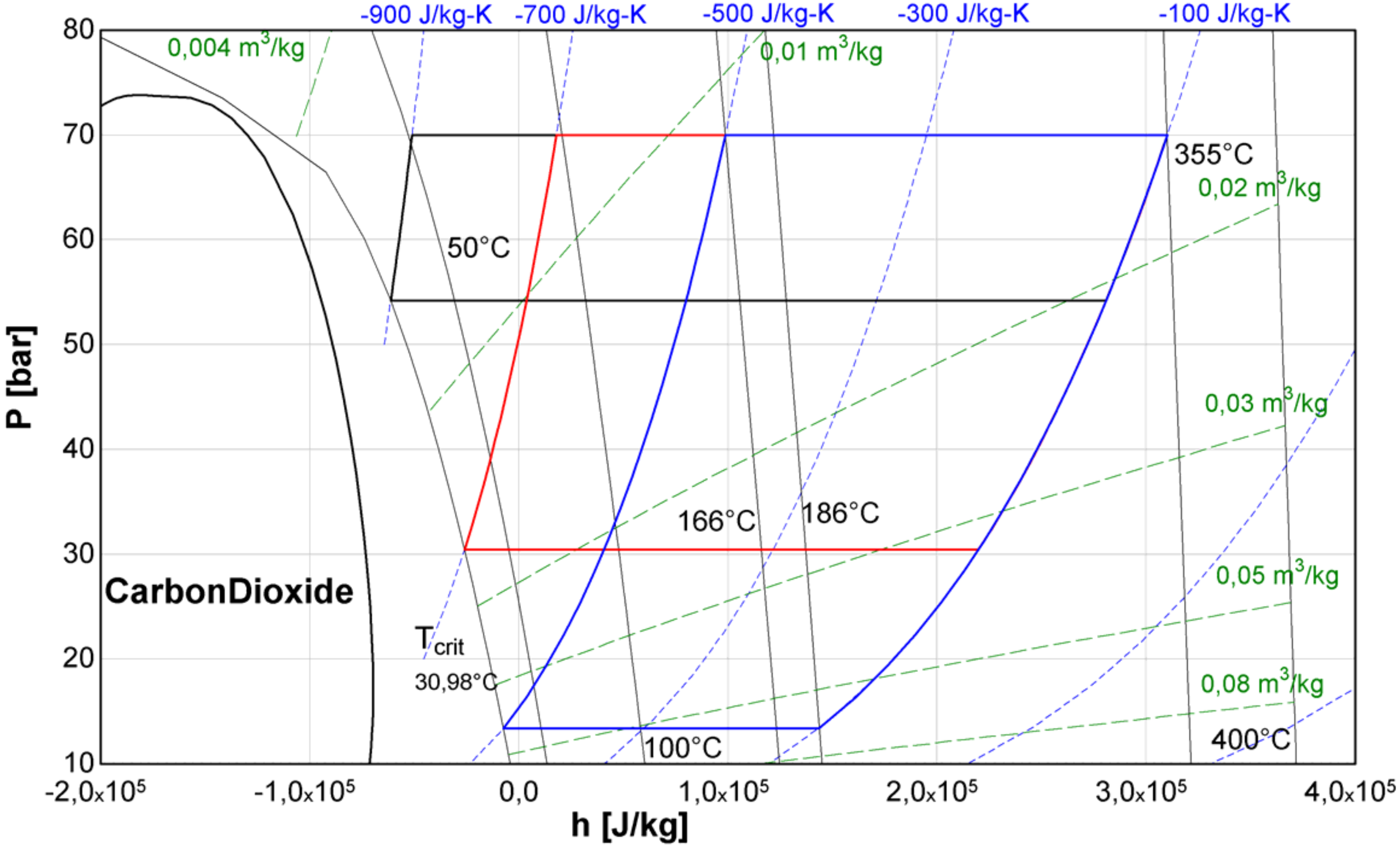
Brayton integrated in a CO2 solar plant



Close-to-critical point CO2

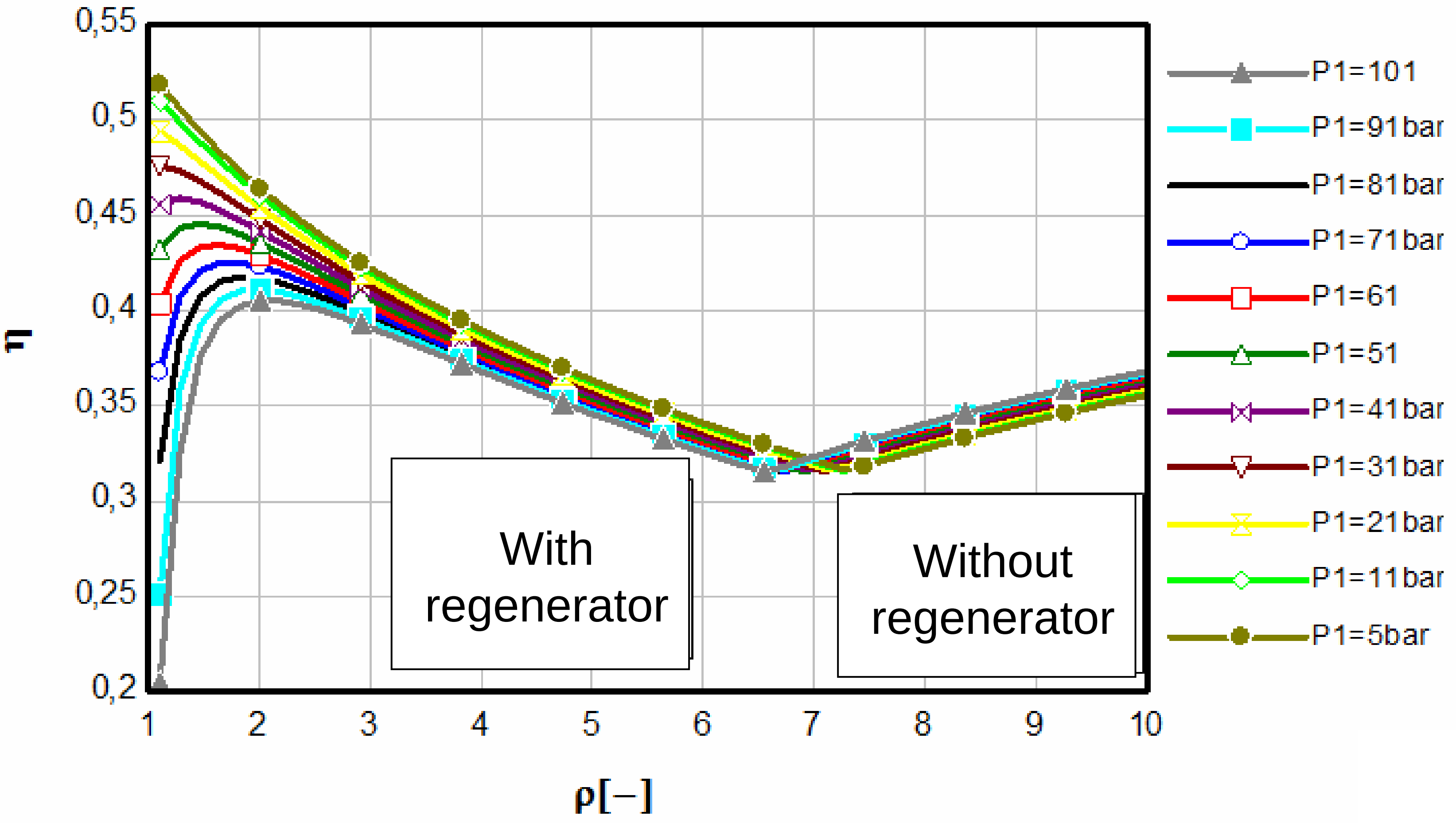


