Article

Interaction between Organic and Inorganic PCMs and Selected Metals

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Abstract: Phase Change Materials (PCMs) are latent heat storage media with high potential of integration in building structures and technical systems. Their solid-liquid transition is commonly utilized for thermal energy storage in building applications. It also means that some kind of encapsulation is necessary. This is often solved with metal containers that also have high thermal conductivity and resistance to mechanical damage enhancing the performance these so called latent heat thermal energy storage (LHTES) systems. However selection of suitable metal is rather challenging. It depends, among other things, on the elimination of undesirable interaction between storage medium and surrounding metal. Heat storage medium must be reliably sealed in metal container especially when the storage system is integrated in systems like domestic hot water storage tanks, where PCM leaks can negatively affect human health. The aim of this study was evaluation of interaction between selected commercially available organic and inorganic PCMs and metals. The evaluation is based on the calculation of corrosion rate and use gravimetric method for determination of the weigh variations of the metal samples. Results show that aluminium is the most suitable container material with lowest mass loss and suffered only minimal visual changes on the surface after prolonged exposure to PCMs.

Keywords: Phase Change Materials (PCMs); metals; container; latent heat storage; corrosion

1. Introduction

Latent heat thermal energy storage (LHTES) systems use reversible phase change in the storage medium. Although the heat of fusion predominates a lot of heat is stored in solid and liquid state by sensible heat storage. LHTES has the potential to replace common sensible heat storage (SHS; often represented by water tanks) in energy storage units due to higher heat storage density. Therefore the major advantage of LHTES over SHS is much higher energy storage capacity per unit of volume or mass leading to lower spatial requirements. Heat storage in almost isothermal conditions is another advantage of LHTES, [1]. These reasons suggest that application of LHTES could be advantageous in solar thermal systems, heating and cooling systems, building structures, thermal regulating textiles (smart textiles), concentrated solar power systems, food services, thermal management of automotive engines, spacecraft thermal control, and other technologies, [3].

Substances which are ready for use in LHTES systems are called Phase Change Materials (PCMs). Suitable PCMs have temperature range of melting and solidification in accordance with the proposed application, high heat of fusion, and is safety for use, inexpensive and reliable. The fact that PCMs transform from solid to liquid state during operation necessitates appropriate encapsulation. One option is so called macroencapsulation. It represents a common method of mechanical packaging [2] where the PCM is filled into a macro-capsule (container) of required shape

and size. The geometry of the container, material and thickness of its walls all depend on the intended purpose of the particular LHTES system. Design of these parameters is crucial for flawless heat exchange between the PCM and surrounding environment as well as reliability and durability of the system. There are three major issues affecting reliability of LHTES [4, 5, 6]:

- tightness of the container as   migration of PCM or components can lead to loss of heat storage capacity or undesirable interaction with indoor environment;
- stability of the container in contact with PCM – e.g. corrosion of metals due to exposition to PCM can occur;
- elimination of reaction between PCM and container – material of container must be chemically compatible with PCMs.

These issues suggest that compatibility of heat storage media with encapsulating material is a key parameter if long service life of LHTES should be ensured. Moreover container must have necessary strength and be flexible due to the stresses resulting from the volume changes during phase change. Material of container must be stable to UV exposure and allow rapid heat transfer for charging and discharging of PCMs. Metals are therefore often suggested as container material, especially in cases of PCMs with high melting range when other solutions (commonly plastics) cannot be utilized. Metals have high thermal conductivity and regular crystalline structure serving as barrier for diffusion of small gas molecules. On the other hand they are susceptible to corrosion. Three types of PCM-induced corrosion of metals can occur, [6]:

- oxidation of the metal – PCM corrupts porous surface layer of the container, which leads to its uniform perforation (typical for mild steel);
- pitting corrosion – corrosion starts at a point, accelerates and produces deep "pits" (typical for stainless steel, aluminium and coated metals with pinholes);
- stress crack corrosion – corrosion occurs at stress region and results in sudden failure (typical for stainless steel).

Uniform corrosion is commonly determined by weight loss tests. Pitting corrosion requires microscopic evaluation of depth and extension of the corroded pits.

There are already numerous studies evaluating compatibility of PCMs with container materials, [7]. Most of these studies focus on the compatibility between organic and inorganic PCMs with carbon steel, aluminium, copper, brass and stainless steel. The corrosion resistance of metals exposed to PCMs in low temperature LHTES is commonly assess by calculatied corrosion rates (CR) in these studies, [8]. The procedure applied for preparing of metal samples for removing corrosion products and for evaluating the corrosion damage of specimens is describes in ASTM G1 [9].

