Dynamic modeling and control strategy analysis of a micro-scale CSP plant coupled with a thermocline system for power generation

Introduction

Concentrated solar power systems are characterized by strong transients and require proper control guidelines to operate efficiently. In this context, a dynamic model of a 5 kW_e solar ORC system is developed in the ***Modelica* language** to investigate the possible advantages of coupling a concentrating solar power system with a thermocline packed-bed storage. A first regulation strategy is proposed and results of a three-day simulation using real meteorological data are analyzed. Models developed in this work are based on the **open-source *ThermoCycle* library** which is dedicated to the modeling of thermal power systems and in development at the University of Liège. Thermo-physical properties of the fluids are computed with the **open-source *CoolProp* library**.

System description

Solar Field:

- 25 PTC in series
- A_{tot} = 60 m² (SM =1,5)
- HTF: Therminol 66

Thermal Energy Storage:

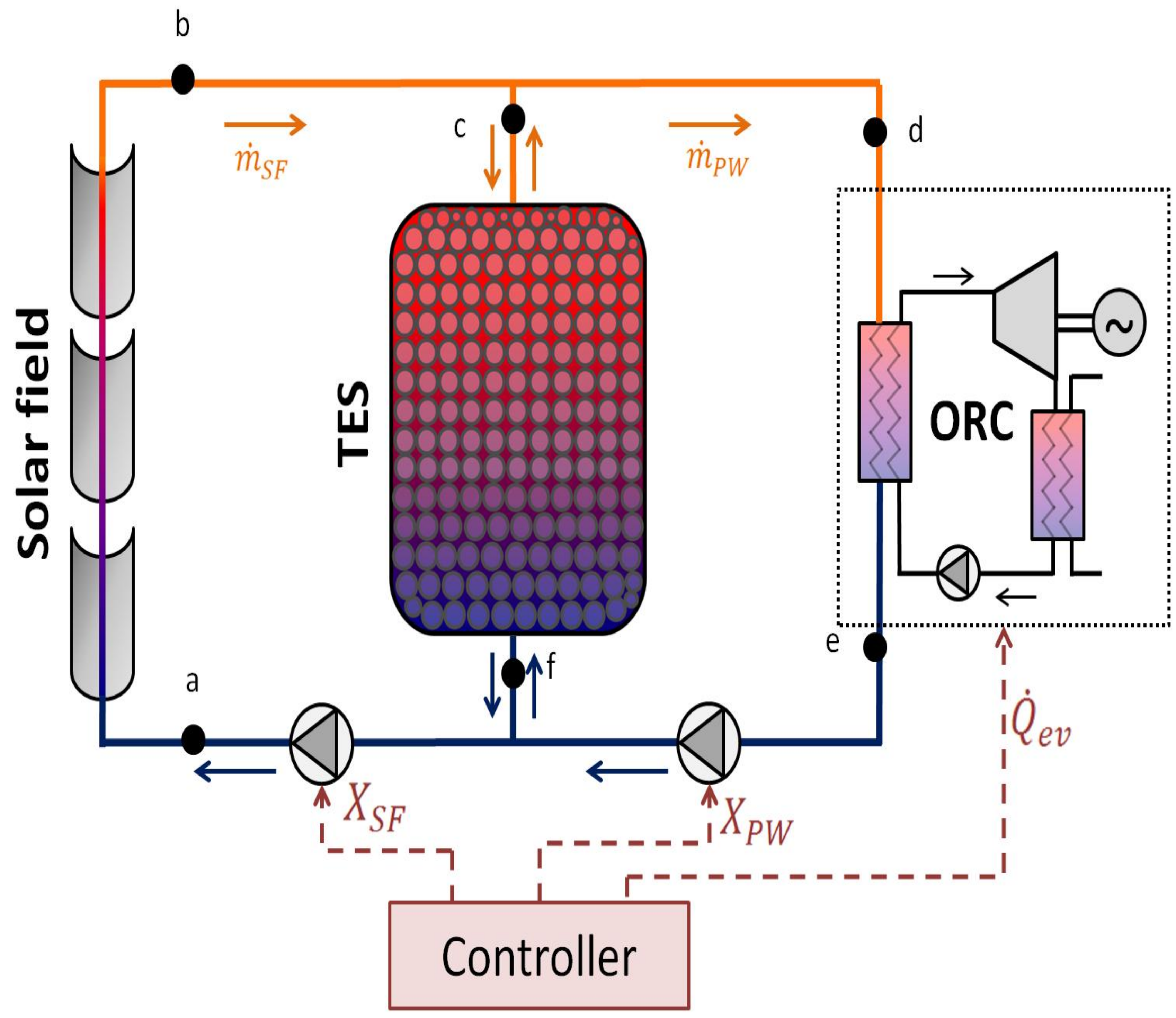
- Thermocline packed-bed tank
- Filler : Quartzite (ε=0.22)
- Tank volume: 8 m³- 3.3h @ $\dot{W}_{nom}$