Close-to-critical regenerative Brayton



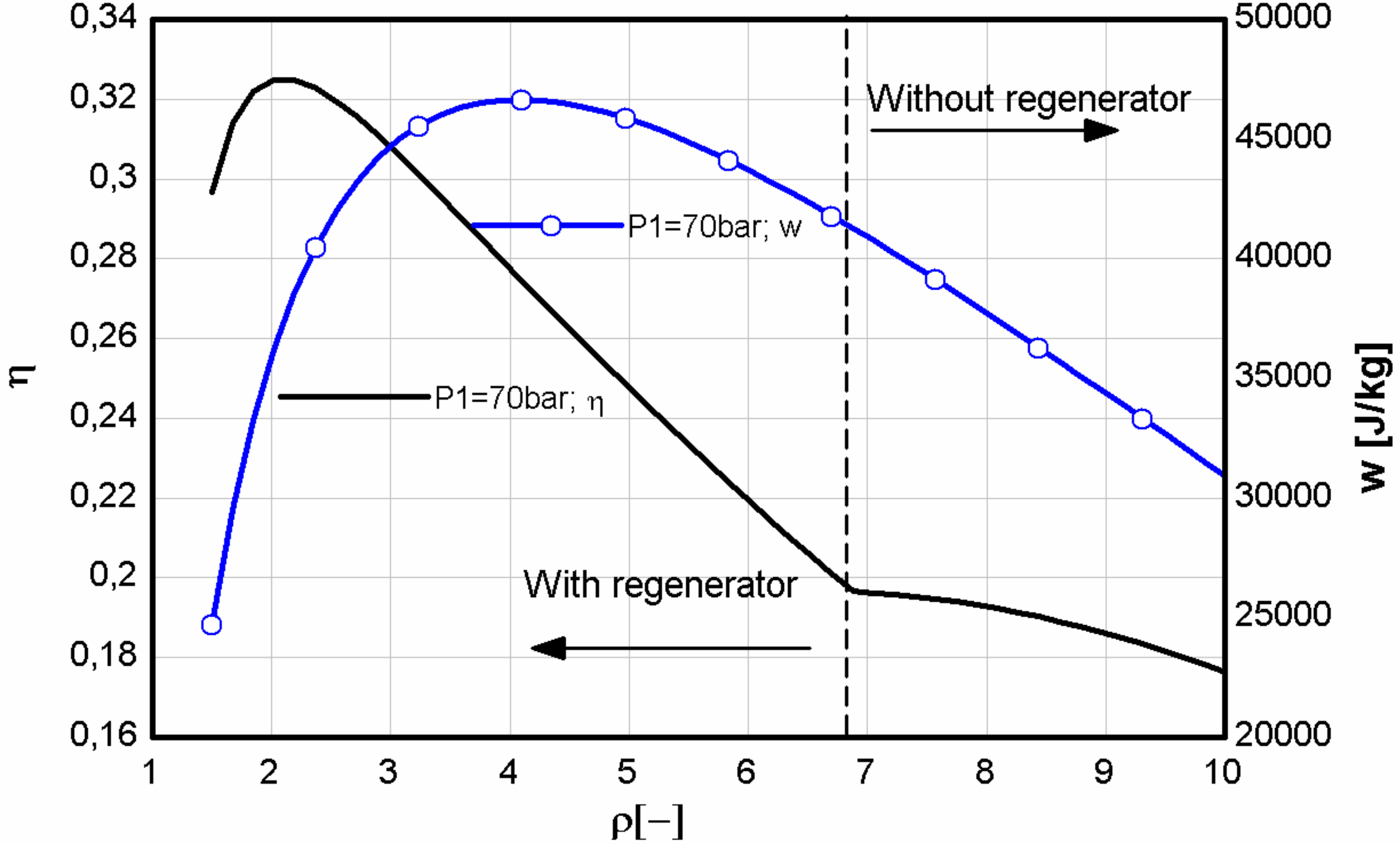
A new design window for linear receivers

