

# Compact Solar Receivers: Emerging Opportunities for Industrial Heat Processes

M.J. Montes, J.I. Linares, J.R. Pérez-Domínguez,  
D. D'Souza, M. Ibarra, and L. Valenzuela

María José Montes: [mjmontes@ind.uned.es](mailto:mjmontes@ind.uned.es)  
Energy Department  
National University of Distance Education (UNED)



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## ➤ Solar Heat for Industrial Processes (SHIP)

- ✓ **32%** of global energy consumption is used in industry.
- ✓ **74%** of industry energy consumption is thermal energy.

INDUSTRY	150 °C		TEMPERATURE RANGE
	LOW TEMPERATURE (T < 150 °C)	MEDIUM TEMPERATURE (150 °C < T < 400 °C)	
CHEMICAL	- Boiling	- Distilling	
FOOD & BEVERAGE	- Boiling - Pasteurising	- Drying - Sterilising	
MACHINERY	- Cleaning	- Drying	
MINERY	- Copper electrolytic refining - Mineral drying processes	- Nitrate melting	
TEXTILE	- Washing	- Bleaching - Dyeing	
WOOD	- Steaming - Cooking	- Compression - Pickling	

SOLAR COLLECTOR	100 °C	200 °C	300 °C	400 °C
	STATIONARY (T < 150 °C)		TRACKING (150 °C < T < 400 °C)	
	Flat plate (T < 100 °C)	PTC / CLF non-evacuated receiver (100 °C < T < 250 °C)		
	Vacuum tube (T < 120 °C)	PTC / CLF evacuated receiver (250 °C < T < 400 °C)		
	Vacuum tube CPC (T < 150 °C)			



Flat plate



Vacuum tube



Vacuum tube CPC

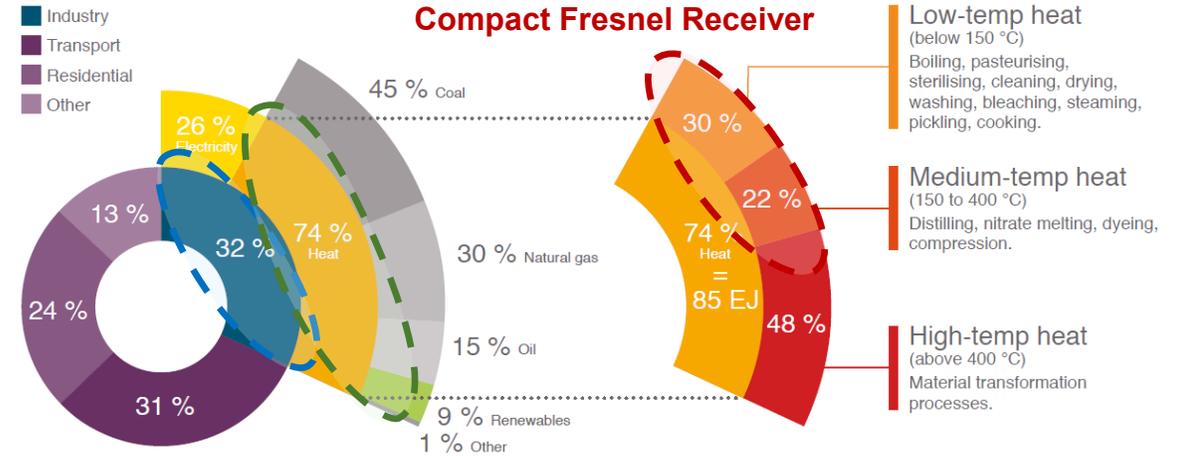


Parabolic Trough Collector (PTC)



Linear Fresnel Collector (LFC)

## ENORMOUS GLOBAL HEAT DEMAND IN INDUSTRY



TOTAL FINAL ENERGY CONSUMPTION 2014: 360 EJ (EXAJOULE, see Glossary page 17); IEA [1]

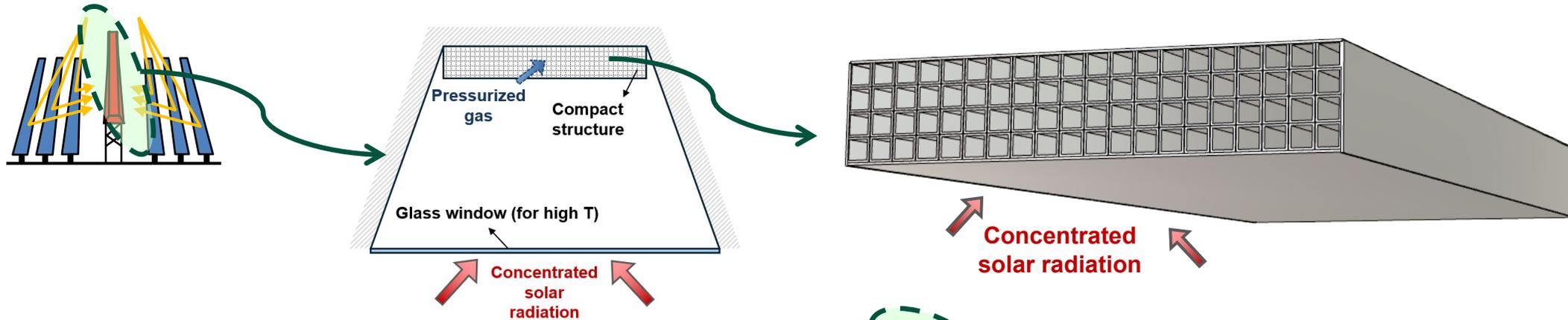
IRENA [2]

Source: *Solar Payback, Solar Heat for Industry – Solar Payback, 2017*

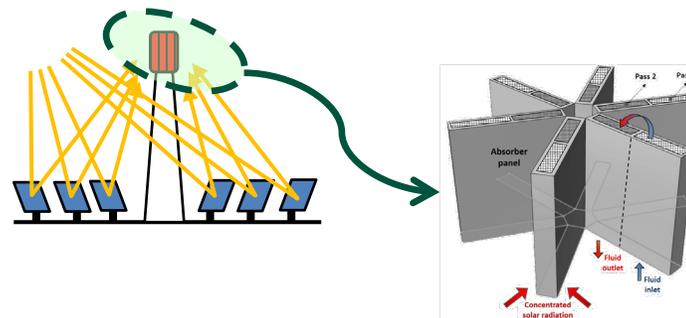
## Compact Fresnel Receiver

- ✓ **30%** of heat consumption occurs at temperatures below 150 °C, **22%** at intermediate temperatures between 150 °C and 400 °C, and **48%** at high temperatures above 400 °C.

## ➤ Compact solar receiver for linear Fresnel collector



➤ Concept already explored for central solar receivers (microchannel radial solar receiver, SolarPACES 2024)



➤ **Key advantage:** using high-conductivity materials at low- and medium-temperature, the compact structure performs as a **heat sink**.

