MODELING AND EXPERIMENTAL EVALUATION

OF COMBINED LATENT AND SENSIBLE HEAT THERMAL ENERGY STORAGE IN A PILOT SCALE THERMOCLINE TANK

Journées Nationales sur l'Énergie Solaire

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Odeillo

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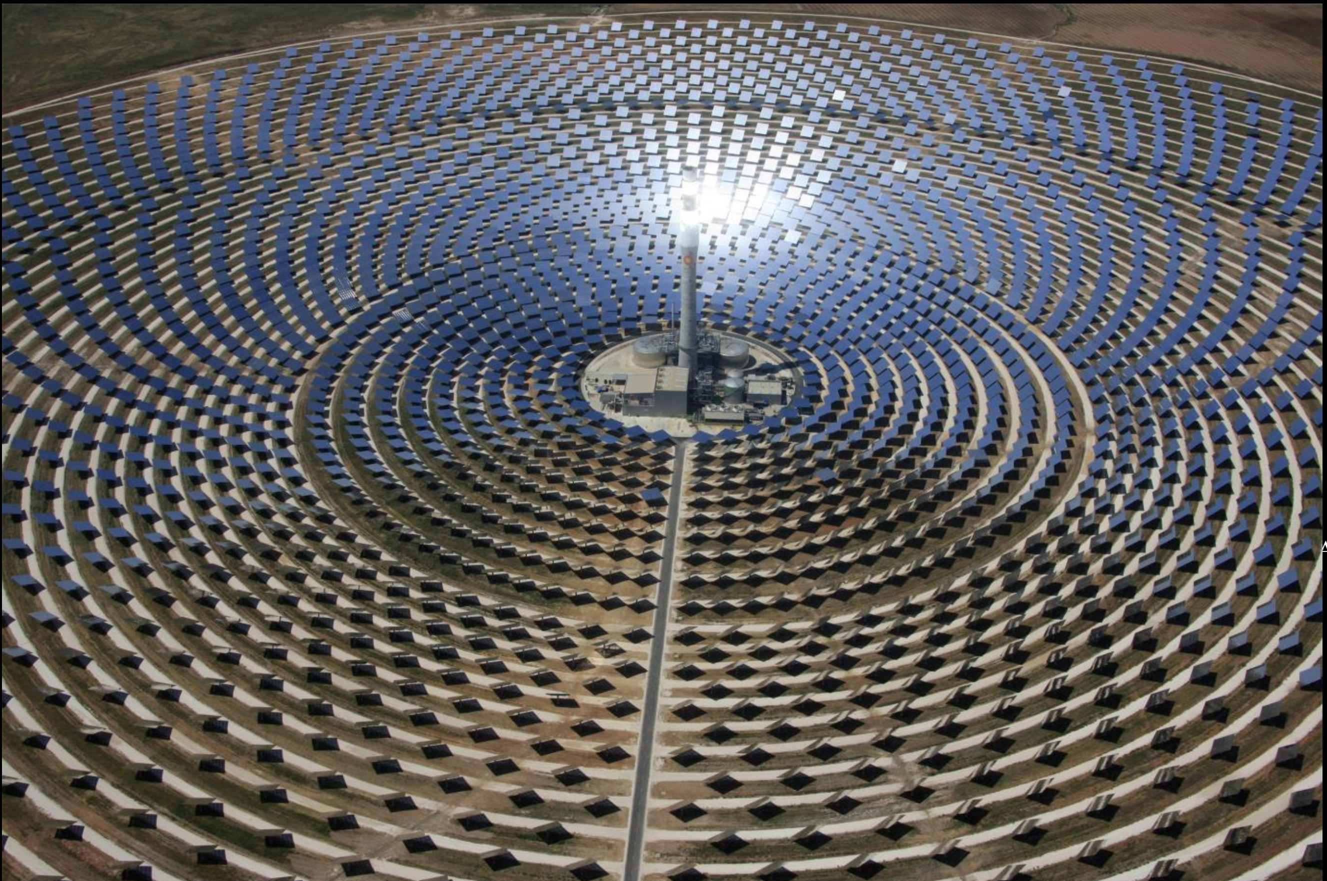
OUTLINES

1. INTRODUCTION
2. OBJECTIVES
3. EXPERIMENTAL WORK
4. MODELLING APPROACH
5. CONCLUSIONS
6. PERSPECTIVES

Concentrated solar power CSP

2050

620 GWe



A), “Renewable energy medium-term market report 2015.
2050 - Executive Summary,” p. 14, 2015

Commercially CSP - TES

ANDASOL Granada Spain

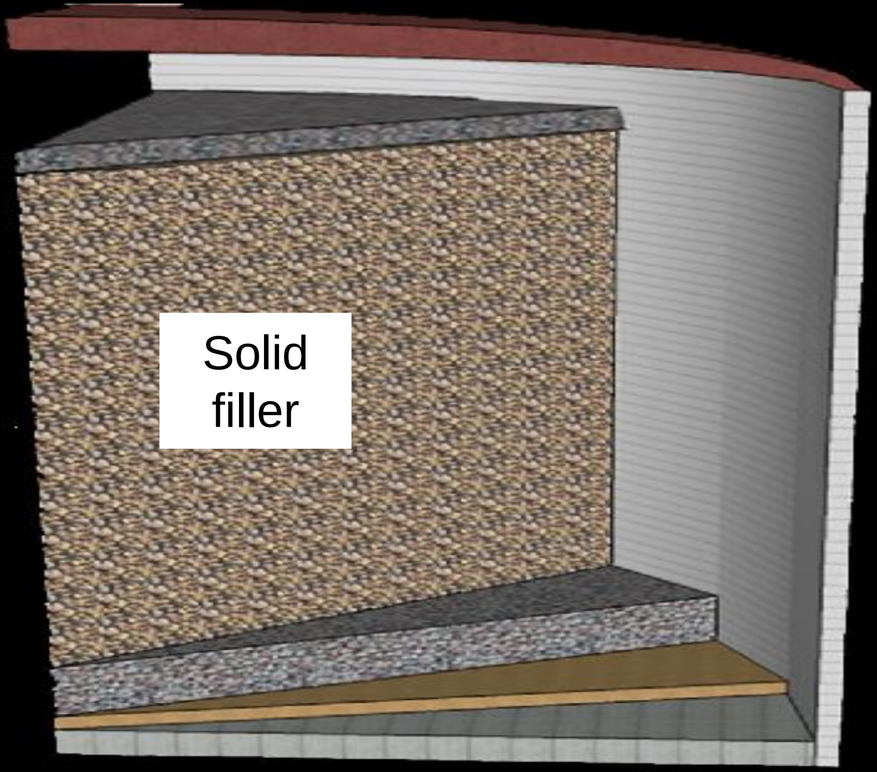
50 MWe - 7.5 h storage (28 000 t molten salt binary nitrate)
625 collectors (12m length, 6m aperture) HTF solar oil

http://www.bp.com/outlook-explained-7-things-to-know-about-the-energy-future

Two-tanks Vs One-tank TES

> 33%

[05] Pacheco et al.



