Innovative Latent Heat Thermal Storage Elements Design Based on Nanotechnologies

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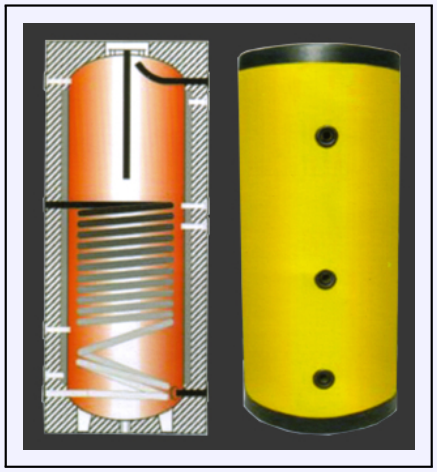
Outlines

Introduction

SHS vs LHS

Sensible Heat Storage:

- Well known system;
- Storage material is the work "material";
- Storage material is very cheap (water);
- Low energy density;



Latent Heat Storage:

- High energy density;
- Storage material isn't the work material;
- Storage material can be expansive;
- Corrosive behaviour;
- Instabilities;

Example: SHS vs LHS

Sensible:

$$Q = mc_p(T_f - T_s)$$

for example, $1kg$ of water ($c_p = 4186 J/kgK$) between 50 and $70°C$ may store:

$$Q = 1 \cdot 4186 \cdot (70 - 50) = 83720J \approx 84kJ$$

Latent:

$$Q = mc_p(T_m - T_s) + m\lambda + mc_p(T_f - T_m)$$

for example, $1kg$ of Sodium Acetate ($T_m = 58°C$, $c_p = 3600 J/kgK$, $\lambda = 288000 J/kg$) between 50 and $70°C$ may store:

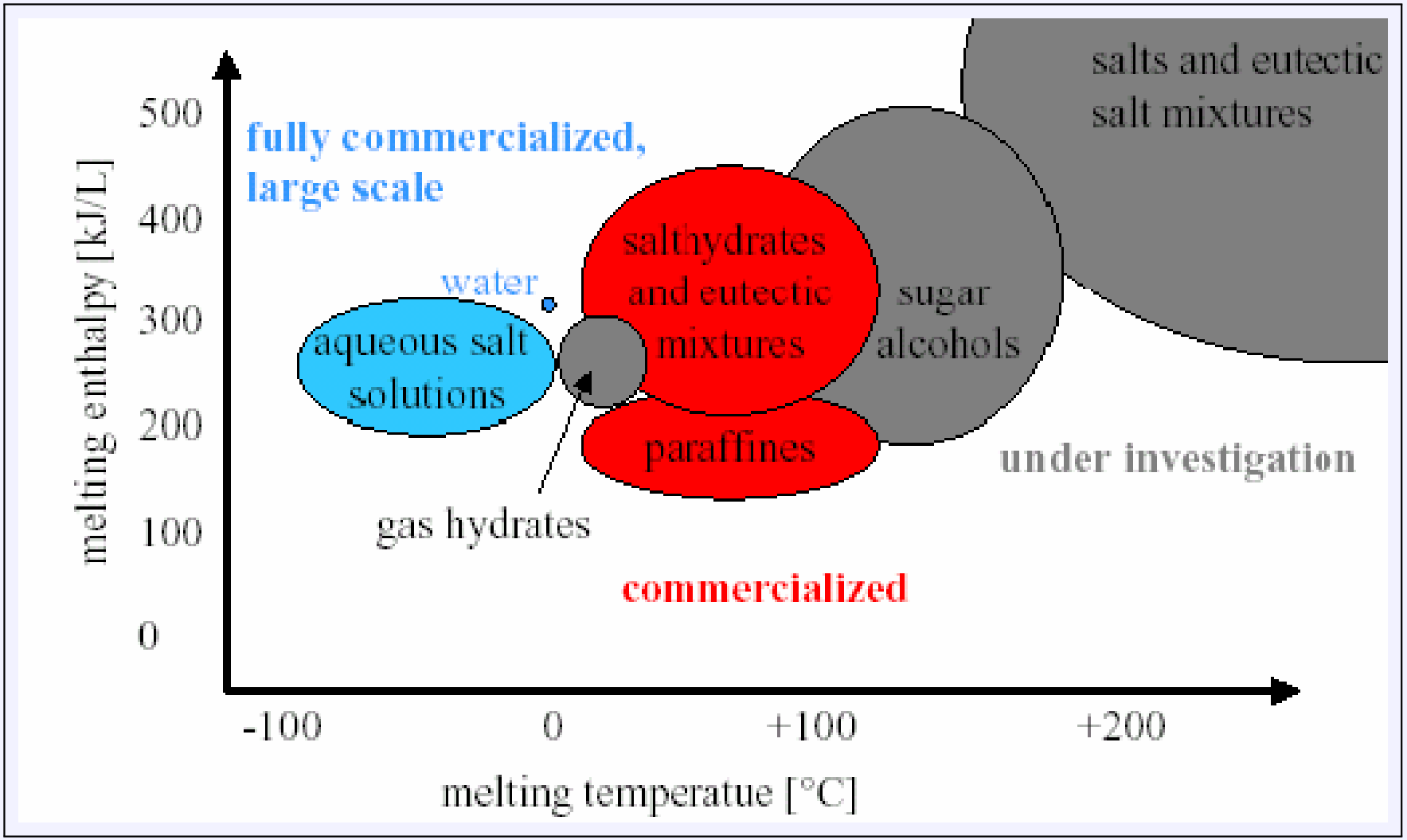
$$Q = 1 \cdot 3600 \cdot (58 - 50) + 1 \cdot 288000 + 1 \cdot 3600(70 - 58) = 360000J = 360kJ$$