### Materials:

- LFR: CuCrZr alloy (C18150)  $\Rightarrow$  Thermal conductivity  $k = 340 \text{ W/m}^\circ\text{C}$
- Central receiver: Inconel 617  $\Rightarrow$  Thermal conductivity  $k = 22.5 \text{ W/m}^\circ\text{C}$

## ➤ Why use pressurised gas?

Working temperature	Heat Transfer Fluid	Advantages	Disadvantages
T < 400 °C	Synthetic Thermal Oil	<ul style="list-style-type: none"> <li>Proven technology for linear collectors.</li> <li>Non-critical freezing risk</li> <li>Good heat transfer efficiency</li> <li>Good control and operational flexibility</li> </ul>	<ul style="list-style-type: none"> <li>Flammability and potential toxicity risks</li> <li>Direct thermal storage capacity is limited by the above risks; indirect thermal storage is possible as an alternative (at higher cost)</li> <li>Thermal degradation at high temperature (390-400°C)</li> <li>Relatively high cost</li> </ul>
	Water-steam	<ul style="list-style-type: none"> <li>Proven technology for point-focus and linear collectors.</li> <li>Easy coupling with most industrial processes (direct steam generation)</li> <li>Good heat transfer efficiency</li> <li>Low cost and widely available</li> </ul>	<ul style="list-style-type: none"> <li>Complex control (phase change)</li> <li>Direct thermal storage capacity is limited by heat capacity</li> <li>Freezing risks at 0 °C</li> </ul>
	Pressurised gas	<ul style="list-style-type: none"> <li>Fluid stability over a wide temperature range</li> <li>Non-corrosive and non-toxic</li> <li>Good control and operational flexibility</li> <li>Low cost and widely available</li> </ul>	<ul style="list-style-type: none"> <li>Unproven technology, not commercially available</li> <li>Difficult to implement a cost-effective direct thermal storage</li> <li>Low heat transfer efficiency</li> <li>High compression work required because of pressure loss and low density</li> </ul>

O&M and control

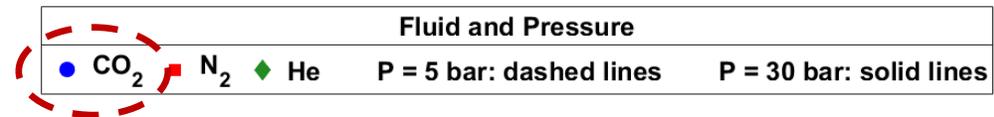
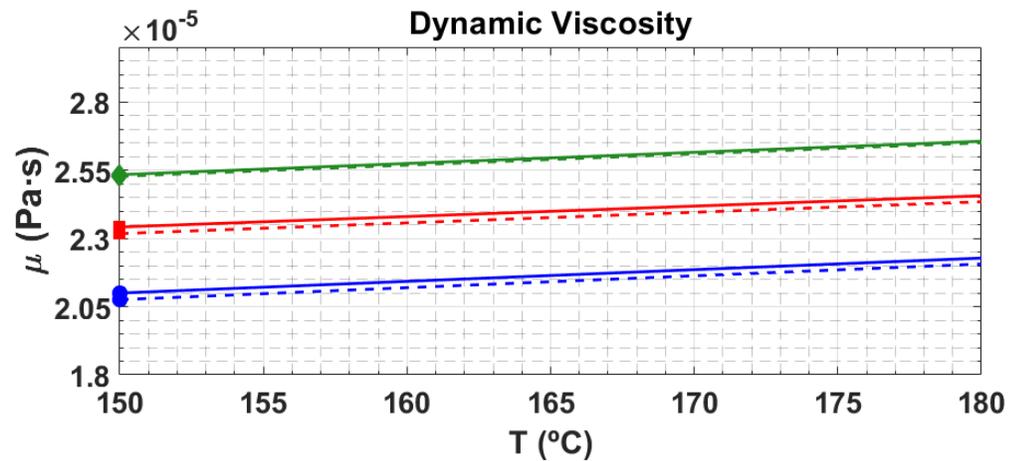
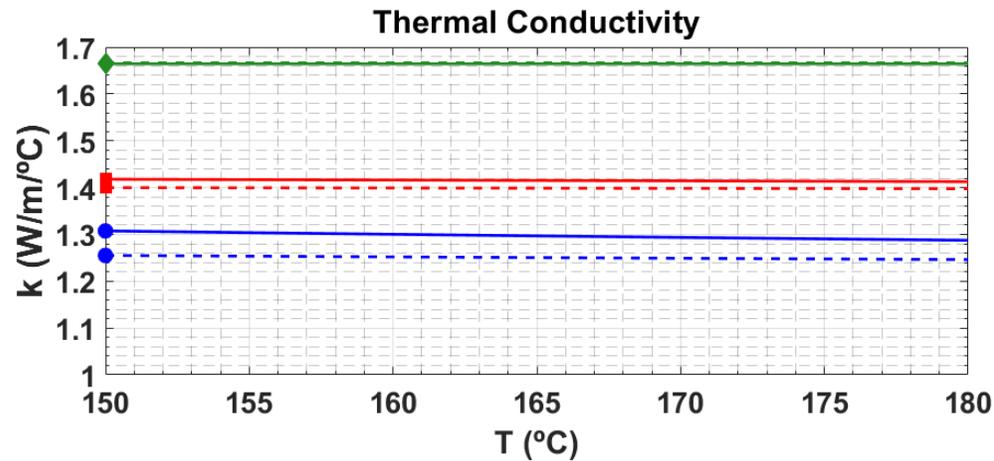
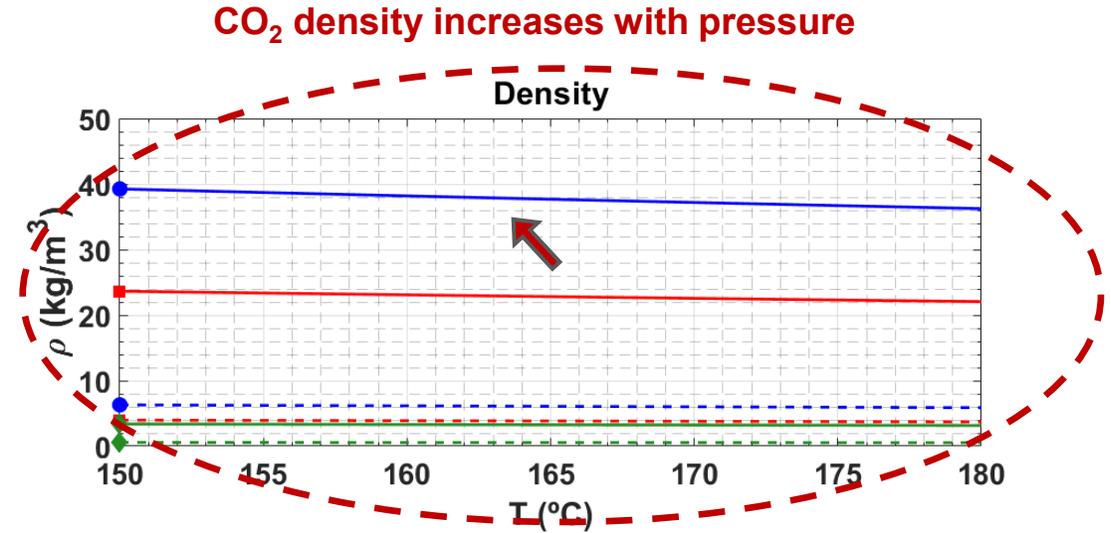
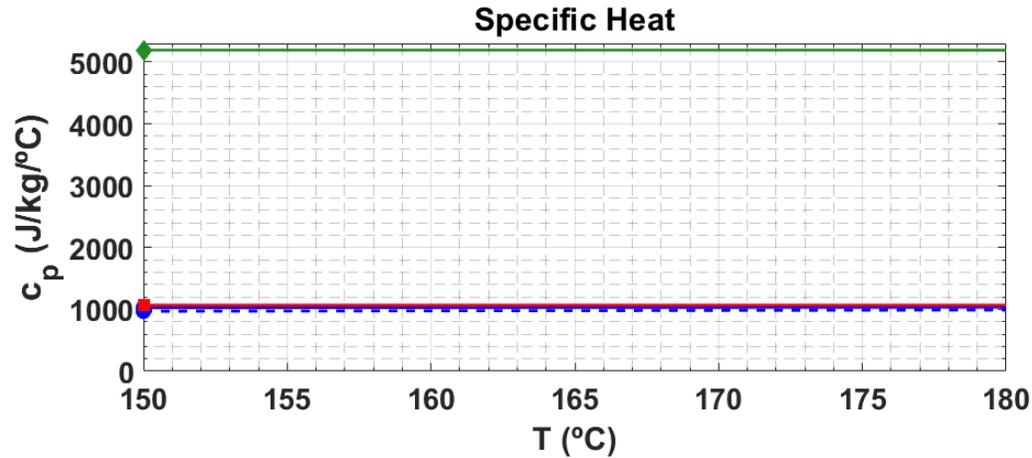
Heat transfer and pressure loss

