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DYNAMIC SIMULATIONS OF FRESNEL SOLAR POWER PLANTS

SOLARPACES 2013

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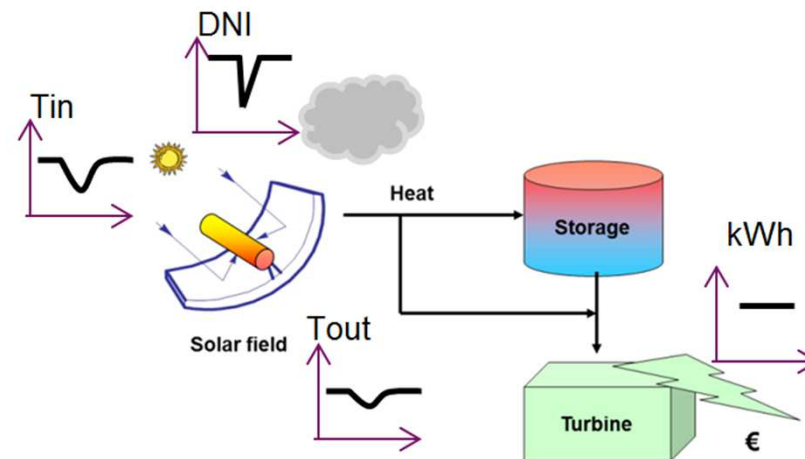
- Solar energy is an intermittent energy source (clouds, sunrise, sunset)

→ sharply variable source

- CSP benefits from:

- Thermal inertia
- Dispatchability

→ dynamic behavior



- Plant requirements: to deal with these transients to provide constant temperature and pressure to the thermodynamic cycle and to deliver controlled power on the grid

→ transient simulations required

- **Dynamic simulations** enable to optimize
 - component sizing
 - starting procedures and control schemes

- **Computing tools:**

- Language: Modelica



- Software: Dymola



- Open source library: Thermosyspro



1. FRESNEL PROTOTYPE WITH OIL AS HTF

- 1.1 Description of the plant
- 1.2 Dynamic model
- 1.3 Results

2. FRESNEL PROTOTYPE WITH water/steam as HTF

- 2.1 Description of the plant
- 2.2 Dynamic model
- 2.3 Results



1. FRESNEL PROTOTYPE WITH OIL AS HTF

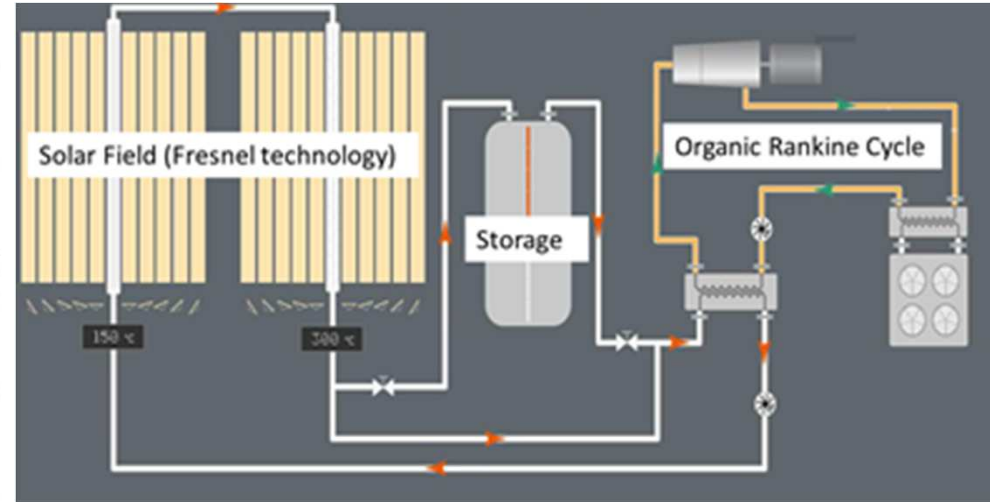
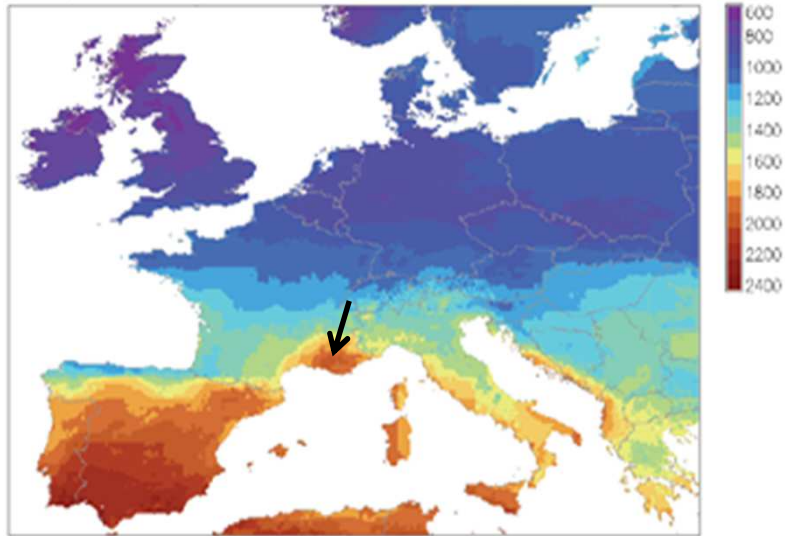
- 1.1 Description of the plant
- 1.2 Dynamic model
- 1.3 Results

