TESSe2B
the smart energy storage

Thermal Energy Storage Systems
for energy efficient building an integrated solution for residential building energy storage by solar and geothermal resources

Development of heat exchangers and PCM tanks for heating, cooling and domestic hot water

First Workshop & B2B Meeting

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European Commission

Main Objectives

- ✓ Design a modular concept of a thermal storage tank/container for the candidate PCMs.
- ✓ Design and optimize the Heat Exchanger for the candidate PCMs.

Initial concept design – Rectangular / Cuboid

Tank without supporting ribs

Tank with horizontal supporting ribs

Tank with horizontal and vertical supporting ribs

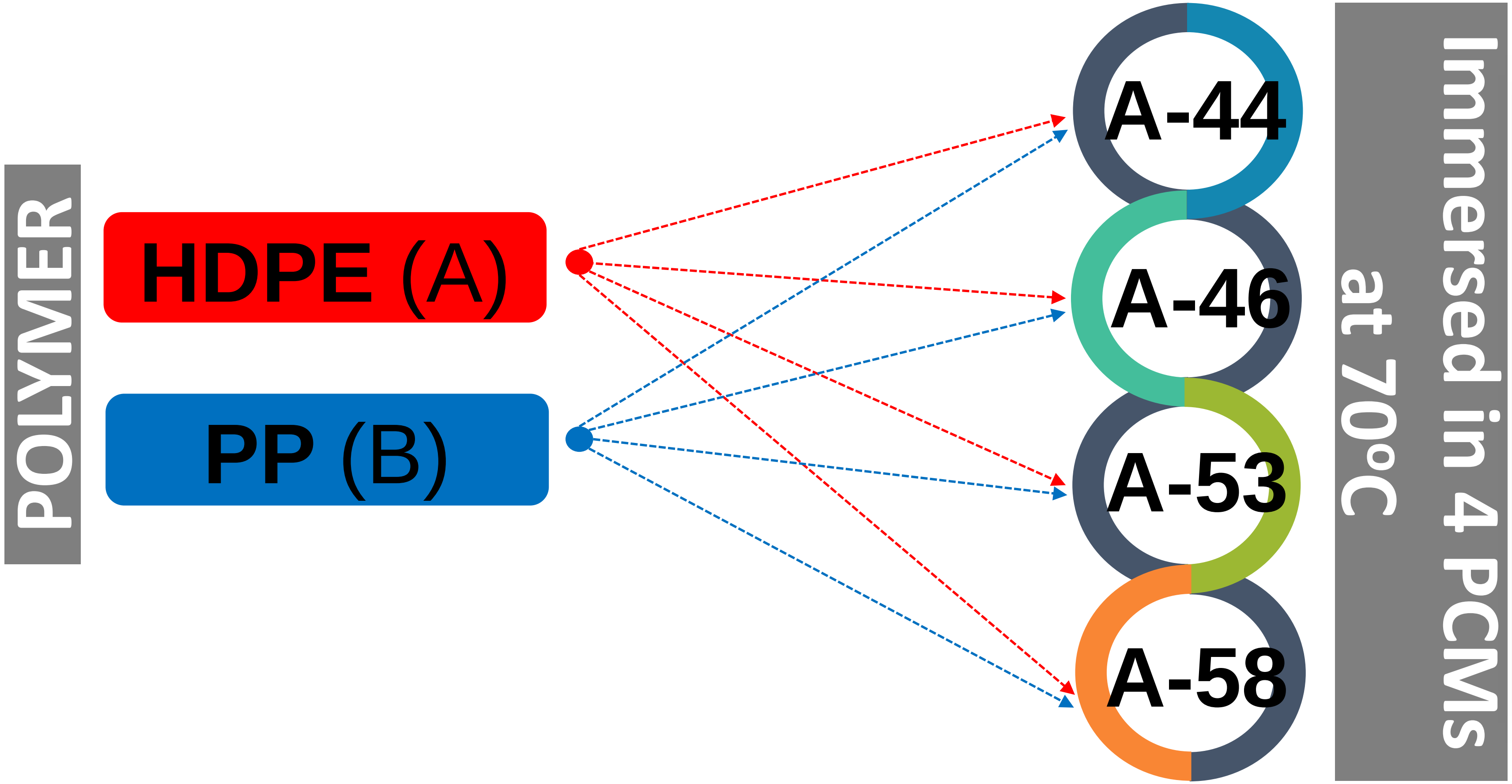
According to EN12573 standard

Tank Material – 3 main options

	HDPE	PP-H	GRPs
Long term operational temperature upper limit	**~75ºC Acceptable**	**~90ºC Acceptable**	**~100ºC Acceptable**
Compatibility with salt hydrates	**OK**	**OK**	**OK**
Compatibility with Paraffins	**experimental study ISO 175:1999**	**experimental study ISO 175:1999**	**OK**

Experimental studies in finalizing tank material

Immersion of HDPE and PP-H samples into organic PCMs (ISO 175:1999 Methods of Test for the determination of the effects of immersion in liquid chemicals.

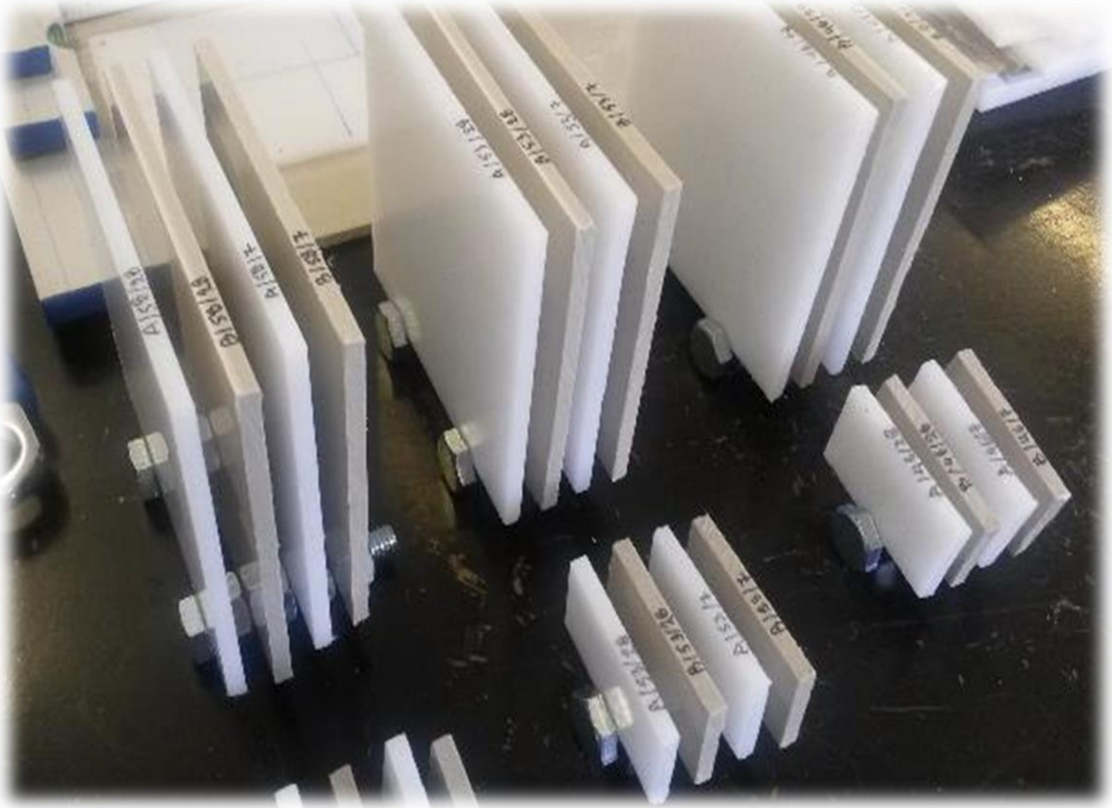


AMPREG 21

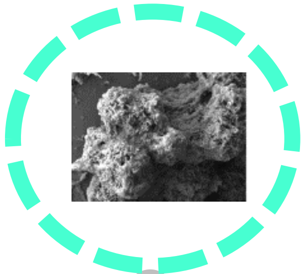
EPOXY WET LAMINATING SYSTEM

- Low initial mixed viscosity
- Good cure progression from ambient only cures
- Non pigmented Resin and Hardeners
- Improved Health and Safety
- Optimised for hand lay-up
- Excellent fibre wetting
- Germanischer Lloyd approved
- Mix ratio of 100:33.3 (by weight)