## How to overcome challenges in pressurised gas

- ✓ Since it is a closed circuit, gases **other than air can be used: CO<sub>2</sub>, N<sub>2</sub>, He**, which may have more suitable thermophysical properties (high density at high pressure).
- ✓ Pressurised gases are particularly suitable for **compact structures**: compact receivers that enable smaller solar fields and reduced exposed areas (hence lower heat loss).
- ✓ A novel direct thermal storage system has been developed and is to be patented.

# Proposal of a novel compact solar receiver

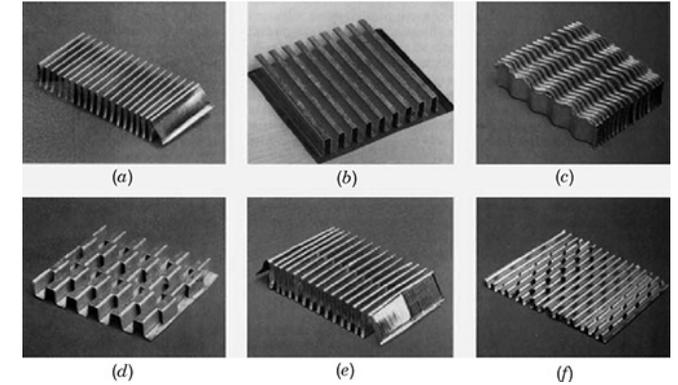
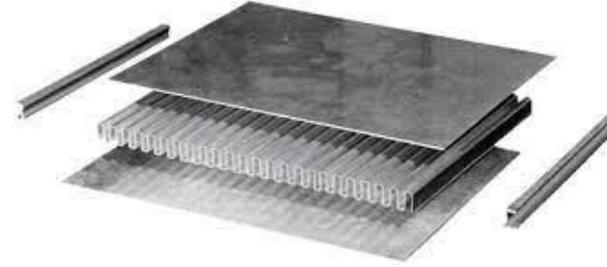
## ➤ Why use pressurised gas?



# Proposal of a novel compact solar receiver

## ➤ Why using compact geometries?

➤ **Robust technology:** Compact Heat Exchanger (CHX)



➤ **Compact solar receivers**

➤ **Smaller** primary mirror fields for the same required thermal power

➤ **Lower investment costs.**

➤ **Compact solar receivers**

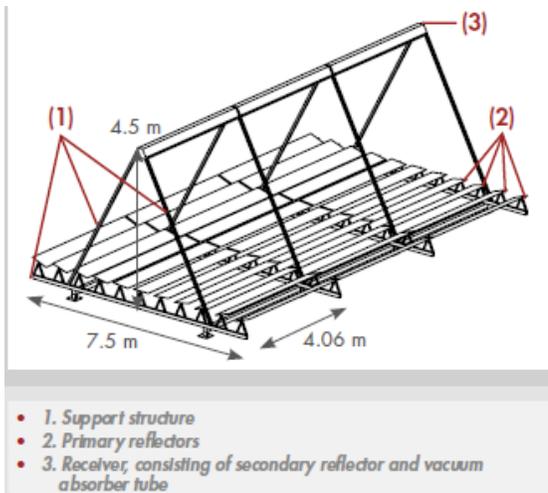
➤ **Reduced absorber area**

➤ **Lower heat loss** from the receiver to the ambient.

➤ Improved convective heat transfer coefficient compared to conventional tubes.

## ➤ Case study: assessment of a compact solar receiver integrated into a FLT20 Fresnel collector

- ✓ FLT20 Fresnel collector for solar heat production (SOLATOM company)
  - Simplicity and low investment cost
  - Integration of a **pebble bed thermal storage**



<b>Primary mirror field</b>	
Number of primary mirrors	11
Module width (m)	7.5
Module length (m)	4.06
Mirror width (m)	0.5
Mirror height above ground(m)	0.5
Receiver height above primary mirror surface (m)	4
Mirror reflectivity	0.93
<b>Solar receiver</b>	
Type of solar receiver	SCHOTT PTR 70
Thermal emittance at 380°C	0.09
Solar absorptance	0.95



# Methodology

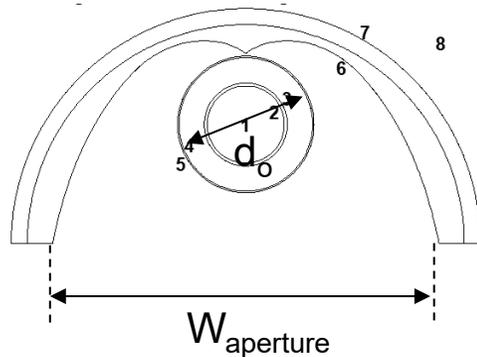
## ➤ Case study: assessment of a compact solar receiver integrated into a FLT20 Fresnel collector