2. FRESNEL PROTOTYPE WITH water/steam as HTF

- 2.1 Description of the plant
- 2.2 Dynamic model
- 2.3 Results



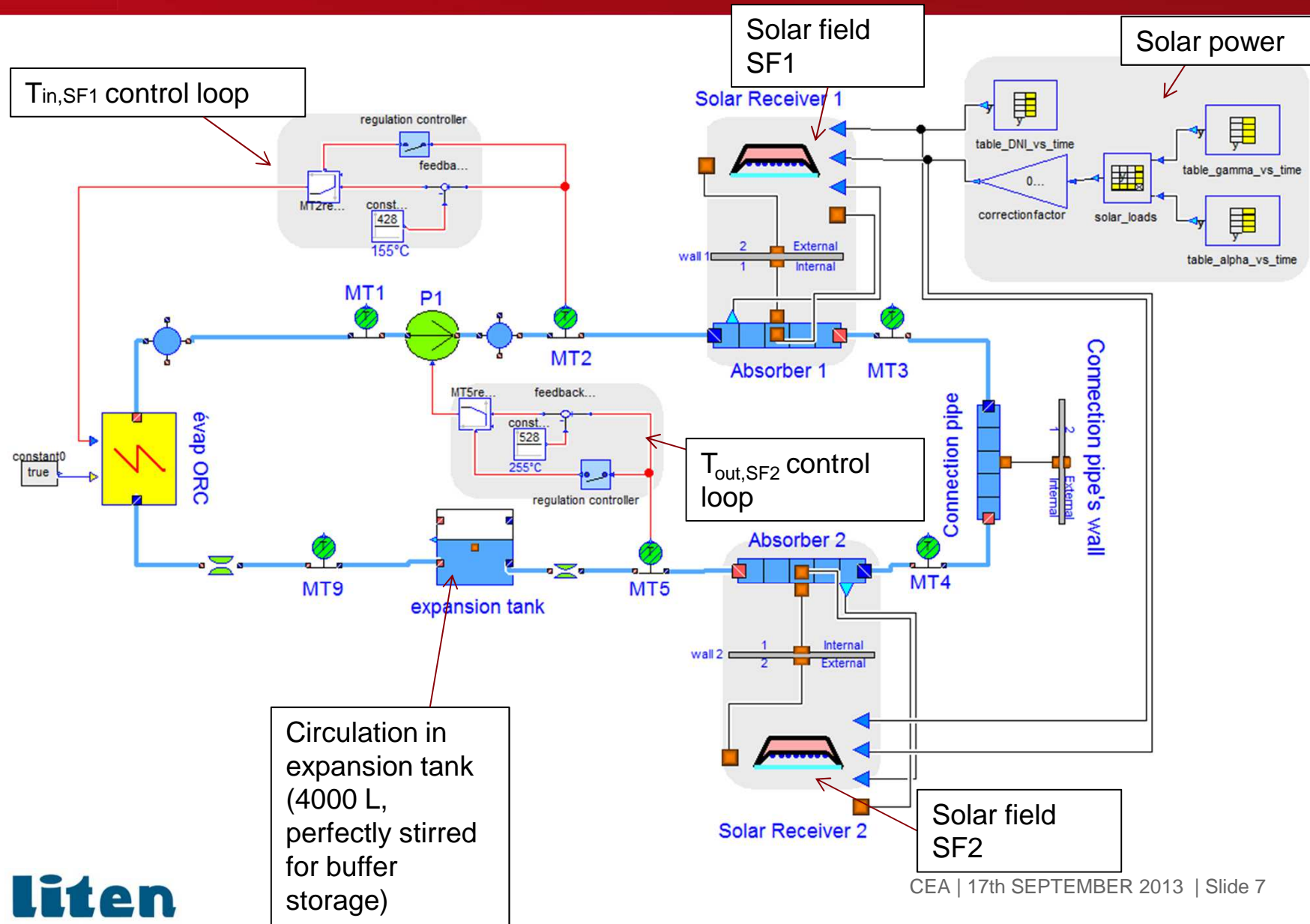
1.1 DESCRIPTION OF FRESNEL PROTOTYPE WITH OIL AS HTF



- Localisation: Cadarache
Southern France
Latitude=43.69°
Longitude=5.76°
- DNI(Meteonorm)=1610 kWh/m²/year