- Coupling the heat carrier fluid from the receiver to a new family of Brayton cycles. The case for CO2



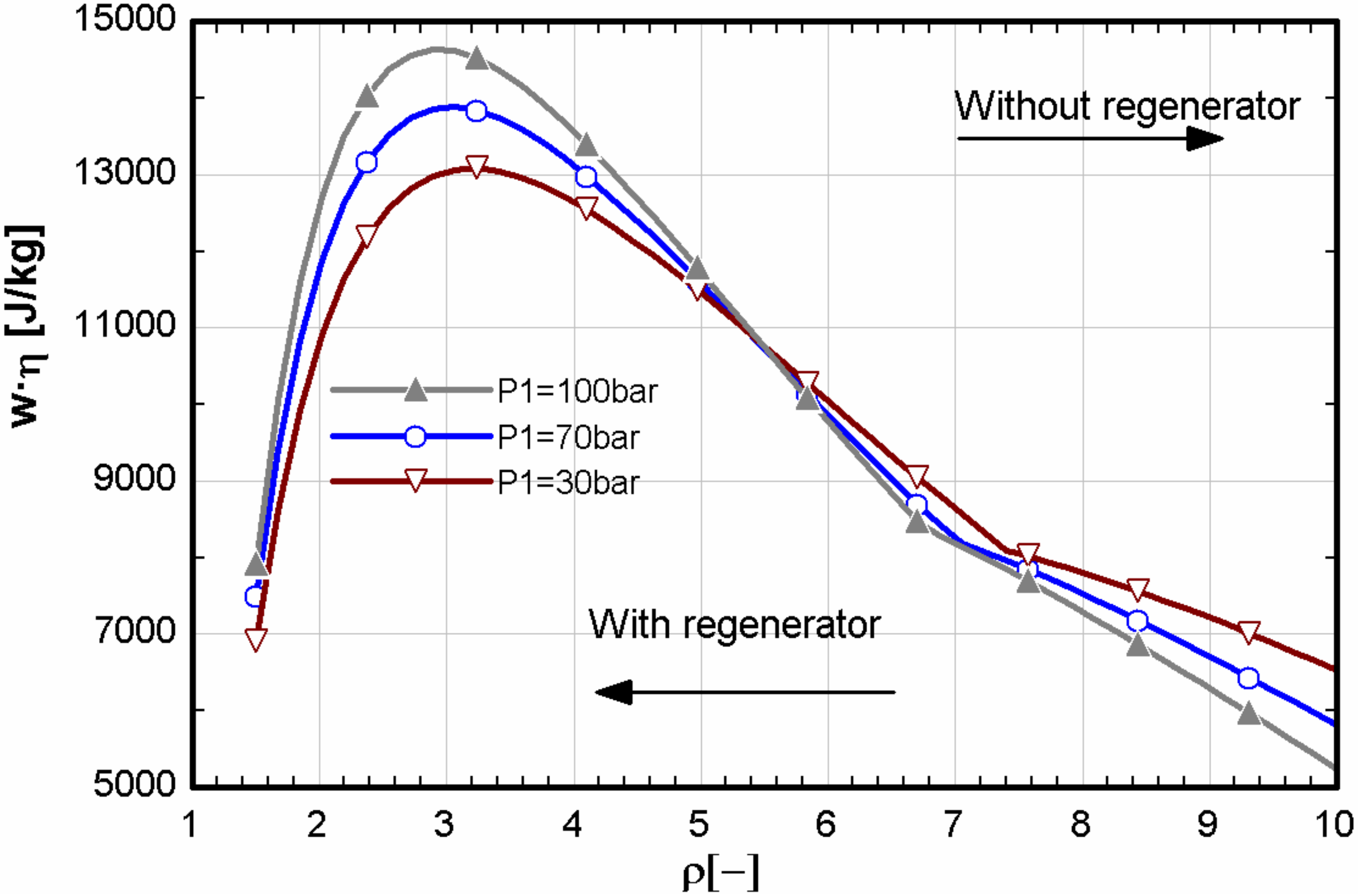
Real turbomachinery

- Maximum specific work (w) is near to the maximum cycle efficiency (η) than in the case of real turbomachinery



