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Corrosion Monitoring and Mitigation Techniques on Advanced Thermal Energy Storage Materials for CSP Plants

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Abstract

High temperature corrosion is one of the most important issues for materials selection, structure design and service life prediction of engineering parts that are exposed to high temperature environments. The prevention of high temperature corrosive attacks on materials plays a critical role in aspects such as reliability, quality, safety and profitability of any industrial sector associated with high temperature process and in the study case, concentrated solar power (CSP) market, using inorganic molten salts as storage material. The aim of this research is the development of corrosion tests through conventional gravimetric techniques focussed on thermal energy storage (TES) materials as well as electrochemical impedance spectroscopy (EIS) analysis for storage systems monitoring. To mitigate corrosion, different alumina forming austenitic (AFA) alloys were exposed to the most promising molten salts to be proposed for the new generation of CSP plants, nitrate, carbonate and chloride molten salts. Ni base alloys showed a better behaviour in the corrosive environments and electrochemical impedance tests revealed the formation of a protective layer in the first 100 hours. The gravimetric results and the scanning electron microscopy (SEM) analyses that were performed, confirmed the excellent behaviour of the steels tested in nitrate salts reducing the corrosion in these promising novel molten salts compared with the solar salt currently used in commercial CSP. On the other hand, carbonate and chloride molten salts showed a higher corrosion rate in the materials proposed, especially chloride molten salts.

Keywords: Electrochemical Impedance Spectroscopy; Molten salts; Corrosion; Alumina Forming alloys

1. Introduction

Current power tower CSP technology was developed from the THEMIS experimental plant in the 1980s. This embodiment is considered to be the second generation of CSP technologies which uses molten salt heat transfer fluid (HTF) heated by concentrated sunlight to store thermal energy for its use to produce superheated steam on demand for a steam-turbine at 560°C [1].

On average, the projected cost for a CSP plant dropped about 9 ¢/kWh cents per kilowatt hour, from 21 ¢/kWh in 2010 to 12 ¢/kWh in 2015 and anticipated to reach 10 ¢/kWh in 2018 [1]. Nevertheless, a higher cost reduction is necessary in order to compete with PV technology and conventional energy plants.

Particularly, increasing the maximum operating temperature and thereby the thermal to electric conversion efficiency reduce the required capacity of the entire plant strongly influencing cost reduction. Steam turbines operating temperature is limited by the molten salt heat transfer fluid at 565°C, resulting in a net design point efficiency of 42% [1], so molten salt technologies require other alternative salt chemistries such as chloride or carbonate salts, able to work at higher temperatures.

Regarding the cations used for molten salt formulations, lithium is recognized as a critical material [2], due to its particular properties that make it well suited for storage applications, increasing heat capacity and energy density in electric and thermal systems.

In recent years, lithium nitrate (LiNO_3) was considered as a good additive to improve the thermal performance of molten salts [3]. These additions improved the temperature work range by lowering the melting point as well as increasing the thermal stability to higher temperatures.

For this reason, the selected salts in this study were the most promising Li based eutectic candidates to be used in the new generation of CSP plants:

- 30wt.% LiNO_3 + 57wt.% KNO_3 + 13wt.% NaNO_3 m.p. 130°C
- 32wt.% Li_2CO_3 + 33wt.% Na_2CO_3 + 35wt.% K_2CO_3 m.p. 397°C

- 45wt.% LiCl + 55wt.% KCl

m.p. 353°C

Ternary eutectic carbonate $\text{Na}_2\text{CO}_3/\text{K}_2\text{CO}_3/\text{Li}_2\text{CO}_3$ has excellent energy density, much higher than the nitrate solar salt, because it has higher heat capacity ($\sim 1.6 \text{ J/g}\cdot\text{K}$) and liquid density ($\sim 2 \text{ kg/L}$) [4].

Because of their low cost and high decomposition temperatures, molten chlorides are being considered as good candidates. However, these molten salts introduce a set of technological and engineering challenges because of their very corrosive characteristics for typical materials [5,6]. In this case, an eutectic mixture composed by 45wt.% LiCl and 55wt.% KCl will be tested. The storage temperatures able to reach these molten salts are 550°C (nitrates), 650°C (carbonates), and 750°C (chlorides). Corrosion tests were carried out at these temperatures using conventional gravimetric techniques and in the last case, chloride molten salts, also an experimental corrosion monitoring technique based on EIS has been performed.