Experimental studies in finalizing tank material



Experimental studies, laboratorial testings



Mass measurement → Optical Microscopy → DSC → Mechanical Tests → SEM Observation

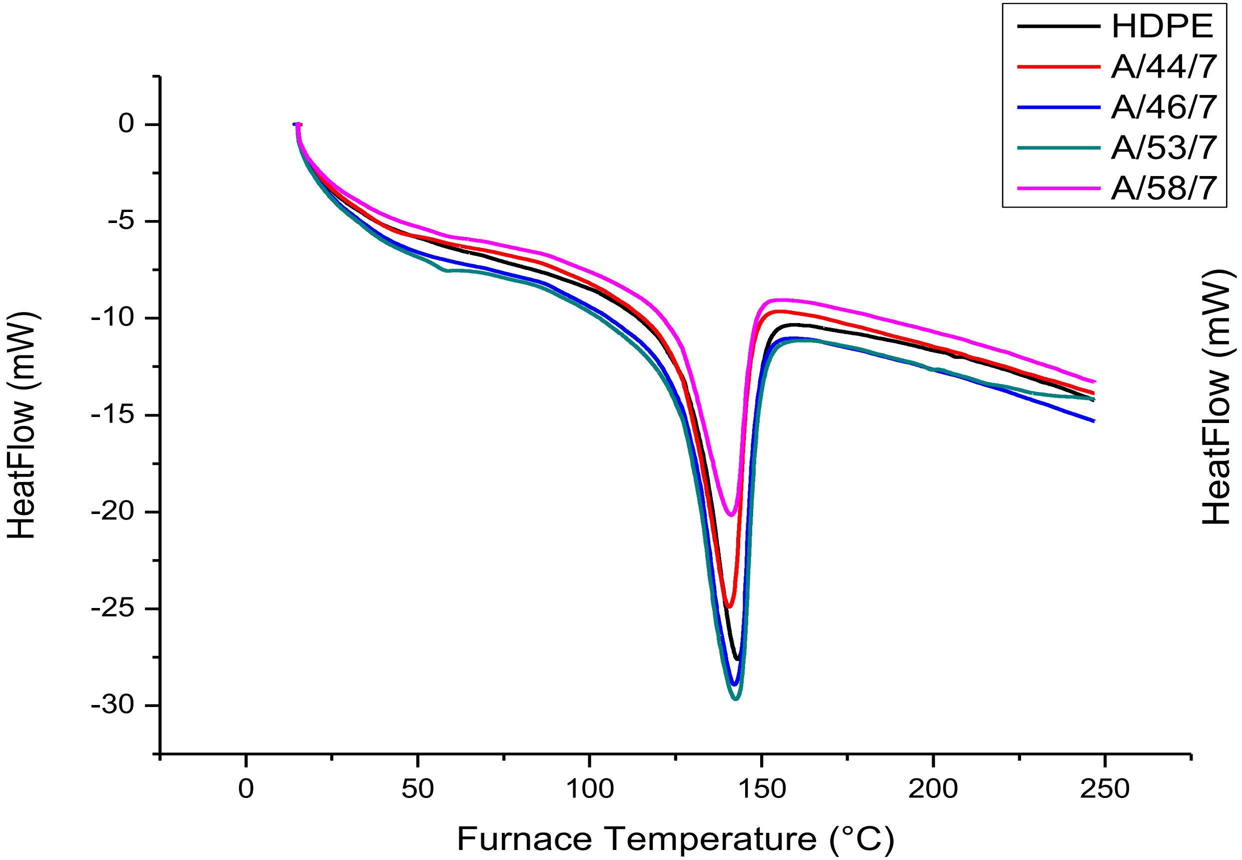
Frequency

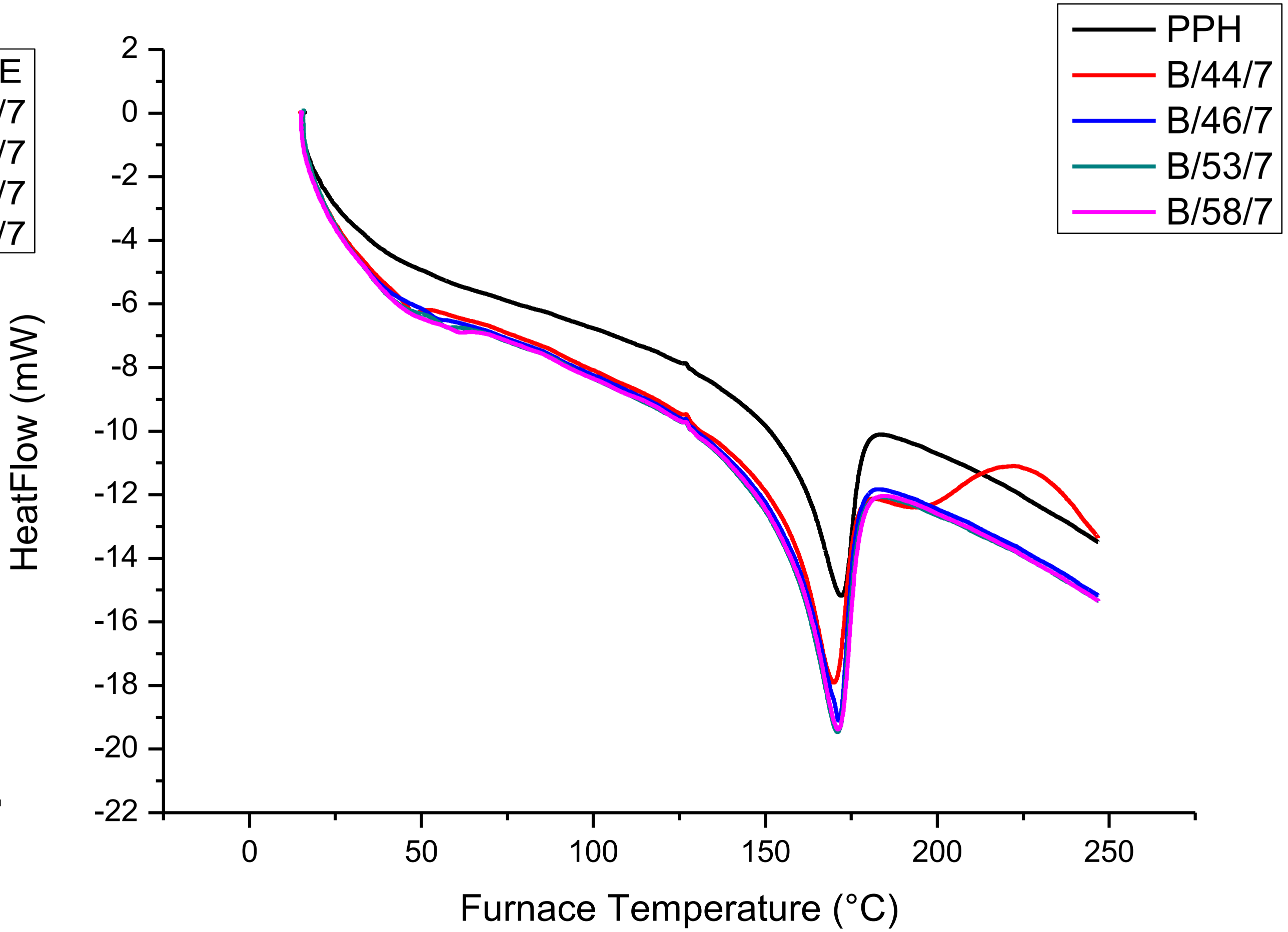
7 days	28 days	40 days

70°C

Experimental studies, DSC results

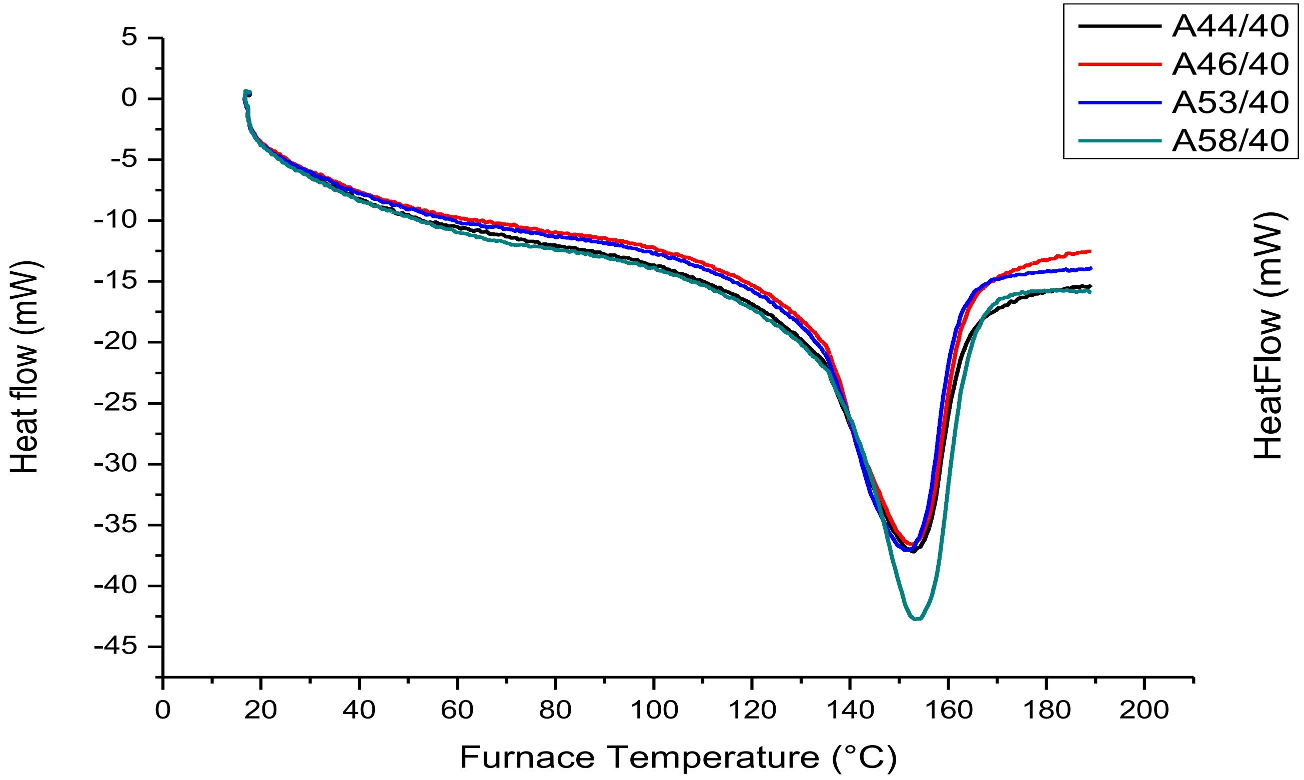
70ºC/7 days

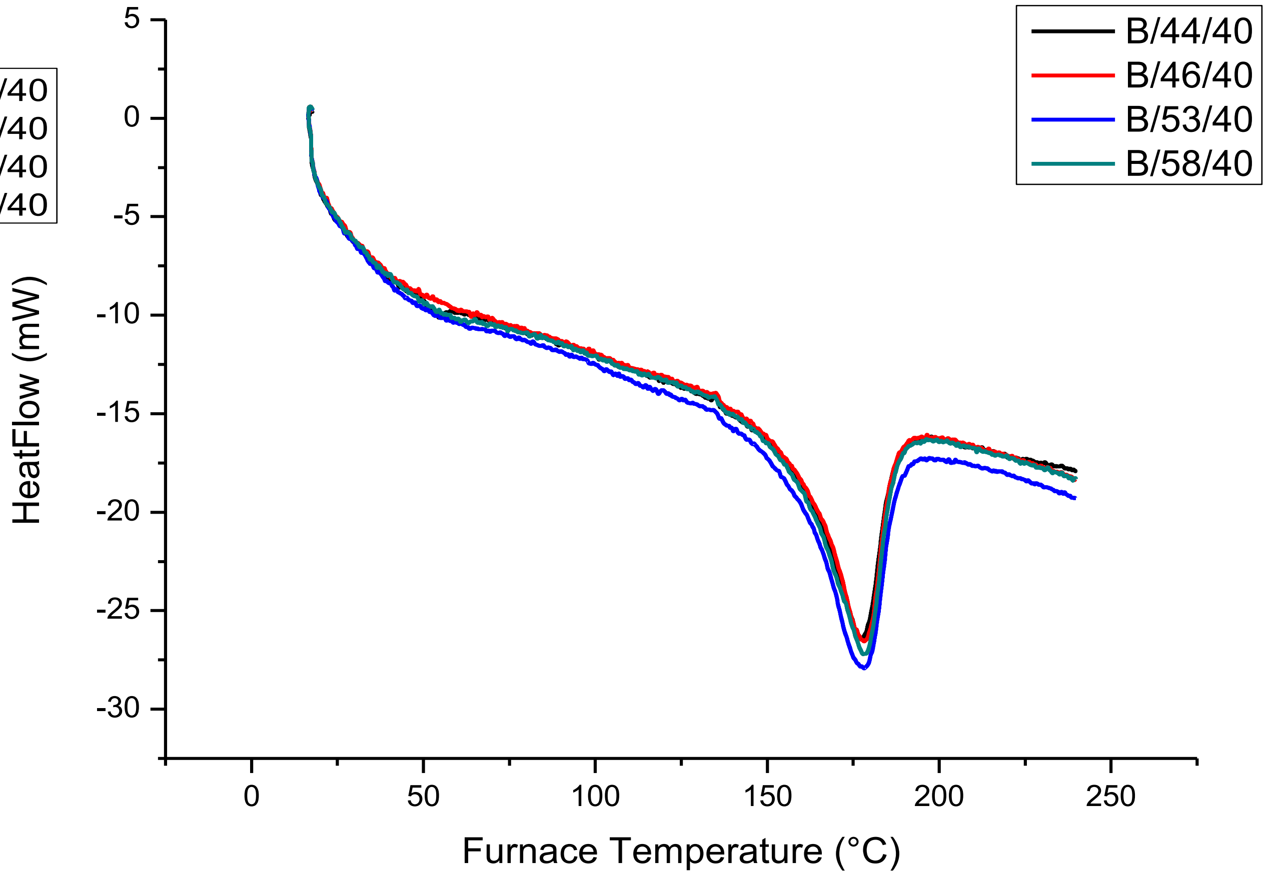




Experimental studies, DSC results

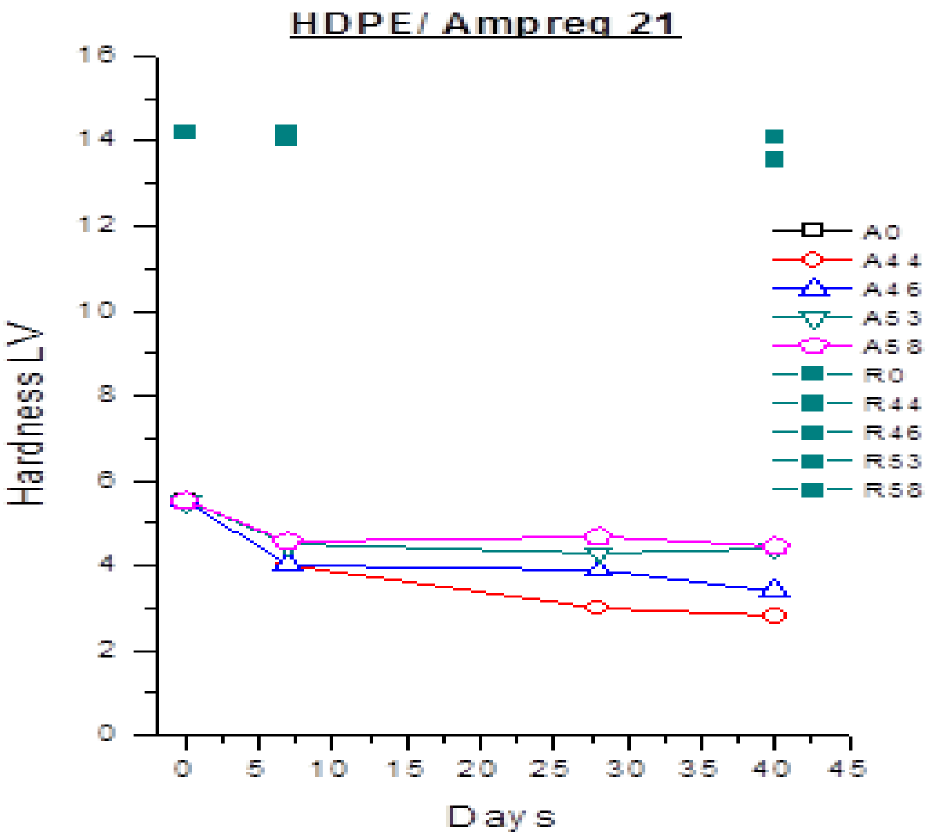
70ºC/40 days

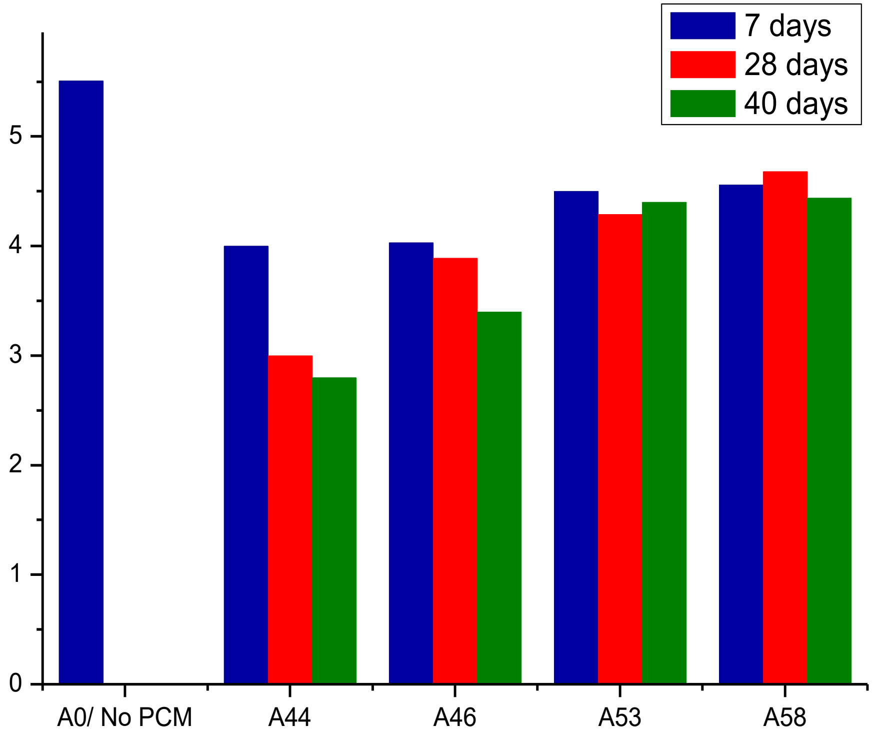




Experimental studies, Hardness H_V

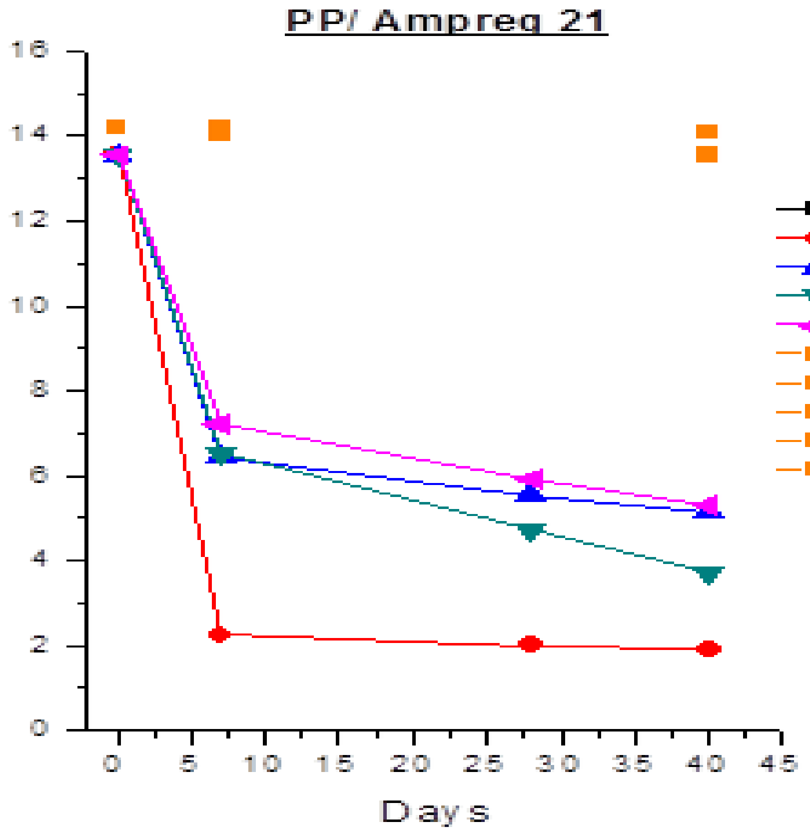
HDPE samples at 7, 28 and 40 days

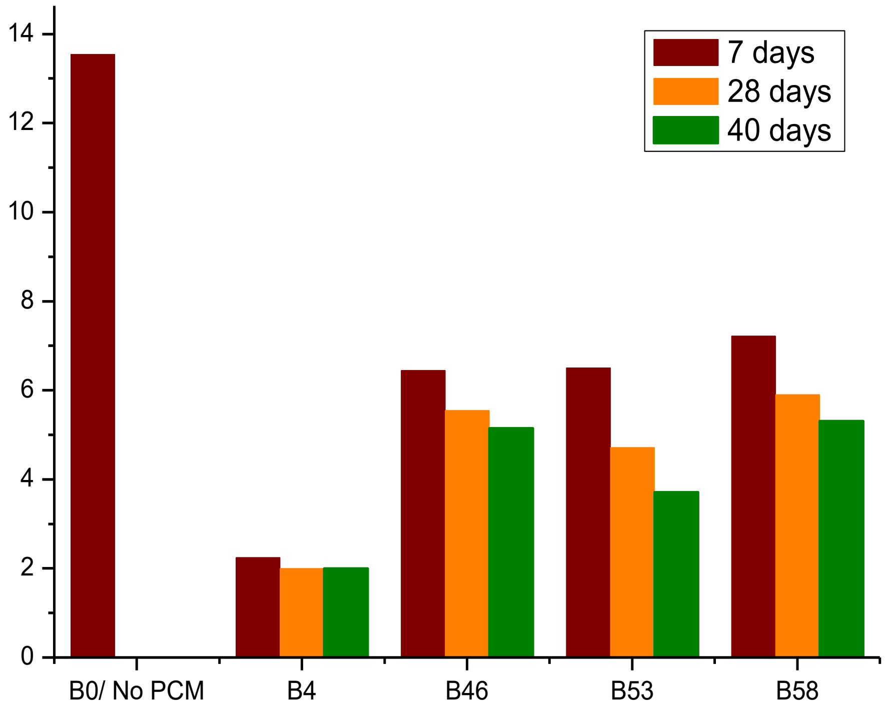




Experimental studies, Hardness H_V

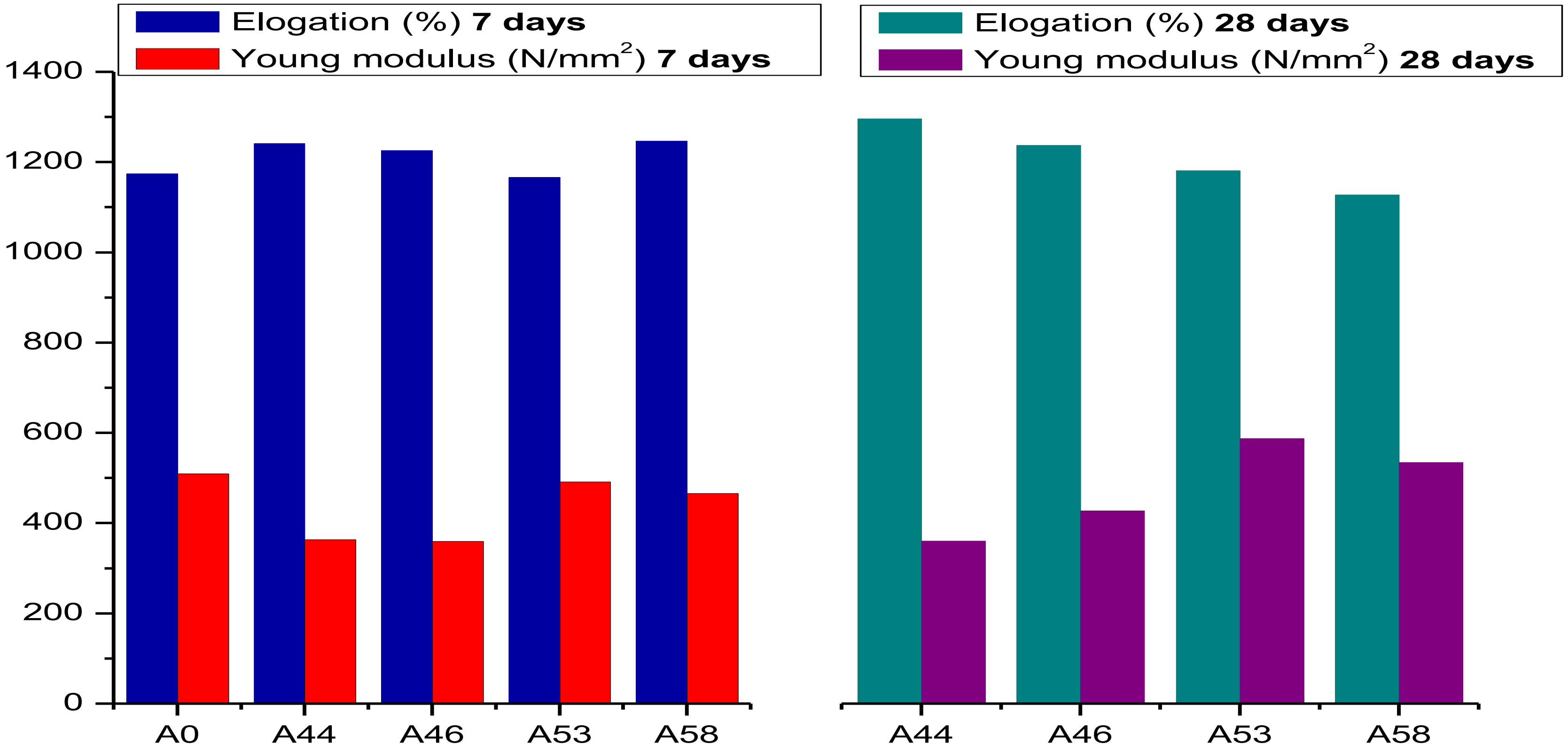
PP samples at 7, 28 and 40 days





Experimental studies, Mechanical Strength

HDPE samples at 7 and 28 days



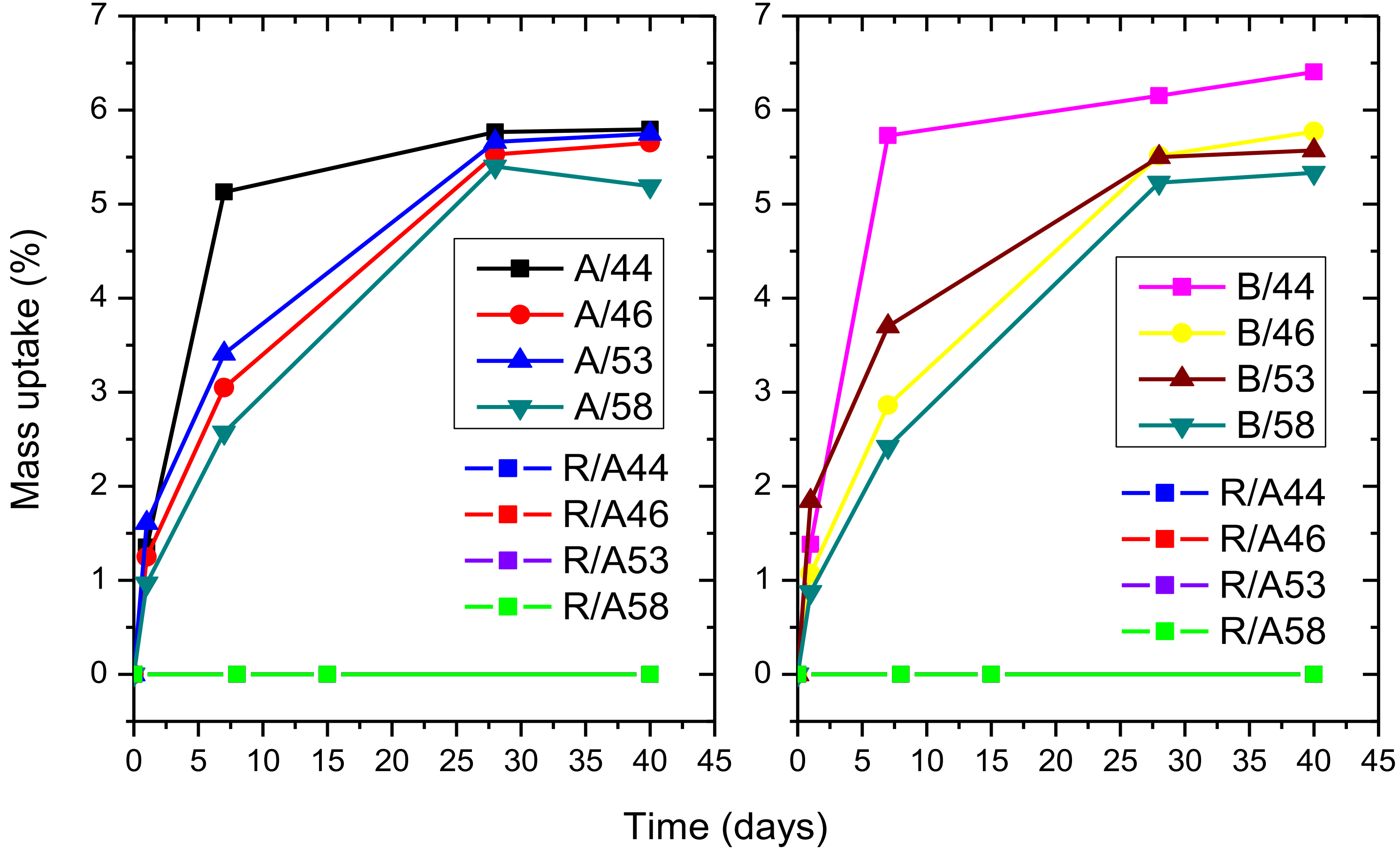
Experimental studies, % weight uptake

BOTH polymers are affected

A44: highest uptake in both HDPE & PPH

A58: lowest uptake

Ampreg 21 is stable



GPRs – Organic PCMs compatibility

The 'back up' solution

Based on market and literature review:

GRP can offer excellent corrosion resistance to a wide range of fluids and gases at ambient temperatures and even at higher temperatures.

GRP is compatible to the paraffin wax and if the compatibility experiments show HDPE or PP-H polymers are inadequate (even when a protection layer is applied), then GRPs could be another option for the TESSe2b tank with

The main reasons for insisting in HDPE and PPH compared to GRPs are:

higher cost

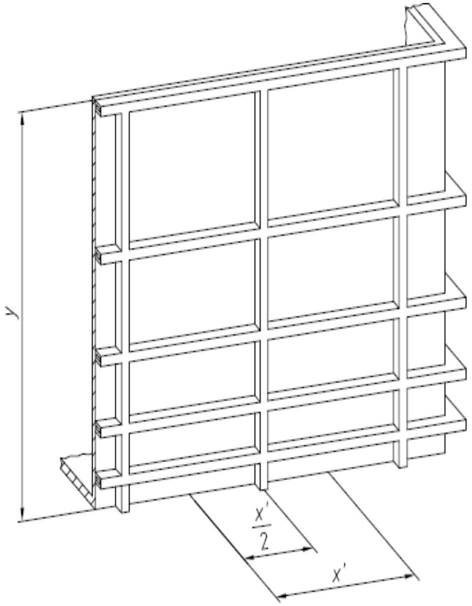
higher weight

Designing of the PCM Tank

The tank design (side plate thickness and dimensions of the reinforcing bars) was designed in accordance to standard EN 12573-3: 2000 (Design and calculation for single skin rectangular tanks).