The assessment of the compatibility between PCM (magnesium nitrate - PlusIce S83) and three metals (aluminium alloy, copper alloy and carbon steel) was presented by Calabrese *et al.* [10]. They performed short-time immersion corrosion tests at 120 °C and used two electrochemical methods for evolution of metal degradation during immersion in PCM: open circuit potential measuring and electrochemical impedance spectroscopy. Electrochemical activity of metals immersed in PCM was analysed by evolution of the impedance curves at increasing immersion time. Results of the study indicate that carbon steel and copper alloy are unsuitable container materials due to their low electrochemical stability. Aluminium alloy was evaluated as a suitable material for encapsulation of selected PCM. Farrell *et al.* [11] examined corrosion resistance of aluminium alloy and copper in contact with commercially available salt hydrate PCMs PlusICE E17 and ClimSel C18. Firstly, they tested separate samples of each metal immersed in the PCMs. The results of this test show higher mass loss of copper samples. Secondly, they tested galvanic corrosion of combined samples of aluminium alloy and copper immersed in the PCMs. Authors concluded that aluminium fins combined with copper heat pipes in a heat exchanger are prone to galvanic corrosion caused by both examined PCMs. Cabeza *et al.* [12] tested five metals (aluminium, brass, copper, steel and stainless steel) in contact with selected salt hydrates (zinc nitrate hexahydrate, sodium hydrogen phosphate dodecahydrate and calcium chloride hexahydrate). The melting temperature of the tested PCMs is

99   32 and 36 °C. The evaluation was based on the calculation of CR as mass loss red meter and day. The
100 samples were removed from PCMs after three, seven and 14 days. The results showed that
101 aluminium and steel should be avoided in PCM containers due to their high corrosion rates. Slower
102 corrosion was observed for brass and copper. Stainless steel was evaluated as corrosion resistant.
103 The immersion corrosion test with the same metals and two salt hydrates (sodium acetate trihydrate
104 and sodium thiosulfate pentahydrate) with melting temperature 58 and 48 °C respectively was
105 presented by Cabeza *et al*. [13]. In this case the metal samples were immersed in pure PCMs and
106 PCMs enhanced with graphite (for increased heat transfer). Immersion time was one, two, four and
107 ten weeks. Based on the calculated CRs authors discouraged application of brass and copper as
108 container materials for long-term storage of the tested PCMs. Aluminium, steel and stainless steel
109 proved to be suitable container materials for both PCMs, however authors recommended
110 monitoring of steel in contact with graphite. Study [14] generally recommends stainless steel as
111 container material for inorganic PCMs. It evaluates CRs and industry recommendations of 6 metals
112 (aluminium, brass, copper, steel, stainless steel and carbon steel) and 13 salt hydrate PCMs. Carbon
113 steel is not recommended or cautiously recommended for the tested PCMs. Ushak *et al*. [15]
114 investigated corrosion effect of bischofite (composed primarily of $MgCl_2 \cdot 6H_2O$) and commercial
115 $MgCl_2 \cdot 6H_2O$ (more than 99 % purity) on copper, aluminium and stainless steel. The contact times
116 between the metals and the salts were 250, 500, 750 and 1 000 h. Calculated mass loss was used as
117 criterion for the evaluation of corrosion effect. The highest mass loss was calculated for copper,
118 while stainless steel showed the lowest mass loss. Moreno *et al*. [16] tested corrosion potential of five
119 inorganic PCMs for cooling applications (melting range 10 – 15 °C) and six inorganic PCMs for
120 heating application (melting range 45 – 48.5 °C). Copper, aluminium, stainless steel were selected as
121 potential container materials. Samples of these metals were immersed in test tubes containing PCMs
122 at constant temperature 22 °C (cooling application) or 60 °C (heating application) for one, four and
123 12 weeks. Results confirmed previous studies: corrosive resistance of stainless steel for all tested
124 inorganic PCMs. The same result was obtained from immersion test conducted by Oró *et al*.[17].
125 They tested copper, aluminium and carbon steel as well. CR was significantly slowed down by 1 %
126 of oxyethylmethylcellulose to thickening the solution in their tests. Danielik *et al*. [18, 19]
127 investigated corrosion resistance of carbon steel and copper in contact with $Mg(NO_3)_2 \cdot 6H_2O$,
128 $Mg(NO_3)_2 \cdot 6H_2O + 0.5wt\% \ Mg(OH)_2$, $Mg(NO_3)_2 \cdot 6H_2O + 0.5wt\% \ Sr(OH)_2$, $Mg(NO_3)_2 \cdot 6H_2O +$
129 $Ca(NO_3)_2 \cdot 4H_2O$ (1:1) and $Ca(NO_3)_2 \cdot 4H_2O$. Melting temperatures of the studied PCMs were 42.7 –
130 88,9 °C. Magnesium hydroxide and strontium hexahydrate were added due to the stabilization of
131 supercooling of magnesium nitrate hexadyrate. During immersion time the ambient temperature
132 was repeatedly changed from 20 °C up to temperature slightly above the melting range of each PCM.
133 The comparison of results in both papers [18, 19] shows that CR of carbon steel (4.6 – 33.3
134 $mg \cdot cm^{-2} \cdot year^{-1}$) is much higher than CR of copper (1.5 – 8.9 $mg \cdot cm^{-2} \cdot year^{-1}$).