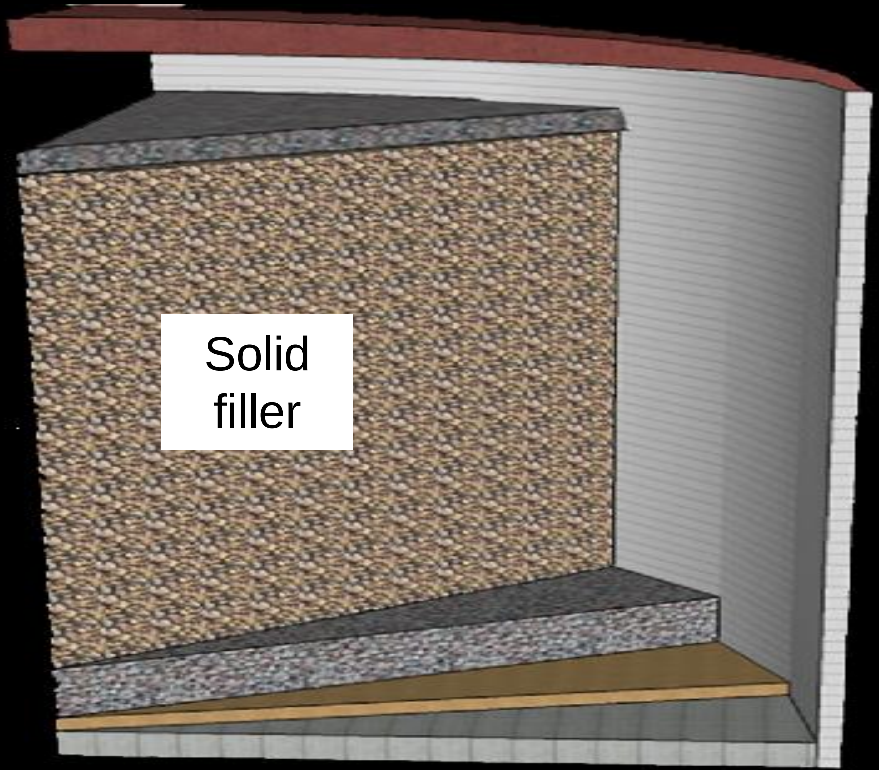
Two-tanks Vs One-tank TES

> 33%

>> HTF

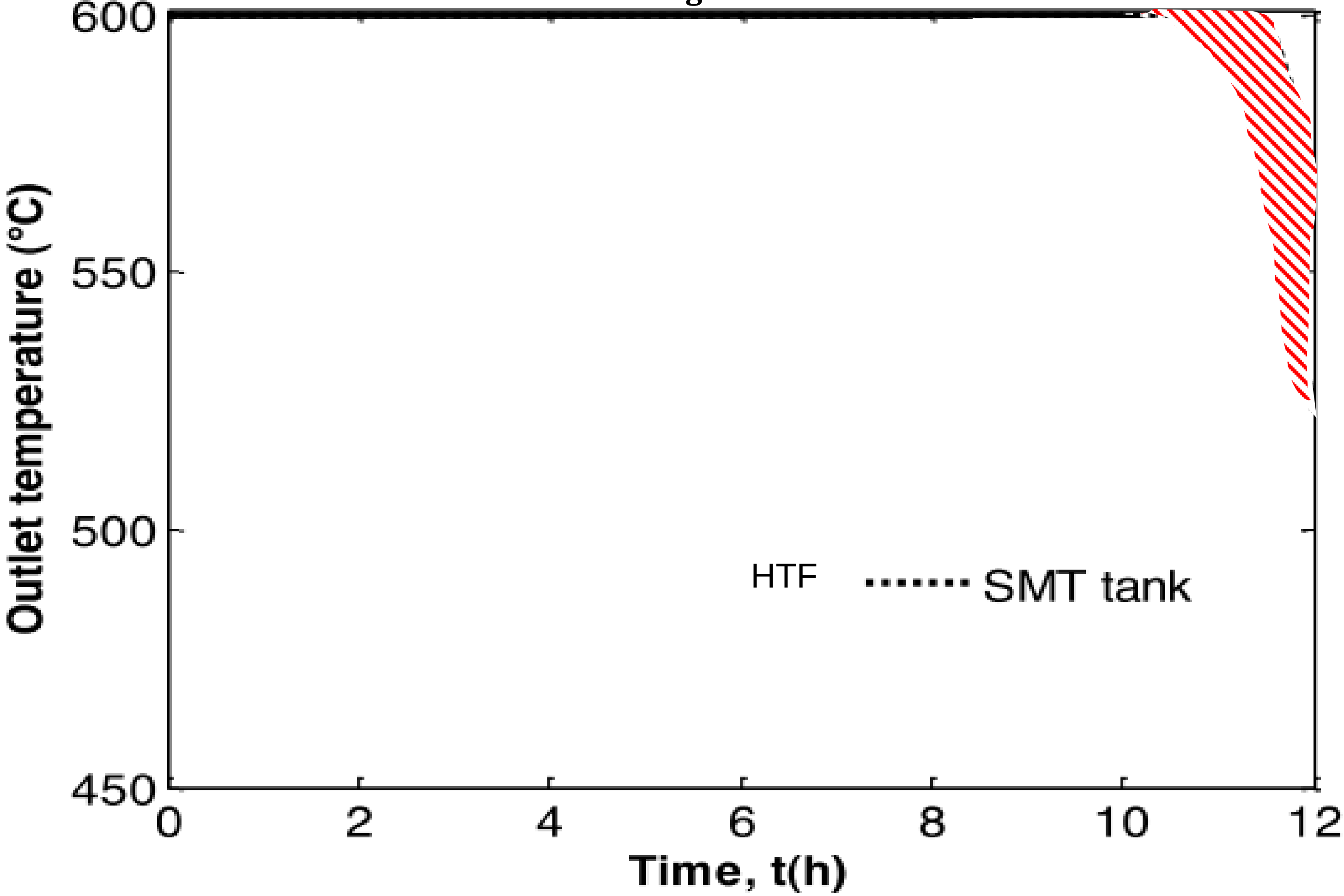
>> Construction

[05] Pacheco et al.



SMT Vs DMT TES [06] C. Mira-Hernández,

$\mathbf{T_f = T_{High}}$



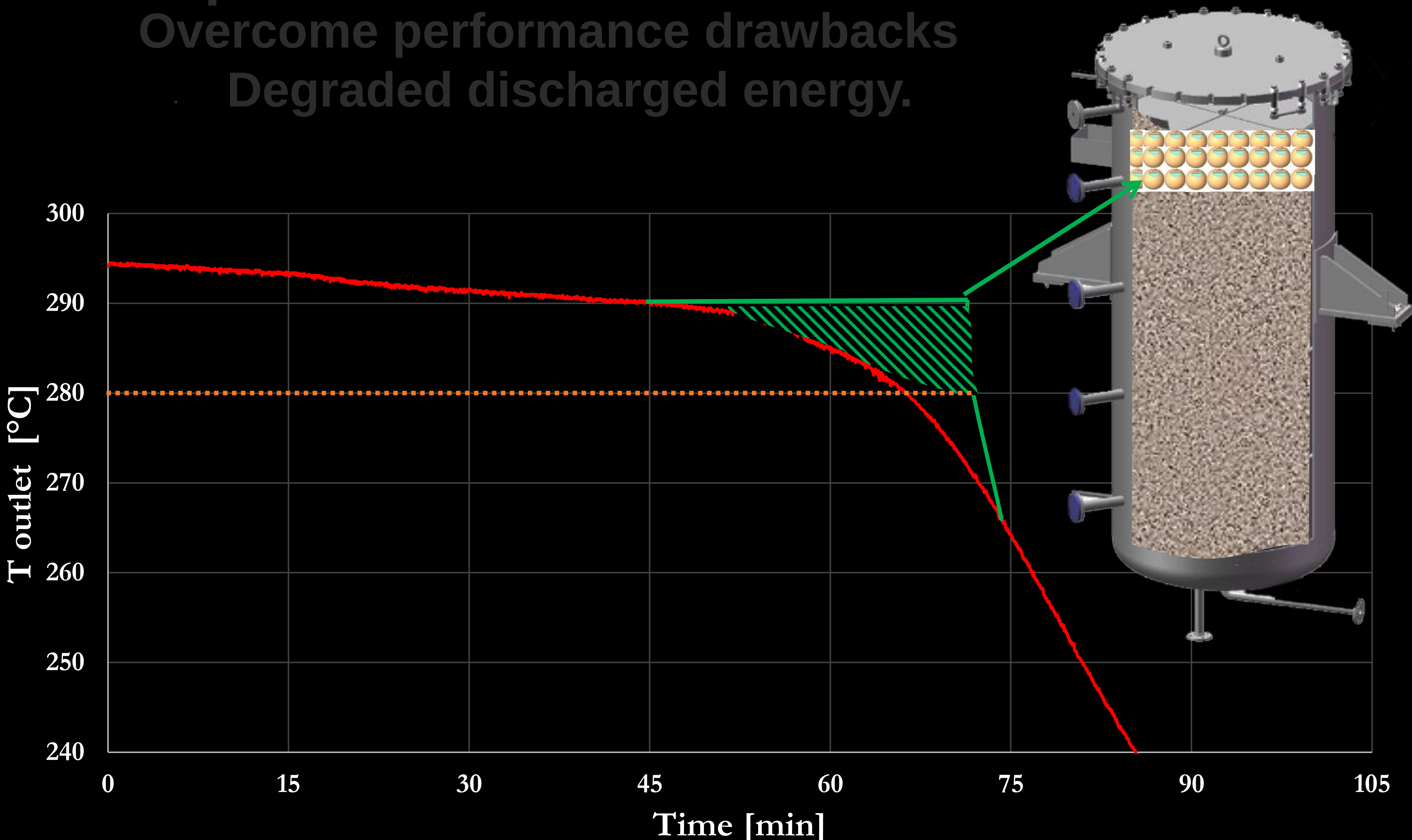
Outflow temperature history for dual-media and single-medium thermocline tanks.

Improve energy quality during discharge

Development of the one-tank TES for CSP

Overcome performance drawbacks

Degraded discharged energy.