The mechanical properties of the candidate plastics are extracted from the standard EN 1778: 2000 (Characteristic values for welded thermoplastics constructions & Determination of allowable stresses and moduli for design of thermoplastics equipment).

EN 12573-3: 2000 – Screenshot of calculation sheet



CALCULATION OF RIM STIFFERING			
Moment of inertia of stiffener	J	1,700,000	mm^4
Elastic modulus of the stiffener material	E	133	N/mm^2
Deflection of the rim stiffener	f	5.732963654	mm
Check the rim stiffering for assumed as fixed support	OK	6	mm
Maximum bending moment in the rim stiffener	M	22964.229	Nmm
Number of vertical sections	N_v	4	
Number of horizontal sections	N_h	7	

Rim calculation

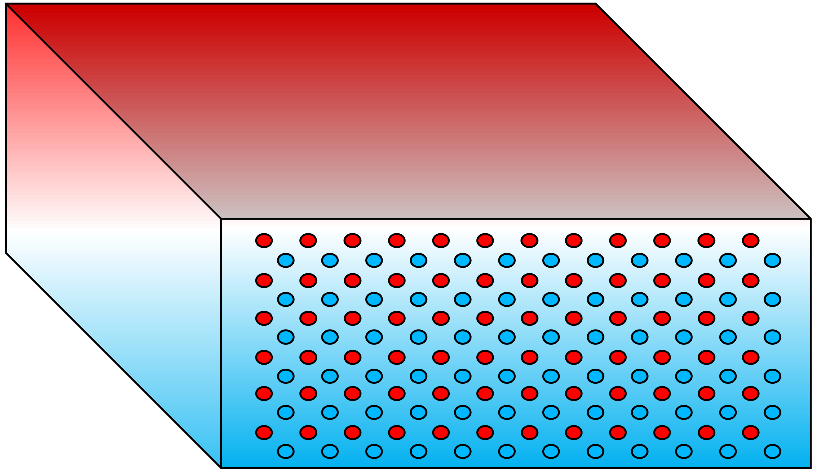
CALCULATION OF THE HORIZONTAL STIFFENERS			
Moment of inertia of stiffener	J	14,000,000	mm^4
Calculation of section	n	1	
Distance between vertical stiffeners	x	850	mm
The effective depth of panels	y'	86	mm
The excess pressure	P_n	0.00454	N/mm^2
Maximum deflection	f	0.852423	mm
Check the rim stiffering for assumed as fixed support	OK	0.857142857	mm
Maximum bending moment in the rim stiffener	M	28119.46	Nmm
Moment of resistance of rim stiffeners	W	48008.841	mm^3

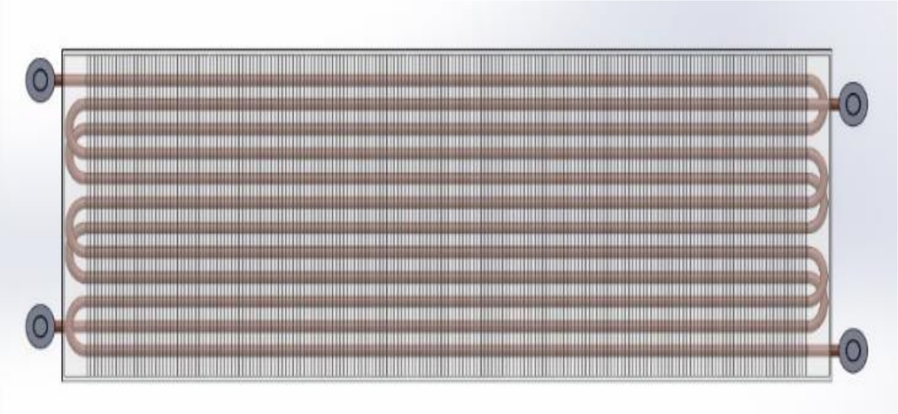
CALCULATION OF VERTICAL STIFFENERS			
Moment of inertia of stiffener	J	5,500,000	mm^4
Calculation of section	n	1	
The effective length of panels	x'	213	mm
Distance between horizontal stiffeners	y	600	mm
The excess pressure on the tank base	P	0.00530	N/mm^2
Maximum deflection	f	0.78211784	mm
Check the rim stiffering for assumed as fixed support	OK	0.857142857	mm
Maximum bending moment in the rim stiffener	M	23157.21	Nmm
Moment of resistance of rim stiffeners	W	39536.693	mm^3

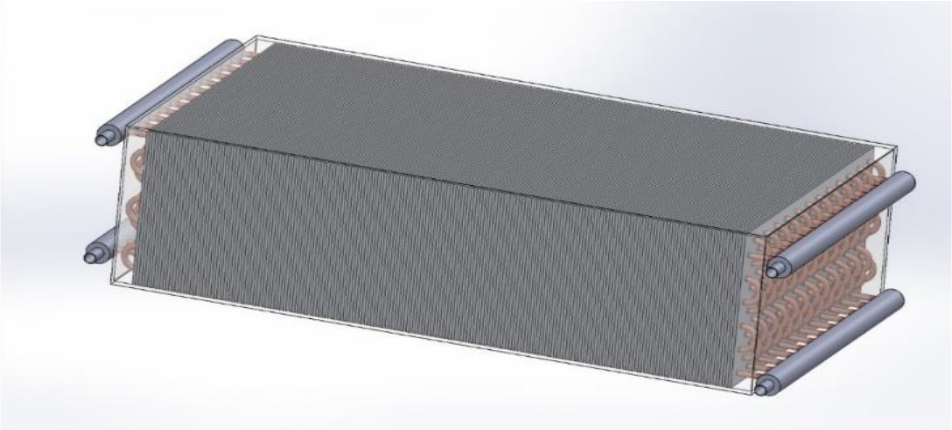
Skin thickness calculation

Aspect Ratio X/Y>2			
Calculation of section	m	7	
The excess pressure on the base of rim	P_r	0.00076	N/mm^2
Aspect Ratio	As=X/Y	2.479166667	TRUE
Thickness	t	1.95	mm
		5.00	mm
Maximum deflection	f	0.070202	mm
Check	f<0.5*t	2.50	ok

Final design of PCM Tank (Heating and Cooling)