135   Many studies also focused on organic PCMs and their corrosion potential. Kahvaji *et al*. [20]
136 selected 16 samples of potential container materials or supplementary gasket materials. These
137 included nine metals or metal alloys and seven plastics. Study focused on the compatibility potential
138 of these materials with five fatty acids and one alcohol representing the PCMs. Materials were
139 immersed in liquid PCMs with temperature of 75 °C for one, six and 12 weeks. The evaluation was
140 based on the results from CR calculations. Stainless steel alloys and aluminium alloys showed good
141 compatibility with all PCMs. Ferrer *et al*. [21] tested compatibility of selected metals (stainless steel
142 SS-316 and SS-304, copper, aluminium and carbon steel), two commercially available PCMs
143 (inorganic SP21E and bio-based PureTemp 23) and two fatty acid eutectics. The melting range of all
144 PCMs was between 21 and 23 °C. Immersion times for evaluation were one, four and 12 weeks.
145 Based on the CR calculation results they concluded that all tested metals can be recommended as
146 container for bio-based PCM (PureTemp 23). Stainless steel and copper also proved resistant to
147 inorganic PCM. On the other hand both fatty acid eutectics caused low corrosion on copper only.
148 Sari *et* Kaygusuz [22] presented study focused on the thermal stability of stearic acid, palmitic acid,
149 myristic acid and lauric acid and their compatibility with carbon steel, stainless steel, aluminium and
150 copper. The evaluation was based on the gravimetric and metallographic analysis. Highest CRs were

151 calculated for steel C20 and copper in contact with myristic acid and copper immersed in stearic acid.
152 In contrast, the lowest CR was calculated for stainless steel. Browne *et al.* [23] chose aluminium, brass,
153 copper, stainless steel and mild steel for corrosion experiments with capric acid, capric-palmitic acid,
154 capric-lauric acid, sal hydrate SP22 and Micronal®. Authors concluded that only stainless steel is
155 suitable container material for all PCMs tested. All metals except aluminium were recommended for
156 use in combination with SP 22. Similarly, all metals except mild steel were recommended for
157 applications with Micronal®. Caution was recommended for other metal-PCM pairs.
158   Presented literature review shows the necessity for compatibility tests of selected metal and
159 organic and inorganic PCMs pairs. It also shows lack of knowledge on the performance of
160 commercially available PCMs (in metal containers) with melting temperature range suitable for
161 installation in the occupied rooms. This issue is stressed by the authors of this paper, who performed
162 a three-year experiment focused on the influence of PCMs on the indoor environment: Figure 1, left
163 shows the installation of aluminium containers fixed on the walls and suspended ceiling in test room
164 at Brno University of Technology. The original aim of this installation was evaluation of suitability of
165 LHTES integration in building structures for improving indoor thermal comfort. However leakage
166 of PCM from many containers (Figure 1, right) was observed during and after the experiment. This
167 was the starting point of the author's research on PCM-metal compatibility. This study follows the
168 literature review above and evaluates impact of long term exposure (visual changes, corrosion) to
169 PCMs on selected metals: aluminium, brass, copper and carbon steel.
170

173 **Figure 1.** PCM encapsulated in aluminium container: (**left**) Experimental installation in the test room;
174 (**right**) PCM leakage on the surface of aluminium container.

2. Results

176   This section presents the results of the compatibility test described in Section 4. The evaluation
177 of the results is divided in two parts. First part includes visual evaluation of the samples, i.e. the
178 color, shape and other changes on the surface of samples encountered after removal from the PCMs.
179 Second part includes evaluation of the CRs that was calculated according to equation (1) described
180 in Section 4.
181   Immersion in organic PCMs caused no visual changes on surface of brass, aluminium and
182 carbon steel samples. Change the color on part of the surface (darker stains) and tarnishing occurred
183 on copper samples. The extent of these changes increased with longer exposure to the PCMs (see
184 Figure 2, top). More pronounced changes were encountered on samples immersed in inorganic
185 PCMs. All samples were tarnished as early as one week after immersion. Noticeable dark brown
186 stains appeared on the surface of copper and brass samples. Corrosion also occurred on the surface
187 of copper (blue corrosion) and carbon steel (dark red and brown corrosion) samples. Progress of
188 tarnishing and corrosion in time is visible in Figure 2 (bottom).