$$\frac{Q_{LHS}}{Q_{SHS}} \approx 4$$

Energetic VS Heat Transfer Problem

- Huge storage potentialities $\frac{Q_{LHS}}{Q_{SHS}} \approx 4$
- Very poor conductivity $(0.2 \div 0.7 W/mK) \Rightarrow$ Very inefficient heat transfer mechanism;

Overview


salts and eutectic salt mixtures
fully commercialized, large scale
salthydrates and eutectic mixtures
water
sugar alcohols
aqueous salt solutions
paraffines
under investigation
gas hydrates
commercialized
500
400
300
200
100
0
melting enthalpy [kJ/L]
-100
0
+100
+200
melting temperatue [°C]

Salt-hydrates VS Paraffins

Salt-hydrates:

- Generally cheap;
- Good latent heat/density;
- Well defined phase change temperature;
- Non-flammable;
- Need careful preparation;
- Need additives to stabilise for long term use;
- Prone to supercooling;
- Can be corrosive to some metals;

Paraffins:

- Simple to use;
- Non-corrosive;
- No supercooling;
- Generally more expensive;
- Lower latent heat/density;
- Often give quite broad melting range;
- Can be combustible;

LHS Boiler

Project Data

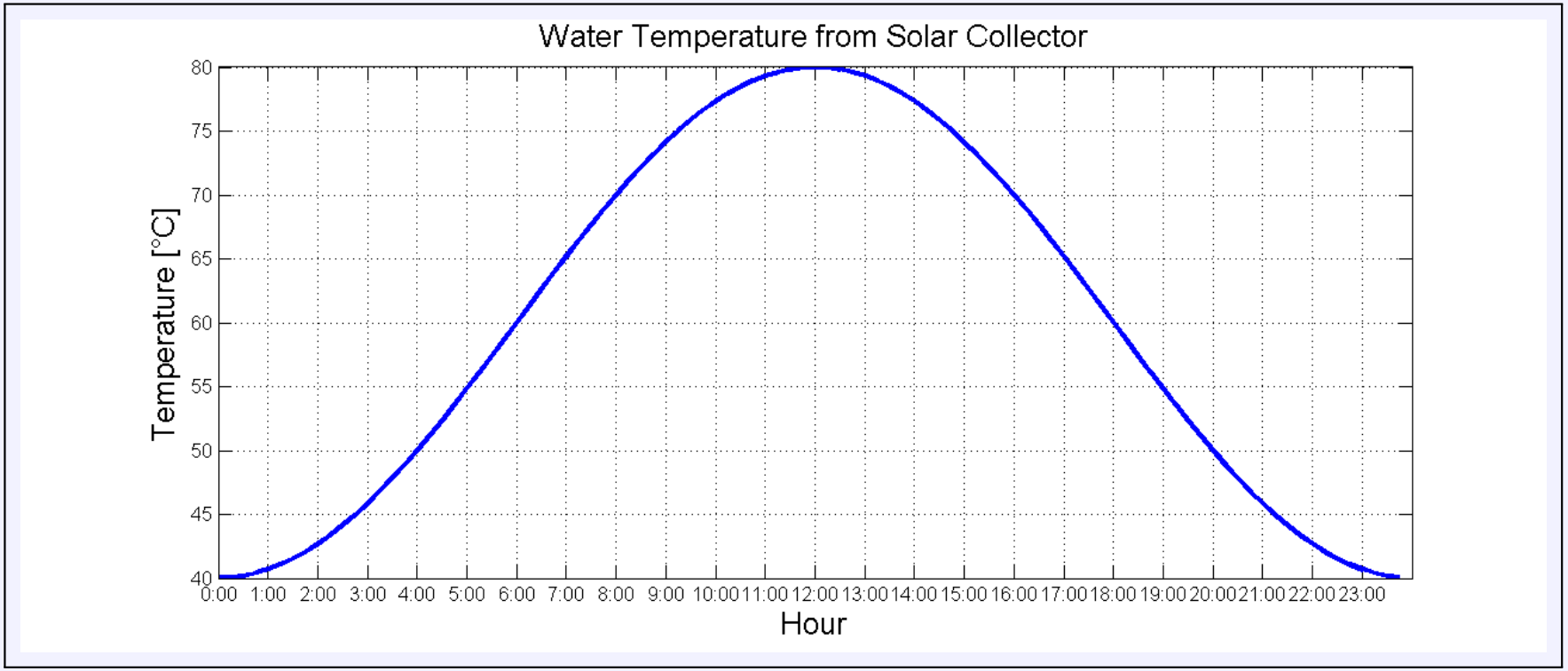
Plant Properties:

- $DHW = 200\ l/day$ (4 persons);
- Hot water from Thermal Solar Panels: $\dot{m} = 0.056 l/s$;
- Temperature from hydraulic grid: $15°C$;

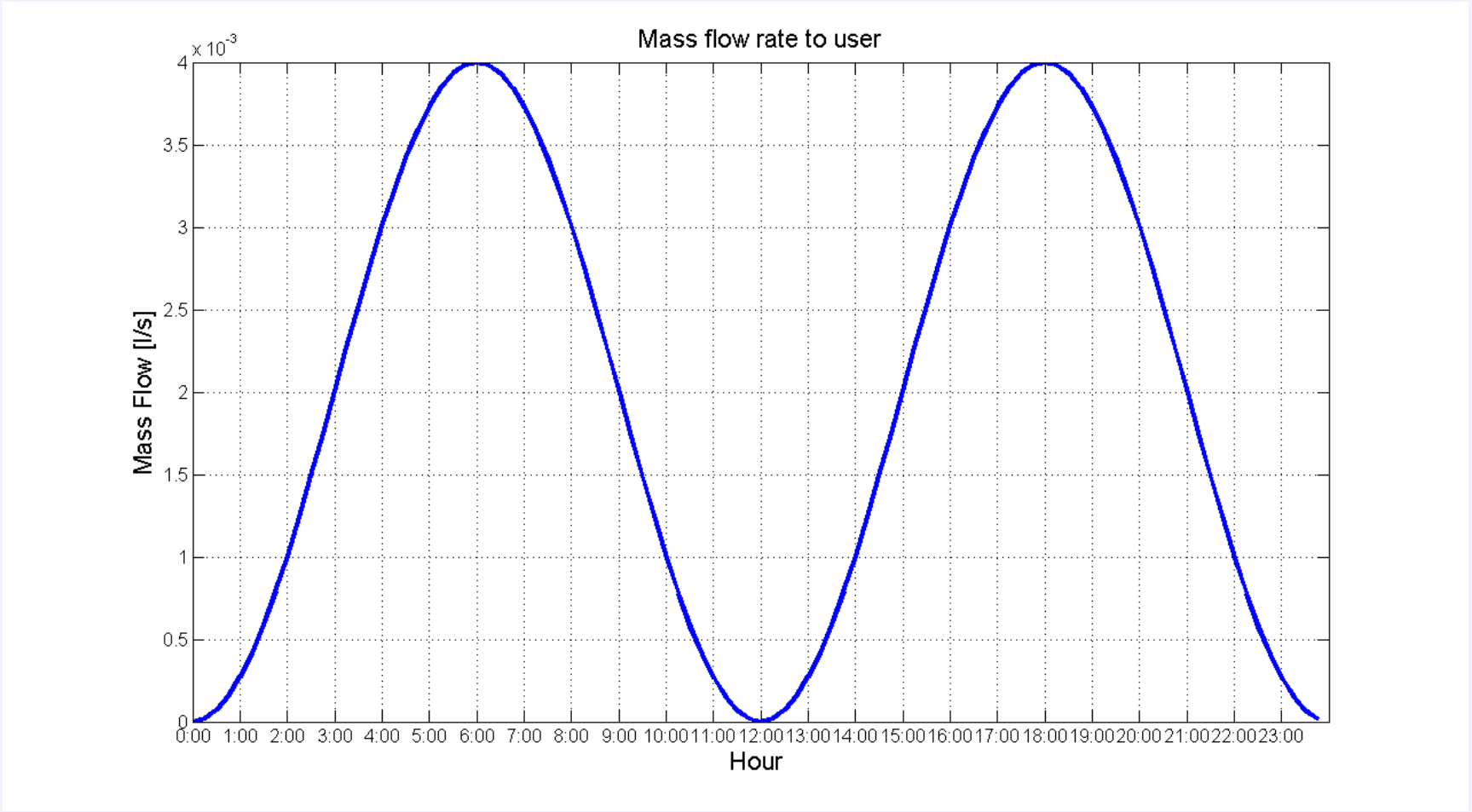
Boiler Properties:

- $T_{inside} = 50 \div 70°C$;
- $T_{surr} = 20°C$;
- $\alpha = 10 W/mK$;

Project Data

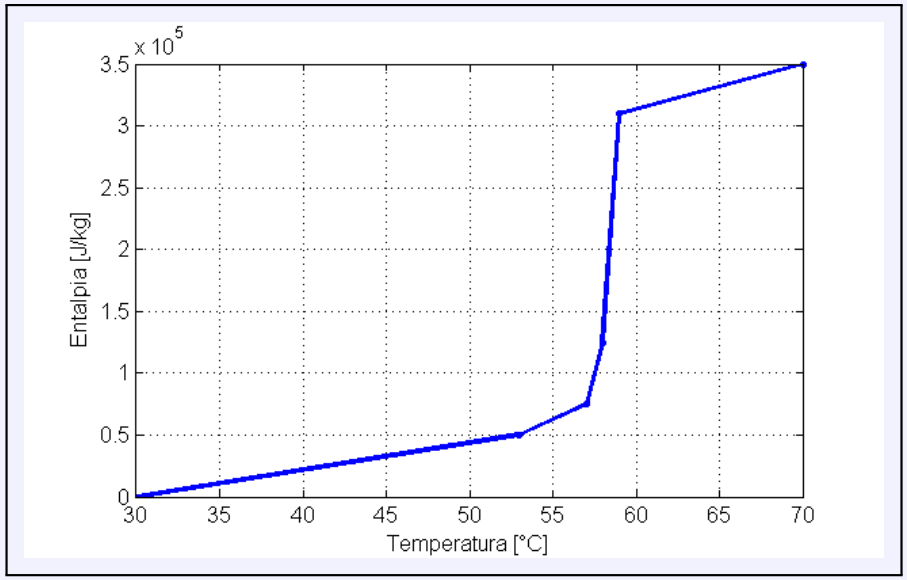


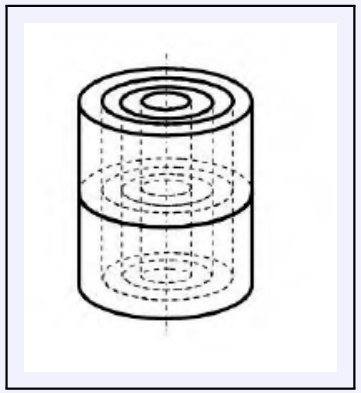
Project Data



Numerical Analysis

- C script;
- FVM;
- Implicit code;
- Enthalpy Method;
- PCM elements with onion-peel approach;
- Time step $30s$;
- Total Time $7\ days = 604800s$;
- CPU time $< 15s$;