FE Analysis of final TESSE2b tank

The cases are investigated and analysed through the EN12573 standard and the FEA simulations. The tank is analysed for a service life of 10 years.

	case 1	case 2	case 3
Tank material	HDPE	HDPE	HDPE
Tank thickness (mm)	12	5	9
Rim material	steel	steel	HDPE
Rim type	orthogonal tube	orthogonal tube	orthogonal beam
Tube wall thickness (mm)	1.5	1.5	-
Rim cross section dimensions (mm)	40x20	50x25	61x100
Ribs	-	horizontal	-
Number of ribs	-	1	-
Rib cross section dimensions (m)	-	50x25	-
HDPE mass (Kg)	23.1	9.5	39.4
metal material mass (Kg)	5.1	12.7	-

FE Analysis of final TESSE2b tank

HDPE mechanical properties used in FEA

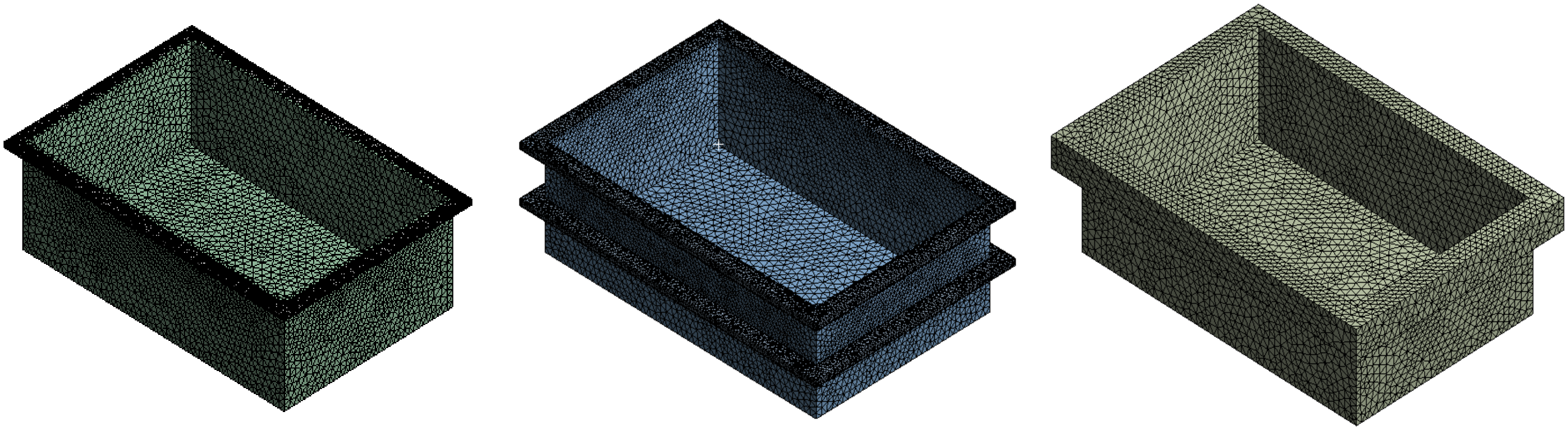
Material	HDPE
Density (Kg/m3)	950
Young modulus (Mpa)	800
Poisson's ratio	0.42

Boundary conditions

Fixed support for the bottom face of the tank

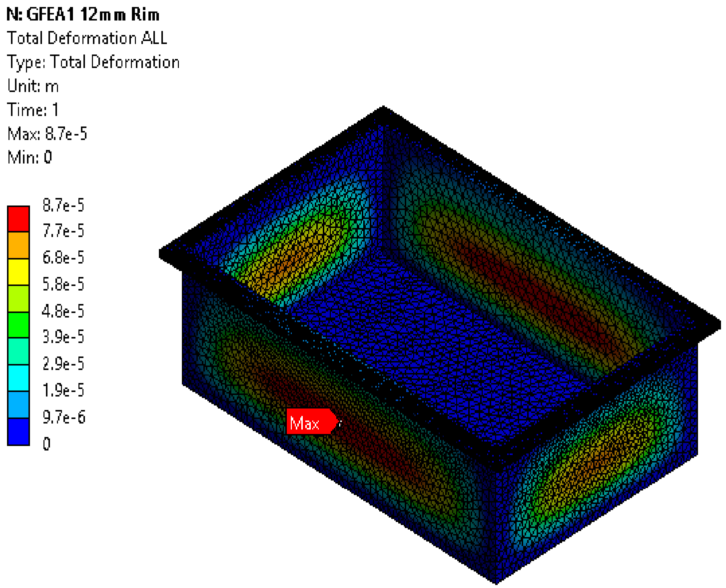
Hydrostatic pressure for the inner skin of the tank due to the PCM in liquid phase

FEA results (Computational Domain)

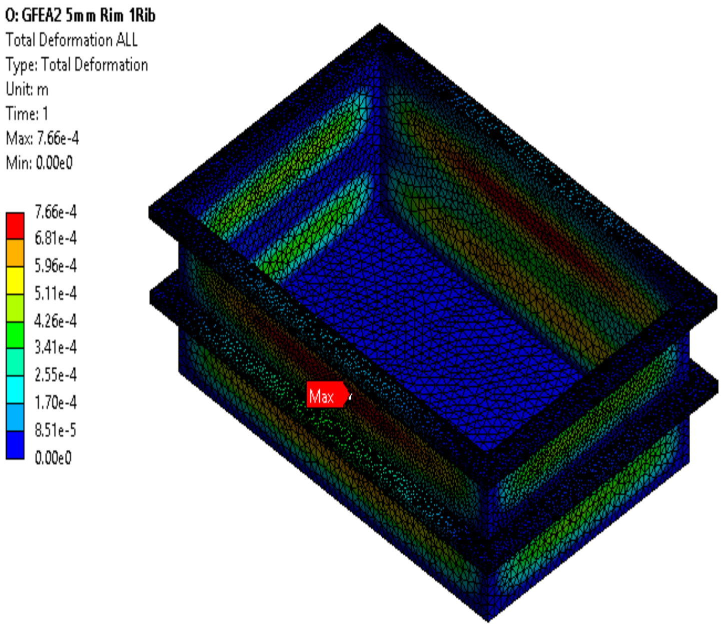


Case 1 **Case 2** **Case 3**

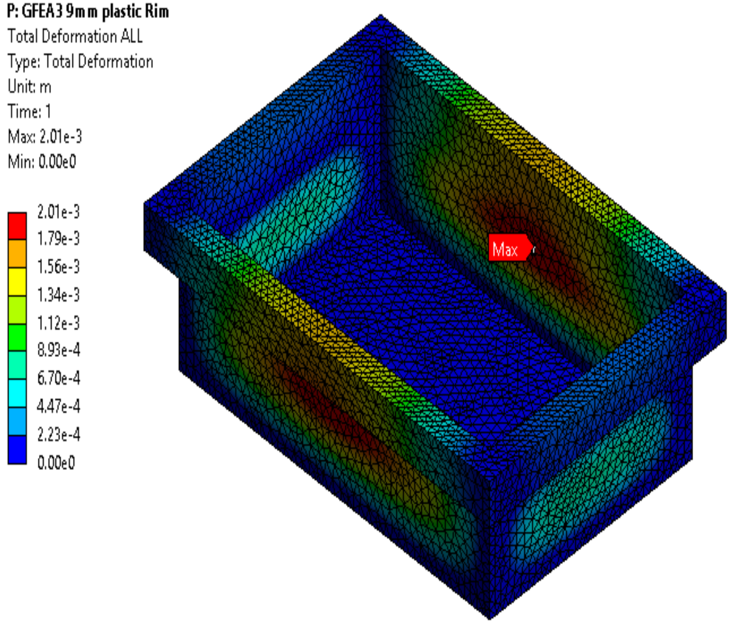
FEA results – Total deformation (m) / HDPE