Power unit:

- Non-recuperative ORC
- $\eta_{exp,is}$ = 70%; $\eta_{pp,is}$ = 50%
- η_{orc} = 10%
- P_{ev} adjusted to keep $pinch_{ev}$ close to 30°C

Nominal operating conditions

- $T_{b,nom}$ = 175 °C
- $T_{e,nom}$ = 140 °C
- $Q_{ev,max}$ = 46 kW
- $\dot{W}_{net,nom}$ = 5 kW



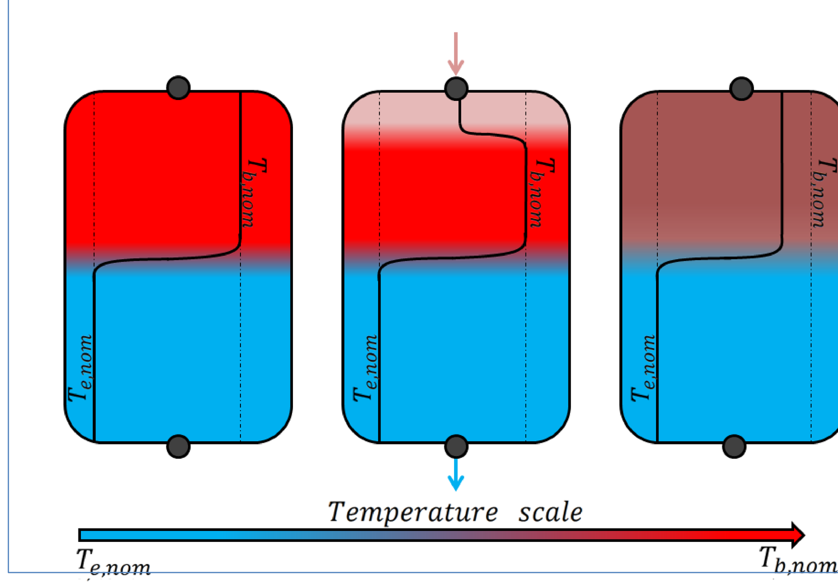
Plant control

Control variables:

- Heat exchanged in the evaporator (Q_{ev})
- Solar loop pump speed (X_{SF})
- Power loop pump speed (X_{PW})