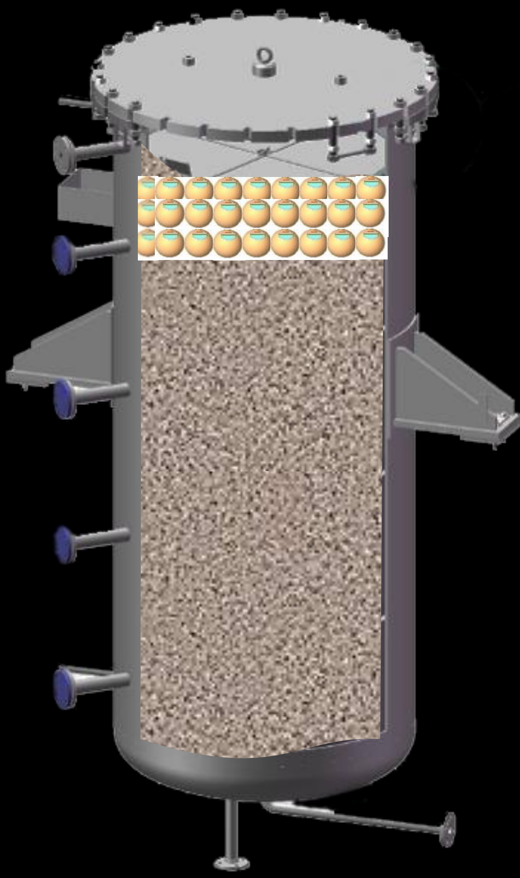


Combining PCM layer to Sensible TES

Development of the one-tank TES for CSP

Overcome performance drawbacks

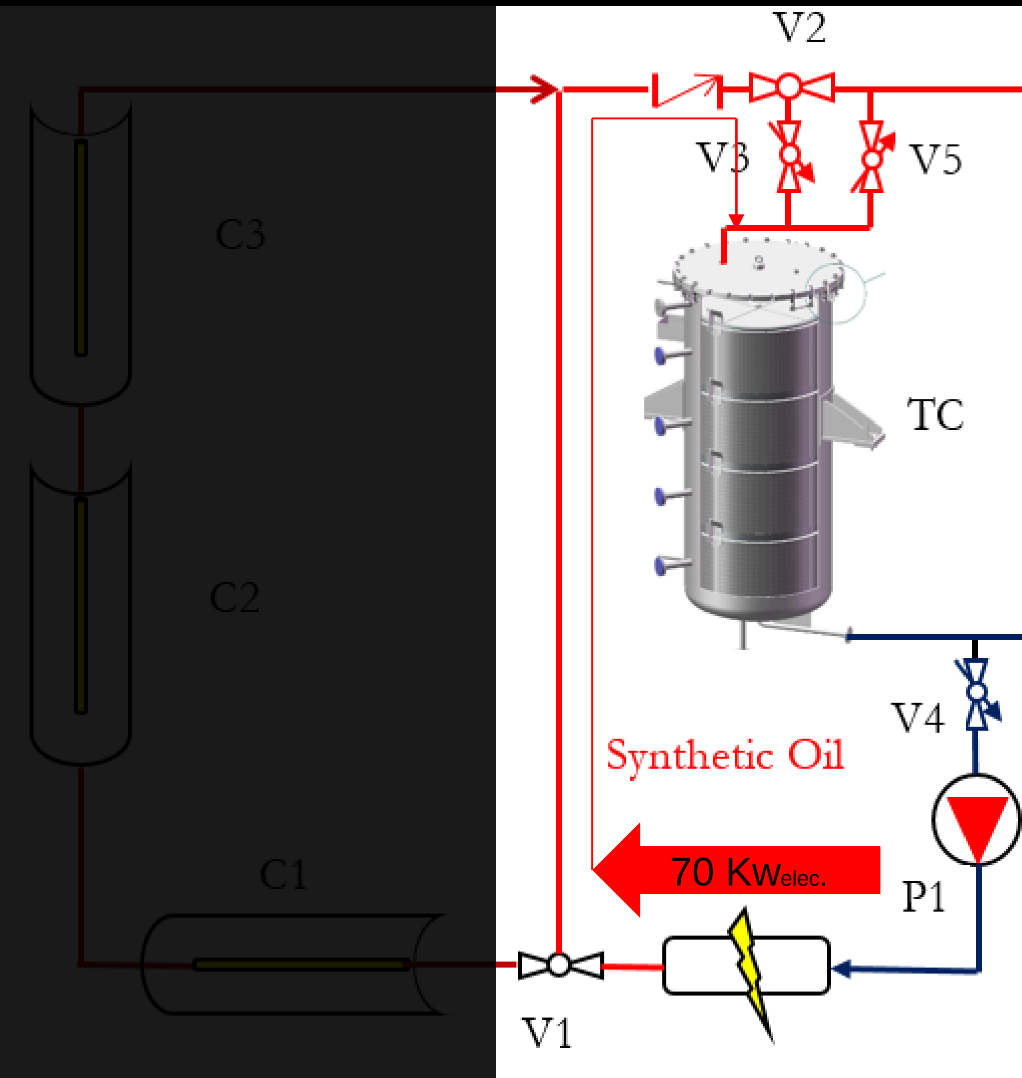
Degraded discharged energy.



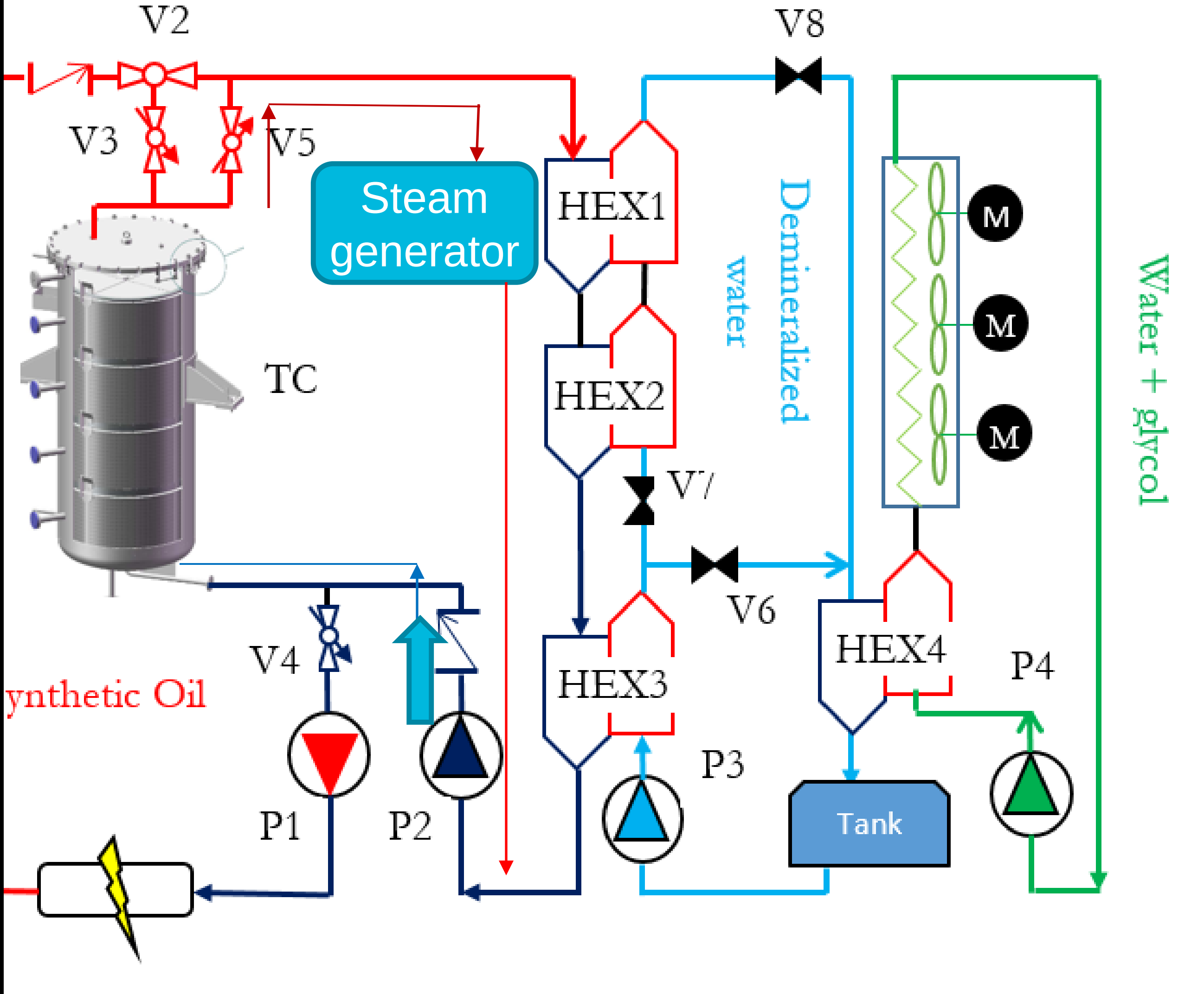
- PCM layer design
- Experimental evaluation
  (latent-sensible TES one-tank)
- Model (latent-sensible TES one-tank)

MicroSol-R Odeillo (PROMES)

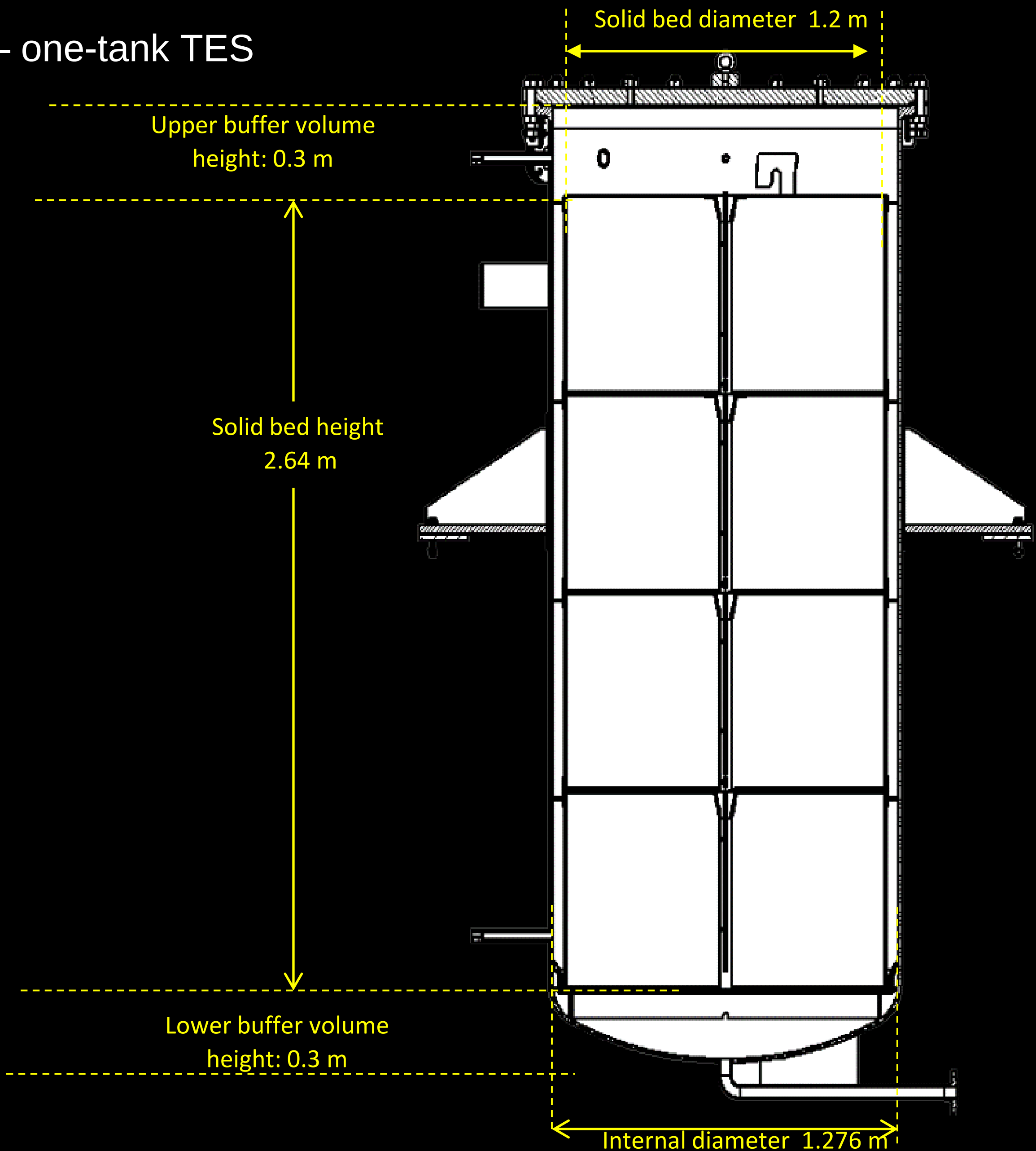
MicroSol-R -Charging circuit



MicroSol-R -Discharging circuit



MicroSol-R – one-tank TES



Design Constraints

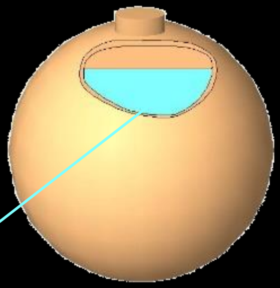
- Alumina spheres (continuation to previous work)