Case 1

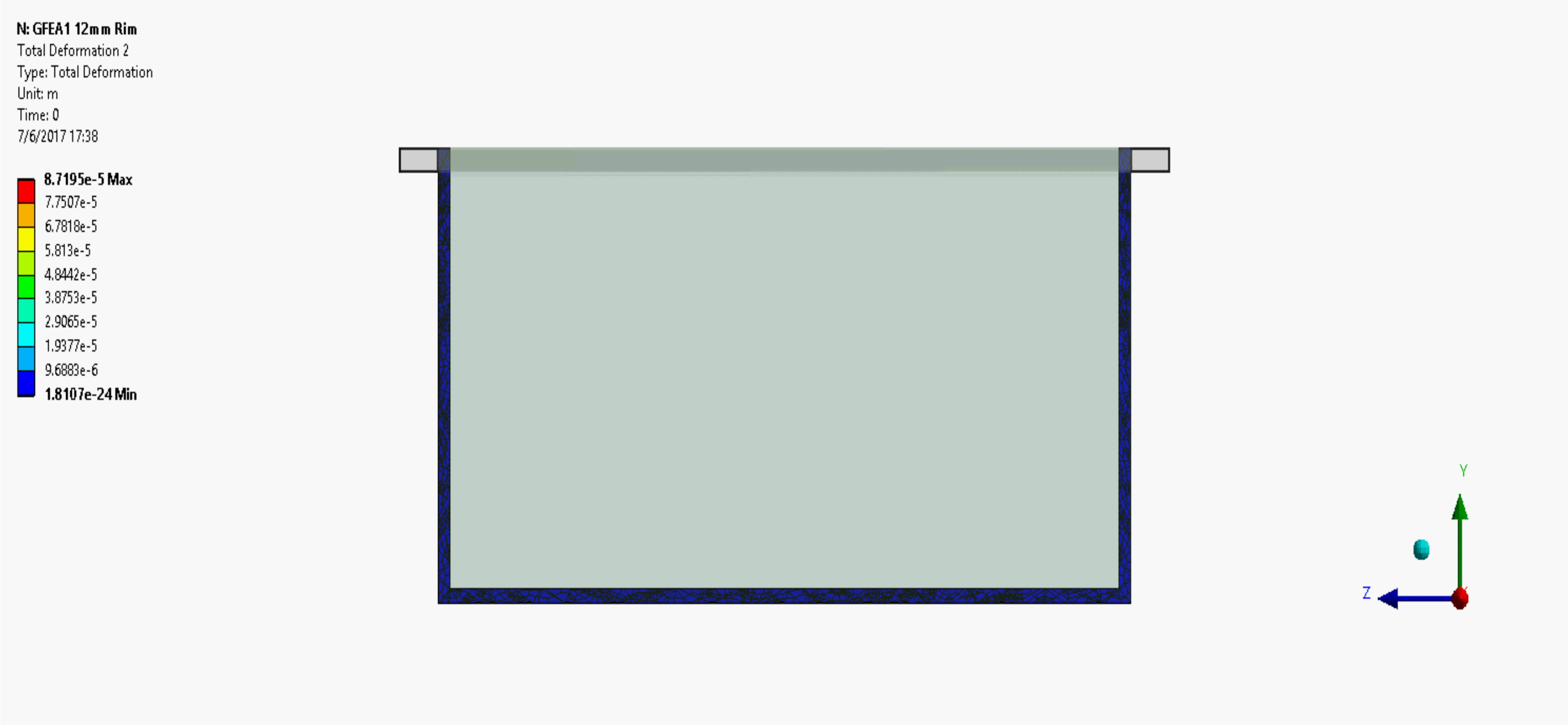


Case 2

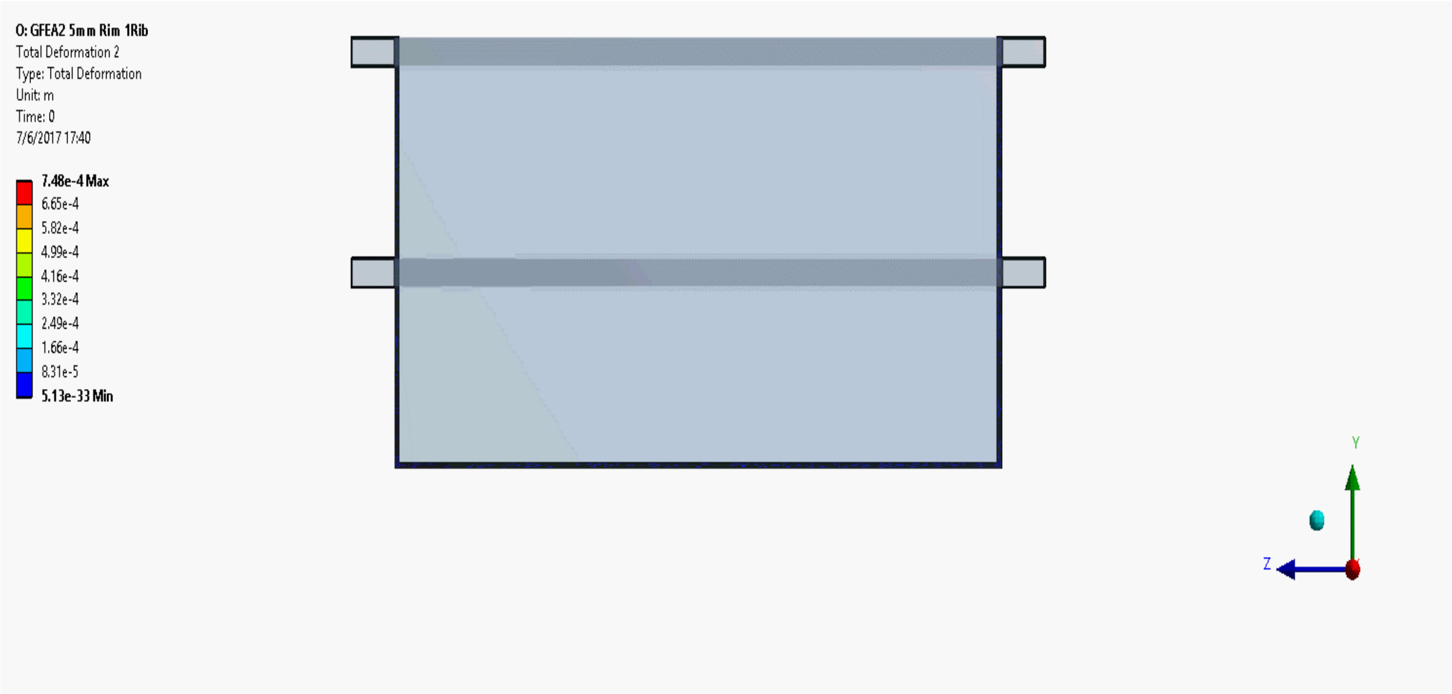


Case 3

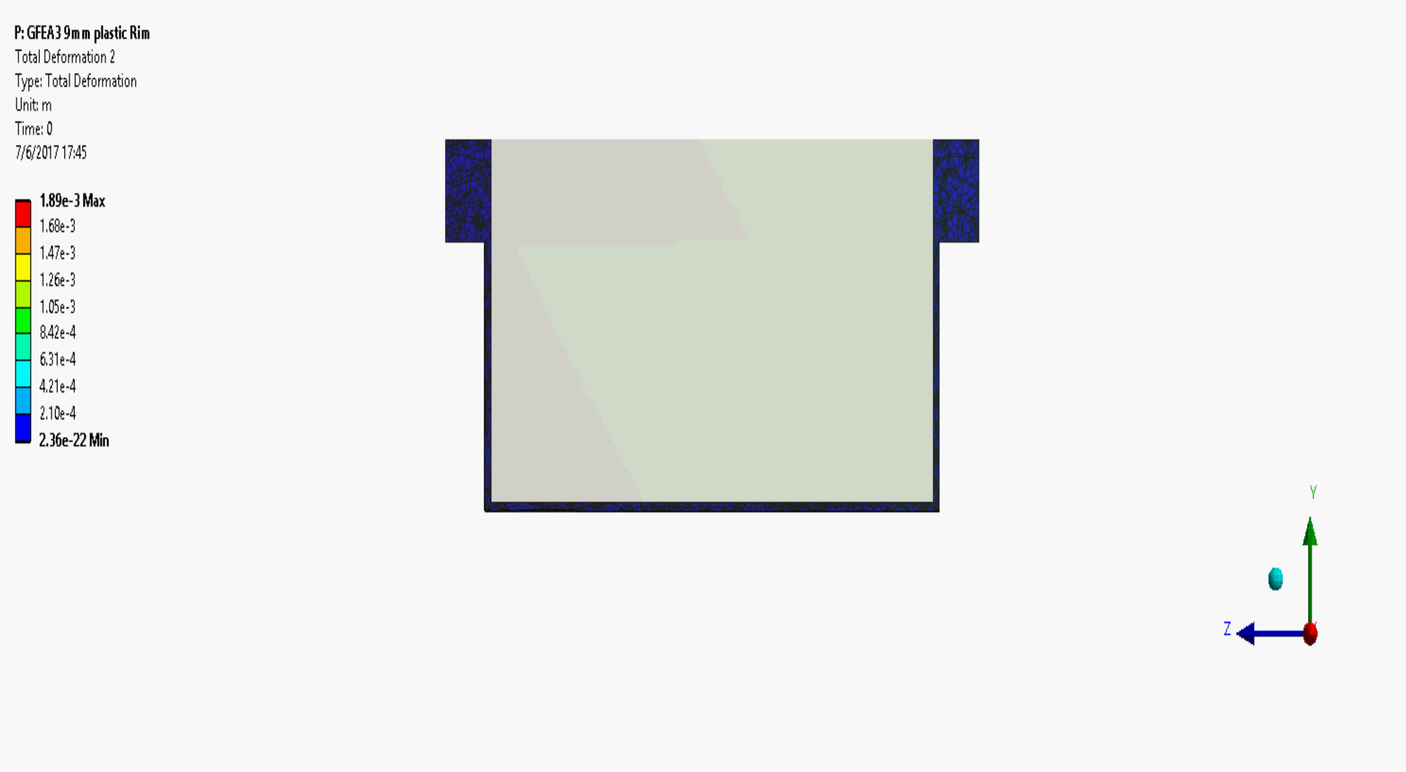
FEA results – Total deformation (m) / HDPE (x100)
Video – Case 1 – Thick Tank (12 mm), no ribs, small rim



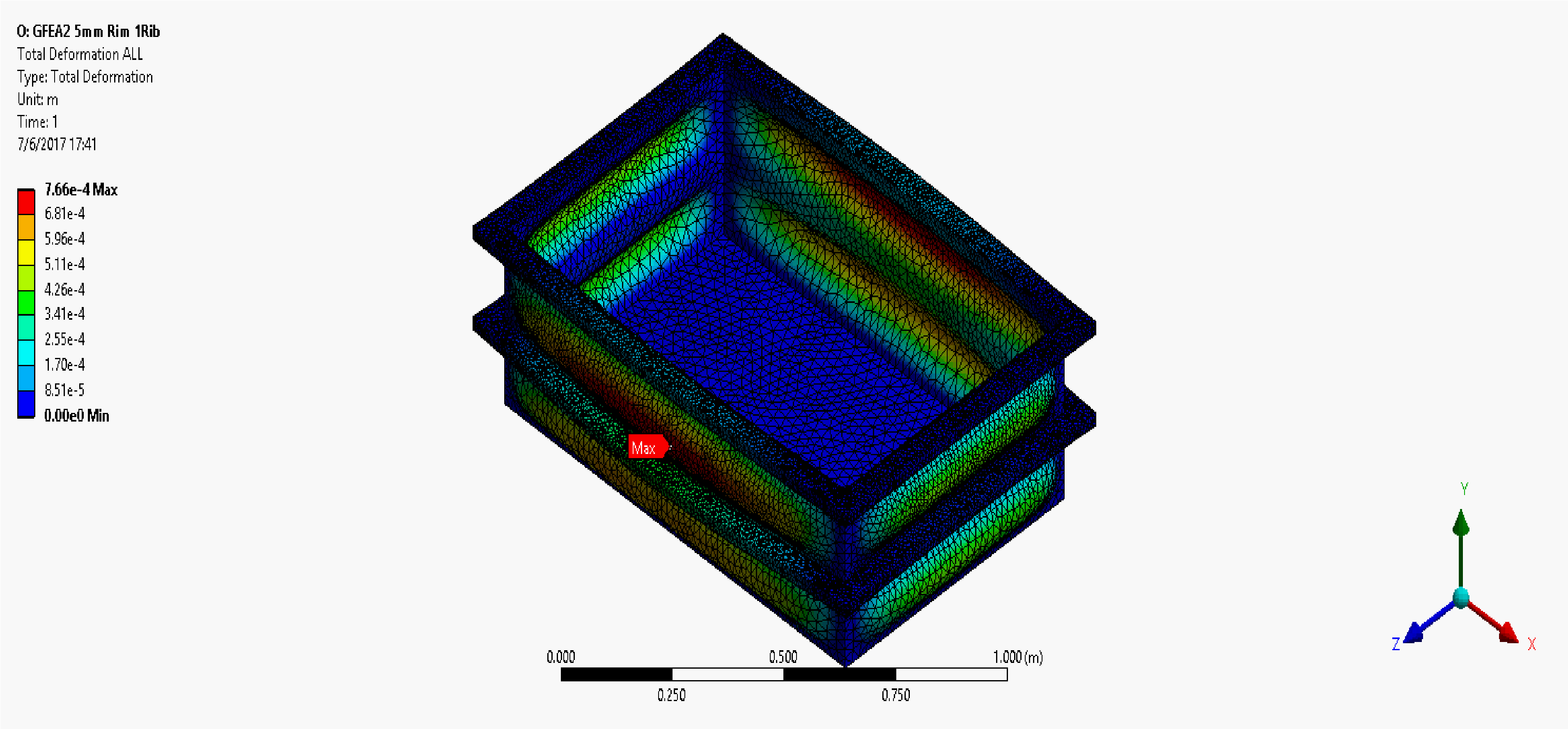
FEA results – Total deformation (m) / HDPE (x100)
Video – Case 1 – Thin Tank (5 mm), rib, small rim



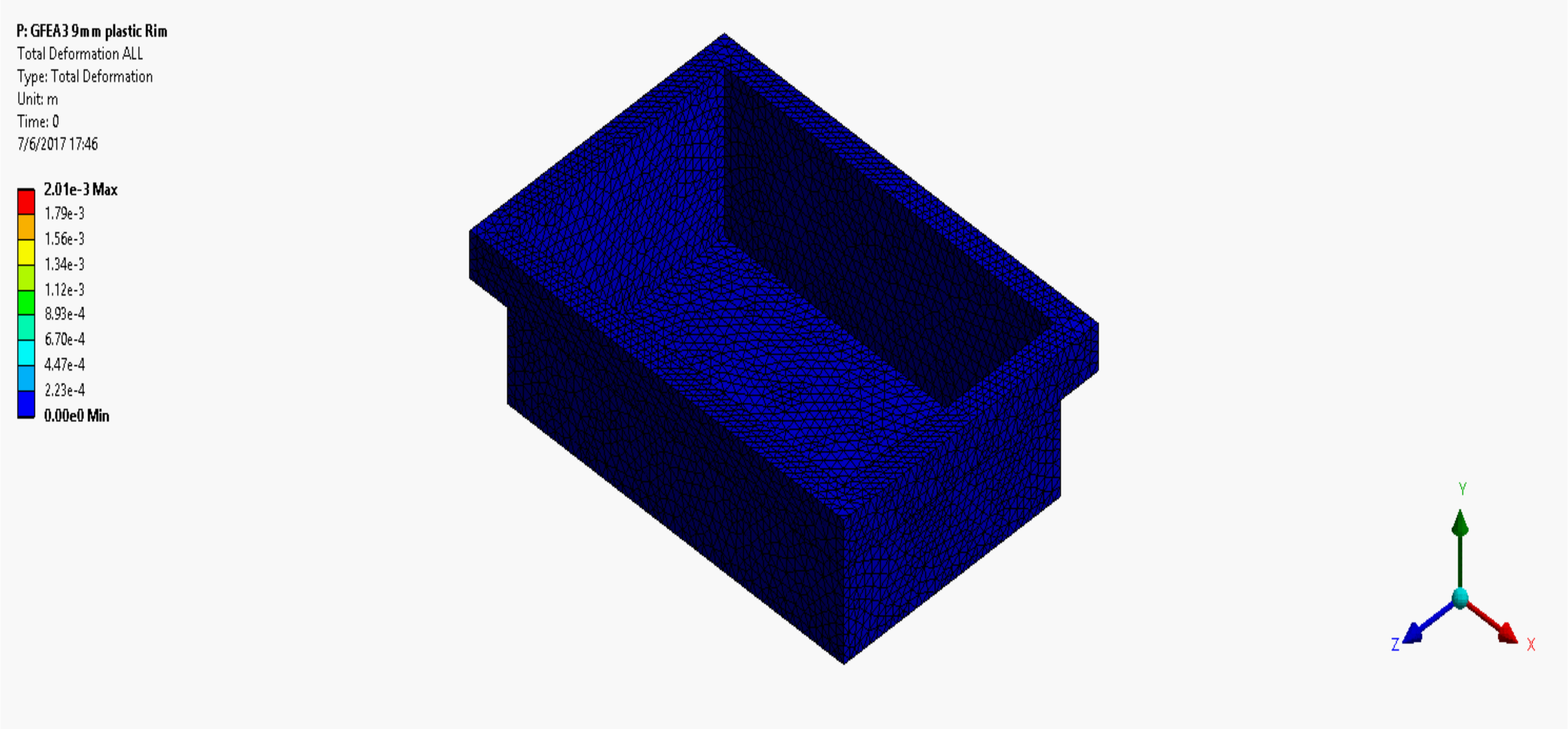
FEA results – Total deformation (m) / HDPE (x100)
Video – Case 1 – Medium Tank (9 mm), no ribs, thick rim



FEA results – Rib deformation (m) / HDPE (x100)



FEA results – Rim deformation (m) / HDPE (x100)



FEA results

	case 1	case 2	case 3
MAX Deformation Skin (m)	$8.71x10^{-5}$	$76,6x10^{-5}$	$201x10^{-5}$
MAX Deformation Rim (m)	$1.69x10^{-5}$	$18,1x10^{-5}$	$198x10^{-5}$
MAX Deformation Rib (m)	-	$37x10^{-5}$	-
MAX equivalent Von Mises stress_Skin (Pa)	$1,41x10^5$	$10,6x10^5$	$18,3x10^5$
MAX equivalent Von Mises stress_Rim (Pa)	$5,63x10^6$	$30x10^6$	$1.83x10^6$
MAX equivalent Von Mises stress_Rib (Pa)	-	$4,26x10^6$	-
EN12573 compatible	Yes	Yes	Yes

Design and optimization of integrated Heat exchangers for PCM tanks

Experimental work

Small experimental rig: used as a first approach to study the heat transfer phenomena taking place in the system using different PCM materials

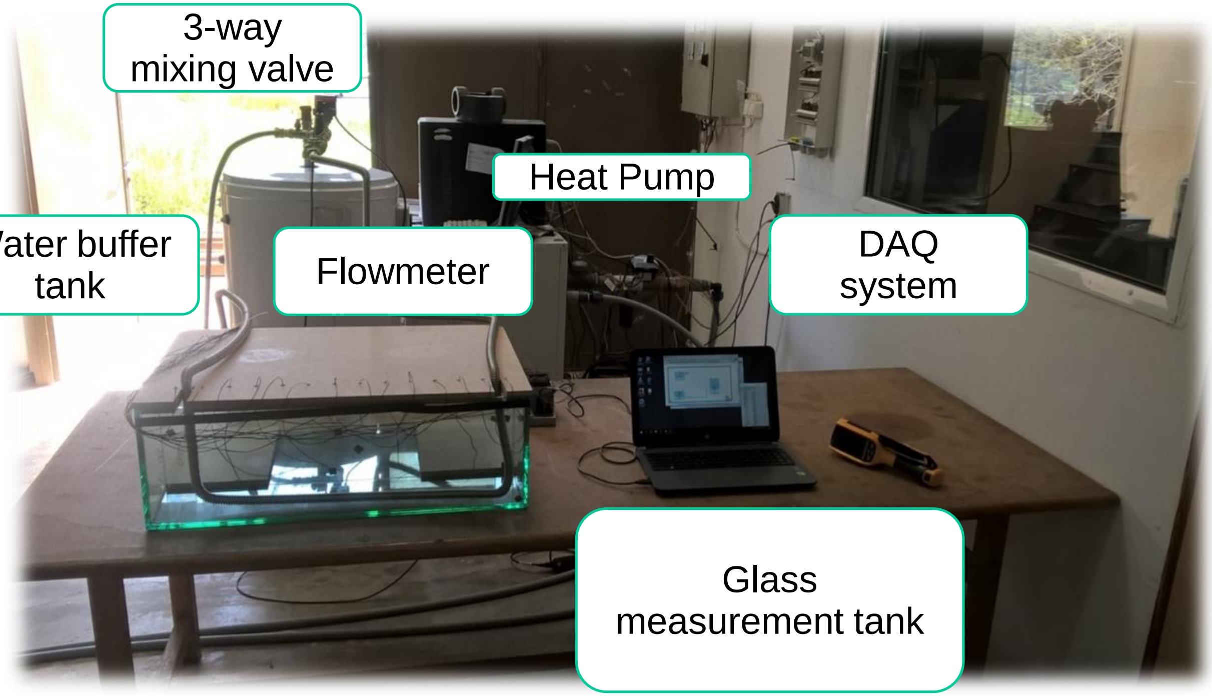
Big experimental rig: to study the system at working real conditions (demo site simulation)

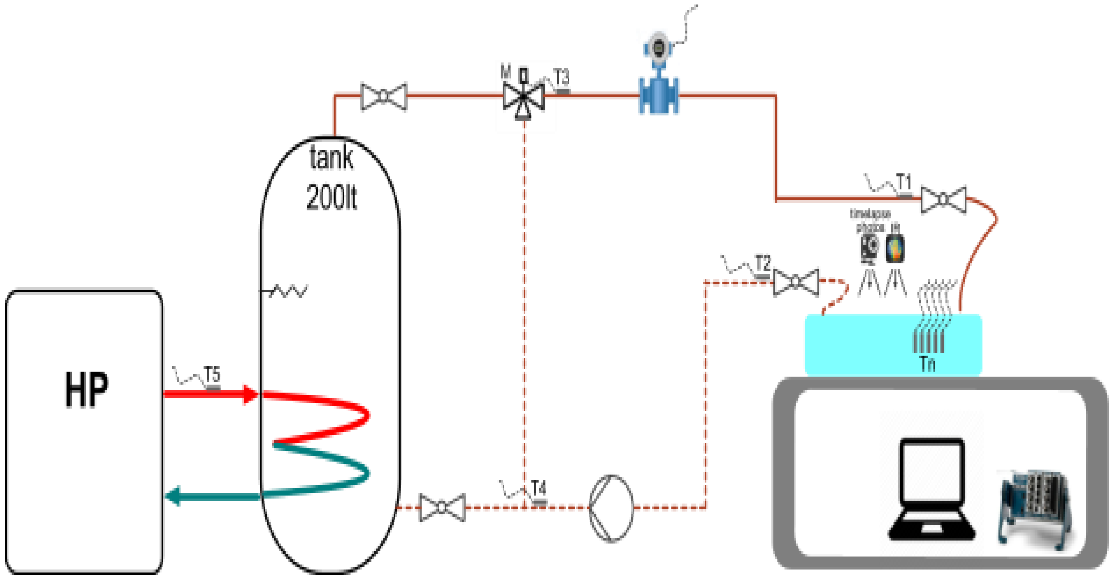
Experimental work, outcomes and validation