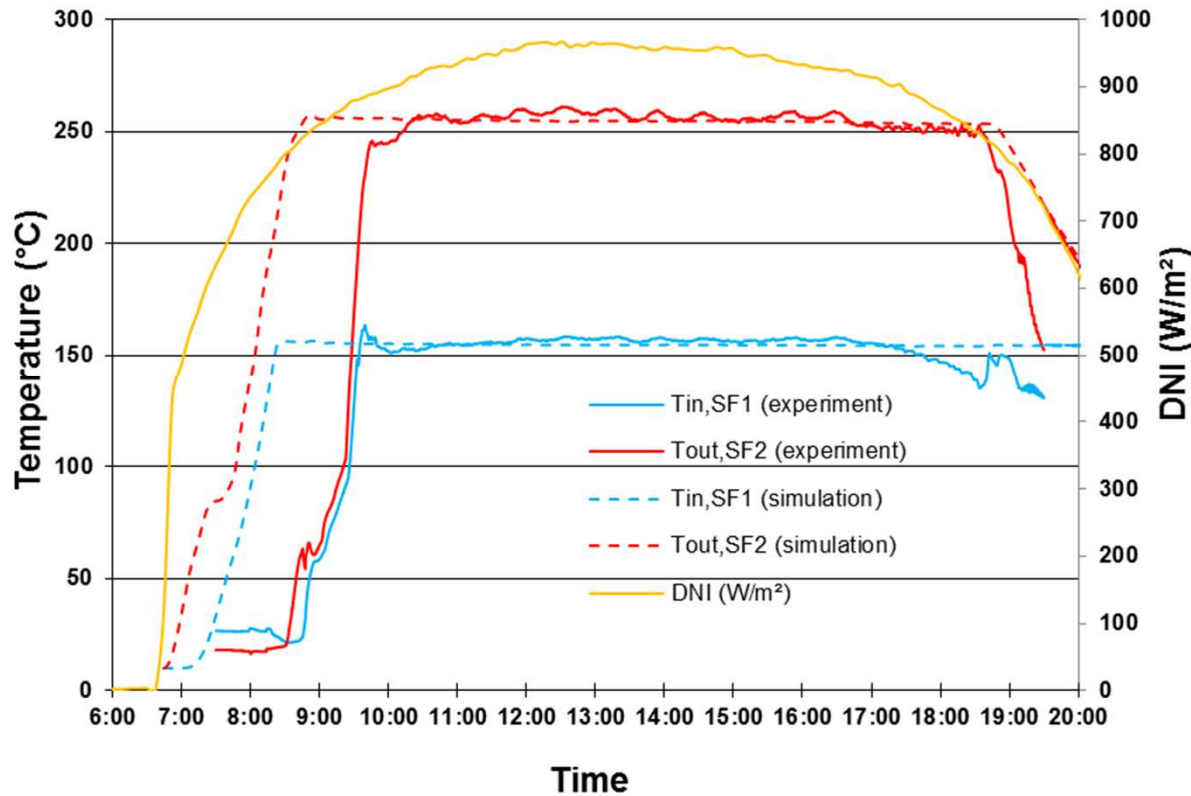
- Fresnel technology
- 1000 m² of mirrors (10 rows per field)
- Thermal oil
- Maximum working temperature 300°C
- Organic rankine cycle
- Thermocline thermal storage