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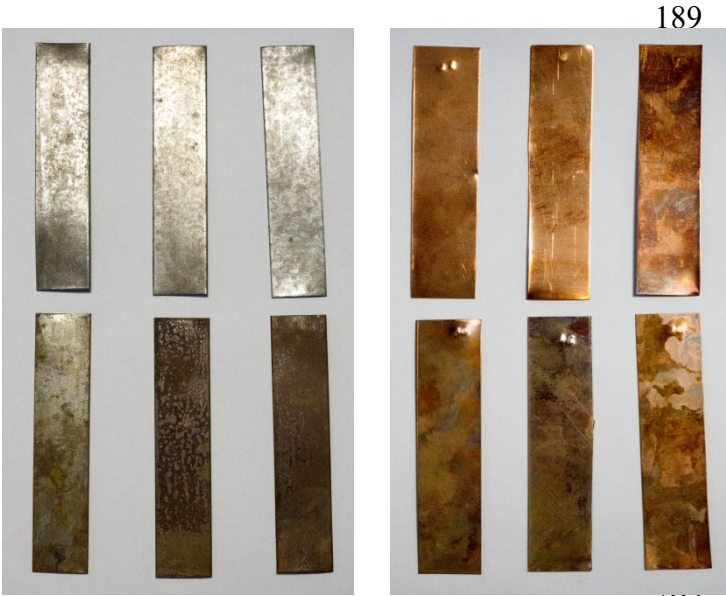
Figure 2. Corrosion, change of appearance and color of the metals samples after testing.

(left) Carbon steel samples removed from organic PCM Linpar 1820 (top row) and inorganic PCM Rubitherm RT SP25 (bottom row) after one, four and twelve weeks (left to right).

(right) Copper samples removed from organic PCM Linpar 17 (top row) and inorganic PCM Rubitherm RT SP25 (bottom row) after one, four and twelve weeks (left to right).

205

206   **Table 1.** CRs of tested metals exposed to particular PCMs (organic Linpar and inorganic Rubitherm)

| Metal	Exposure time	Corrosion rate [mg·cm^{-2}·year^{-1}]			
		Linpar 17	Linpar 1820	RT SP22	RT SP25
Carbon steel	1 weeks	4.058	2.562	11.236	13.897
	4 weeks	0.589	0.492	1.723	3.413
	12 weeks	0.214	0.135	0.712	1.029
Aluminium	1 weeks	1.049	0.762	1.765	1.024
	4 weeks	0.219	0.190	0.991	0.292
	12 weeks	0.053	0.033	0.460	0.194
Copper	1 weeks	1.807	2.564	6.049	5.400
	4 weeks	0.525	0.572	1.013	1.863
	12 weeks	0.174	0.072	0.152	1.004
Brass	1 weeks	1.685	1.926	2.795	3.882
	4 weeks	0.621	0.527	0.894	1.061
	12 weeks	0.044	0.040	0.168	0.476