### ✓ Conventional receiver in FLT20 Fresnel collector

- Single tube with a CPC-type secondary reflector.

$$d_0 = 219.9 \text{ mm}$$

$$W_{ap} = 363.1 \text{ mm}$$

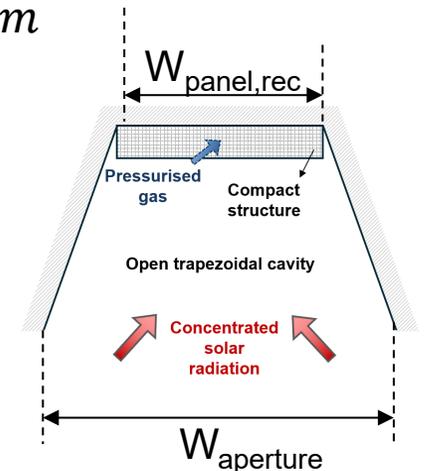


### ✓ Compact solar receiver

- Trapezoidal cavity, no glass window at the aperture.

$$W_{panel,rec} = \pi \cdot d_0 = 219.9 \text{ mm}$$

$$W_{ap} = 363.1 \text{ mm}$$



Data provided by the manufacturer for 1 module performance	
Direct Normal Irradiation (DNI, W/m <sup>2</sup> )	900
Ambient temperature (°C)	30
Module orientation	N-S
Incidence angle modifier (-)	0.979
Optical efficiency (%)	63.2
Inlet fluid temperature (°C)	150
Outlet fluid temperature (°C)	180
Useful Heat Gain (kW <sub>th</sub> )	14.5

Performance framework

Useful Heat Gain

- Pressurised fluid: CO<sub>2</sub>, N<sub>2</sub>, He.
- Fluid inlet pressure: P<sub>in</sub> = 5 - 30 bar
- Channel width (cuadrangular shape): W<sub>ch</sub> = 6 - 16 mm
- Number of rows (solar flux direction): N<sub>rows</sub> = 2 - 3 - 4

## ➤ Some definitions and assumptions

- Receiver integrated in a FLT20 collector:  $A_{abs,rec} = cte$ ,  $\dot{Q}_{in,rec} = cte$ .
  - Fluid inlet pressure:  $P_{in} = 5 - 30$  bar
  - Channel width (cuadrangular shape):  $W_{ch} = 6 - 16$  mm
  - Number of rows (solar flux direction):  $N_{rows} = 2 - 3 - 4$
- $$\left. \begin{array}{l} t_{fin} \text{ (thickness}_{fin}) \text{ \& } t_{plate} \text{ (thickness}_{plate}) = f(P_{fluid}, W_{ch}) \\ R_{eq,total} = f(h_{conv}, W_{ch}, t_{fin}, t_{plate}, N_{rows}) \end{array} \right\}$$

- Energy efficiency:

$$\eta_{en} = \frac{\dot{Q}_{HTF}}{\dot{Q}_{solar, in}} = \frac{\dot{Q}_{solar, in} - \dot{Q}_{loss}}{\dot{Q}_{solar, in}}$$

$\eta_{en}$  accounts for heat loss

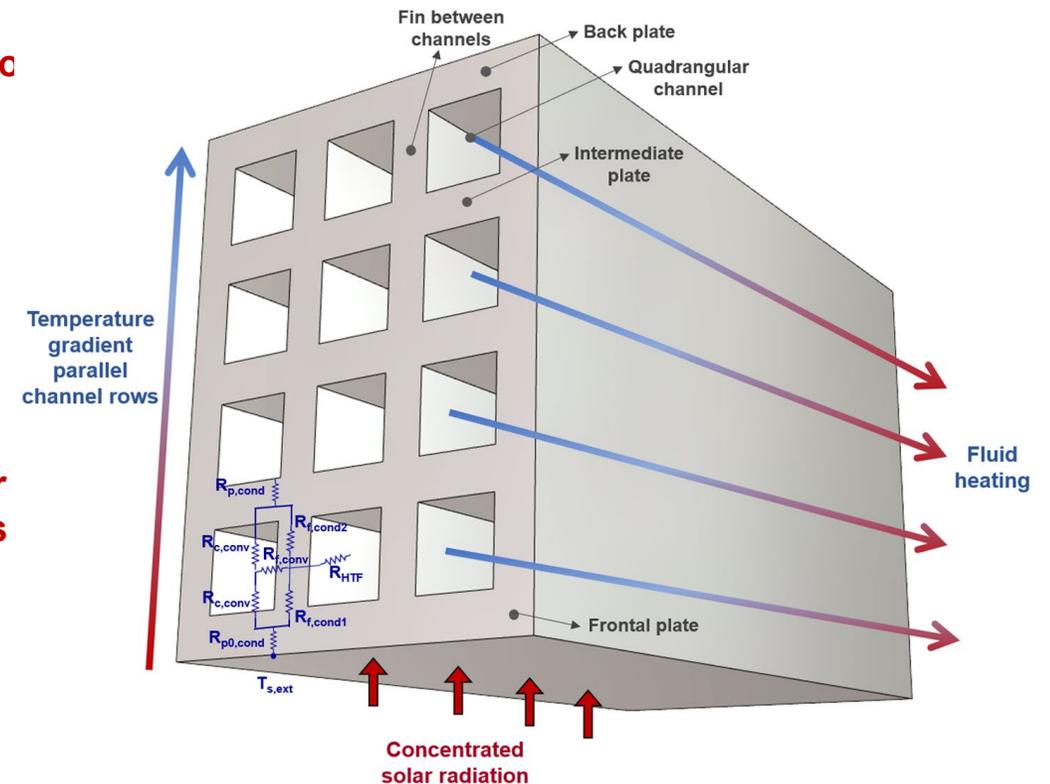
$$\dot{Q}_{loss} = \dot{Q}_{loss,rad} + \dot{Q}_{loss,conv} + \dot{Q}_{loss,ref}$$