1.2 DYNAMIC MODEL



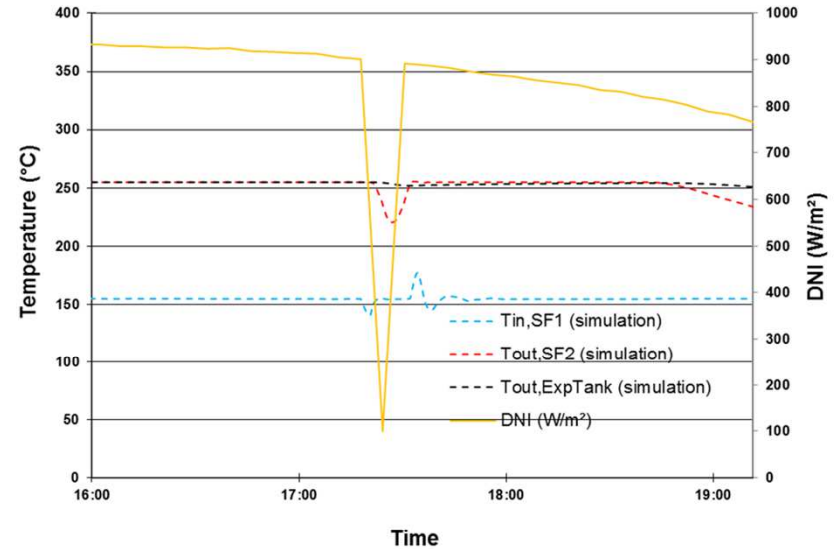
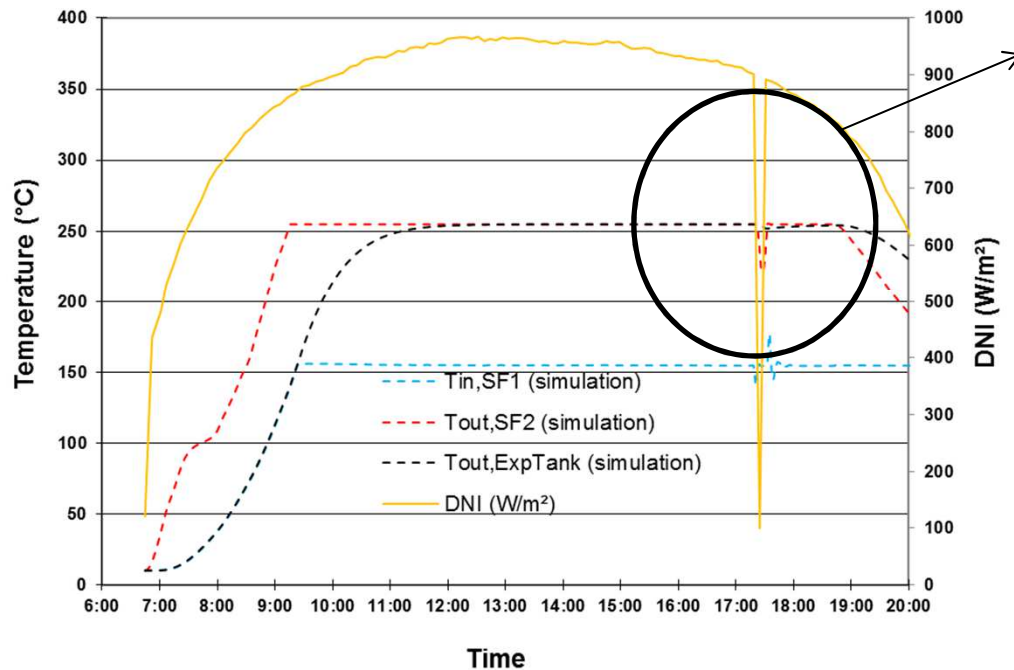
1.2 RESULTS

- Comparison between experimental data and model for a typical summer day
All the mirrors are tracking the sun for the simulated run



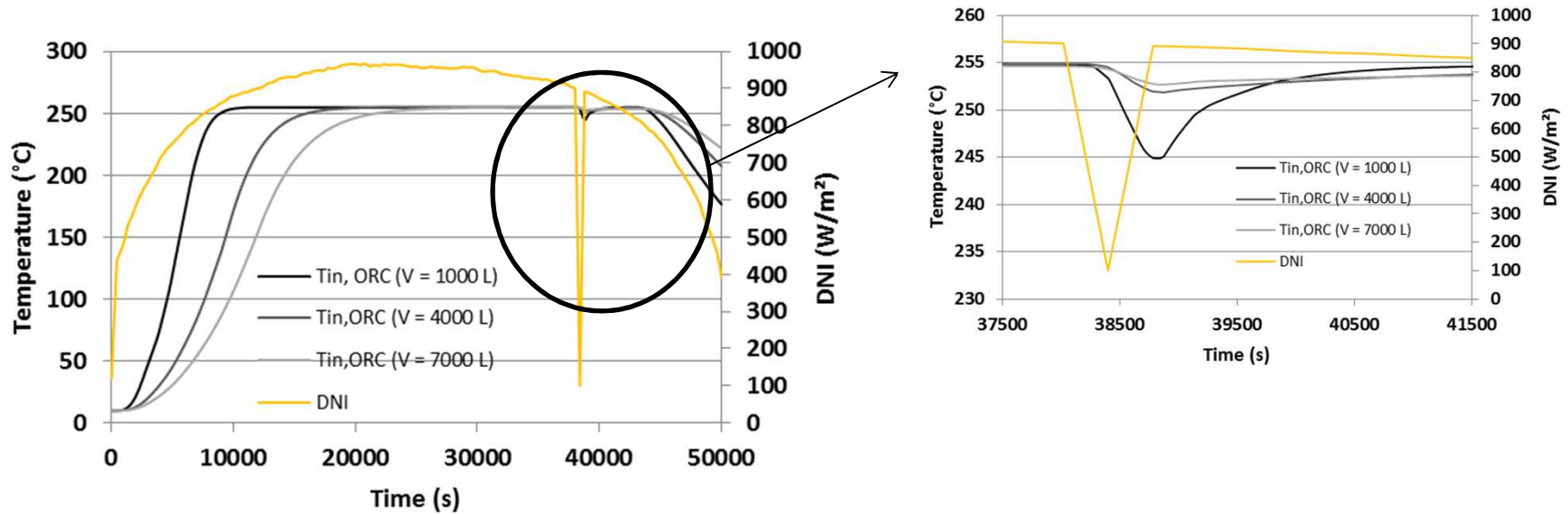
- Good agreement between model and experiment
- Starting of the plant could have begun earlier
- What would happen if there was a cloud ?