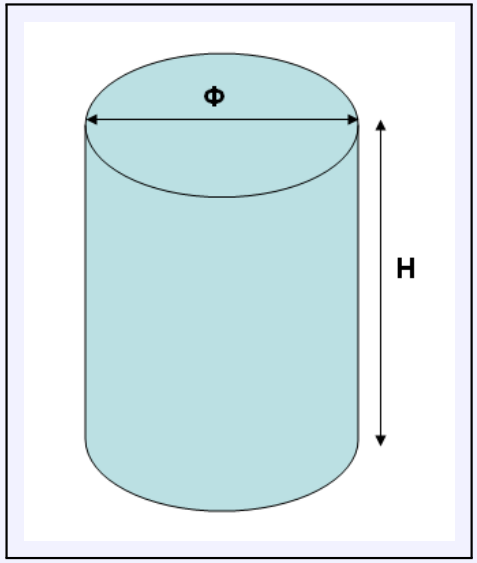
SHS Boiler

Water Properties:

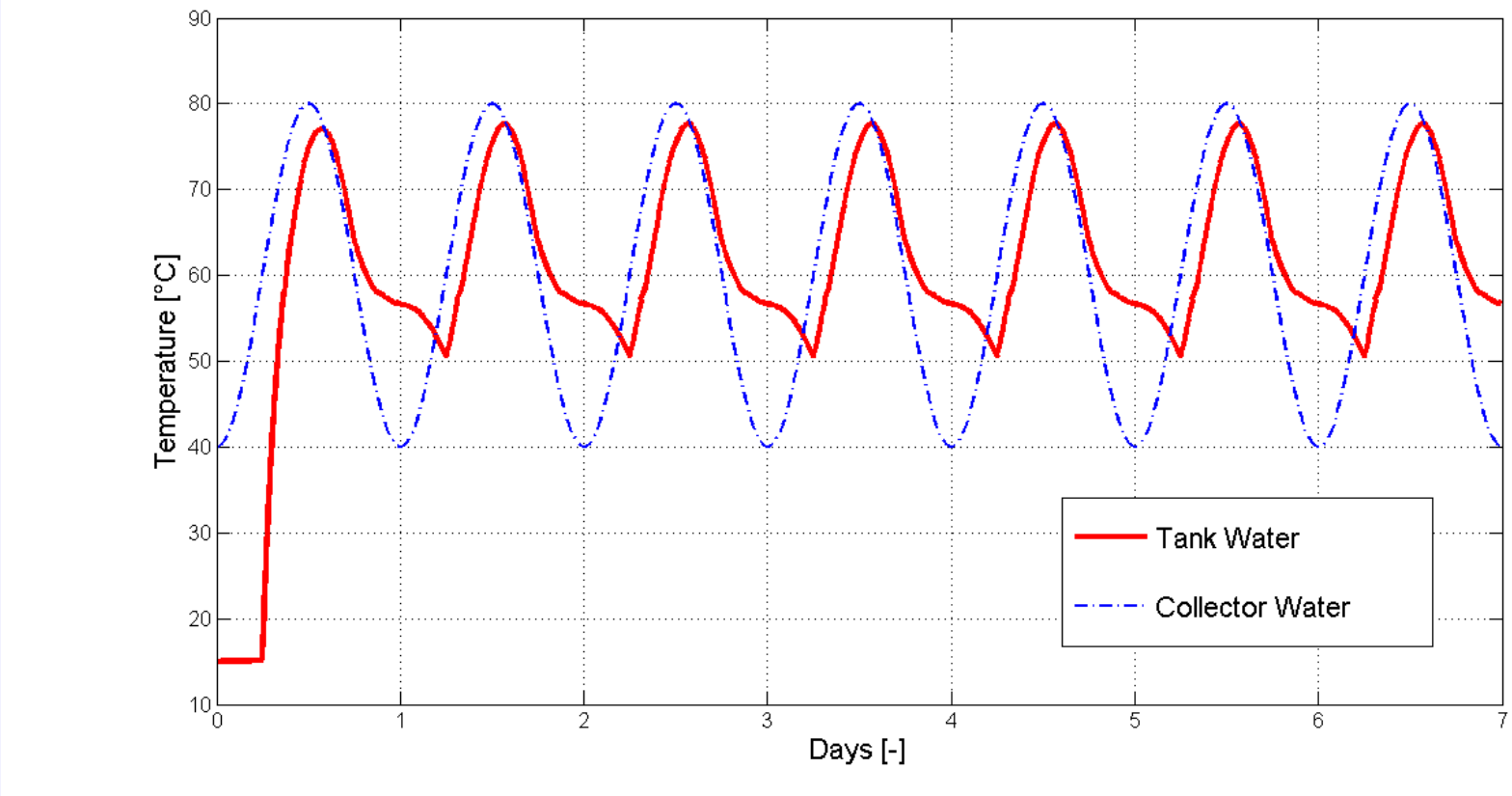
- $\rho_{H_2O,62} = 982 kg/m^3$;
- $c_p = 4188 J/kgK$;
- $k = 0.656 W/mK$;
- $Pr = 2.87$;
- $g\beta/\nu^2 = 2.54 \cdot 10^{10} (m^3 K)^{-1}$;