Design Constraints

- Alumina spheres (continuation to previous work)
- Operating temperature 300 °C - 220 °C (design)
- HTF Jarytherm® DBT 0 °C - 350 °C (design)

Combining PCM layer to alumina spheres TES – PCM material

✓ PCM $T_{melting}$ 300ºC.

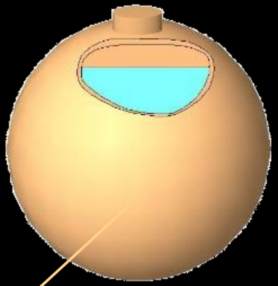


$NaNO_3$ $T_{melting}$ (306ºC - 310ºC)

[17] Mohamed et al. [18] Pincemin et al.

Combining PCM layer to alumina spheres TES – envelope material

- ✓ PCM $T_{melting}$ 300ºC - 310ºC.
- ✓ Envelope compatible with PCM.



$NaNO_3$ $T_{melting}$ (306ºC - 310ºC)

Stainless Steel (304&316) $NaNO_3$ up to 350ºC

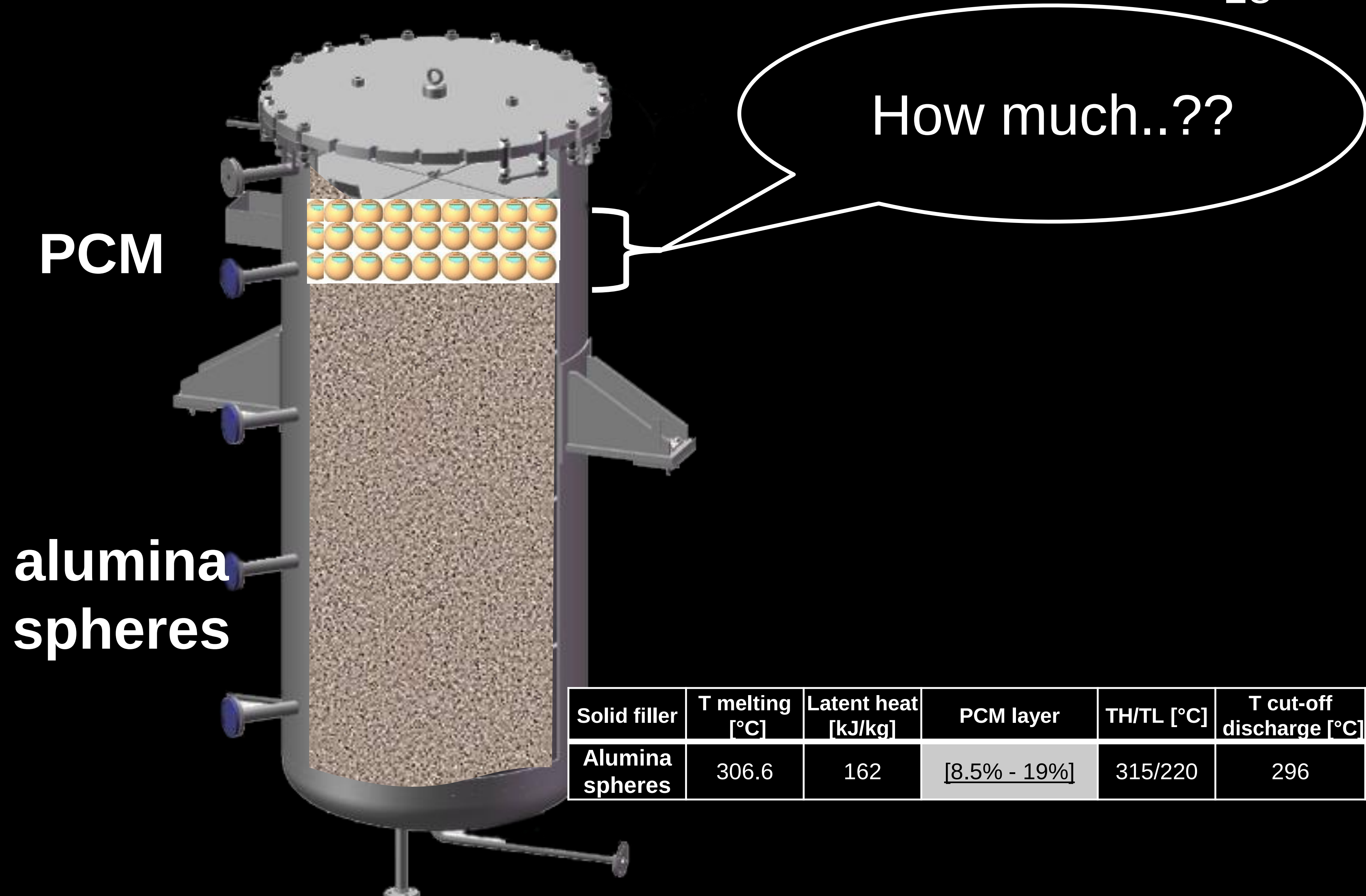
[20] Kuravi et al.

[21] Goods et al.

Envelope

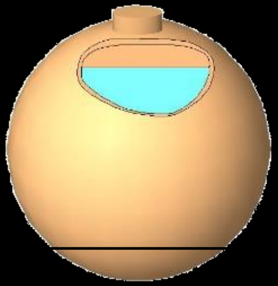
- Mechanical and Thermal stability.
- Good for heat transfer.
- Corrosion resistance. [19] Riffat et al.

Combining PCM layer to alumina spheres TES – PCM layer size



Solid filler	T melting [°C]	Latent heat [kJ/kg]	PCM layer	TH/TL [°C]	T cut-off discharge [°C]
Alumina spheres	306.6	162	[8.5% - 19%]	315/220	296

Combining PCM layer to alumina spheres TES – PCM layer Producibility



Number of spheres

110555

11750

3305

1359

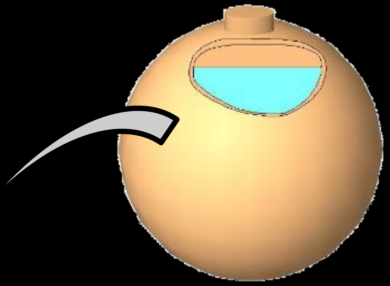
Manufacturers and their specifications of encapsulated PCMs.

Trademark name/ Industry	PCM (s)	Shell material (s)	Container (s)	Average container size	Application (s)
Cristopia	Eutectic salts	Polyolefin	Spherical balls	77 mm	Industrial refrigeration, building conditioning
ClimSel/climator	Sodium acetate, sodium sulphate	–	Pouches	–	Medicine transportation, clothing, air-conditioning, electronic cooling, fire protection
Rubitherm	Paraffin, salt hydrate in granulate, powder and compound forms	Aluminum, plastic	Box, bag	–	Storage and transport of food, medical equipments, storage materials for textile
Latest™/ TEAP Energy	Glauber's salt, soda ash, sodium acetate and paraffin wax	Aluminum, steel and polyethylene	Bottles, balls	25.4 mm	Hot pads and solar heating, telecom enclosure, back-up air-conditioning, cold storage
PCM Products Ltd.	Eutectics, salt hydrates, organic materials, and high temperature salts	Rubber, HDPE plastic	Tube, ball, pouches, plate	40 mm	Space International space station, automotive passive cooling, solar heating and heat recovery
MPCM/Microtek Laboratories Inc.	Paraffin	polymer	–	17–20 μm	Active wear clothing, woven and non-woven textiles, building materials, packaging, and electronics
Micronal®/BASF	Paraffin wax	Polymer	Microcapsules impregnated with gypsum wall boards	5 μm	Building conditioning, surface cooling
DuPont™ Energain™	Paraffin wax	Aluminum	Wall panels	–	Building conditioning, fire protection
Aegis	Inorganic salts	High density polyethylene	Panels, spherical balls, pouches	75 mm ball dia., 145 mm × 260 - mm size pouch	Cold storage, boilers, solar water heaters, transport of blood, frozen food, fruits and vegetables etc.

[23] SALUNKHE et al.