- Exergy efficiency

$$\eta_{ex} = \frac{\Delta E x_{HTF}}{E x_{solar, in}}$$

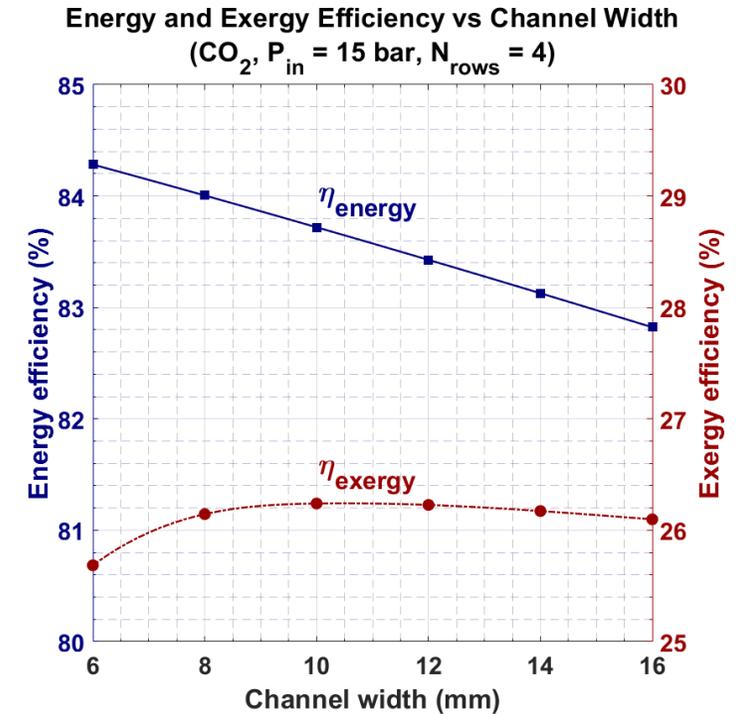
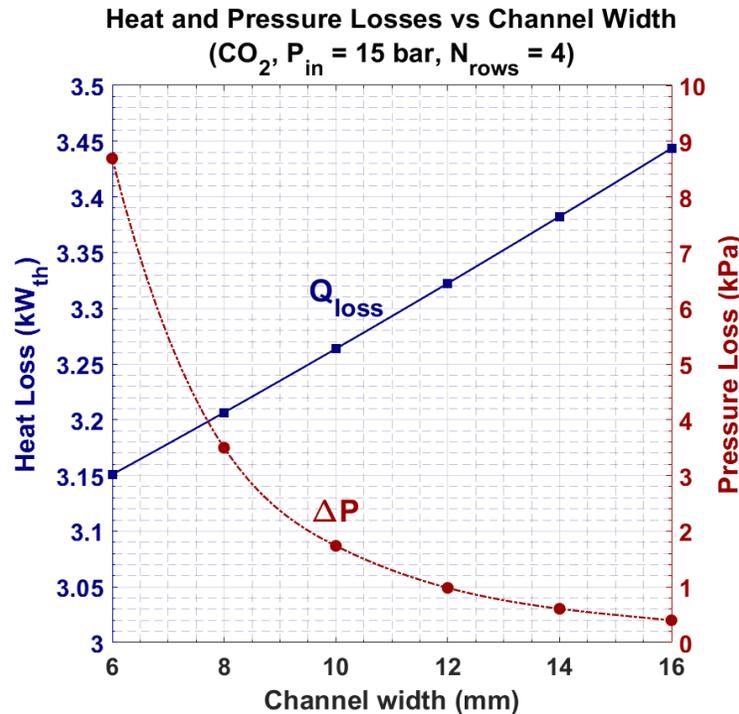
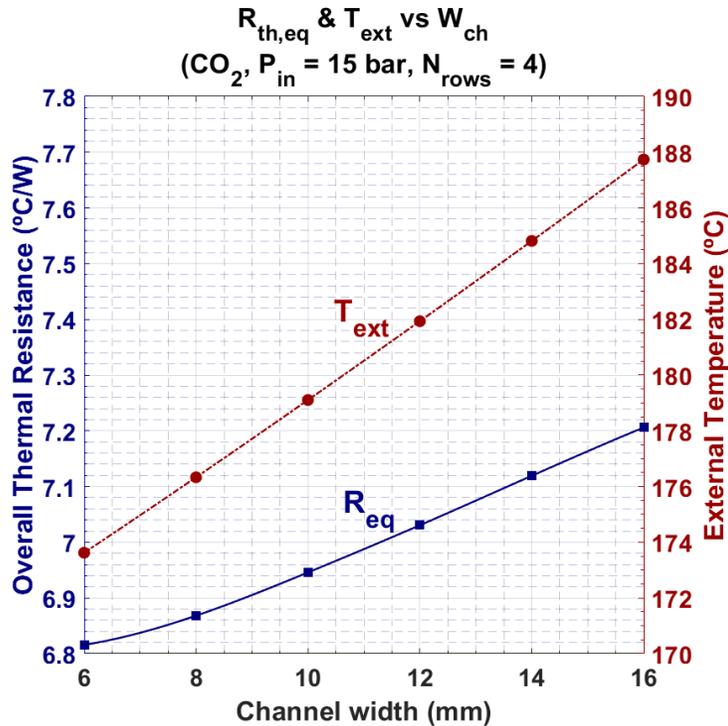
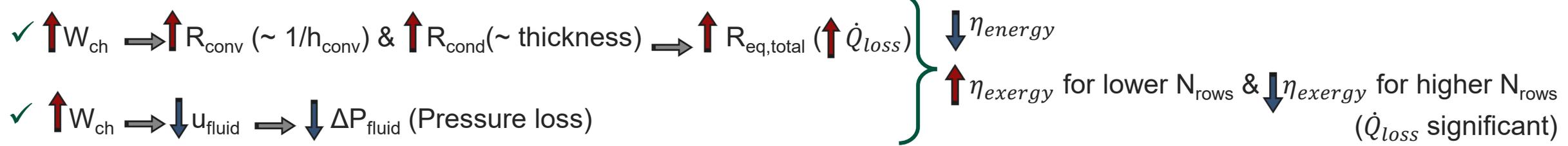
$\eta_{ex}$  accounts for pressure losses

$$\Delta E x_{HTF} = \dot{m}_{HTF} \cdot \left[ \Delta h \cdot \left( 1 - \frac{T_0}{T_{s,mean}} \right) - R \cdot T_0 \cdot \ln \left( \frac{P_{in}}{P_{out}} \right) \right]$$