Boiler Properties:

- Cylindrical shaped;
- $\Phi = 0.7m$;
- $H = 0.8m$;
- $Volume = 308l$;
- $Mass = 302kg$;



SHS Boiler


Temperature [°C]
Days [-]
Tank Water
Collector Water
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7

PCM Container Properties

PCM Properties:

- Salt Hydrate $C58$ by Rubitherm;
- $T_m = 58 \pm 0.5°C$;
- $\rho = 1460 kg/m^3$;
- $\lambda = 288000 J/kg$;
- $c_p = 3600 J/kgK$;
- $k = 0.5 \div 0.7 W/mK$;

Elements Properties:

- Large external surface;
- Small dimension;
- N cylinders filled up with PCM;

Final Remarks

In conclusion:

- Using PCM elements it's possible storing large amount of energy in smaller volumes;
- Mass reduction of $30 \div 40\%$ of the system;
- Store energy for some days (good insulation);

Nano-doped PCMs

Tasks

- Problem: very low conductivity $(0.2 - 0.7W/mK)$;
- Improve heat exchange: optimizing surface (fins,..), doping with highly conductive materials (macro and micro);
- Drawback of doping: reduction of melting enthalpy;

If we use nano-doping?

Material and Experimental Setup

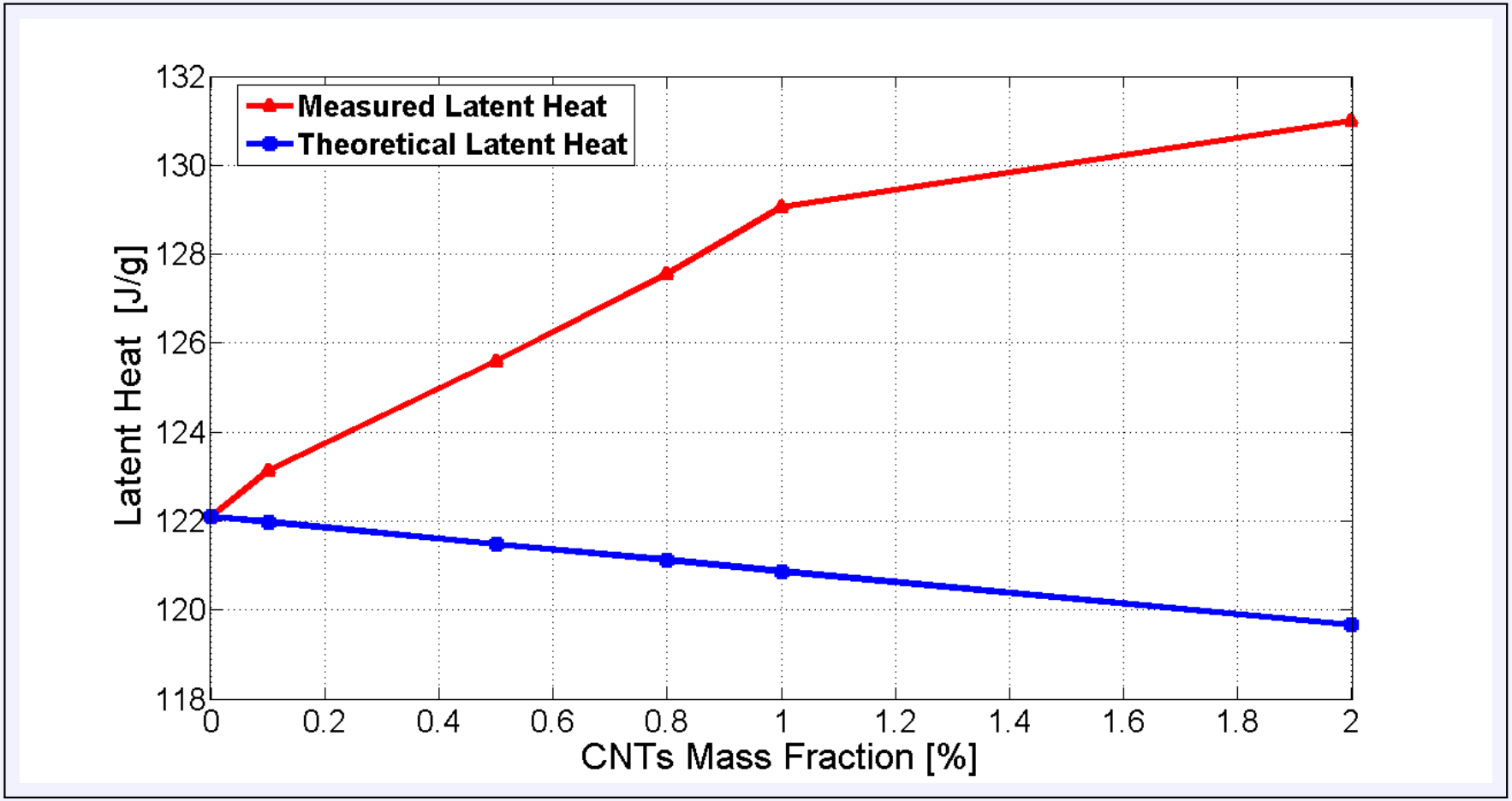
- Single Walled Carbon Nanotubes (by Helix Material Solution) with high purity (90%), diameter $\phi = 1.3\ nm$ and length $L = 0.5 - 40\ \mu m$,;
- Commercial Paraffin Wax, with melting temperature of $57°C$;