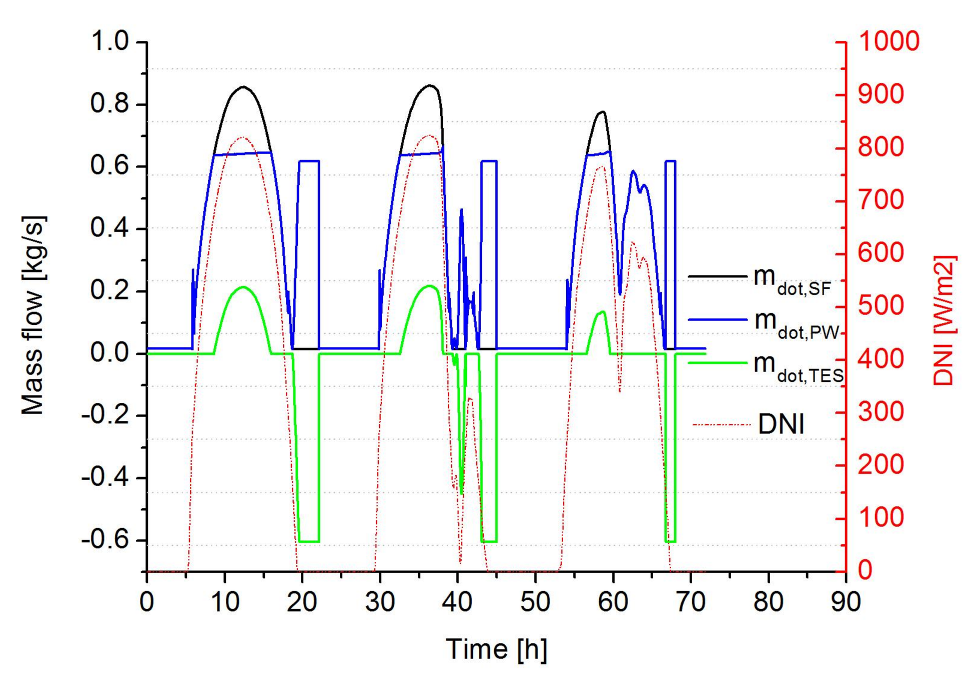
Control strategy:

Keep the temperatures T_b and T_e as close as possible to their nominal values $T_{b,nom}$ and $T_{e,nom}$ → Avoid any thermocline degradation in the tank in case of unpredicted charge or discharge of the TES