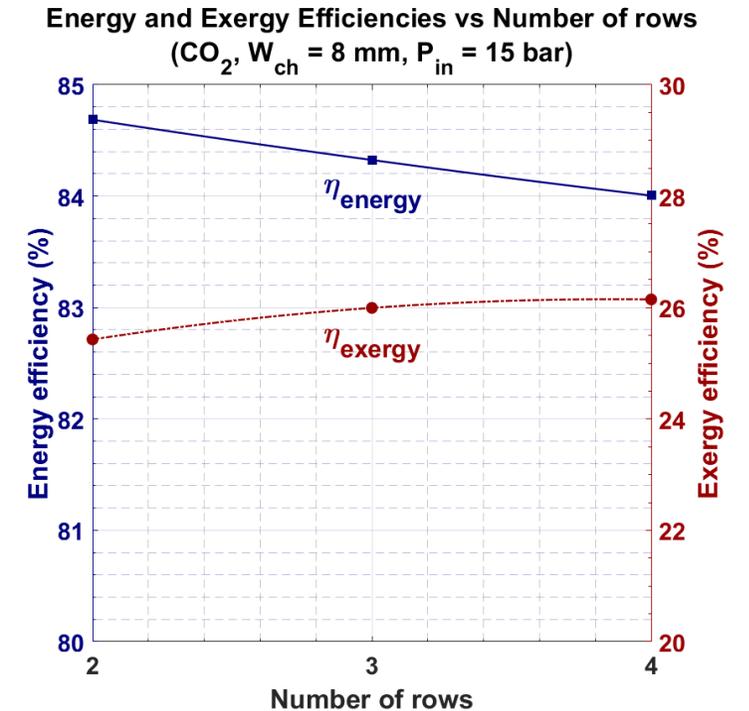
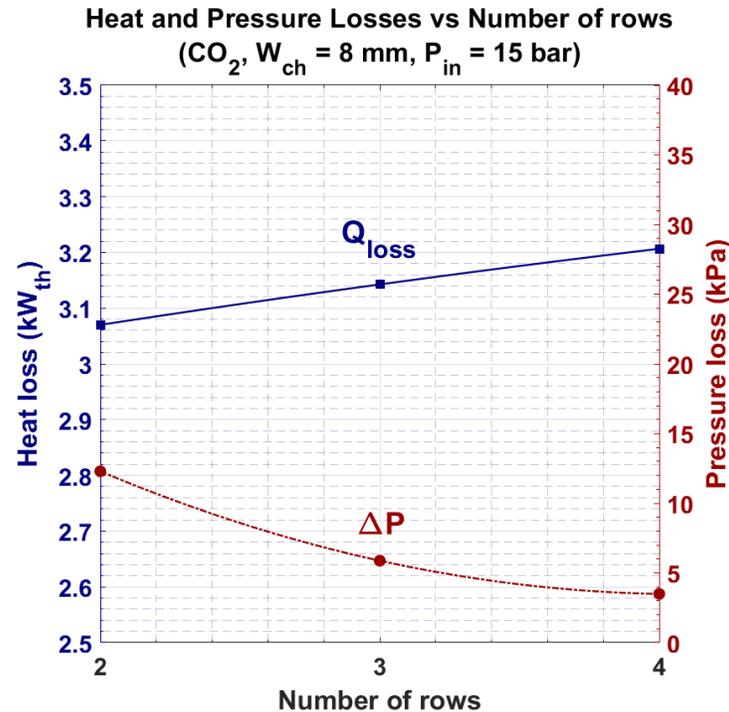
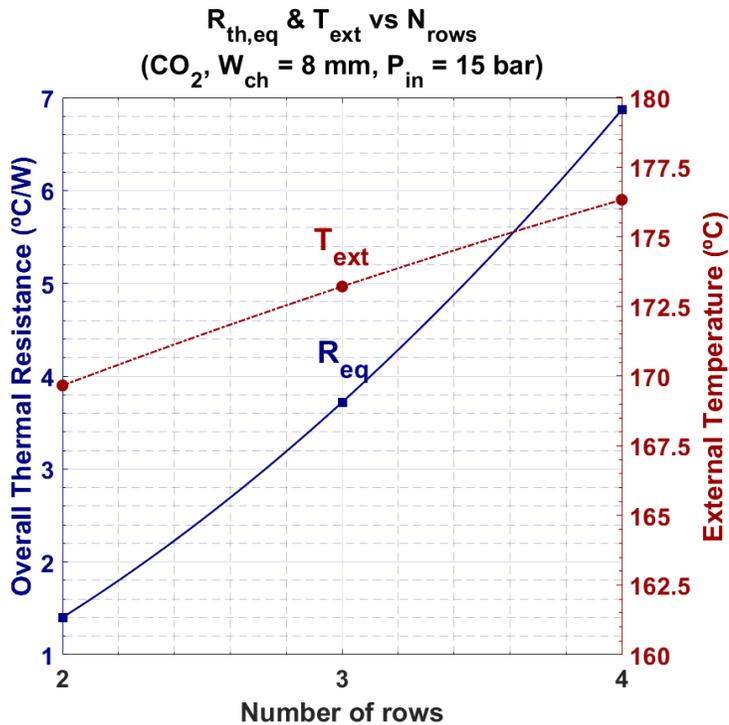
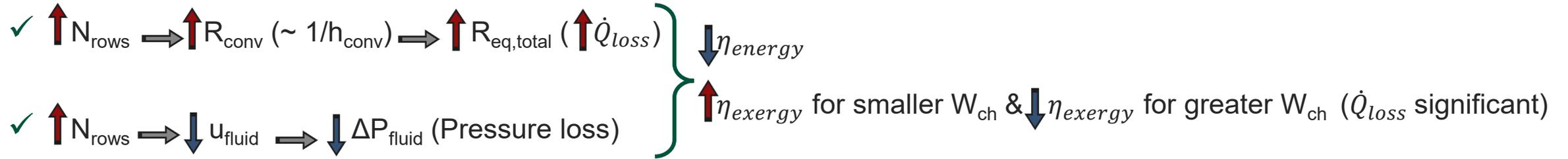
## ➤ Effect of the channel width $W_{ch}$ (from 6 to 16 mm)

For  $P_{in} = cte$ ,  $N_{rows} = cte$ : Increasing channel width is beneficial for the pressure loss but reduces heat gain.



## ➤ Effect of the number of rows $N_{rows}$ (from 2 to 4)

For  $P_{in} = cte$ ,  $W_{ch} = cte$ : Increasing number of rows is beneficial for the pressure loss but reduces heat gain.