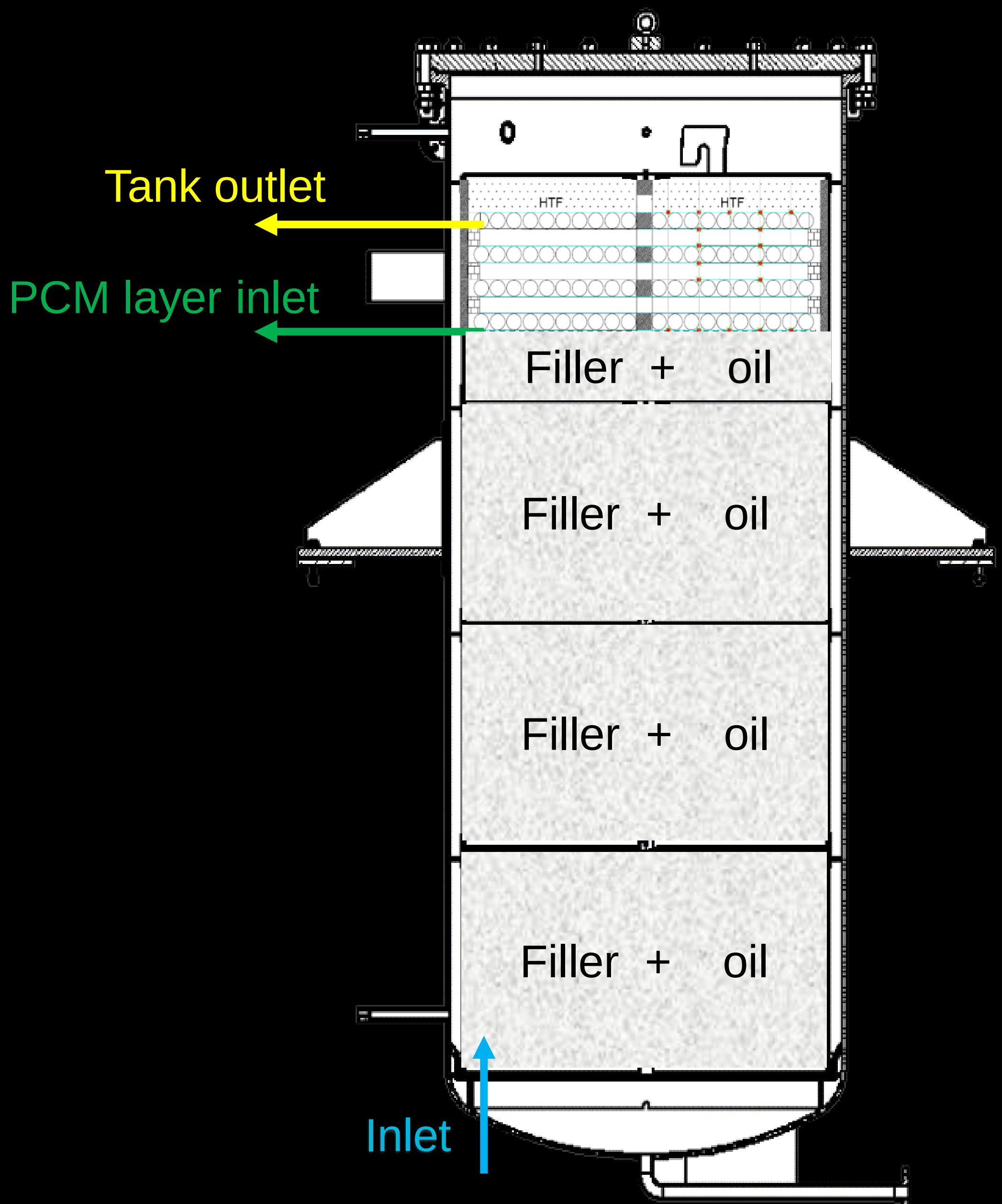
Combining PCM layer to alumina spheres TES – PCM layer final design

PCM vol. ratio 8.5% → 5.5% (budget limit)

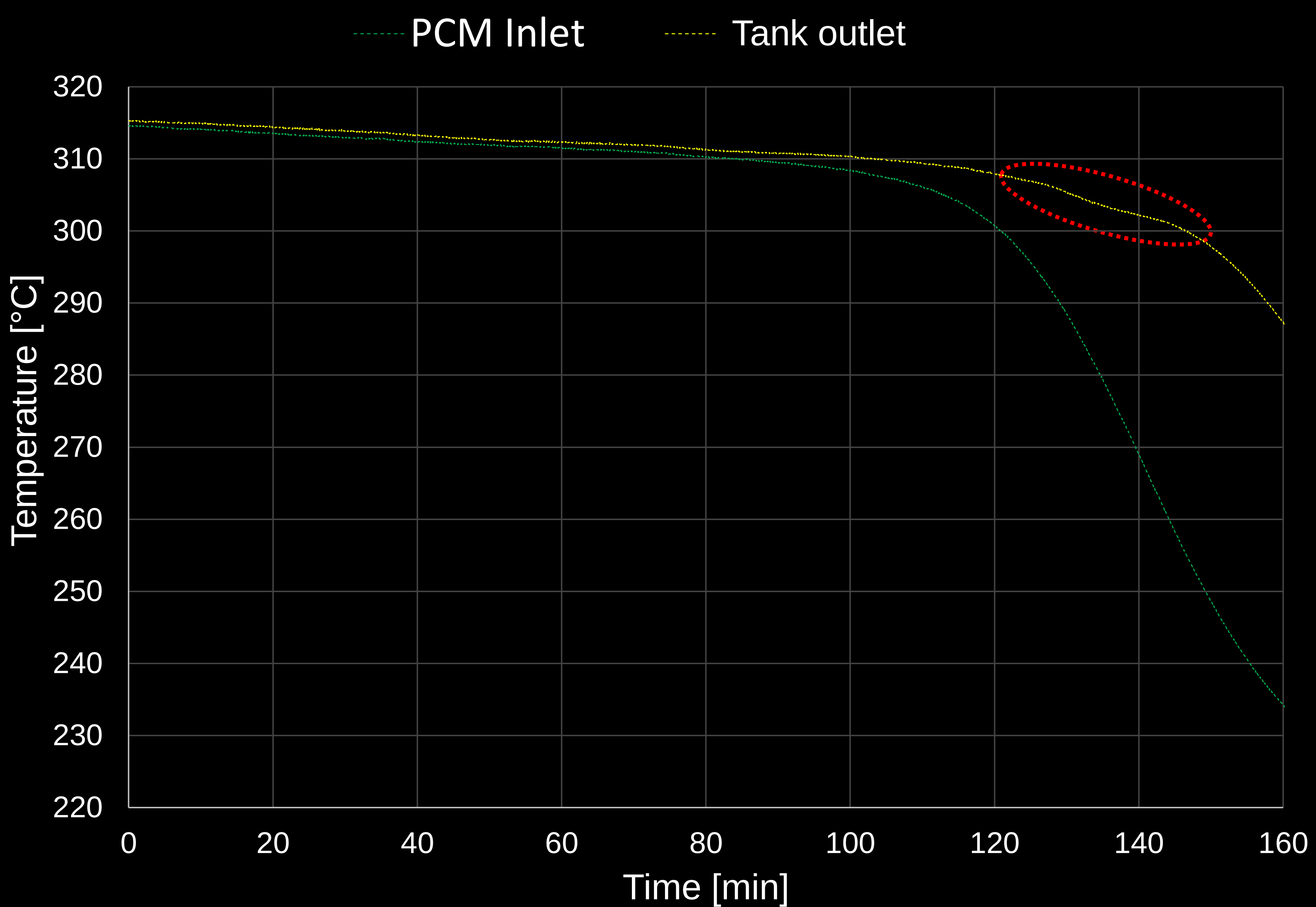


Combining PCM layer to alumina spheres TES – PCM layer storage material

Combining PCM layer to alumina spheres TES - Discharge thermocouples position



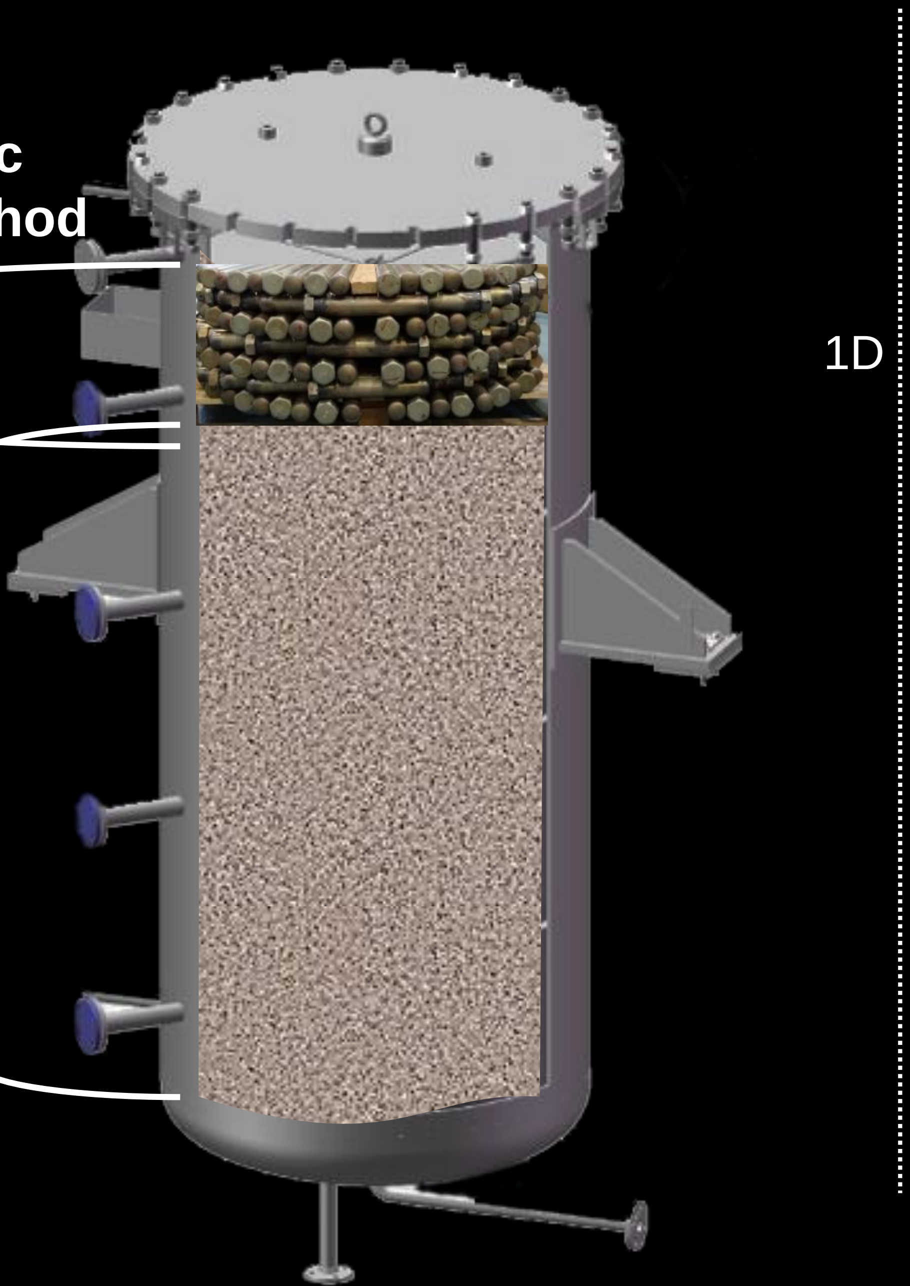
Combining PCM layer to alumina spheres TES - **Discharge 1600 [kg/h]** 315 → 220 °C