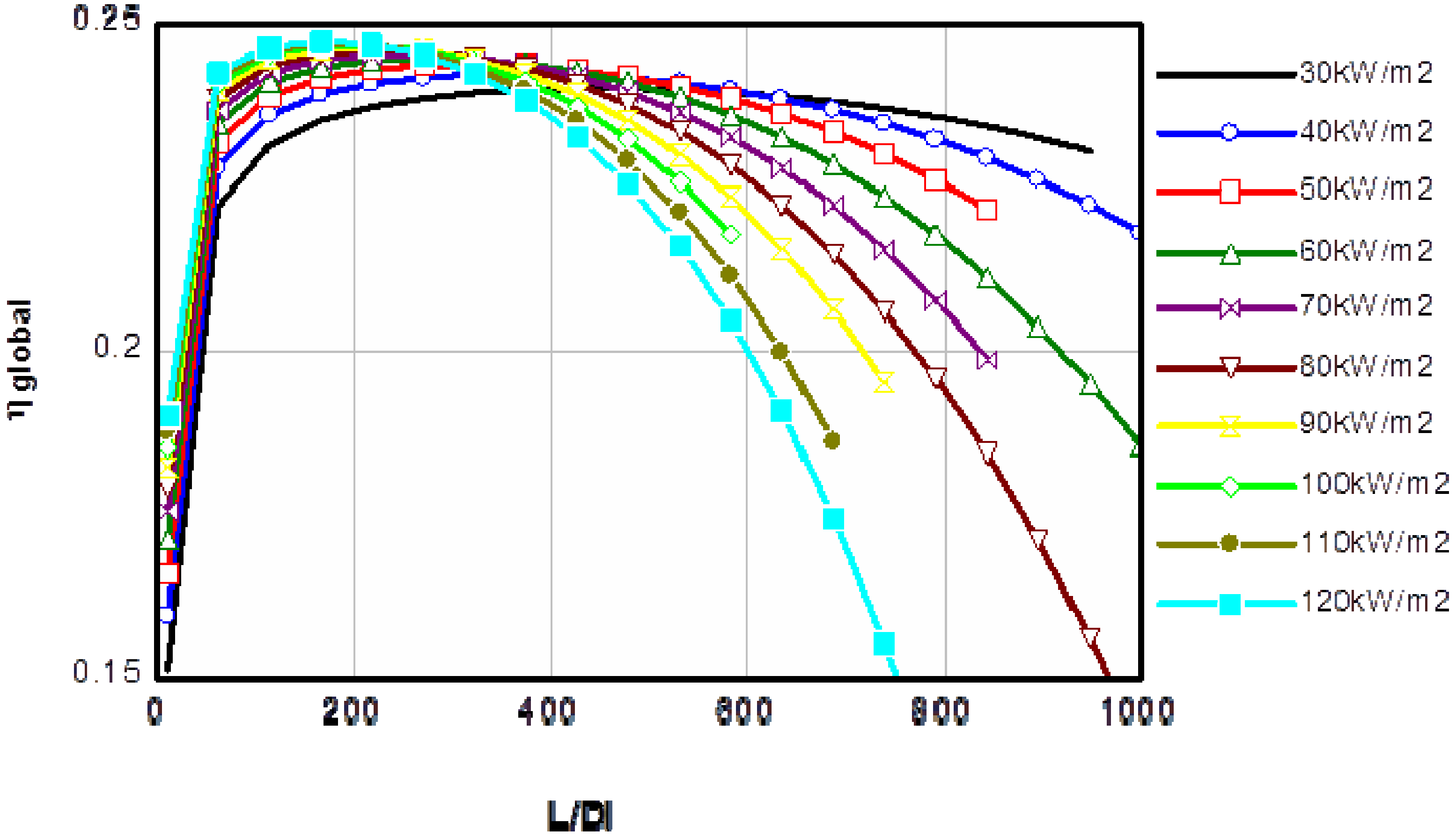
Real turbomachinery: w·η Vs. ρ

- Cycle efficiency (ρ) and specific work (w) product shows an adequate tendency to a preliminary design:



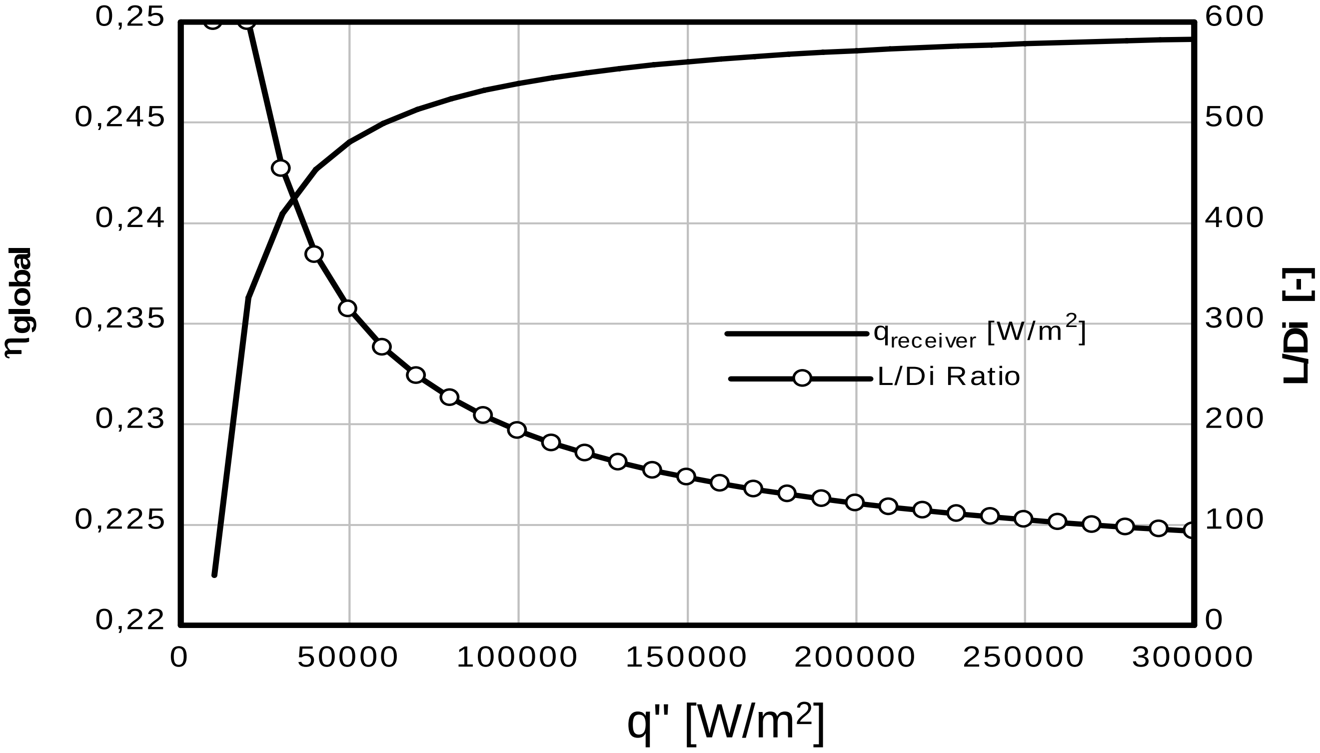
Acoplamiento receptor lineal y ciclo Brayton

- Rendimiento del conjunto 'receptor+ciclo de potencia' con CO2:
  - Entrada turbina 355ºC/70bar; Salida 45ºC/30bar



Acoplamiento receptor lineal y ciclo Brayton

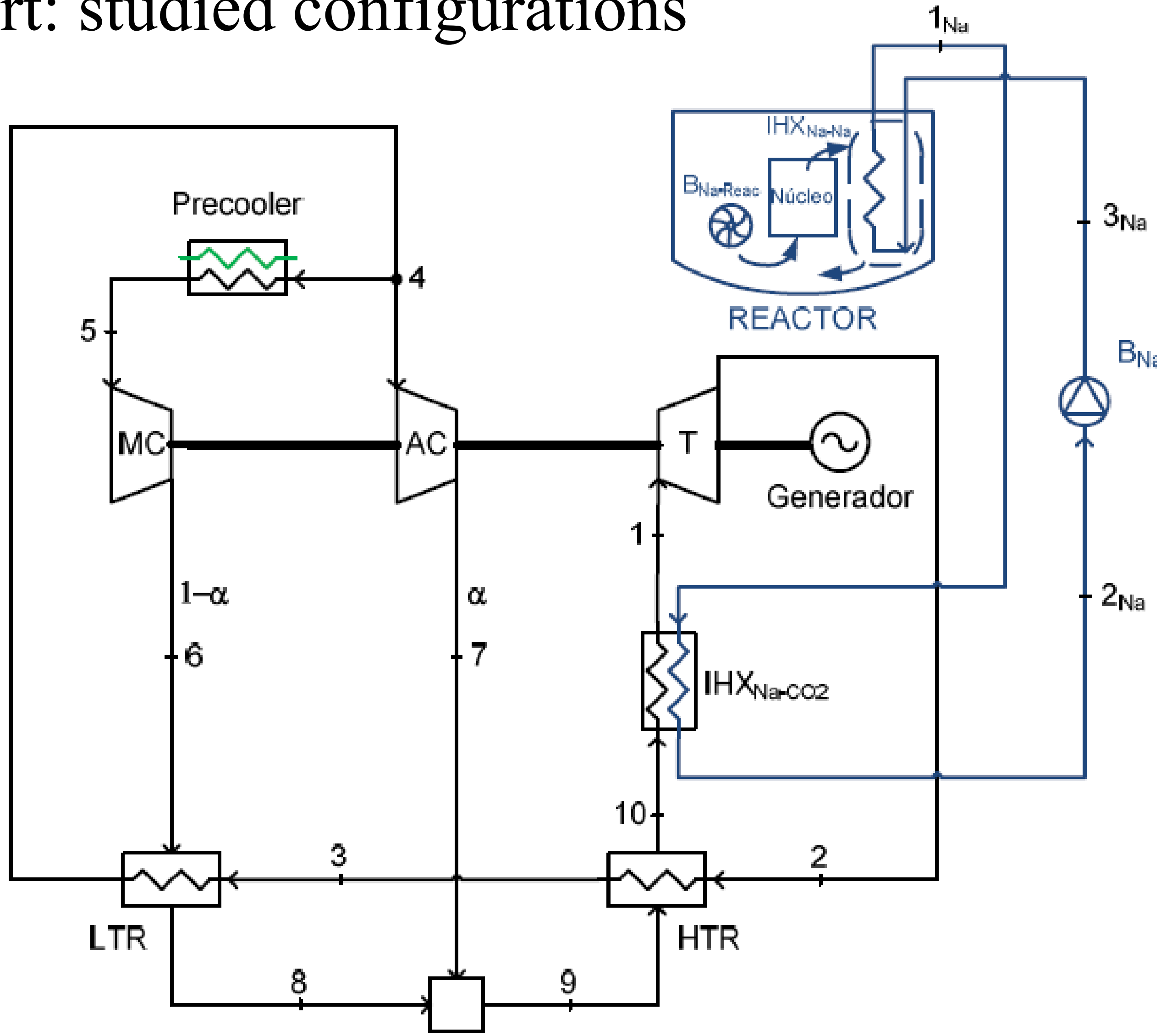
- Receiver Width= 50 cm. Fluid : Carbon Dioxide