■ Transient simulation of a cloud passage



- Cloud passage is 13 min long with 90% DNI loss
- Temperature of oil entering the power block will be affected by less than 3 °C.
- 90% decrease of solar power results only in 50% decrease in thermal power available for electricity generation due to thermal inertia
- What would happen for different expansion volumes?

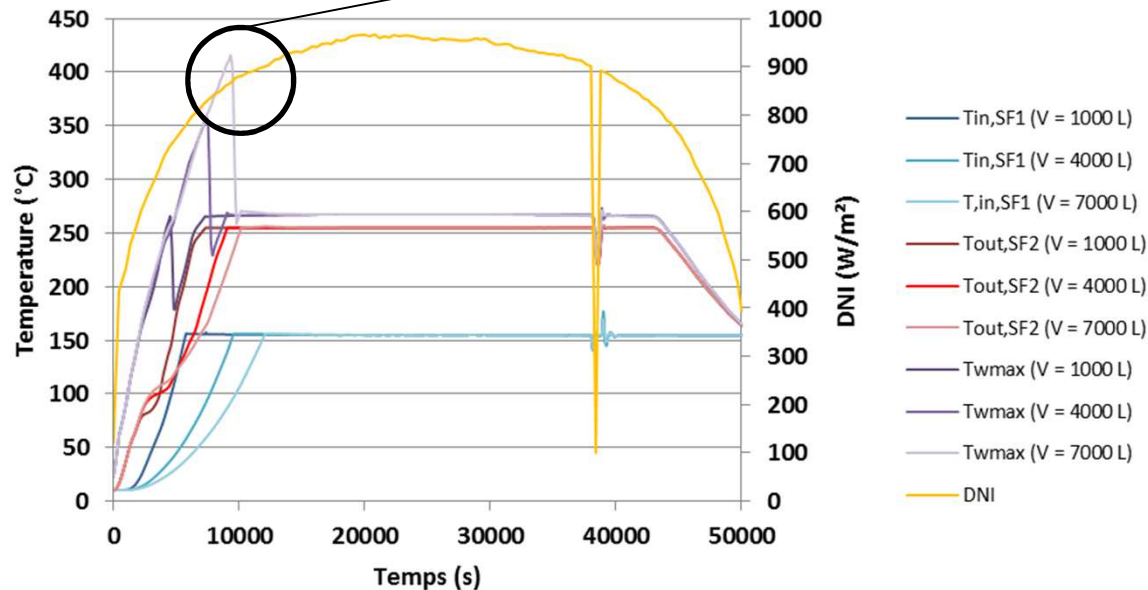
■ Influence of the expansion volume: 1000, 4000, 7000 L



- The bigger the expansion tank, the smoother the ORC inlet temperature
- But the longer the starting time !
- Choice of the expansion volume can be a balance between starting time and smoothing
- Does it have another impact on the operation of the solar field?

Wall temperature

Wall temperature is very high !