Summary

Dispersion –Concentric enthalpy porosity Method

Continuous -Solid



Combined Model PCM-Tubes/Sensible – model's Inputs

PCM vol. ratio 5.5%

$\varepsilon_{\text{pcm-section}}$ =0.508

7 rows of tubes are ~86.5% filled

Tube 48.3 dia. SS304 1.6 mm

$$\left(\rho C_p\right)_{eff-PCM} = \frac{m_{PCM}C_{PH-PCM} + m_{env.}C_{env.}}{V_{Tubes}}$$

[26] Zanganeh et al.

Row	m_{env} [kg]	m_{PCM} [kg]	V_{tube} [m³]	Filling ratio
1	34.72	48.12	0.031	86.63%
2	34.72	48.25	0.031	86.86%
3	34.71	48.07	0.031	86.51%
4	34.72	48.29	0.031	86.87%
5	34.72	48.21	0.031	86.78%
6	34.70	48.10	0.031	86.59%
7	34.69	48.21	0.031	86.80%
Total	242.98	337.24	0.22	

Combined Model PCM-Tubes/Sensible - model's Inputs

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[26] Zanganeh et al.

$$\frac{k_{p-eff}}{k_{PCM}} = 0.18 Ra^{0.25}$$

[25] Wu et al.

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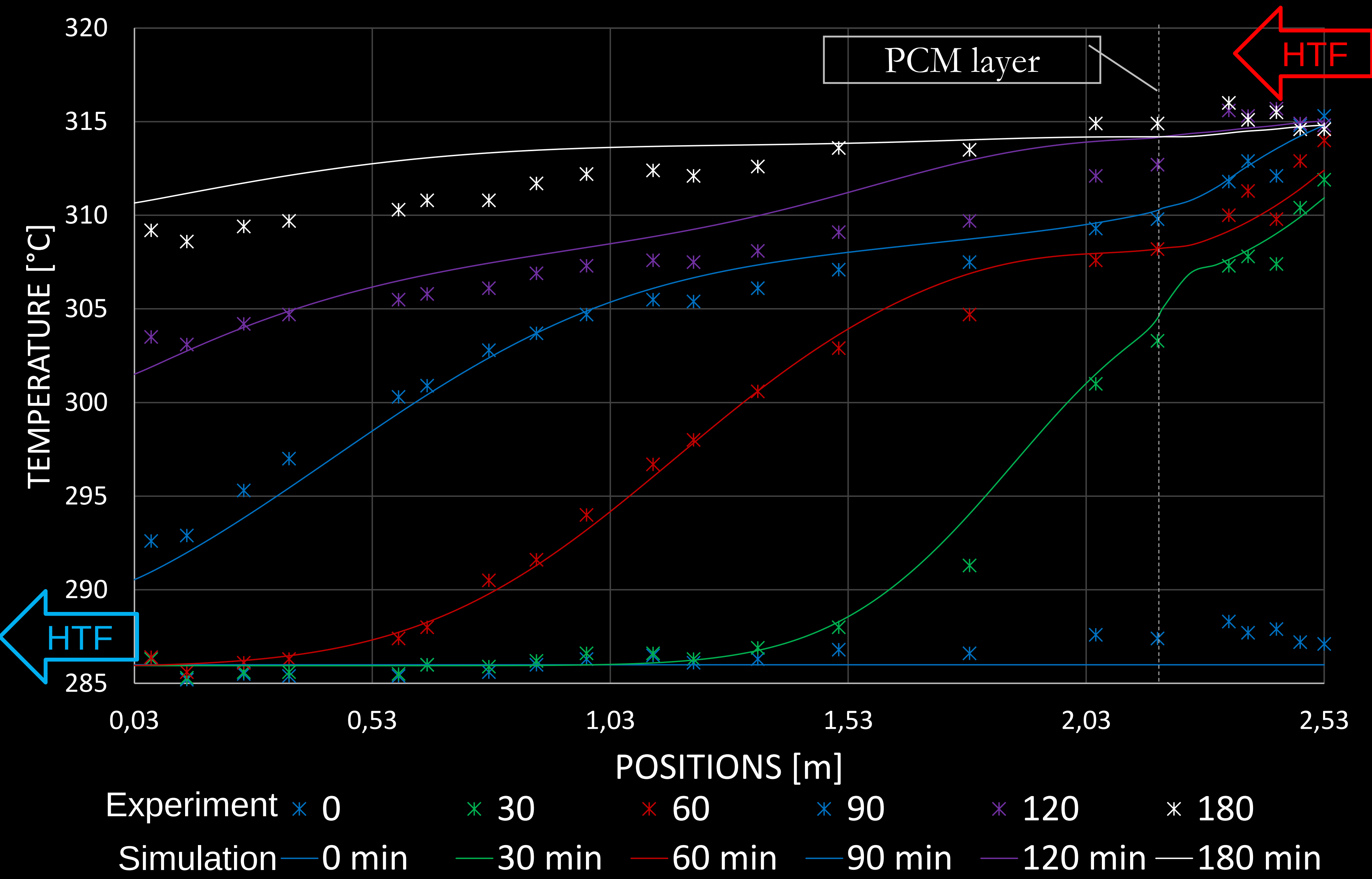
6	34.70	48.10	0.031	86.59%
7	34.69	48.21	0.031	86.80%
Total	242.98	337.24	0.22	

Negligible envelope thermal resistance

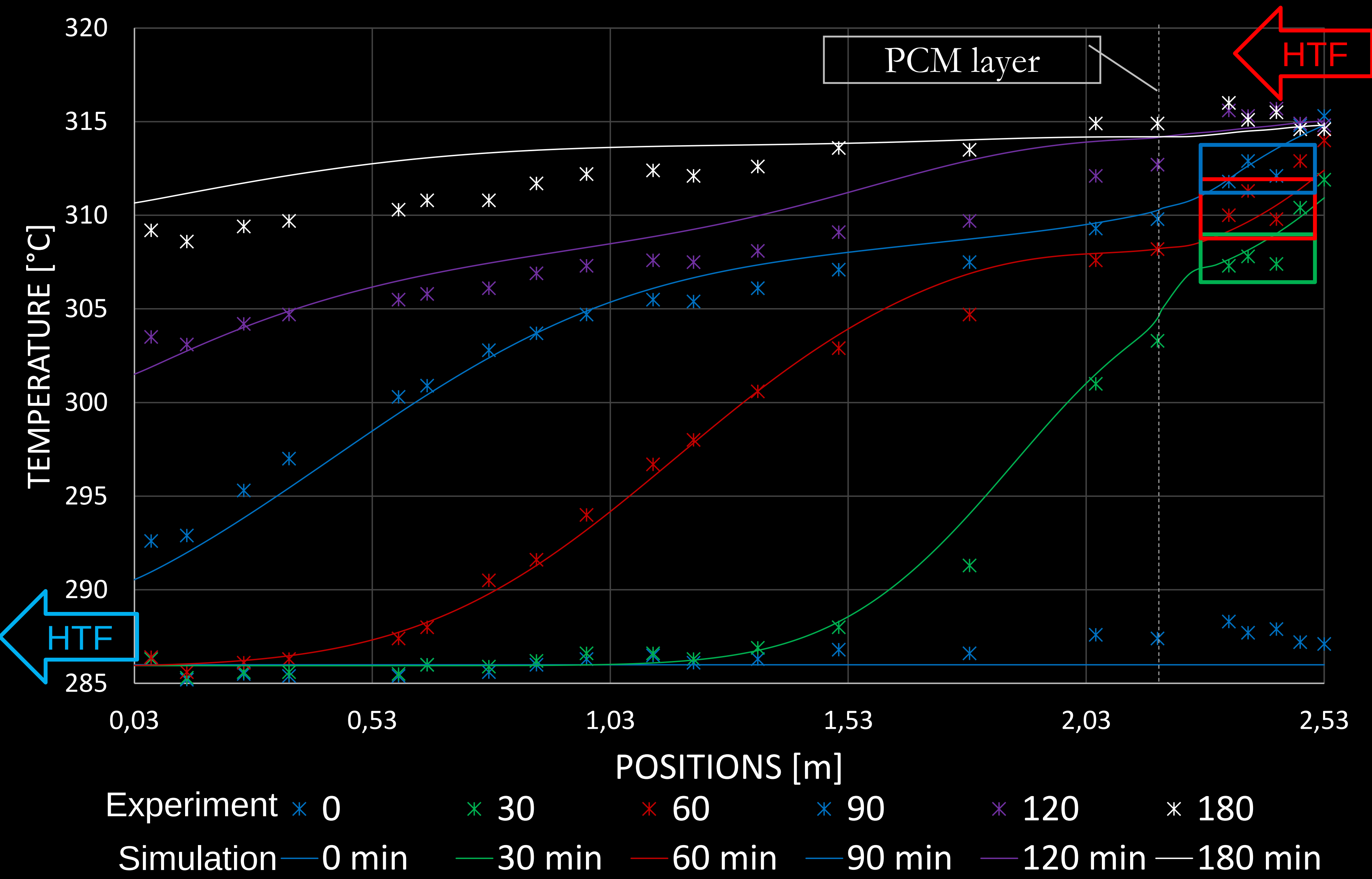
[26] Zanganeh et al. [27] Ismail et al.