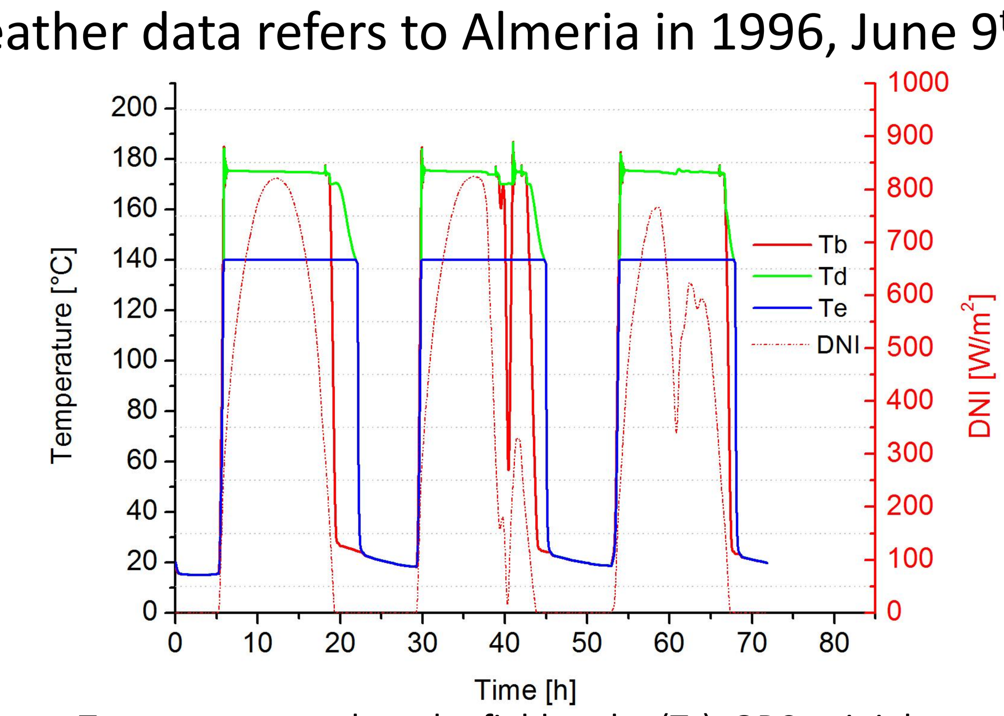


Results and conclusion

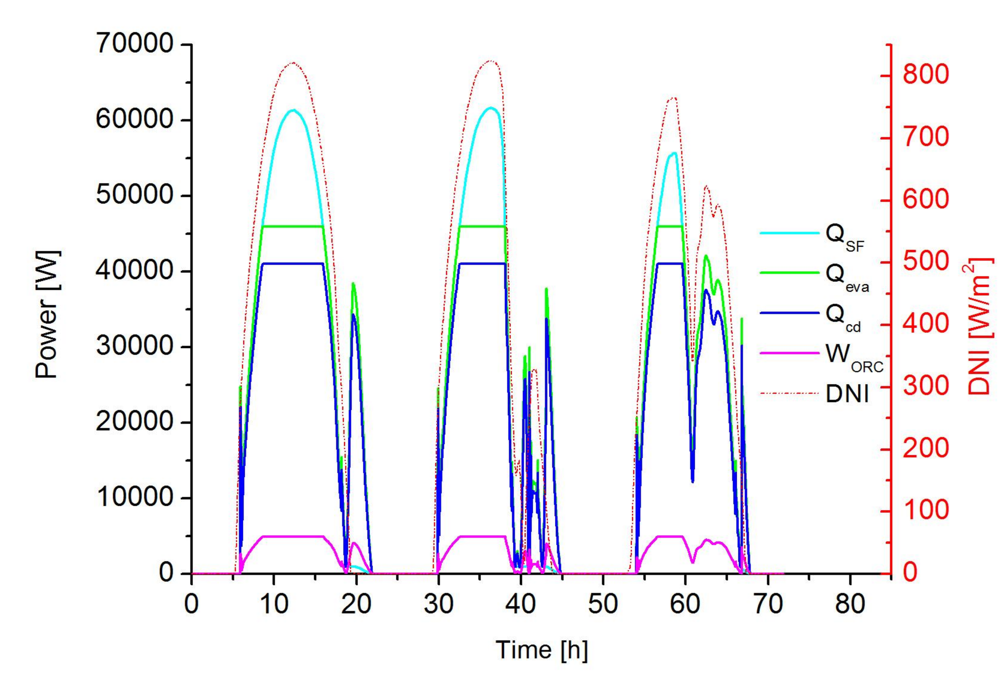
Weather data refers to Almeria in 1996, June 9th – 11th



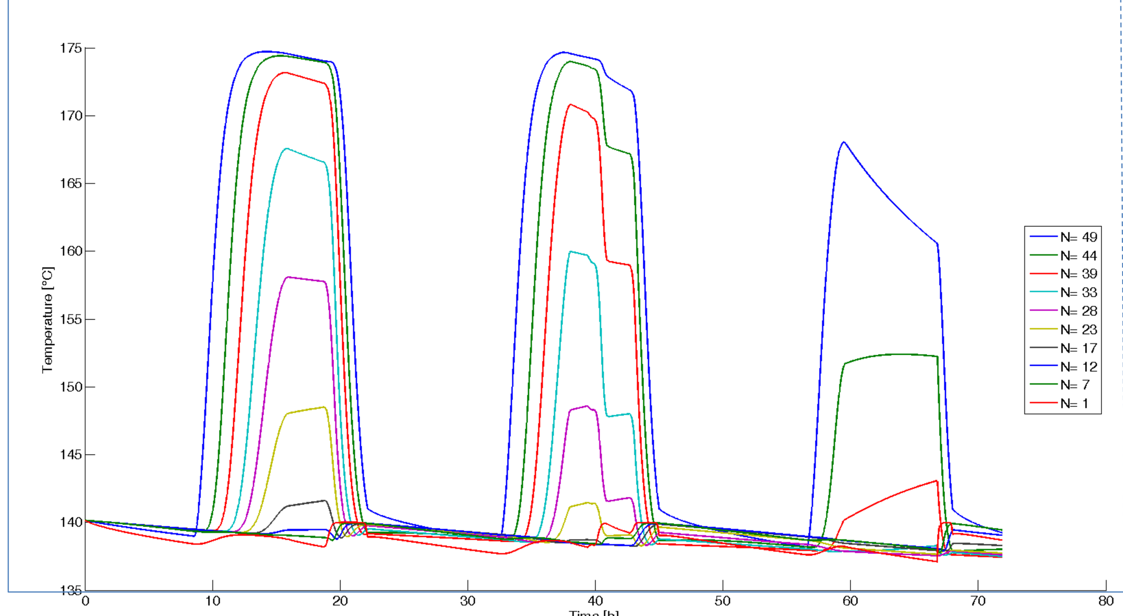
Mass flow rates in the TES ($m_{dot,TES}$), in the solar loop ($m_{dot,SF}$) and in the power loop ($m_{dot,PW}$)