Energy storage inside the PCM	Energy stored for different HTF flow rates HE geometries
Temperature variation of the HTF	HTF flow rate effect (inlet-outlet temperature)
Efficiency of the HE	Type of HE and geometry patterns
Temperature patterns	Mean PCM temperature for different areas inside its volume
Melting/Solidification patterns	Time to complete charge and discharge process – effect of HTF flow rate and HE patterns

Small Experimental Rig

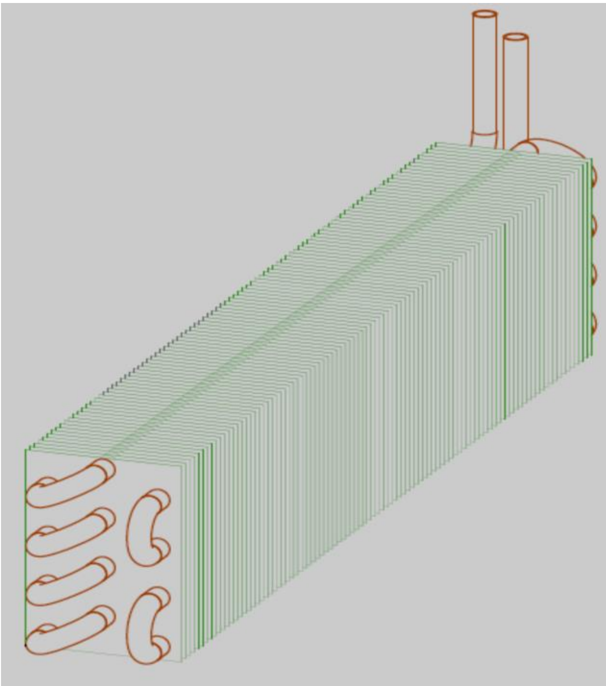
Overall photo view

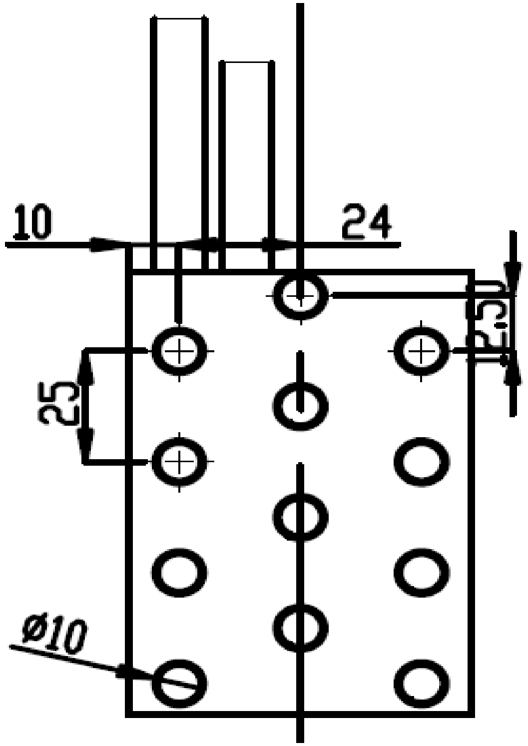




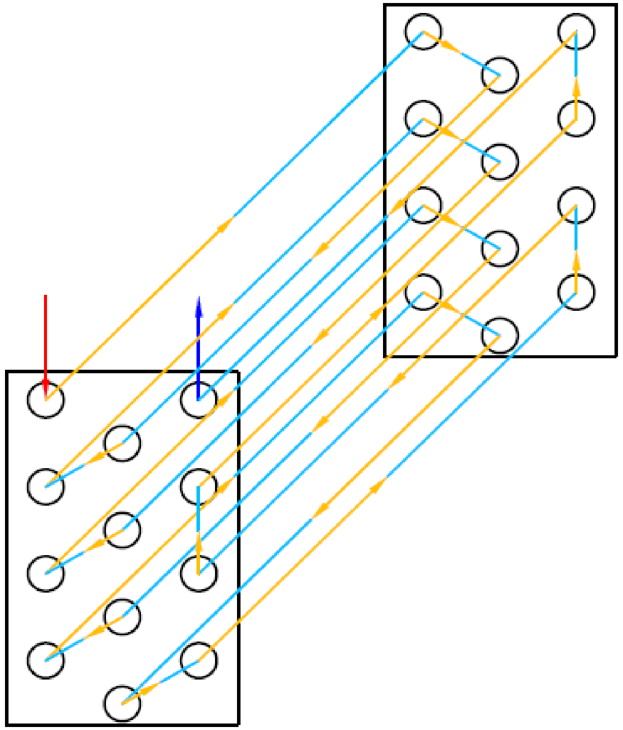
Small Experimental Rig Setup

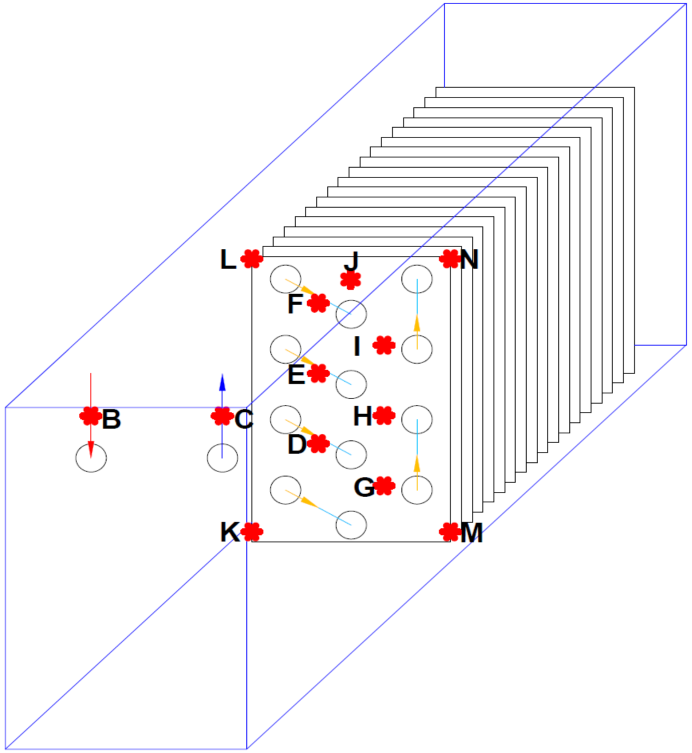
Heat Exchanger length = 500mm. 12 loops – total length = 6m

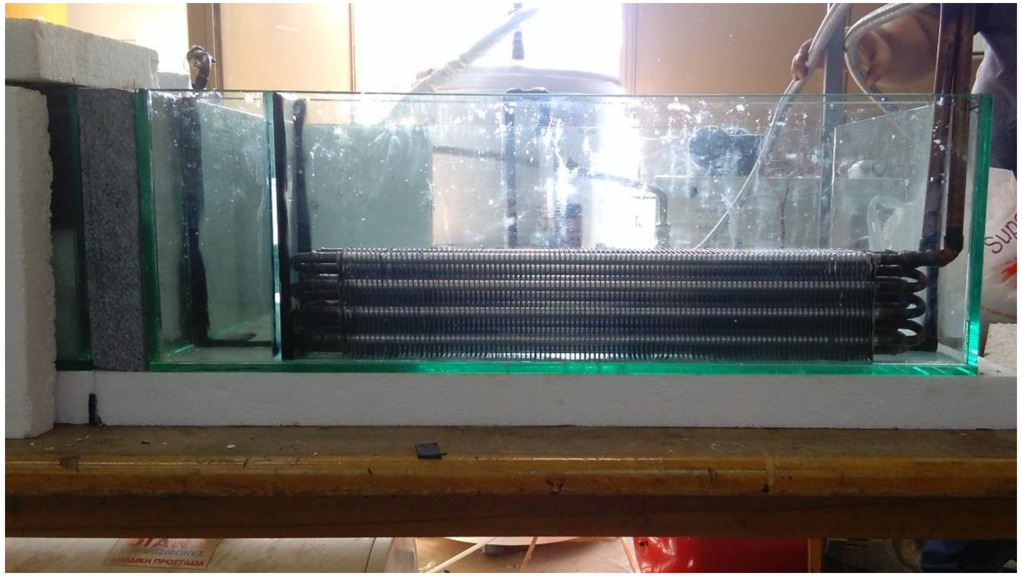




Small Experimental Rig Setup







Small Experimental Rig

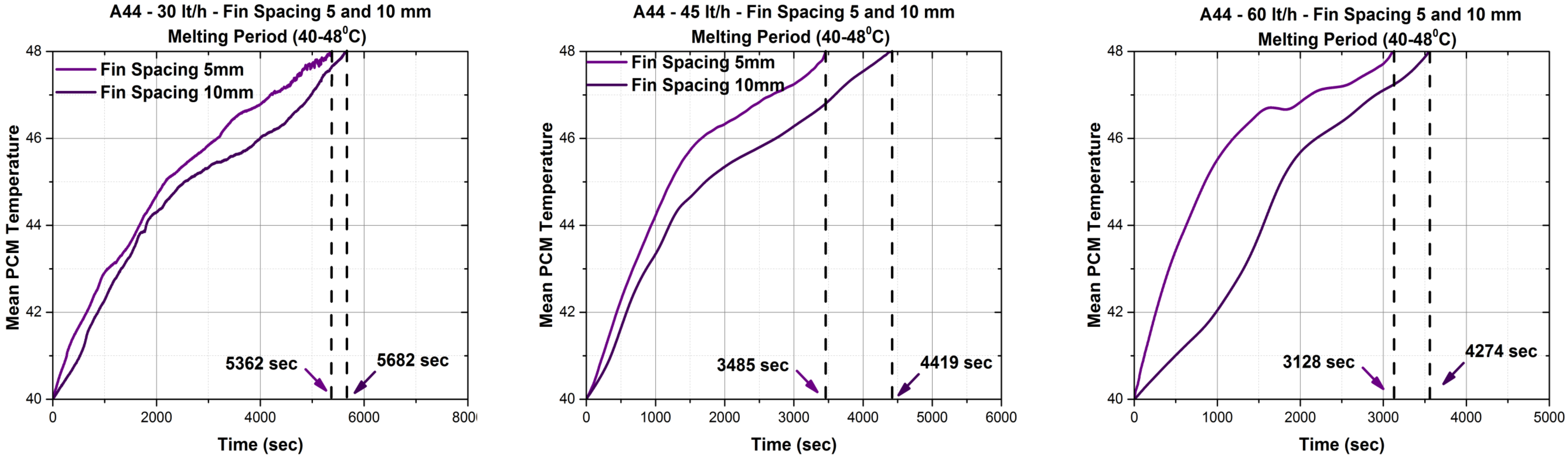
Experimental procedure

Charging (melting) – Hot water was supplied to the HE. Inlet temperature was always adjusted 8°C more than the phase change temperature (if A44 was examined, inlet temperature was 52°C). The process was fulfilled when all thermocouples exceeded the inlet temperature.

Discharging (solidification) – Cold water was supplied to the HE. Inlet temperature was always adjusted 8°C less than the phase change temperature (if A44 was examined, inlet temperature was 36°C). The process was fulfilled when all thermocouples reached the inlet temperature.

Experimental Data – Fin Spacing

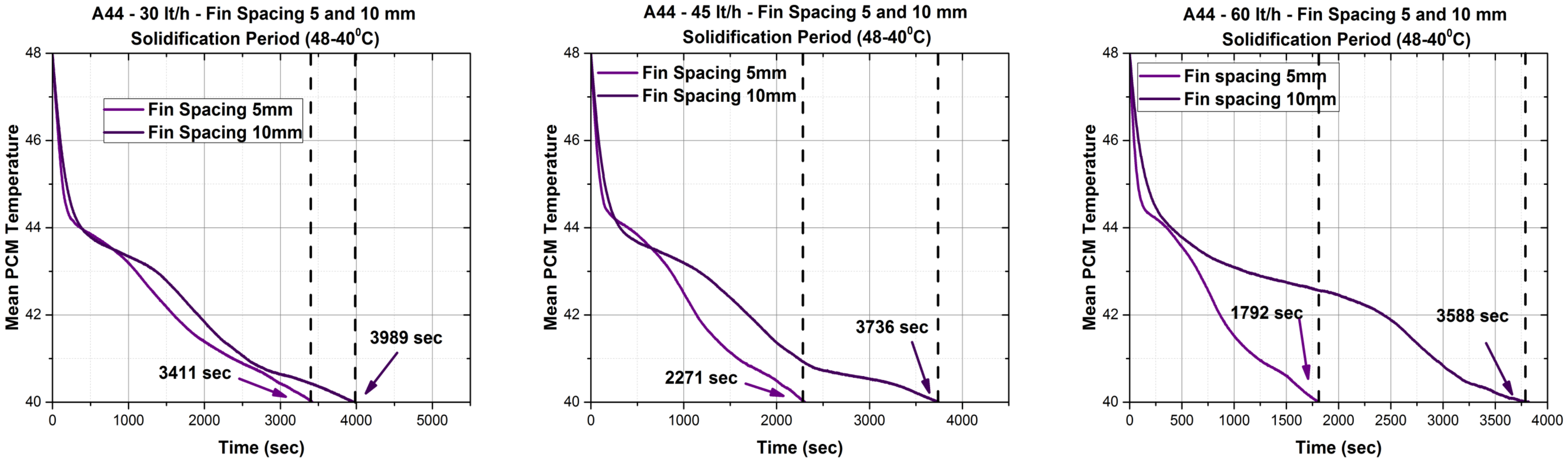
A44 – 30, 45, 60 lt/h – Fin Spacing 5/10 mm Melting (40-48°C)



Fin spacing affects melting time. As fin spacing reduces (more fins placed) melting time decreases. This impact is lowered when HTF flow rates get lower (low HTF flow rates have a smaller affect in total melting time in respect to fin spacing)

Experimental Data – Fin Spacing

A44 – 30, 45, 60 lt/h – Fin Spacing 5/10 mm Solidification (48-40°C)



Fin spacing affects solidification time. As fin spacing reduces (more fins placed) melting time decreases. This impact is lowered when HTF flow rates get lower (low HTF flow rates have a smaller affect in total melting time in respect to fin spacing)

Melting and Solidification time

Heat Transfer Mechanism

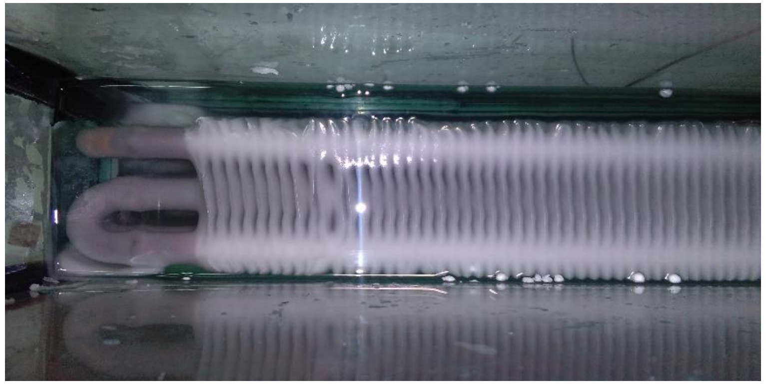
<u>Charging (melting):</u> During the initial steps, conduction is the dominant heat transfer mechanism. As the PCM melts, natural convection undertakes a significant contribution to heat transfer phenomenon

<u>Discharging (solidification):</u> Conduction is the dominant heat transfer mechanism throughout the process