Process	Charge	Discharge
Mass flow rate [kg/h]	2700	2000
Temperature range [ºC]	286 – 315	312 - 226

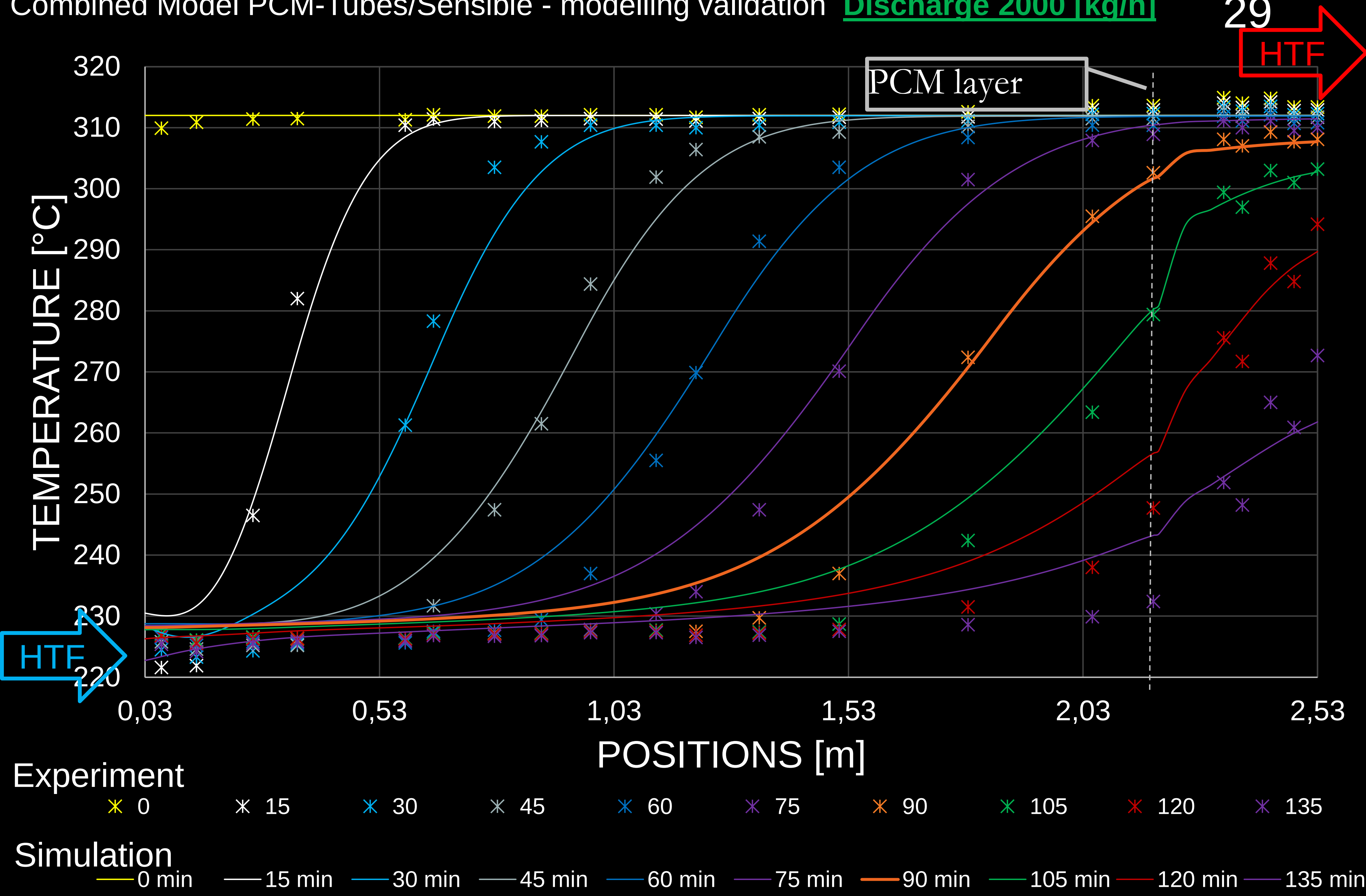
Combined Model PCM-Tubes/Sensible - modelling validation **Charge – 2700 [kg/h]**



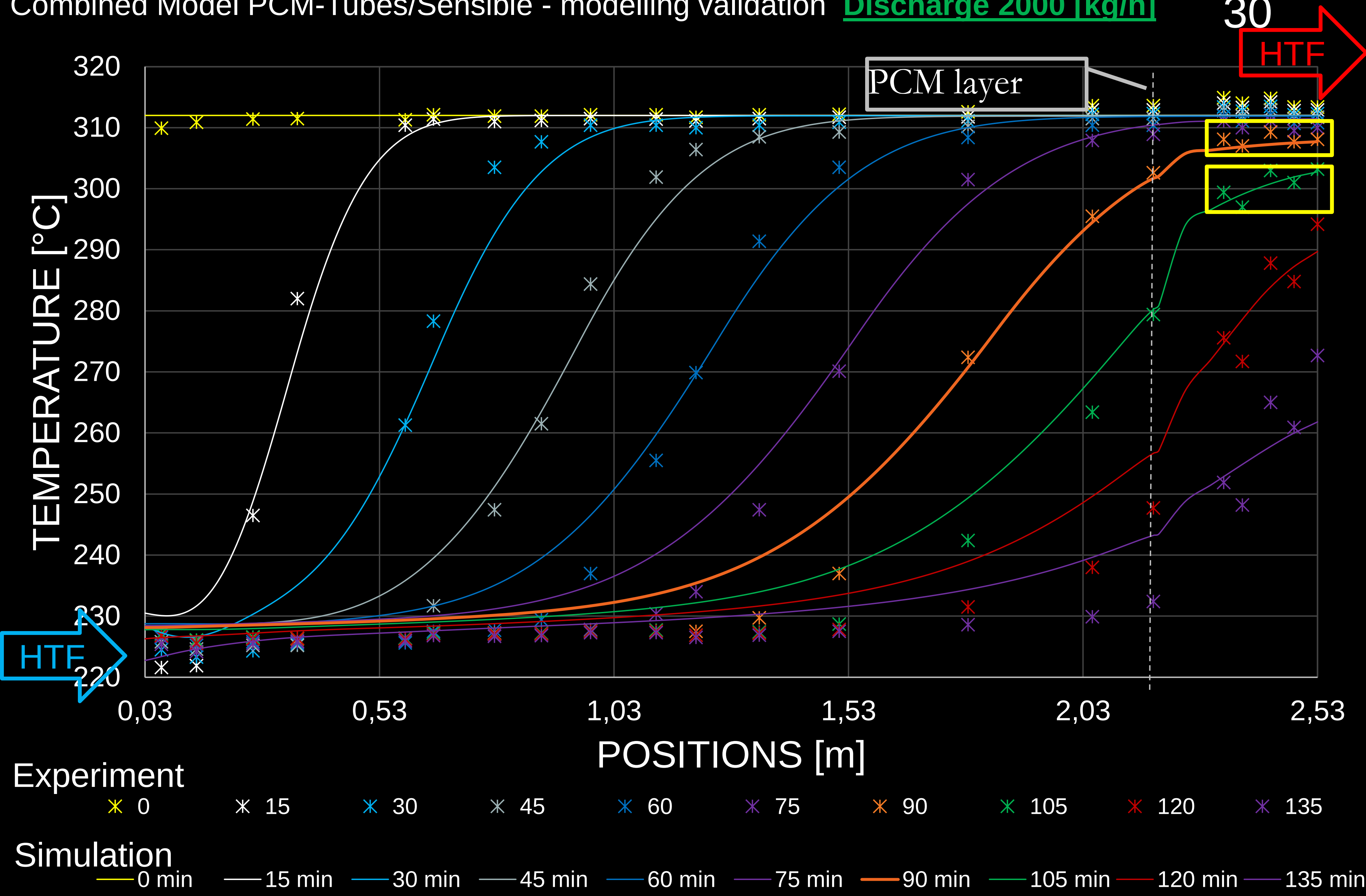
Combined Model PCM-Tubes/Sensible - modelling validation **Charge – 2700 [kg/h]**



Combined Model PCM-Tubes/Sensible - modelling validation **Discharge 2000 [kg/h]**