2. Electrochemical impedance spectroscopy:

In recent years electrochemical impedance spectroscopy (EIS) was successfully applied to the study of corrosion systems. For TES, EIS could be an interesting option to monitor corrosion in energy generation plants. The biggest advantage of this technique is the low intensity of excitation signal used which causes minimal disruption in the electrochemical system state, constituting a non-destructive technique and reducing the error associated with the measurement process [7,8]. Impedance spectra obtained by this method are adjusted to an electrical circuit of a combination of resistors and capacitors (equivalent circuits), in order to interpret the corrosion processes [9].

EIS generally requires additional information to correlate and confirm the selected circuit with a physical phenomenon, such as X-ray diffraction (XRD) and scanning electron microscopy (SEM).

The most common equivalent circuit used to model corrosion of bare metal in an aqueous electrolyte is the Randles circuit. The model can be used to estimate the polarization resistance from the impedance data [10]. Where R (Ω) is the uncompensated solution

resistance, R_p is the polarization resistance and CPE (Constant Phase Element) is the double layer capacitance. Nyquist plots are used to graph the results (Figure 1).

Figure 1. Randles equivalent circuit applied to a Nyquist plot [11]

The Nyquist plot represents the real part of the impedance on the abscissa and the imaginary part thereof on the ordinate axis, both at different frequencies [11]. The semicircle obtained in the parallel RC circuit is used at higher values of Z' and represents the total impedance (Z) of the Randles circuit as:

$$Z = R_s + \frac{1}{\frac{1}{R_{ct}} + j\omega C_{dl}} \quad [\text{Eq. I}]$$

where R_s is the resistance of the solution, R_{ct} is the resistance to charge transfer, $j\omega$ is the imaginary radial frequency and C_{dl} is the capacitance of the double layer.

Different authors [12-14] proposed equivalent circuits that match to the main corrosion processes obtained in a molten salt environment at high temperature.

Zeng et al. [12] established that, if the slope of the line obtained at low frequencies is less than 1, a porous scale could be formed on the metal surface. This scale may be considered to be permeable to the molten salts, and thus the diffusion direction of oxidants have influence in the corrosion process. In this case, the modulus of the Warburg resistance, related to the solubility and diffusion coefficient of oxidants in the melt, should be considered [14].

Figure 2. Equivalent circuit representing: (Left) the corrosion of metals forming a porous scale and corresponding Nyquist plot [12], (Right) the corrosion of metals forming a protective scale and corresponding Nyquist plot.

Fig. 2 (left) shows the equivalent circuit and Nyquist plot obtained for a porous scale behaviour. If the scale is considered as a capacitor, it has a series relation with the double-layer capacitance at the oxide/salt interface, as presented by the equivalent circuit shown in Fig. 2 (right). Correspondingly, the Nyquist plot is composed of double capacitance loops. In the last scenario considered in this section, localized corrosion can be represented by the equivalent circuit represented in Fig. 3.

Figure 3. Equivalent circuit representing the corrosion of metals forming a localized scale and corresponding Nyquist plot [12].

Where C_{dl} and R_t , respectively represent double-layer capacitance and charge transfer resistance along the localized corrosion zone. C_{ox} and R_{ox} represent the oxide capacitance and transfer resistance of ions in the scale along the protective corrosion scale.

EIS and gravimetric techniques have been used in the present paper to evaluate corrosion mitigation using alumina forming alloys as an alternative to reduce corrosion in molten salts at high temperatures (650–750°C) through the formation of a native alumina scale that offers a better oxidation resistance than chromia-forming conventional stainless steels [15,16].

Ni based alloys are also proposed for corrosion mitigation since present great corrosion resistance at high temperature related with the formation of protective layers (alumina and chromia, mainly) in their surface [1].

3. Materials and methods

The molten salts used in this research are NaNO_3 , KNO_3 and LiNO_3 from Merck and with a purity of 98%, and Li_2CO_3 , Na_2CO_3 , K_2CO_3 , LiCl , and KCl from Sigma Aldrich and a purity of 99%. The impurity content (that can influence the corrosion process) in these salts, is shown in Table 1.