Joule-Brayton full supercritical

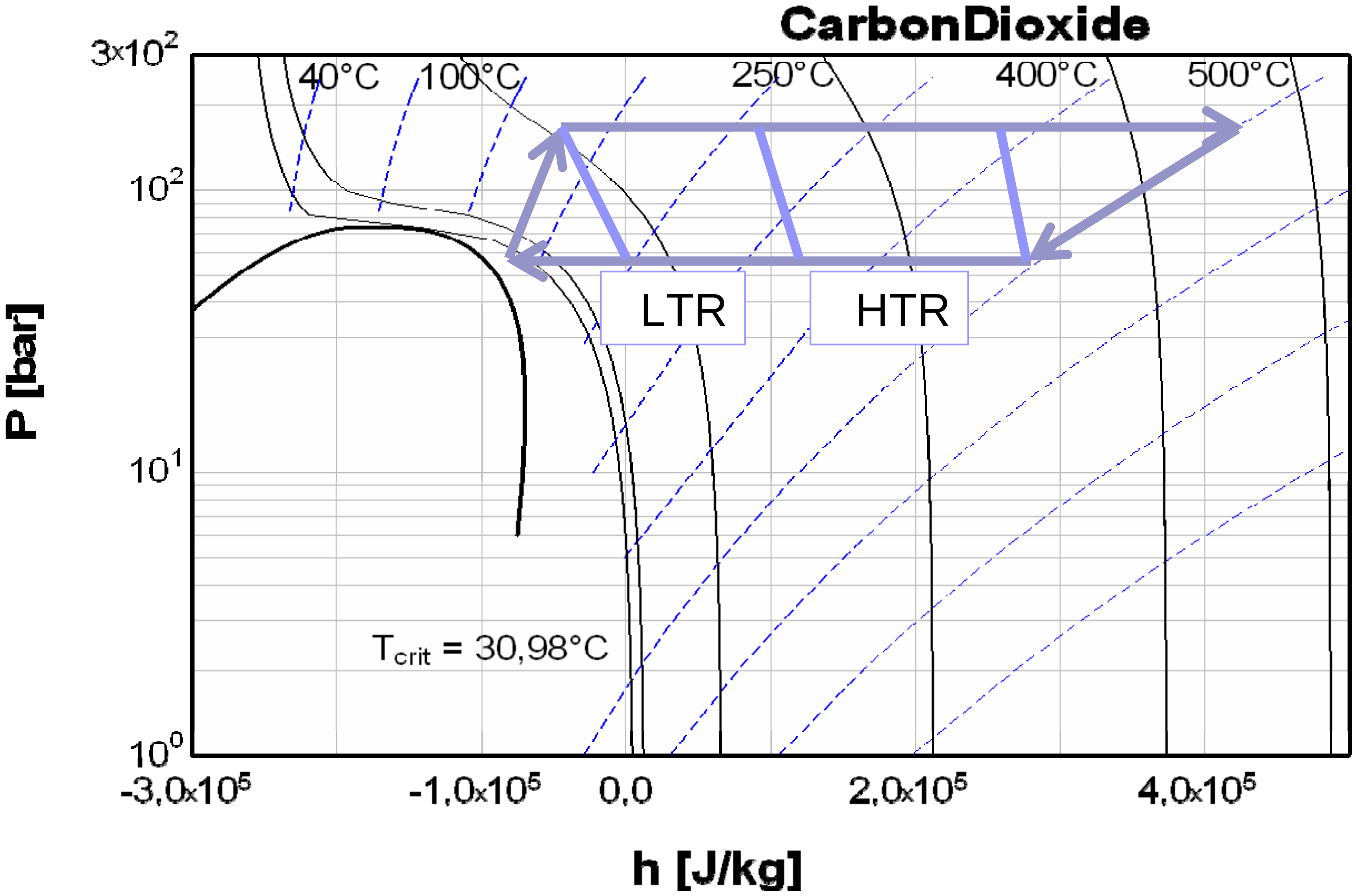
- State-of-the-art: studied configurations