## ➤ Effect of the inlet fluid pressure $P_{\text{fluid,in}}$ (from 5 to 30 bar)

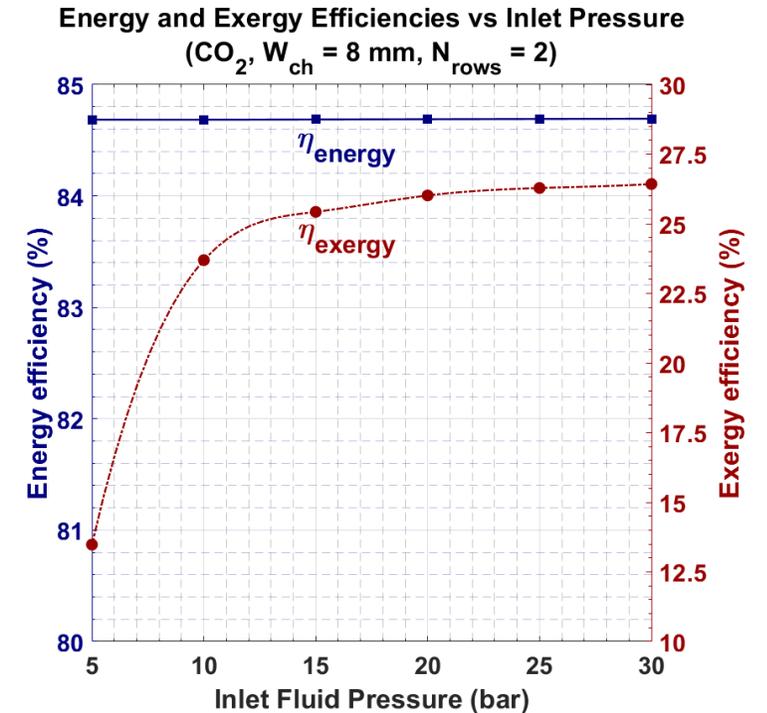
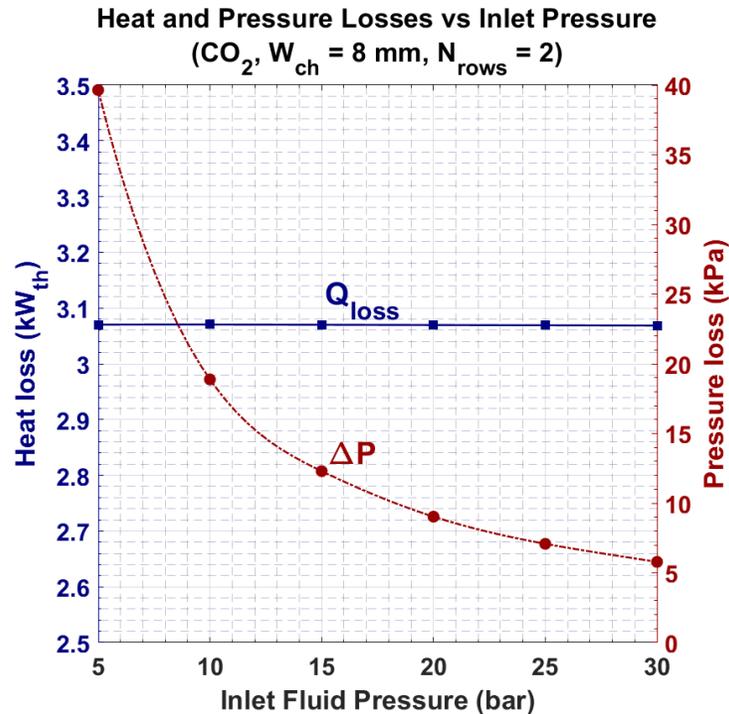
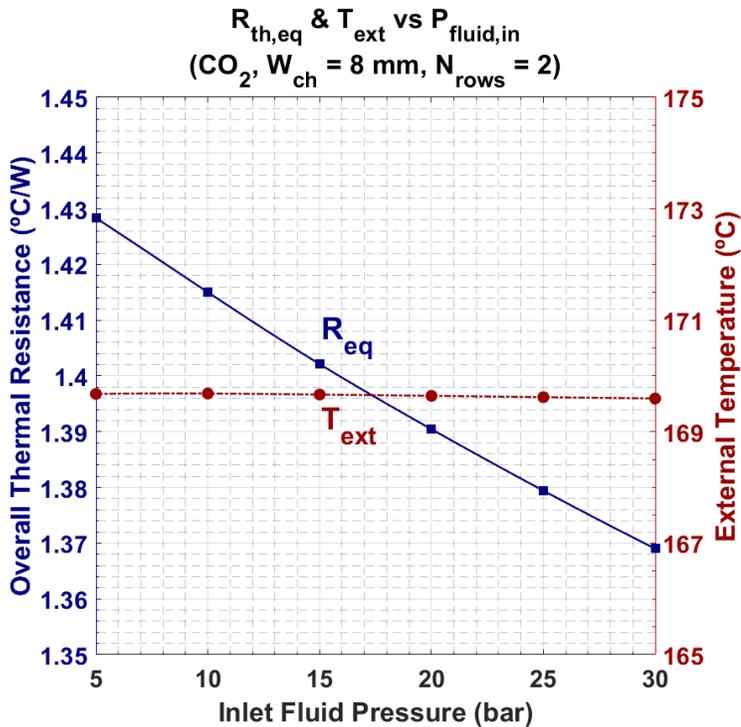
For  $W_{\text{ch}} = \text{cte}$ ,  $N_{\text{rows}} = \text{cte}$ : Increasing working pressure is beneficial, both for the heat transfer and for the pressure loss

✓  $\uparrow P_{\text{fluid,in}} \Rightarrow \downarrow R_{\text{conv}} (\sim 1/h_{\text{conv}}) \ \& \ \uparrow R_{\text{cond}} (\sim \text{thickness}) \Rightarrow \downarrow R_{\text{eq,total}} (\uparrow \dot{Q}_{\text{gain}})$

✓  $\uparrow P_{\text{fluid,in}} \Rightarrow \downarrow u_{\text{fluid}} (\sim 1/\rho_{\text{fluid}}) \ \& \ \uparrow \rho_{\text{fluid}} \Rightarrow \downarrow \Delta P_{\text{fluid}}$