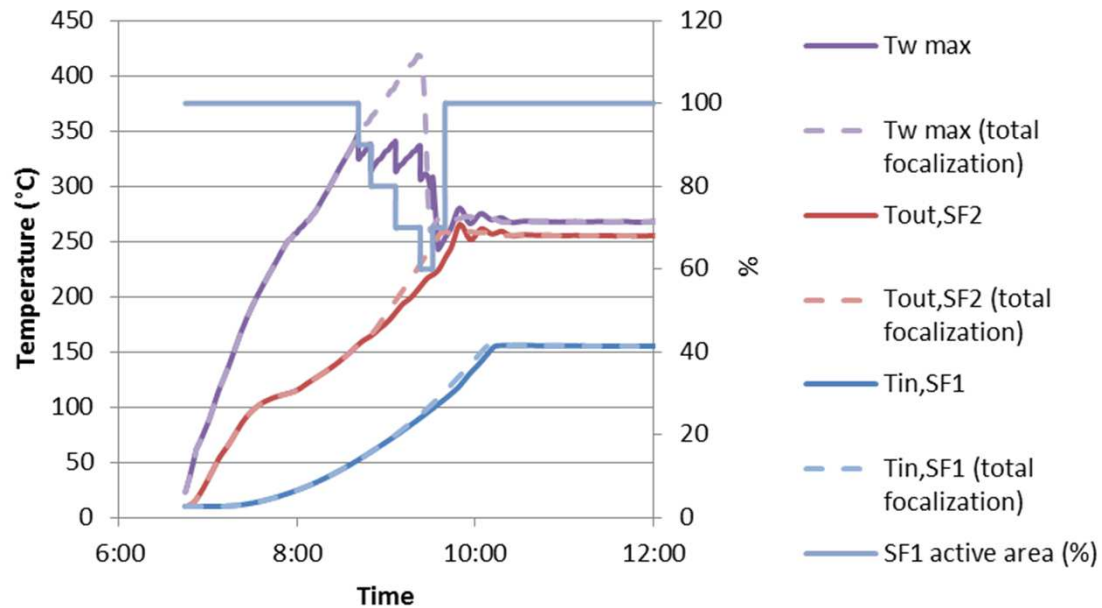


Total focalisation during starting is not possible for a 7000 L expansion volume without burning selective coating because:

- heating of the volume of oil takes a long time (energy is stored)
- oil viscosity at low temperature is high → laminar flow lasts longer
- sun and DNI are rising: high fluxes are reached
- poor transfer heat coefficient for laminar flow → hot wall temperature

→ Defocusing is required but heat will be lost

- Control of the wall temperature thanks to optimized focalization



- Dynamic simulation enables to analyze typical transient phenomenon such as the use of the expansion tank as a buffer storage (sizing, impact on starting time and conditions...)