Example: two regenerators cycle with CO2 for nuclear power plants



Joule-Brayton full supercritical

- Example: two regenerators cycle



Comparison

Cycle type	Peri-critical	Supercritical with one regenerator
Turbine intlet T (ºC)	500	500
Turbine inlet P (bar)	100	250
Tubine outlet P (bar)	50	75
Pressure ratio	2	3,32
Coldest cycle T (ºC)	35	35
Cycle efficiency (%)	**37**	**39**
Orientative conditions	For solar thermal power plants	For nuclear power plants

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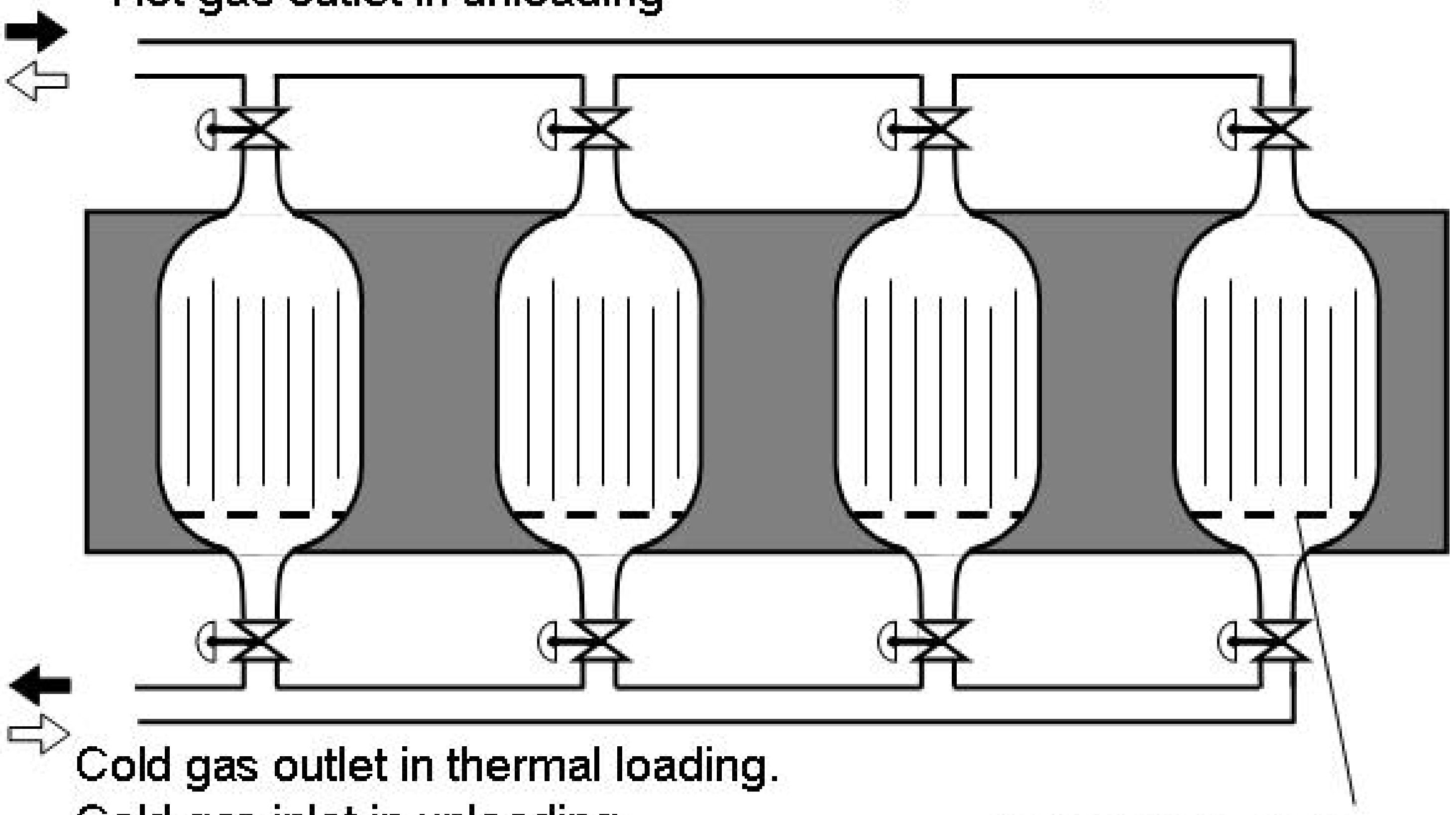
4. Almacenamiento

The challenge of energy storage

- Imagine an energy storage for wind energy based on pumping/turbining water: 1 MWh
- Assume a 100 m tower with a reservoir on top
- 1 MWh = 3.6e09 J = m(kg)·9.8·100 > m=3.6e06 kg = 3,600 m3 = 30m·30m·4m
- The same gross energy by heating water 50ºC
- 3.6e09 J= m(kg)·4.16e03(J/kg.K)·50(K) = m·2.1e05 > m=17,300 kg = 17,3 m3
- A factor of 200 ! (with efficiencies > 100 !)