$\uparrow \eta_{\text{energy}} \ \uparrow \eta_{\text{exergy}}$

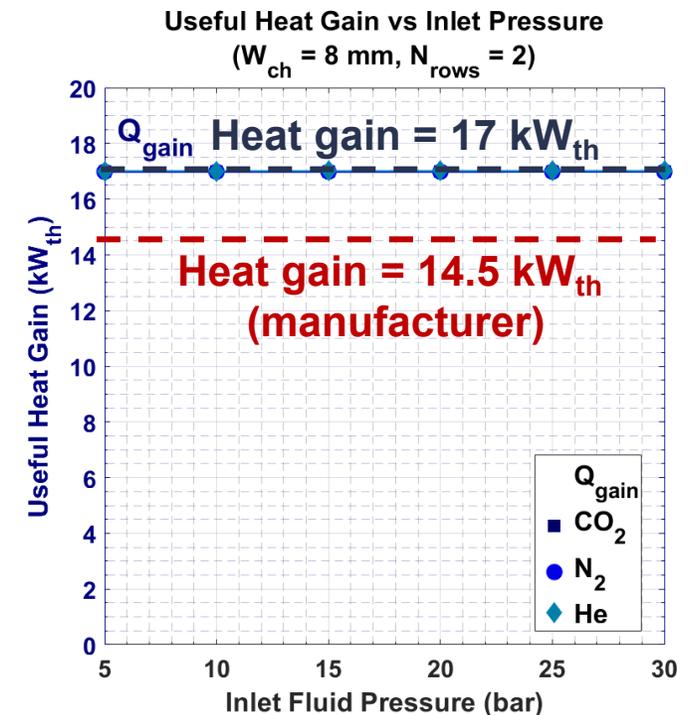
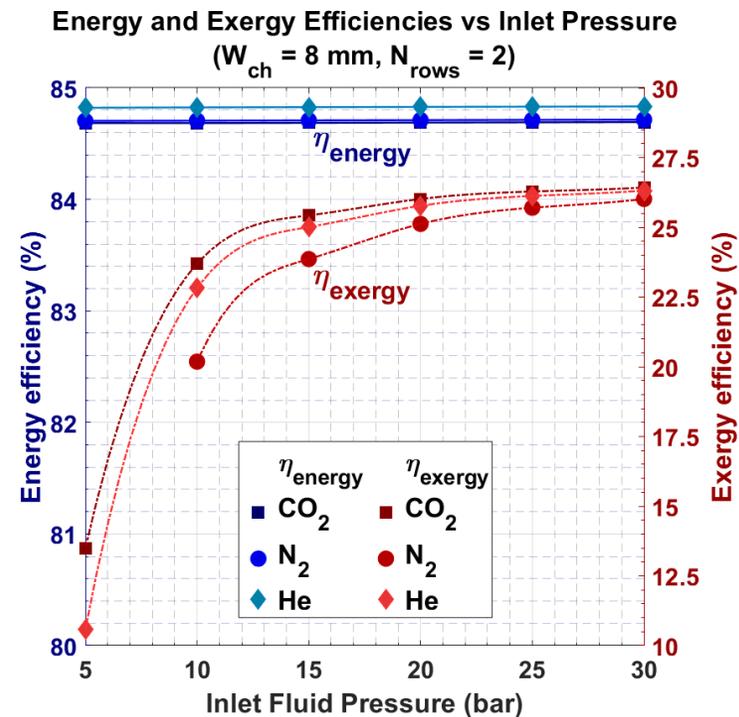
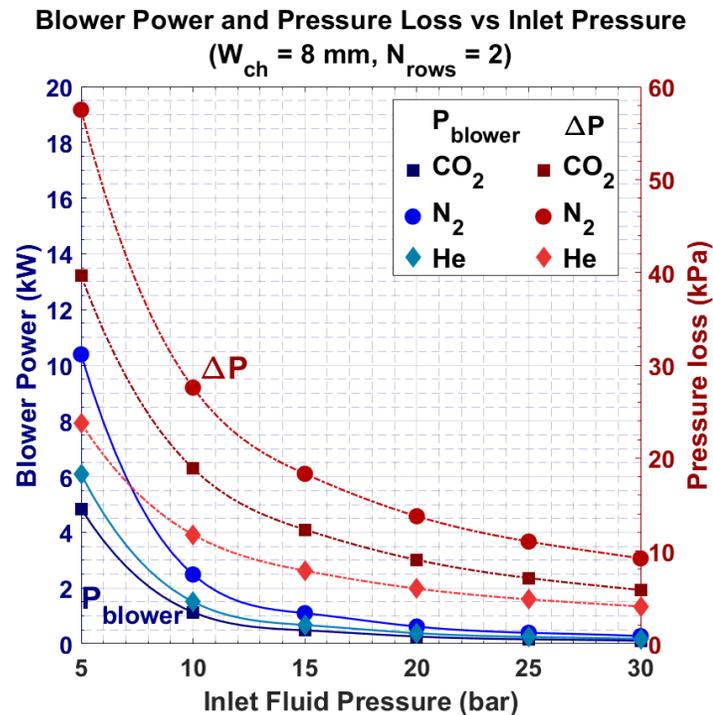
**Threshold pressure ~ 10 – 15 bar:**  
 asymptotic efficiencies beyond this value.



# Methodology

## ➤ Effect of the working fluid (CO<sub>2</sub>, N<sub>2</sub> or He)

- ✓  $\Delta P_{He} < \Delta P_{CO_2} < \Delta P_{N_2}$  but  $P_{blower,CO_2} < P_{blower,N_2} < P_{blower,He} \implies \eta_{ex,CO_2} > \eta_{ex,He} > \eta_{ex,N_2}$
- ✓ Threshold pressure ~ 10 – 15 bar: asymptotic efficiencies beyond this value.
- ✓  $\dot{Q}_{gain}$  and  $\eta_{energy}$  very similar for all the fluids, and greater than using a conventional single-tube receiver.



- ✓ Compact pressurised-gas solar receivers enable efficient, low-cost, and scalable solar heat supply for industry:
  - ✓ Compact receivers require **smaller mirror fields (lower cost)** and **smaller absorber area (reduced heat losses)**.
  - ✓ Compact structures perform as a **heat sink**. The working temperatures for low-medium processes enable the use of materials for the **fin core with high conductivity**.
  - ✓ The use of **pressurised gases** enhances heat transfer and reduces pressure loss and blower power.
- ✓ Effect of different parameters:
  - ✓ Channel width:  $\uparrow W_{ch} \Rightarrow \downarrow \eta_{energy}; \uparrow \eta_{exergy}$  for smaller  $W_{ch}$  &  $\eta_{exergy}$  for greater  $W_{ch}$  ( $\dot{Q}_{loss}$  significant)
  - ✓ Number of rows:  $\uparrow N_{rows} \Rightarrow \downarrow \eta_{energy}; \uparrow \eta_{exergy}$  for lower  $N_{rows}$  &  $\eta_{exergy}$  for higher  $N_{rows}$  ( $\dot{Q}_{loss}$  significant)
  - ✓ Inlet fluid pressure:  $\uparrow P_{fluid,in} \Rightarrow \uparrow \eta_{energy}; \uparrow \eta_{exergy}$   
**Threshold pressure ~ 10 – 15 bar:** asymptotic efficiencies beyond this value.
- ✓ Working fluid:
  - ✓  $\dot{Q}_{gain}$  and  $\eta_{energy}$  very similar for all the fluids, and **greater than using a conventional single-tube receiver**.
  - ✓  $\Delta P_{He} < \Delta P_{CO2} < \Delta P_{N2}$  but  $P_{blower,CO2} < P_{blower,N2} < P_{blower,He} \Rightarrow \eta_{ex,CO2} > \eta_{ex,He} > \eta_{ex,N2}$

- ✓ **Laboratory test campaign** of compact solar receiver samples in the pressurised-gas experimental loop at IMDEA - Energía facilities:



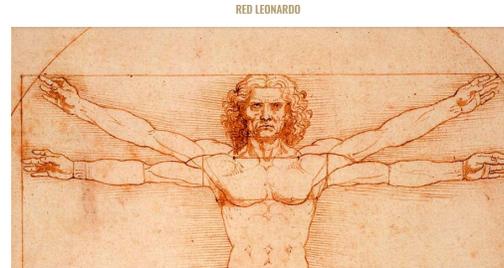
Experimental loop carried out during the Ph.D.:  
“Application of compact flow channel geometries to pressurised solar receivers: a numerical and experimental analysis”  
**(David D’Souza, 2023)**

- ✓ Novel design of a **sensible heat storage system for pressurised gases** (patent pending)
- ✓ Explore the extension of the compact solar-receiver concept to **flat-plate collectors** ( $T < 100\text{ }^{\circ}\text{C}$ )
- ✓ Apply to **national and international project calls** on concentrated solar thermal systems for industrial processes, aiming to construct a prototype compact solar receiver integrated into a Fresnel collector.



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Fundación  
**BBVA**



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THANKS FOR YOUR ATTENTION

María José Montes: [mjmontes@ind.uned.es](mailto:mjmontes@ind.uned.es)  
Full Professor  
Energy Department  
UNED – Industrial Engineering School