1. FRESNEL PROTOTYPE WITH OIL AS HTF

1.1 Description of the plant

1.2 Dynamic model

1.3 Results

2. FRESNEL PROTOTYPE WITH water/steam as HTF

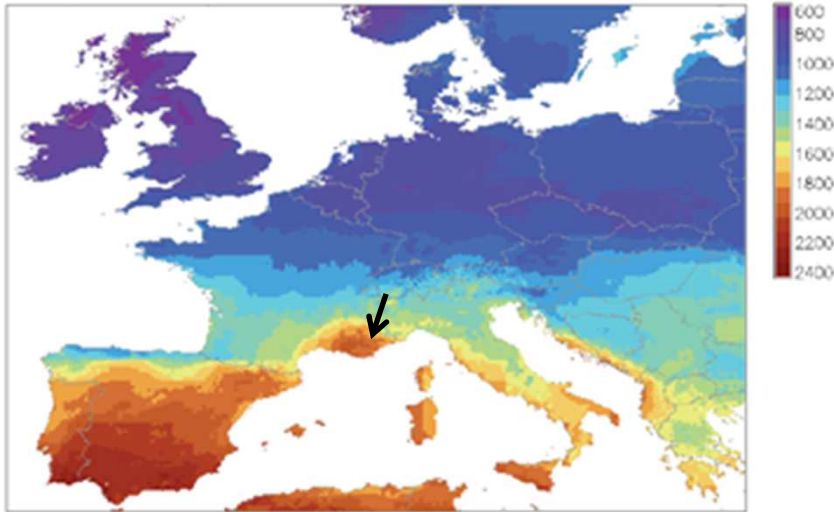
2.1 Description of the plant

2.2 Dynamic model

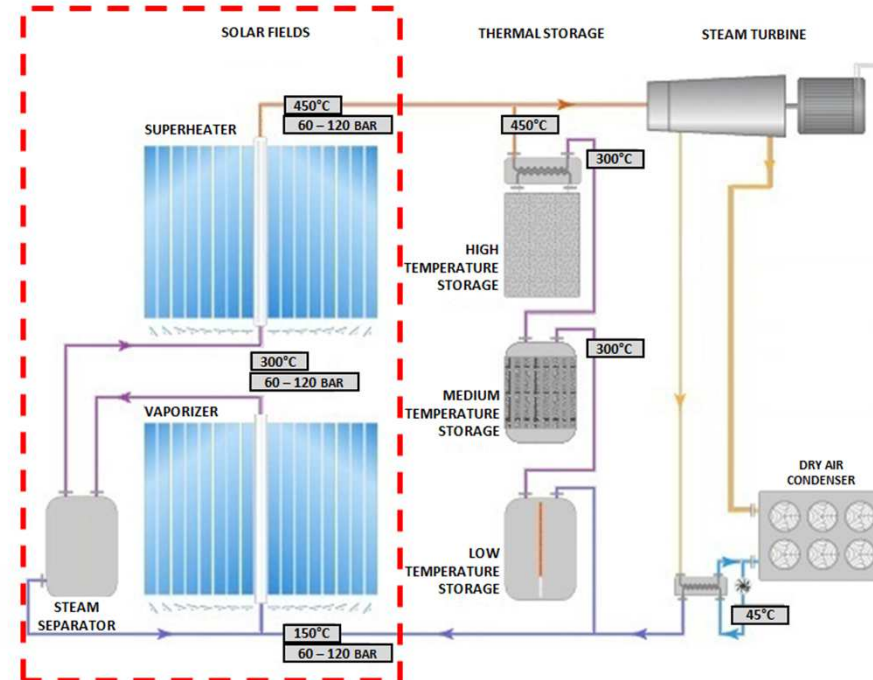
2.3 Results



1.1 DESCRIPTION OF FRESNEL PROTOTYPE WITH WATER/STEAM AS HTF

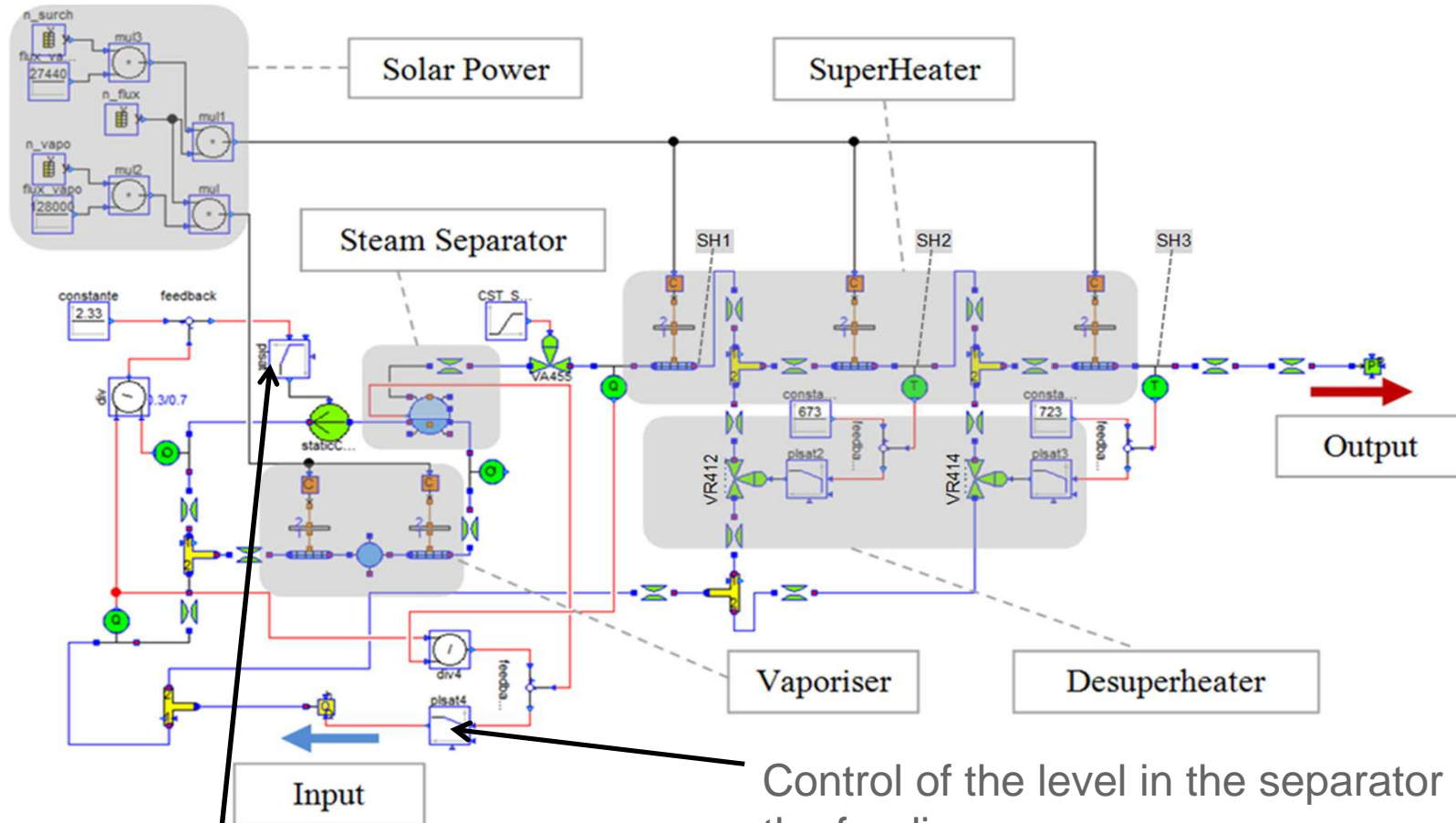


- Localisation : Cadarache
 - Southern France
 - Latitude=43.69°
 - Longitude=5.76°
- DNI(Meteonorm)=1610 kWh/m²/year



- Fresnel technology
- 1600 m² of mirrors
- Water/steam
- Maximum working temperature 450°C (110 bars)
- 3-stage thermal storage