Melting and Solidification time

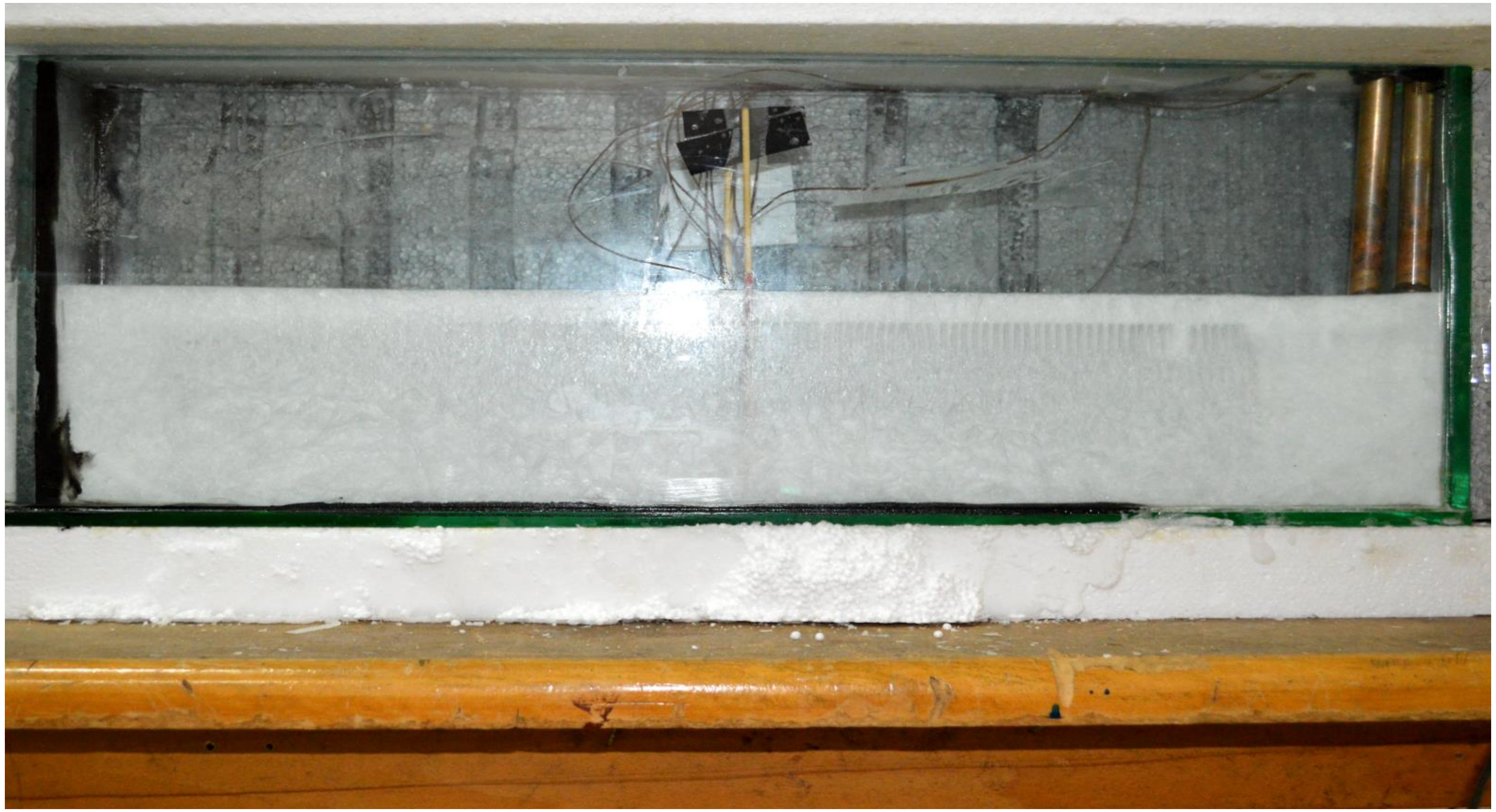
During discharging (solidication) a thin layer of solid material is formed on the surface of the tubes and expands on fin surfaces as process proceeds. This layer eliminates convection heat transfer from the surface of the HE to the PCM.

Conduction in solid state is far more strong that in liquid state as most PCM show different thermal conductivity properties (for A44 which is the optimum PCM for the hot tank due to its melting temperature and high heat of fusion) thermal conductivity in liquid state is $k_{(l)}$=0.12 W/mK and is solid state $k_{(s)}$=0.41 W/mK.



Melting and Solidification Procedure

A44



Melting and Solidification Procedure

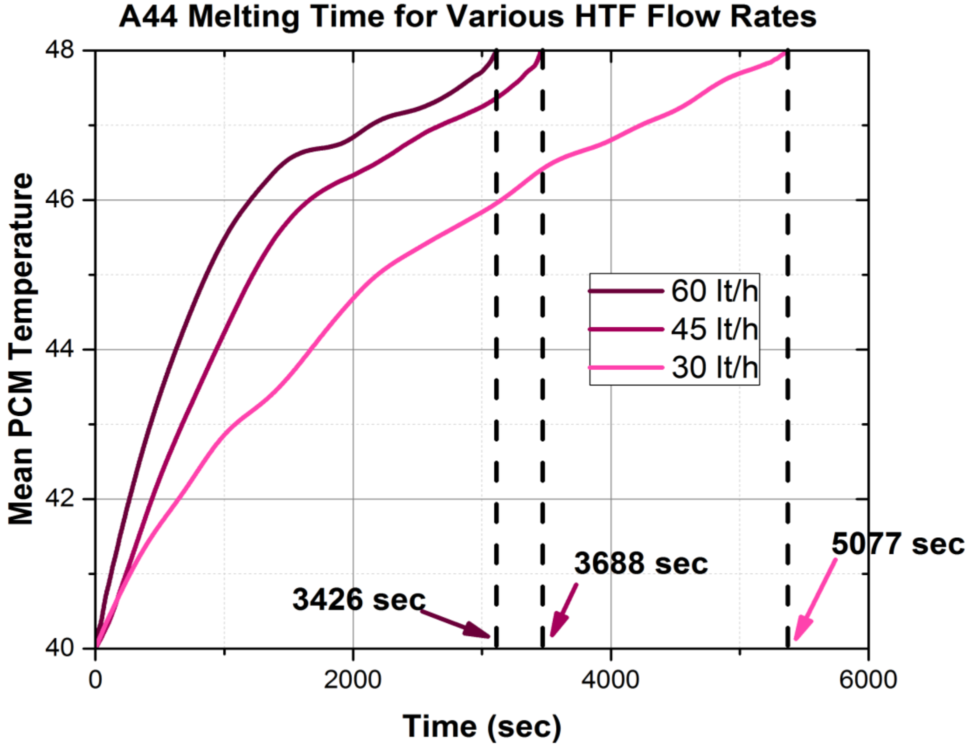
A46

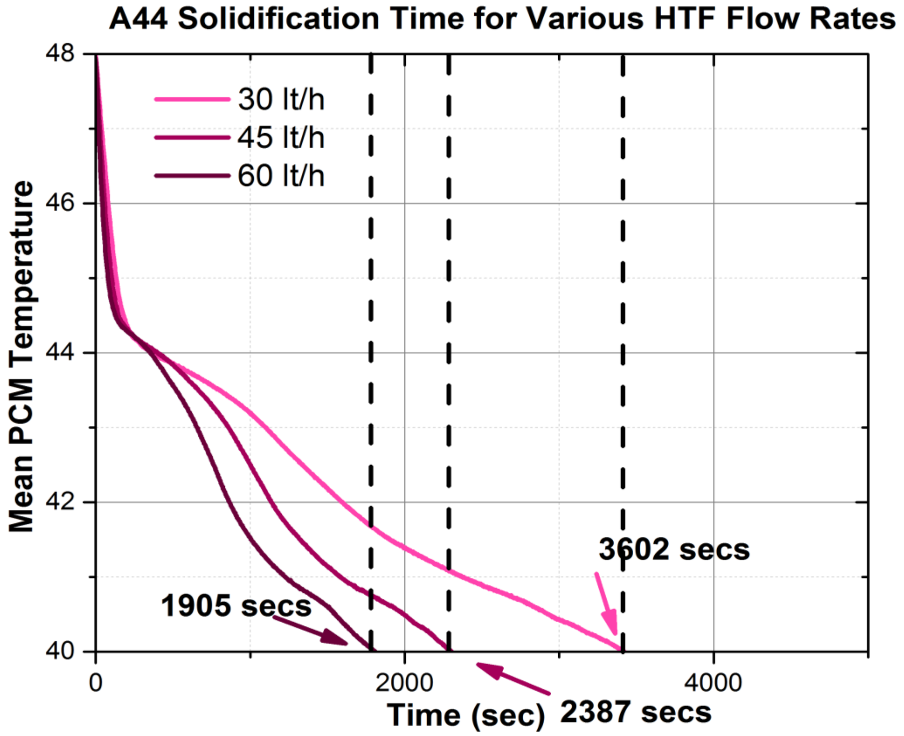
Melting and Solidification Procedure

A53

Experimental Data – HTF Flow Rate

A44 – 30, 45, 60 lt/h – Fin Spacing 5 mm Melting & Solidification

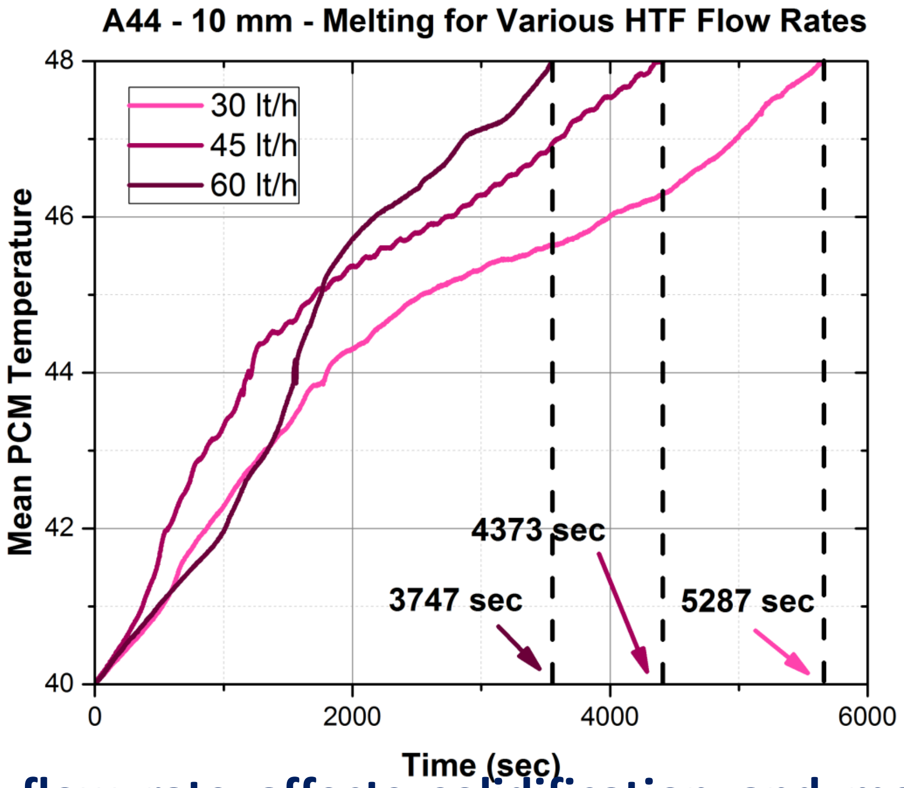


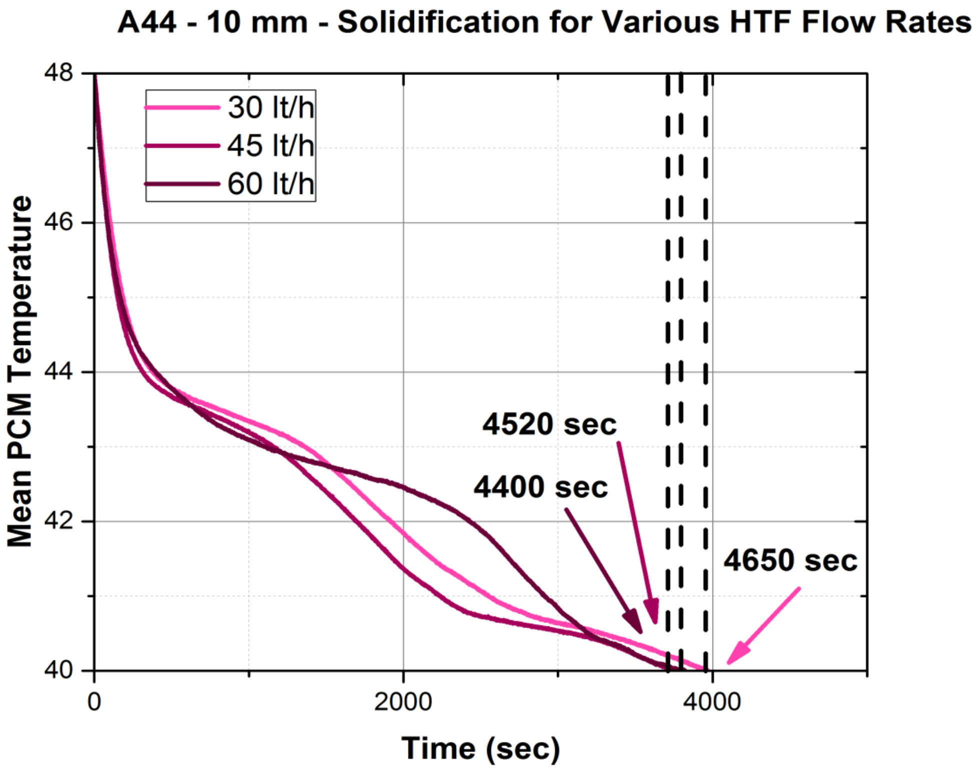


HTF flow rate affects solidification and melting time. As HTF flow rate reduces melting and solidification time decreases.