- Several mixtures (pure PW, $0.1\% - 0.2\% \ldots$ till 2% CNTs);
- 4 hours sonication at $75°C$;
- 24 hours cooling time at room temperature;
- DSC analysis (Q100) between $42°C$ and $70°C$;
- Ramp signal $2°C/min$;

Results

Table: DSC collected data

PCM	CNT mass Frac.	Measured Latent Heat	Enhancement	Theoretical Latent Heat
Pure PW	0	122.10 [J/g]	-	122.10 [J/g]
CNT 0.1	0.1%	123.13 [J/g]	0.84%	121.98 [J/g]
CNT 0.5	0.5%	125.60 [J/g]	2.87%	121.48 [J/g]
CNT 0.8	0.8%	127.55 [J/g]	4.46%	121.12 [J/g]
CNT 1	1%	129.05 [J/g]	5.69%	120.87 [J/g]
CNT 2	2%	131.00 [J/g]	7.29%	119.66 [J/g]

Results


Measured Latent Heat
Theoretical Latent Heat
Latent Heat [J/g]
CNTs Mass Fraction [%]
132
130
128
126
124
122
120
118
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Final Remarks

In conclusion:

- Nano-doping demonstrates an enhancement of latent energy storage of PCMs, unlike what happens with macro-doping; this improvement can be caused by intermolecular attraction between the molecules of nano-additives and wax;
- A similar enhancement is expected on the thermal conductivity;
- **Highly conductive nano-particles seem to be very good candidates for doping thermal storage materials.**

Thank you
for your attention

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