1.2 DYNAMIC MODEL

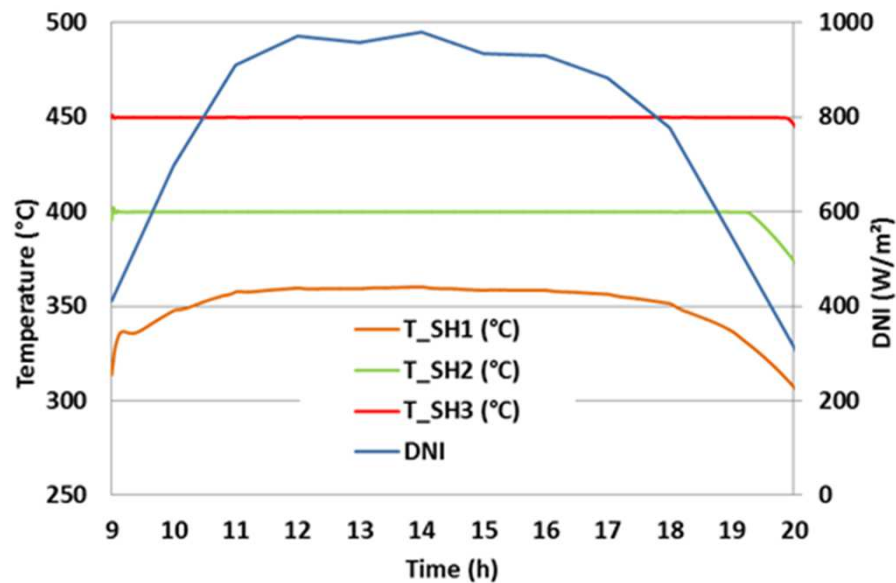


Control of the level in the separator with the feeding-pump

Control of the steam quality at the end of the evaporator with the recirculation pump

1.3 RESULTS

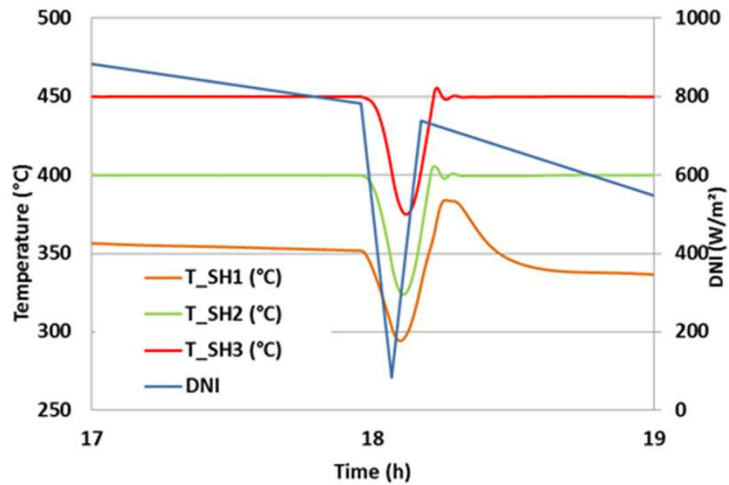
- Simulation results for the same summer day as for the oil plant:



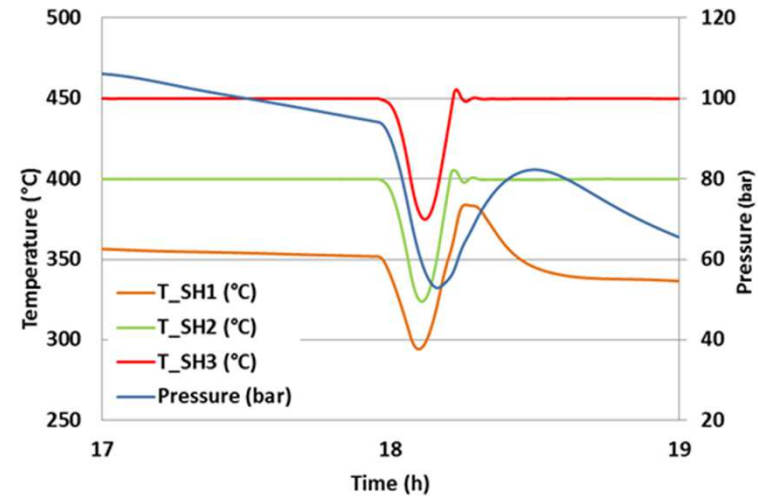
→ Both desuperheaters reach their setpoint and steam temperature is controlled

And if there was a cloud ?

■ Transient simulation of a cloud passage



75°C loss at the exit
(max 18°C/min)



Pressure variation is
slightly delayed due
to water flashing in
the separator

➔ Simulation helps defining the criteria (inertia/buffering, control strategy) to ensure that the turbine requirements are met all the time

- Dynamic simulation is of paramount importance for the correct design and operation of a solar plant.
- Models of Fresnel solar plants are currently implemented at CEA and are being validated on solar plant prototypes.
- The aim is to dispose of a plant simulator allowing to optimize the plant operation strategy, including storage.
- In perspective the dynamic simulation model will be coupled to short term weather forecasts and extended to the study of cogenerative plants (power generation + desalination, cooling...).



THANK YOU FOR YOUR ATTENTION

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