Experimental Data – HTF Flow Rate

A44 – 30, 45, 60 lt/h – Fin Spacing 10 mm Melting & Solidification

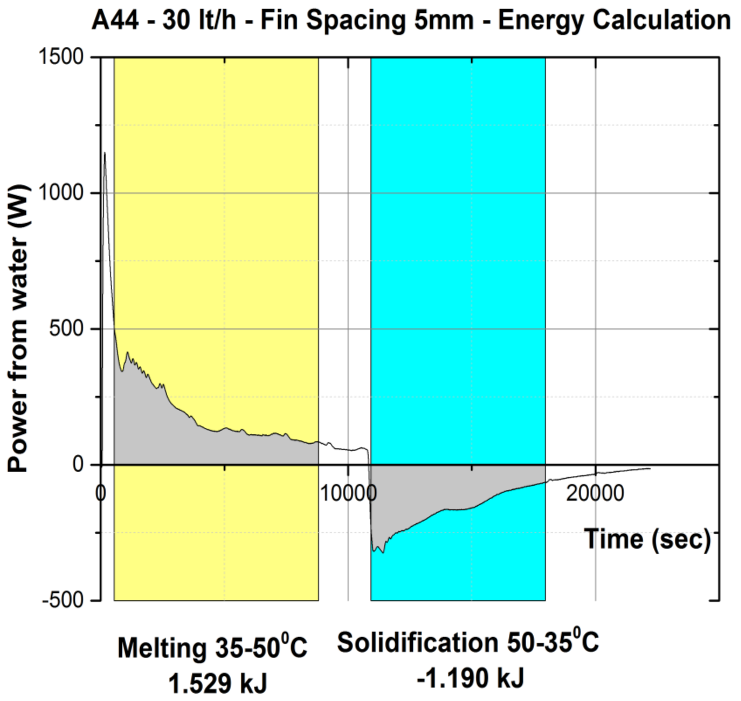


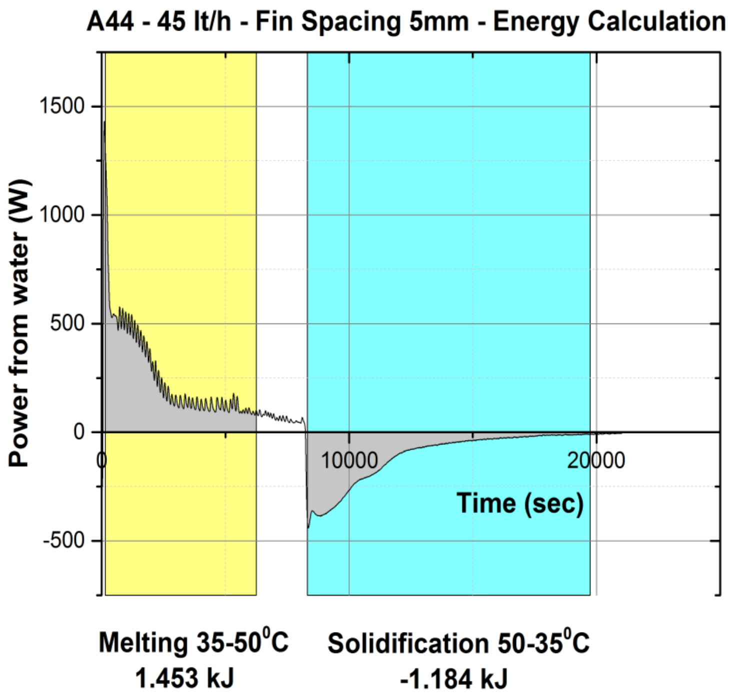


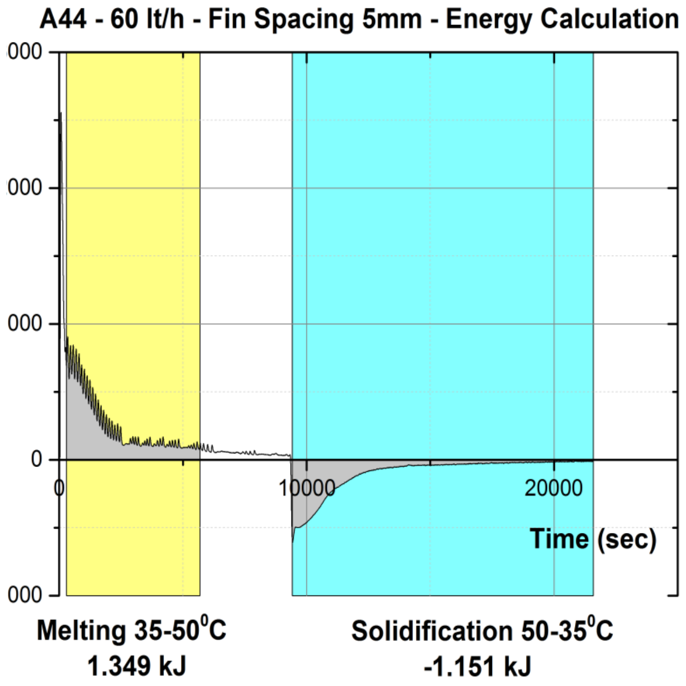
HTF flow rate affects solidification and melting time. As HTF flow rate reduces melting and solidification time decreases. Notice : as fin spacing increases this impact is less.

Experimental Data – Energy Analysis

A44 – 30, 45, 60 lt/h – Fin Spacing 5 mm Melting & Solidification



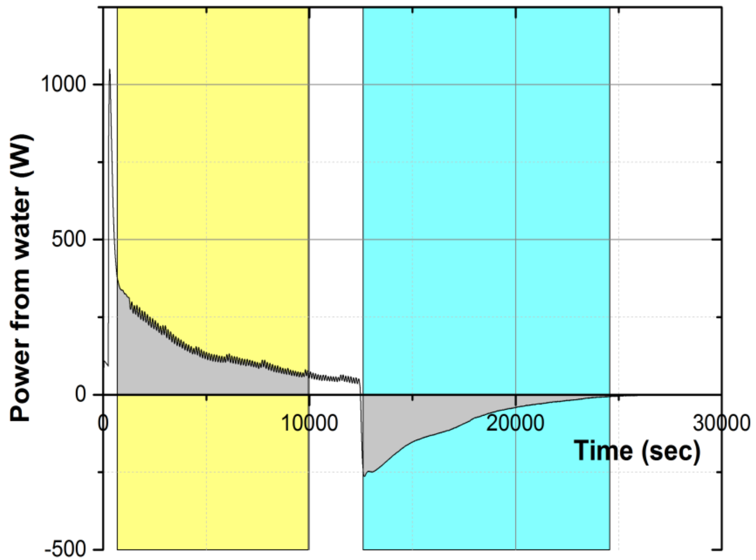




Experimental Data – Energy Analysis

A44 – 30, 45, 60 lt/h – Fin Spacing 10 mm Melting & Solidification

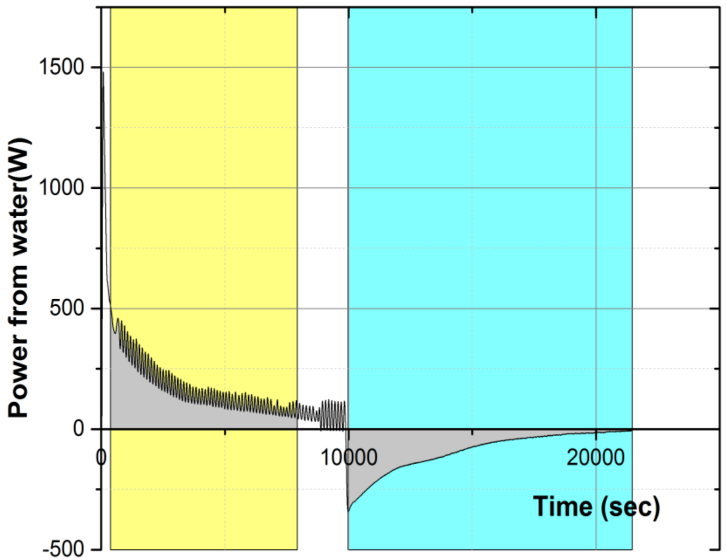
A44 - 30 lt/h - Fin Spacing 10mm - Energy Calculation



Melting 35-50^{0}C
1.413 kJ

Solidification 50-35^{0}C
-1.063 kJ

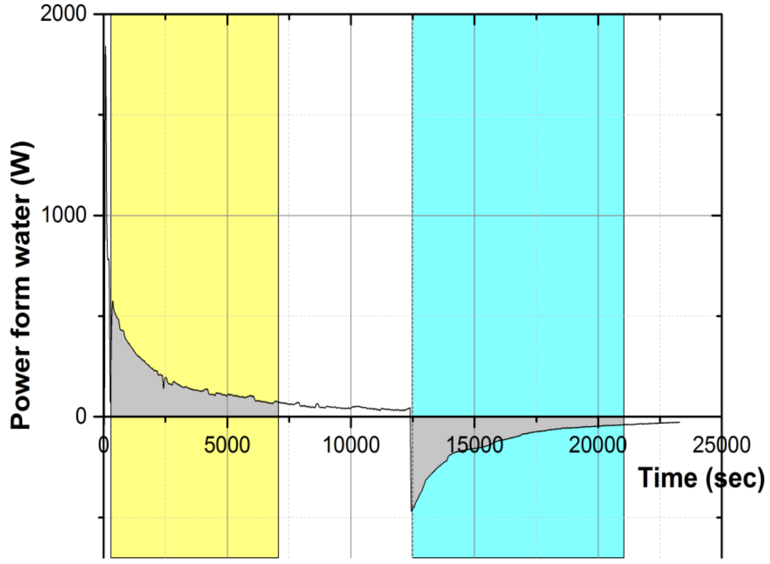
A44 - 45 lt/h - Fin Spacing 10 mm - Energy Calculation



Melting 35-50^{0}C
1.317 kJ

Solidification 50-35^{0}C
-1.026 kJ

A44 - 60 lt/h - Fin Spacing 10mm - Energy Calculation



Melting 35-50^{0}C
1.245 kJ

Solidification 50-35^{0}C
-1.005 kJ

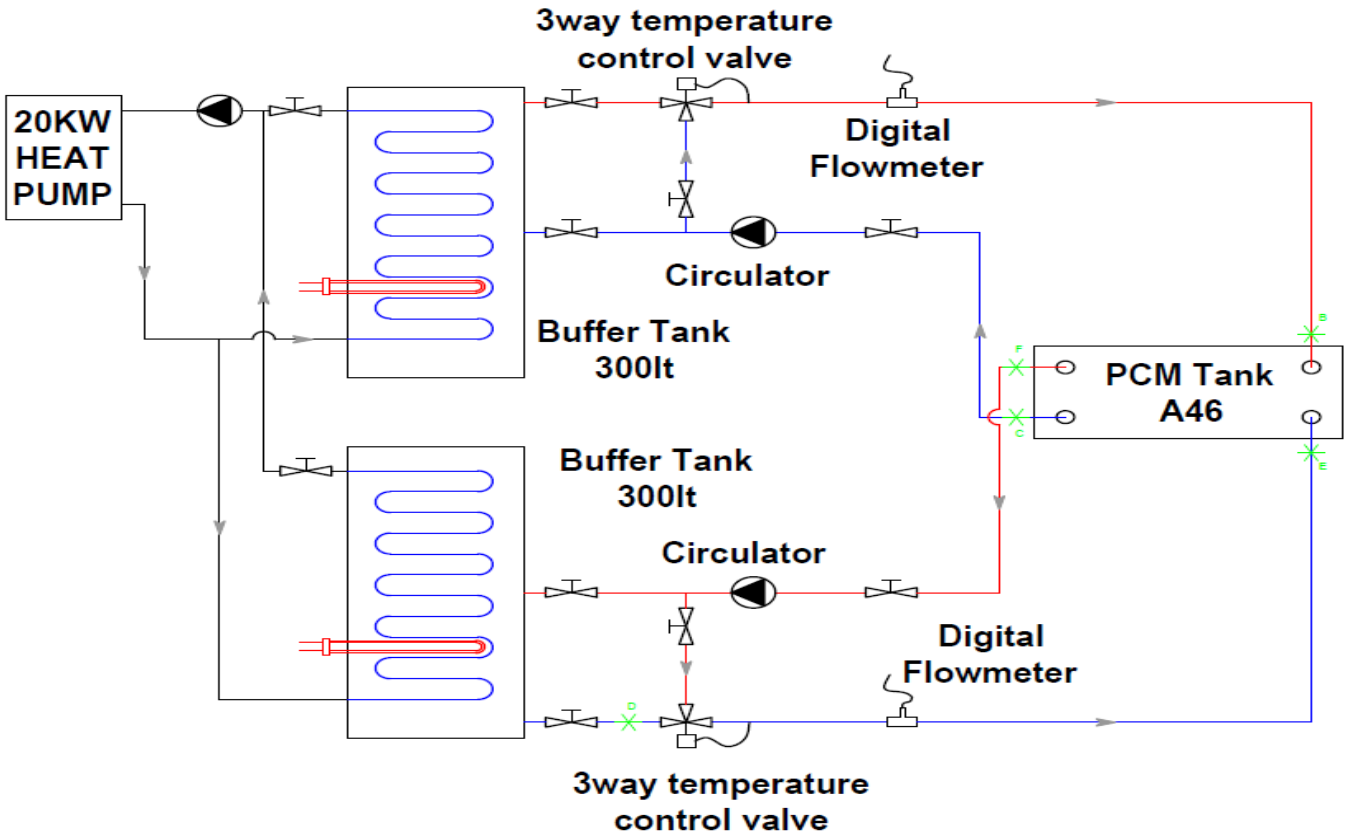
Experimental Data – Energy Analysis

During charging (melting) energy provided by the HTF is more than what required (for tank with adiabatic walls) due to thermal losses. On the contrary during solidification the phenomenon is reversed and as the environment is at higher temperature than the PCM the amount of energy required to fulfill the process is less.

Heat losses increase as the process takes longer (low HTF flow rates and less fins increase energy needed to complete charging and discharging process.

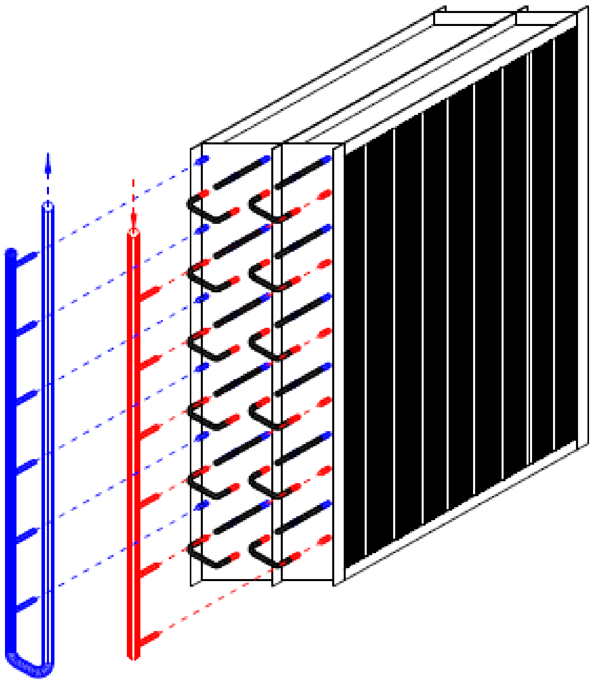
Big Experimental Rig – Site Simulation

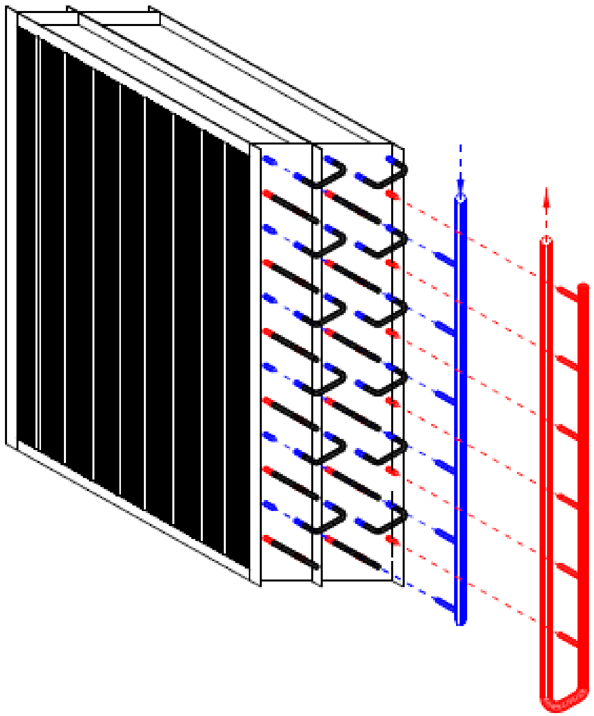
Installation Diagram



Big Experimental Rig – Site Simulation

Staggered Heat Exchanger





Big Experimental Rig – Site Simulation

Big Experimental Rig – Site Simulation

Simulation procedures to validate

1. Charging and discharging of tank individually (energy and time required to fulfil process)

2. Charging and discharging of tank from both circuits (energy and time required to fulfil process)

3. Charging and discharging of tank simultaneously (energy and time required, real time recording)

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Thank for your attention

Thermal Energy
Storage Systems

for energy efficient building an integrated solution for residential building energy storage by solar and geothermal resources

European Commission