207
208   Table 1, Figure 3 and Figure 4 show the CR values of the tested metals in all PCMs. When
209   considering organic PCMs, the results show that higher CR were achieved with long-term
210   immersion of samples in Linpar 17. The highest values were achieved in case of carbon steel, where
211   the CR exceeded 4.0 mg·cm^{-2}·year^{-1}. It should be noted that copper and brass samples immersed in
212   Linpar 1820 had higher CR after one-week immersion. The difference was almost 30 % in case of
213   copper. However CR results of these metals obtained after longer exposure also "favour" Linpar 17.
214   The CR curves of metal samples immersed in inorganic PCMs (Figure 4) are very similar to those in
215   organic PCMs. The difference is in their scale: CRs of metals in inorganic PCMs are much higher.
216   This is illustrated in Figure 5, which shows CR curves of copper and carbon steel (highest CRs of all
217   four metals) The values gradually increase from aluminium to brass, copper and finally carbon steel.
218   Highest values were calculated for carbon steel in Rubitherm SP25 (up to 13.897 mg·cm^{-2}·year^{-1}) and
219   copper in Rubitherm SP22 (up to 6.049 mg·cm^{-2}·year^{-1}).
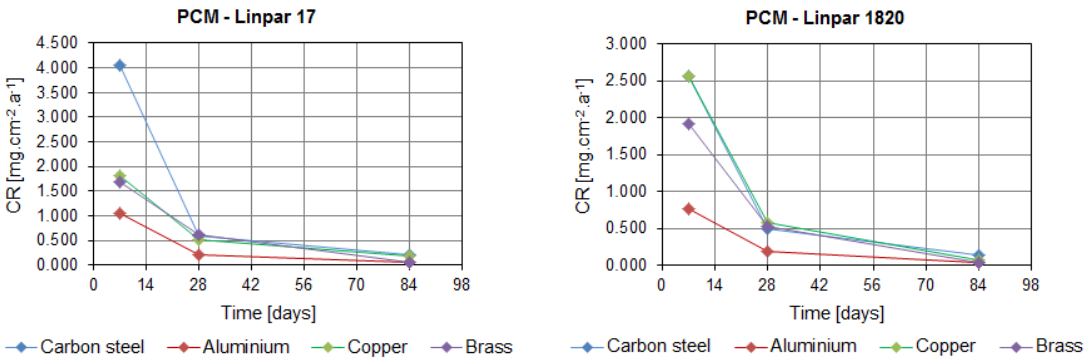
Figure 3. Dependence of CR of tested metals on time of immersed in organic PCMs: (left) in Linpar 17; (right) in Linpar 1820
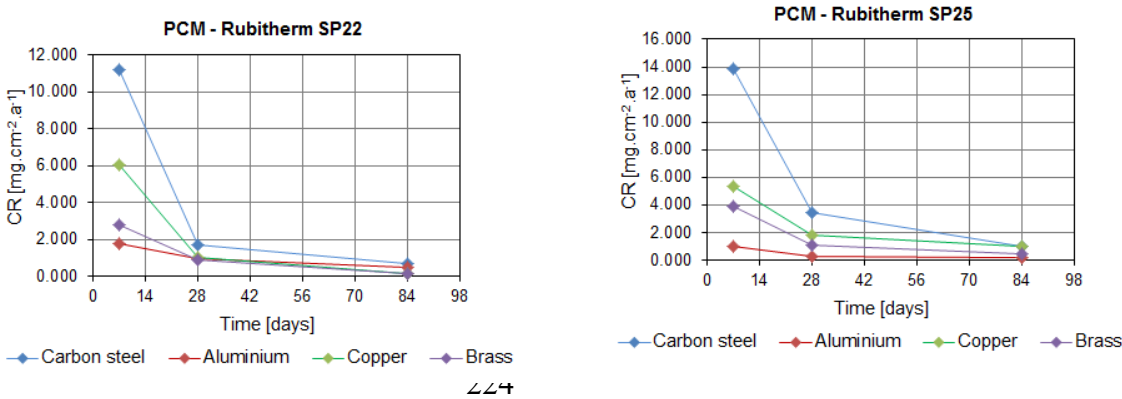

Figure 4. Dependence of CR of tested metals on time of immersed in inorganic PCMs: (left) in Rubitherm SP22; (right) in Rubitherm SP25
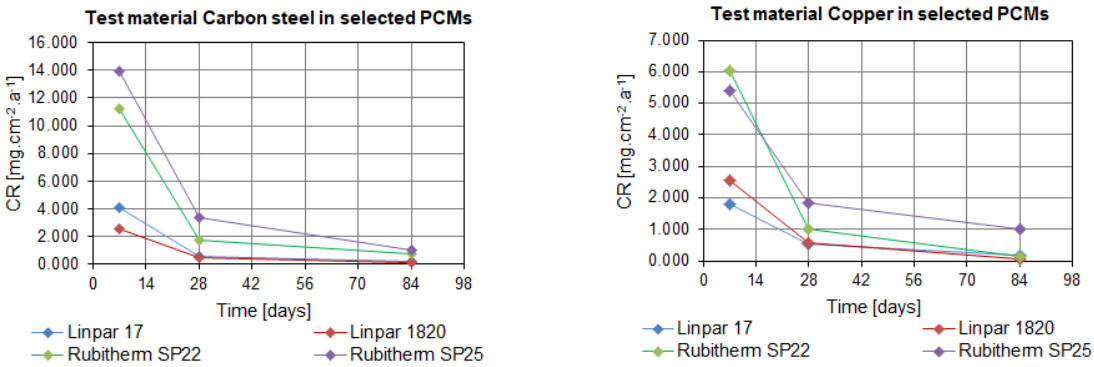
Figure 5. Comparison of the dependence of CR of selected metals in both types organic and inorganic PCMs: (left) for carbon steel samples; (right) for copper samples