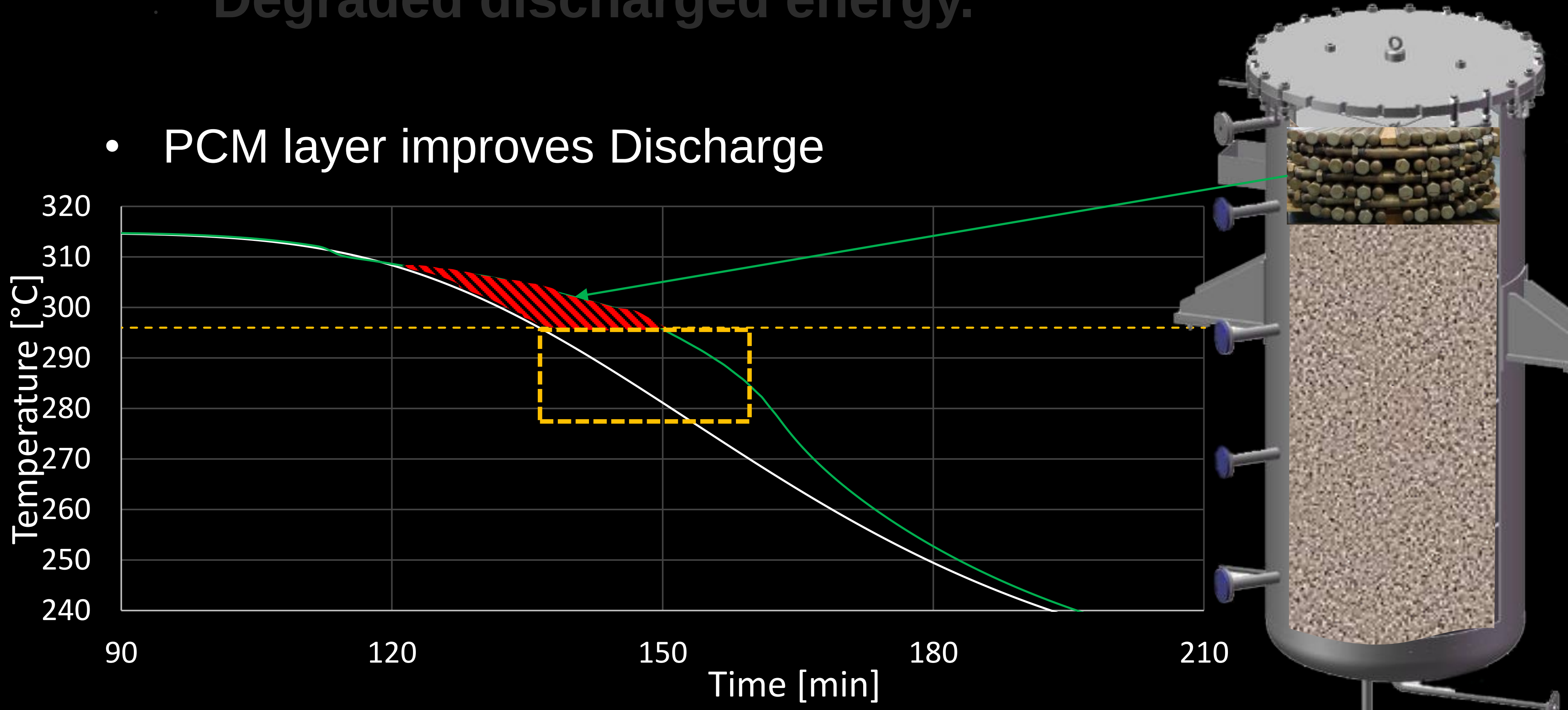
Combined Model PCM-Tubes/Sensible - modelling validation **Discharge 2000 [kg/h]**



Conclusions

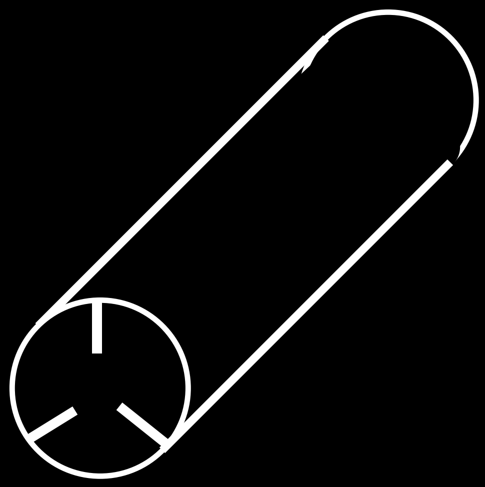
Overcome performance drawbacks
Degraded discharged energy.

- PCM layer improves Discharge



General perspectives

Improve PCM layer thermal performance



Thank you for your listening

Valorization

Keilany, M. A., Milhe, M., Bezian, J. J., Falcoz, Flamant, G., & Fasquelle, T. (2018). Vitrified Asbestos Waste Used as Filler Material in Thermocline Storage Tank. In WasteEng2018 Conference (pp. 244–253). 7th international Conference on Engineering for Waste and Biomass Valorisation.

Keilany, M. A., Milhé, M., Bézian, J., Falcoz, Q., & Flamant, G. (dilos sa etsaw deifirtiv fo noitaulave latnemirepxE .(2020 fo lanruoJ .sisylana cirtemarap htiw egarots ygrene lamreht enilcomreht ni desu srellifEnergy Storage, ,(yraurbeF)29 2020.101285.tse.j/10.1016/gro.iod//:sptth .101285

Ongoing

M. A. KEILANY S. VANNEREMM M. MILHÉ, Q. FALCOZ, J-J. BÉZIAN, G. FLAMANT
EXPERIMENTAL AND NUMERICAL STUDY OF PILOT-SCALE THERMAL ENERGY STORAGE THAT COMBINES LATENT TO SENSIBLE MATERIALS CHARGED WITH A HOT OIL

M. A. KEILANY M. MILHÉ, Q. FALCOZ, J-J. BÉZIAN, G. FLAMANT
GENERAL SIZING APPROACH OF A LAYER OF PHASE CHANGING MATERIAL (PCM) IN A COMBINED LATENT TO SENSIBLE HEAT THERMOCLINE THERMAL ENERGY STORAGE

M. A. KEILANY M. MILHÉ, Q. FALCOZ, J-J. BÉZIAN, G. FLAMANT
EXPERIMENTAL RESULTS OF COMBINING TUBE-ENCAPSULATED PHASE CHANGING MATERIAL (PCM) LAYER TO ALUMINA SPHERES FILLED THERMOCLINE WITH A NUMERICAL INVESTIGATION OF THE PCM ADDED VALUE

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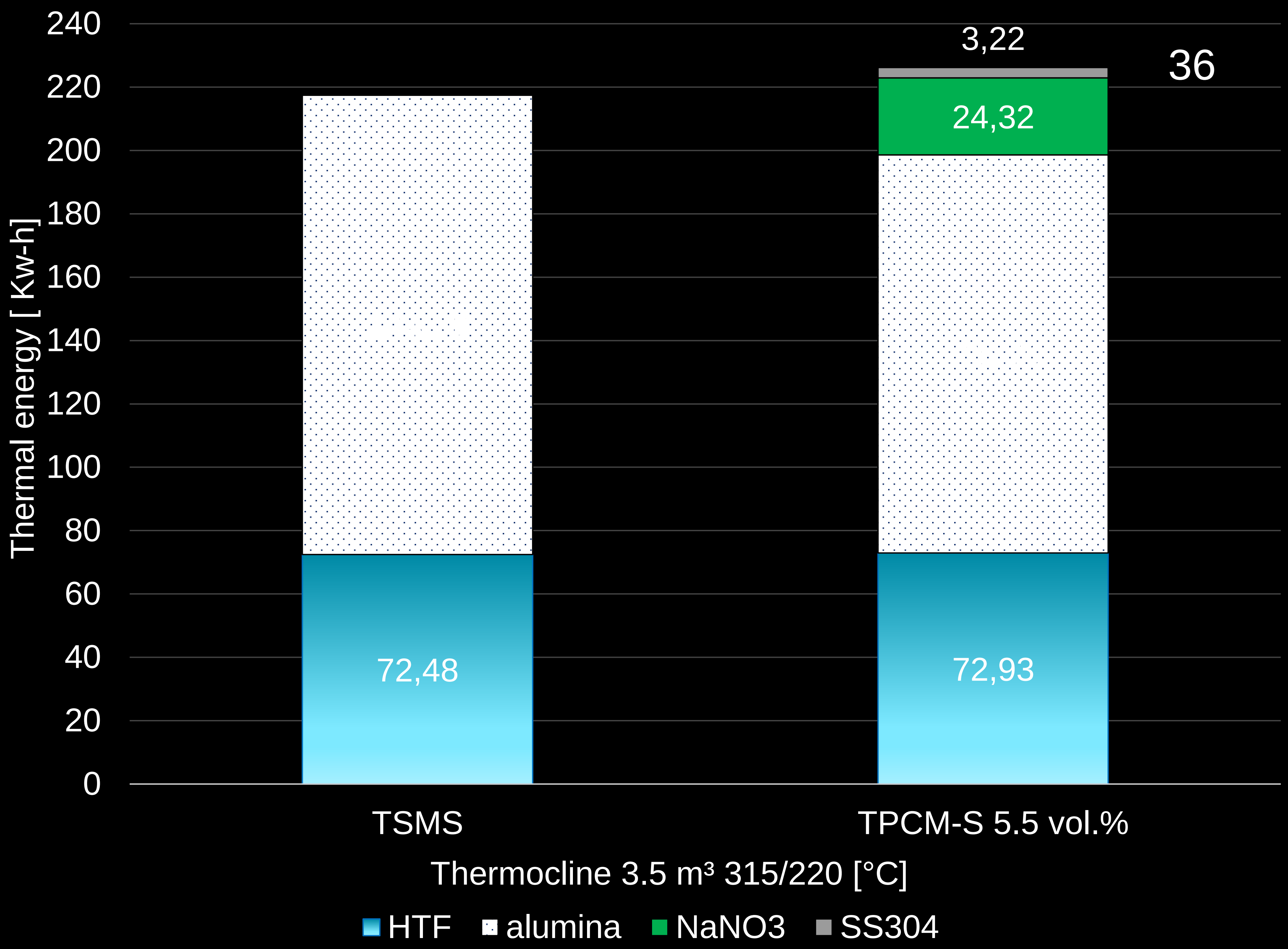

240
220
200
180
160
140
120
100
80
60
40
20
0
Thermal energy [Kw-h]
3,22
24,32
72,48
72,93
TSMS
TPCM-S 5.5 vol.%
Thermocline 3.5 m³ 315/220 [°C]
HTF
alumina
NaNO3
SS304