Tanques de lecho fluido con elevado ratio superficie/masa



Hot gas inlet in thermal loading.
Hot gas outlet in unloading

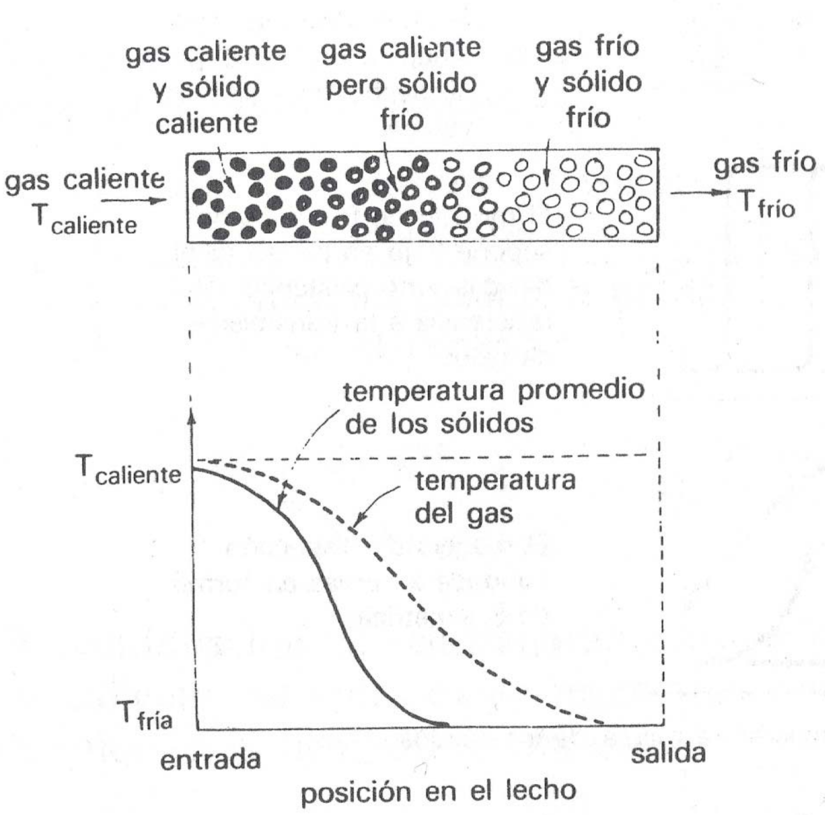
Pebble bed tanks
(insulated)

Cold gas outlet in thermal loading.
Cold gas inlet in unloading

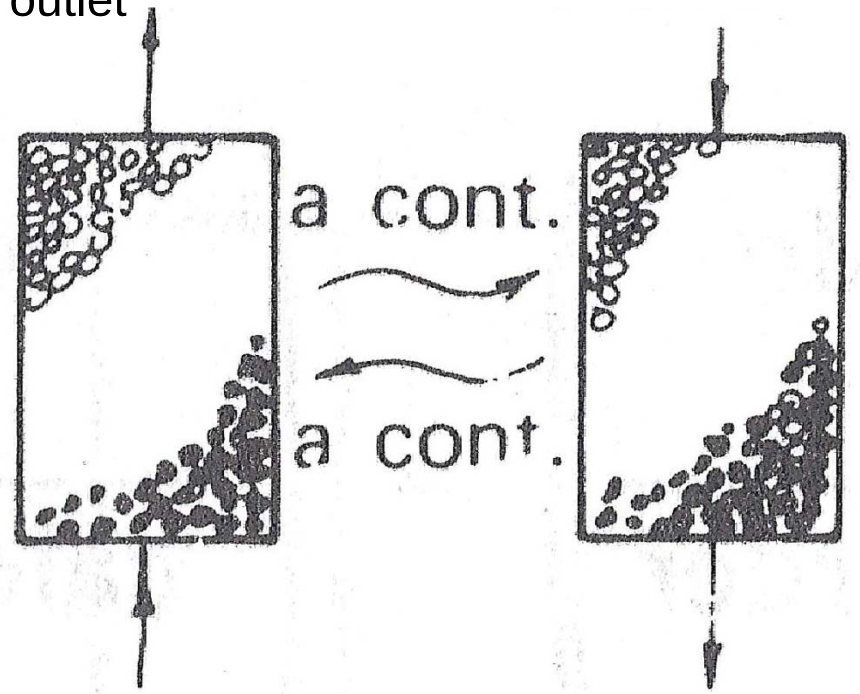
Supporting truss

Sequential operation of tanks

Elongated pebble bed



Conventional system in classical industries



Heated-up gas outlet

Hot gas inlet

Cold gas inlet

Cooled gas outlet

Macro problem of gas-TES

- High pressure is mandatory for reducing pumping power and increasing heat transfer
- As in any storage tank, the product P·V is a lumped parameter of mechanical requirements, agraviated by high T
    - Elongated tanks seem to be the right solution
- Tank thermal insulation likely is the critical point for attaining high storage efficiency.
- Regenerative Brayton cycles can be tuned to lower max T and P, keeping good features

Gracias por su atención