Another evaluated parameter was the mass loss Δm, which is an important information for the evaluation of corrosion effect. The highest mass loss was calculated for copper and carbon steel samples in Rubitherm SP25. It reached 9.6 mg for copper after 12 week of immersion and 11.2 mg for carbon steel after 4 week of immersion (see in Figure 6). In contrast, the lowest mass losses of all tested metals were calculated in samples immersed in organic PCM Linpar 17. In case of aluminium it ranged between 0.5 to 0.8 mg depending on the length of immersion. In contrast, aluminium achieved much higher mass loss of 1.4 to 4.4 mg in inorganic PCMs Rubitherm SP22.
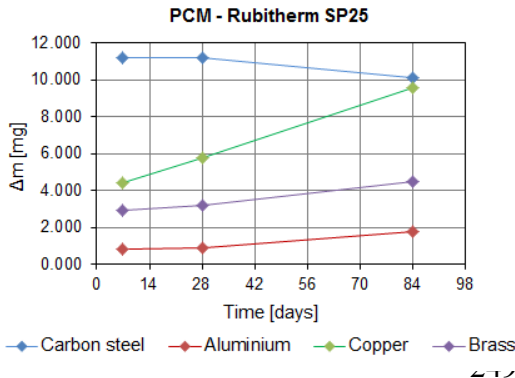
Figure 6. The mass loss of all metals in inorganic Rubitherm SP25

3. Discussion

The results of the study are compiled in Table 2. It shows the range of calculated CR values, surface changes, occurrence of corrosion and evaluation according to the Guide for corrosion weight loss used in the industry [17, 21]. Most tested metal-PCM combinations were evaluated as "Recommended" according to this guide. The exception is carbon steel in combination with inorganic PCMs, which achieved "Cautiously recommended" level. Regardless of the Guide it seems appropriate to further discourage use of copper and carbon steel in combination with inorganic PCMs due to higher CR values, significant mass loss and visible changes on the surface of the samples.

Table 2. Classification of selected PCM–metal combinations according to the CR parameter
[mg·cm^{-2}·year^{-1}] and recommendation according to final appearance of samples (based on Table 1.)

Material (metals)	Criterion	PCMs (organic group Linpar and inorganic group RT)			
		Linpar 17	Linpar 1820	RT SP22	RT SP25
Carbon steel	CR	0.21 to 4.05	0.13 to 2.56	0.71 to 11.23	1.02 to 13.89
	Corrosion	no corrosion	no corrosion	corrosion – red colour	corrosion – red colour
		surface – no change	surface – no change		
	Recommendation	recommended	recommended	cautiously recommended	cautiously recommended
Aluminium	CR	0.05 to 1.05	0.03 to 0.76	0.46 to 1.76	0.19 to 1.02
	Corrosion	no corrosion, shiny surface	no corrosion, shiny surface	no corrosion, surface tarnish, occurrence of cracks	no corrosion, surface tarnish
	Recommendation	recommended	recommended	recommended	recommended
Copper	CR	0.17 to 1.80	0.07 to 2.56	0.15 to 2.79	1.00 to 5.40
	Corrosion	no corrosion, shiny to matt surface with time	no corrosion, shiny to matt surface with time	corrosion – blue colour, surface tarnish	corrosion – blue colour, surface tarnish
	Recommendation	recommended	recommended	recommended	recommended
Brass	CR	0.04 to 1.68	0.04 to 1.92	0.16 to 6.04	0.47 to 3.88
	Corrosion	no corrosion, shiny surface	no corrosion, shiny surface	no corrosion, surface tarnish	no corrosion, surface tarnish
	Recommendation	recommended	recommended	recommended	recommended

263 The results also confirm the literature review (see Section 1) regarding significant differences in
264 exposure of metals to organic and inorganic PCMs (in favour of organic PCMs). All metals
265 demonstrated good compatibility (minimum to no visible changes and low CR) with organic PCMs.
266 This is also confirmed by lower mass loss of tested metals, where the maximum value in organic
267 PCM was 2.1 mg in case of carbon steel in Linpar 1820. This is almost six times lower value
268 compared to the mass loss of carbon steel in inorganic PCM Rubitherm SP25. The results indicate
269 low aggressiveness of tested organic PCMs and confirm suitability of tested metals in the role of
270 their containers.