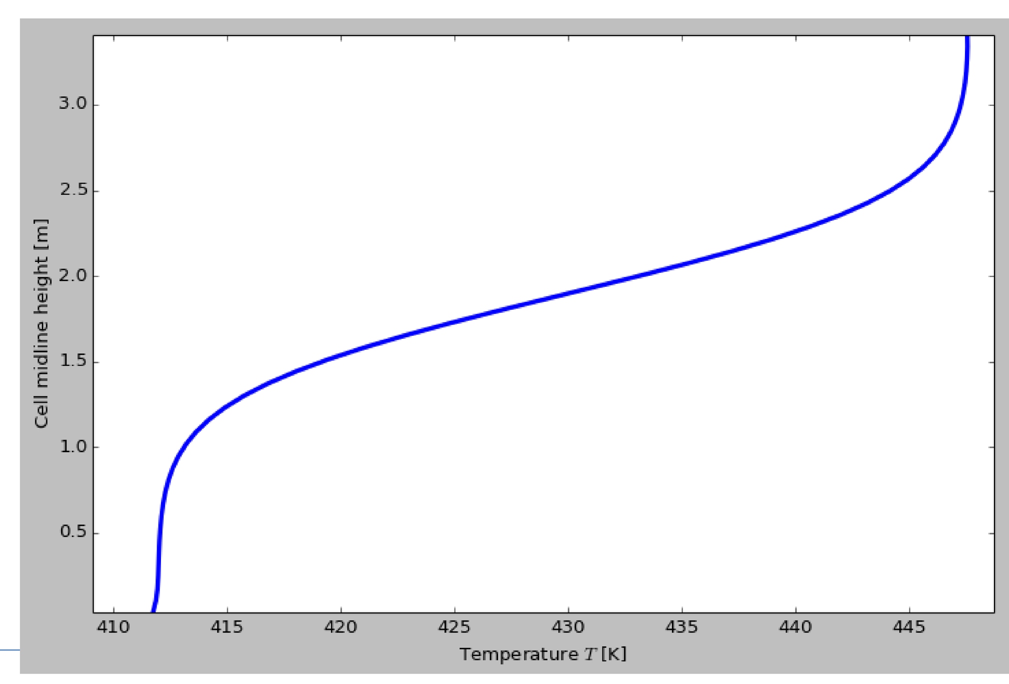
Temperatures at the solar field outlet (T_b), ORC unit inlet (T_d) and outlet (T_e)



ORC unit power output (W_{ORC}) and thermal powers exchanged in the solar field (Q_{SF}), the evaporator (Q_{eva}) and the condenser (Q_{cd})



Temperature profiles at ten vertically-equidistant heights of the TES tank



Screenshot of the ThermoCycle Viewer display showing the temperature profile inside the TES tank at t = 5800 seconds

Conclusions

- Stability of T_d increased by coupling a thermocline TES with the solar field
- Degradation of the thermocline avoided by keeping T_b and T_e close to nominal values
- Discharge of the TES should be controlled by a threshold on Q_{ev} instead that on T_b

Acknowledgements

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ORCNext

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