4. Materials and Methods

272 Long-term experimental measurements were performed to verify compatibility of two types of
273 PCMs (organic and inorganic) with selected metals (representing possible container materials). The
274 aim of the experiment was elimination of metals unsuitable for the role of long-term PCM containers
275 (integrated in building structures). The evaluation was based on weight loss and surface changes (i.a.
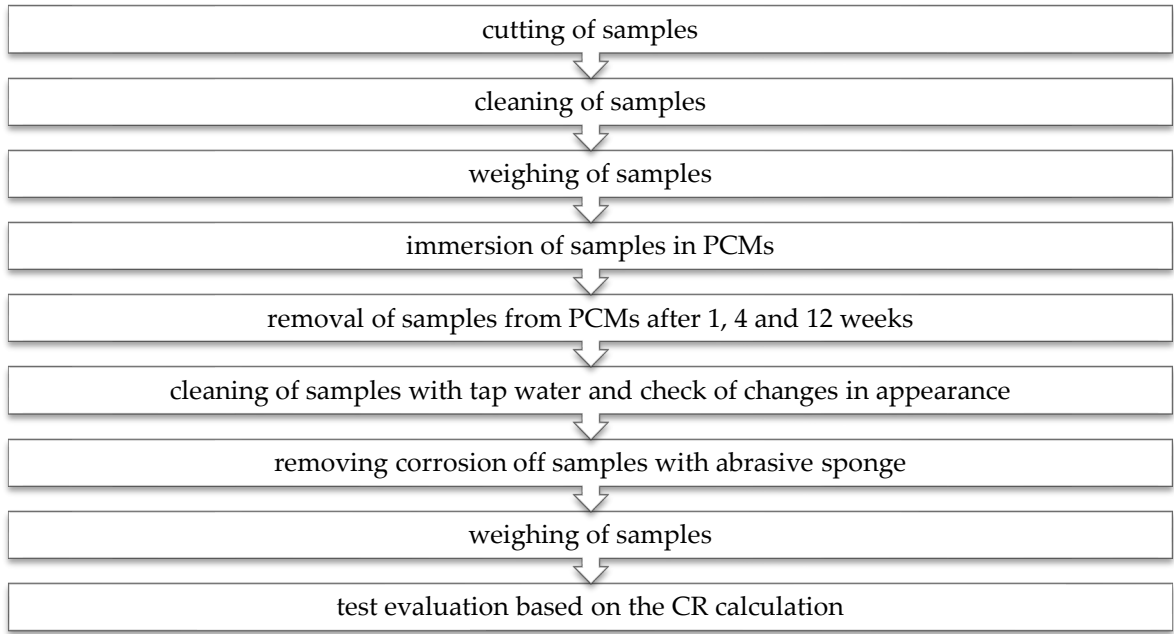276 corrosion, change of color, swelling of the samples).

Figure 7. Experimental procedure.

290 Four metals applicable in the role of PCM containers (based on literature review in Section 1)
291 were selected for the experiment: carbon steel, aluminium, copper and brass. The reasons for
292 selection of the particular metals include low costs and excellent market availability. 36 samples
293 were prepared out of each metal (144 samples in total) for the testing (see Figure 7, right). The
294 samples were divided into 12 sets of 3 samples for each metal. Individual samples were
295 approximately 2.0 cm wide, 10.0 cm high and, 0.1 cm (carbon steel) or 0.05 cm (other metals) thick.
296 Table 3 includes the parameters and product names of the tested PCMs. Paraffin-based Linpar
297 17 and Linpar 1820 represent organic PCMs in the experiment, while salt-hydrate-based Rubitherm
298 SP22 and Rubitherm SP25 represent inorganic PCMs. Parameters in table 3. were acquired using
299 Different Scanning Calorimeter (DSC).
300

301   **Table 3.** Parameters of selected PCMs (measured during melting) with DSC.

Type	Product name	Manufacturer	Latent heat [$J \cdot g^{-1}$]	Onset temperature [°C]	Peak temperature [°C]
inorganic	SP22	Rubitherm	145	14	25
inorganic	SP25	Rubitherm	122	18	28
organic	Linpar 17	Sasol	152	21	22
organic	Linpar 1820	Sasol	141	24	27

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306   **Figure 8.** Metal samples prepared for corrosion testing: (**left**) Test beakers placed in environmental
307   chamber; (**right**) Samples in test beakers.

308   The parameter evaluating of metal-PCM combinations in this study is corrosion rate (CR)
309 defined according to methodology described in [17] and [21]. The Guide for corrosion weight loss
310 used in the industry [16, 17, 21] (see Table 4) was utilized for the classification and verbal evaluation of
311 CR in this study. CR was defined as a change of mass Δm relative to surface area of the metal sample in
312 specific experimental time period. The change in mass is defined as the difference in initial sample
313 weight and the weight at the end of the particular time period.

$$CR = \Delta m/A \cdot (t_0 - t), \qquad (1)$$

314   where CR is the corrosion rate in mg·cm^{-2}·year^{-1}, Δm is mass loss (in mg) and it is defined by the
315 relation $\Delta m = m(t_0) - m(t)$. The value $m(t_0)$ is initial weight of the sample (in mg) before immersion in
316 PCMs and $m(t)$ is final weight of the sample (in mg) after removal from PCMs. The area of each
317 sample is expressed by value A (in cm^2) and $(t_0 - t)$ is the experimental time of PCMs exposure (in
318 years).

319   **Table 4.** Guide for corrosion weight loss used in the industry [17, 21]

CR [mg·cm^{-2}·year^{-1}]	Recommendation
> 1000	Completely destroyed within days
100 to 999	Not recommended for service greater than a month
50 to 99	Not recommended for service greater than 1 year
10 to 49	Caution recommended, based on the specific application
0.3 to 9.9	Recommended for long term service
< 0.2	Recommended for long term service; no corrosion, other than as a result of surface cleaning, was evidenced

320

321   All metal samples were clearly labelled, purified and weighted on microscales prior to the
322 experiment. Excessive material (residuals after cutting) was mechanically removed. Afterwards the
323 samples were visually checked, inserted into supporting foam holder (see Figure 8, right) and placed
324 into testing beakers. There they were fully immersed in liquid PCMs. Special care was taken to
325 prevent mutual contact of metal samples (causing uneven exposure of the surface to the PCM).
326   The test beakers were placed into a small environmental chamber (see in Figure 8, left). There
327 they were exposed to repeating temperature cycling with temperatures ranging from 15 °C to 40 °C.
328 The cycle consisted of four phases, each lasting for two hours (see Figure 9). The cycle started with
329 linear temperature raise (to 40 °C) during first phase. Second phase comprised maintaining of the
330 temperature at this level. The temperature was linearly reduced to 15 °C in the third phase. This
331 temperature was maintained during fourth phase of the cycle. The temperature cycling lasted for
332 twelve weeks (84 days).
333   Sets of samples were withdrawn from the beakers on given time after one week (7 days), four
334 week (28 days) and 12 week (84 days) exposure to the PCMs.
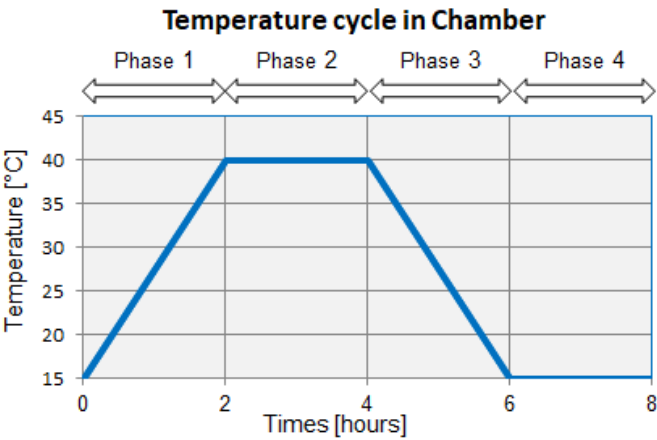
335
336
337 **Figure 9.** Temperature cycle repeated in the small environmental chamber for the duration of the experiment.
338

339   After removal from the test beakers, the samples were visually inspected and cleaned of any
340 liquid residues. Corrosion was removed using abrasive sponge. Cleaned samples were weighted on
341 microscale. The weight of each sample was rounded to 0.1 mg. One sample from each set was
342 selected using the median value.   The weight change of the selected samples was used for
343 calculating CR afterwards. This method was selected to minimize errors and eliminate extreme
344 values.

5. Conclusions

346   This study deals with the issue of compatibility of selected metals and (organic and inorganic)
347 PCMs. It deals with the selection of suitable metal for the role of container material for long term
348 PCM encapsulation. Therefore samples of four metals (aluminium, brass, copper and carbon steel)
349 were tested in combination with four PCMs for up to 12 weeks.
350   The initial premise of the experiment was that exposure the surface of metals to effects of PCMs
351 will affect their shape, surface flatness, color and perhaps the occurrence of surface corrosion will be
352 detected. Literature review suggested that copper and carbon steel are unsuitable for long-term
353 exposition to PCMs. This assumption was confirmed, i.e. the both metals showed signs of surface
354 corrosion and change of color at the end of the experiment. Moreover they both achieved higher CR
355 values and more pronounced mass loss compared to other tested metals (in inorganic PCMs). The
356 results indicate that aluminium is the best (out of the tested metals) suited for the role of PCM
357 container. It had the lowest mass loss and CR and suffered only minimal visual changes on the
358 surface. This long-term stability should ensure durability of whole LHTES system (e.g. prevent
359 leakage due to corrosion).

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