Table1: Impurity content present in molten salts tested

Component	Cl ⁻ (%)	Mg (%)	Ca (%)	SO ₄ ²⁻ (%)
NaNO₃	0.04	0.03	0.06	0.24
KNO₃	0.06	0.03	0.05	0.23
LiNO₃	0.01	-	0.2	0.05
K₂CO₃	0.005	0.0005	0.001	0.02
Na₂CO₃	0.05	0.005	0.02	0.02
Li₂CO₃	0.02	0.02	0.03	0.007
LiCl	Base Content	0.005	0.001	0.01
NaCl	Base Content	0.001	0.005	0.001

Salts were carefully handled in order to avoid the water absorption and a stepwise heating (150-200-250-350-500-550/650/750°C) procedure was carried out in order to melt the salts properly.

The specimens used in the corrosion test need to be measured in order to know the area that will be in contact with the molten salt. The dimensions of the analysed samples in the gravimetric corrosion tests are 20 mm × 10 mm × 2 mm; the dimensions of each sample were measured using an electronic caliber, and each sample was weighed using an analytical balance with an accuracy of 0.00001 g. Samples were cleaned with acetone in an ultrasonic bath and after the corrosion test, coupons were cooled slowly and then dried and weighed. The formula (equation II) used to calculate the mass gain over time is:

$$\frac{\Delta m}{S_0} = \frac{m_f - m_i}{S_0} \quad [\text{Eq. II}]$$

where m_i is the initial mass of the specimen, m_f is the mass of the same at time t , and S_0 is the initial area of the specimen. The gravimetric curve is completed using this value (Y axis) and time of exposure (X axis).

During the drying and handling process the specimen could present spallation and loss of the corrosion layer, due the thermal expansion coefficient variation between the different oxides formed in the steel surface, producing non accurate values during the gravimetric test. In order to avoid this uncertainty, the other way to evaluate the gravimetric corrosion involves the opposite evaluation, analysing the weight lost in the material removing the corrosion layer produced after the corrosion process. The methodology follows the ASTM standard (G1-03) (Reapproved 2011) [17] which involves the corroded metal immersion in a cleaning solution that reacts with the oxide layer depending on the nature of the base material. ASTM standard proposes different solutions and thermal treatments, removing only corrosion products.

For carbonate and chloride salts, the samples were cleaned after immersion using a cleaning solution 10% H_2SO_4 in order to remove the salt remaining. Afterwards, ASTM standard was also used for gravimetric weight loss analysis.

On the other hand, EIS test was the selected technique to determine corrosion mechanism after immersion in 45wt.% LiCl + 55wt.% KCl molten salt at 750°C. A two-electrode arrangement was used with the working electrode (WE) as the sample, the reference electrode (RE), and the counter electrode (CE) were connected in the same sample. The WE potential (E) was continuously recorded starting immediately after its salt immersion until $dE/dt \leq 100 \mu\text{V/s}$ was obtained and thus OCP was established. The potential of the sample (working electrode (WE)) was measured by a potentiostat with respect to the reference

electrode (RE), using platinum wires. Electrical connection of the WE is obtained using a 0.5 mm diameter nickel–chromium welded to the top section of the sample coupon. The wires are electrically insulated using alumina tubes sealed with high temperature castable cement (Fig. 4). This configuration was previously used by Fernandez et al. [18] to study the corrosion produced by binary solar salt (60% NaNO₃ + 40% KNO₃) applied as TES material in CSP plants.

Figure 4. Experimental setup of an electrochemical test [Adapted from 18]

Regarding the container materials selected, during last years, some authors [19-21] have explored the effect of alloying modifications on oxidation behaviour with an emphasis on the variation of Nb content as a function of Ni and Al levels. Niobium content is an important factor in oxidation resistance because the increase of niobium and nickel levels may reduce alloy oxygen solubility, which favours external protective Al₂O₃ scale formation with a superior degree of protection than Cr₂O₃. According to this, the elements composition for the selected materials used in this research is shown in Table 2.

Table 2. Chemical composition of the materials tested in molten salts

Material	Weight (%)							
	Al	Mn	Ni	Cr	Mo	Ti	Nb	Fe
AISI304	-	1.7	8.04	18.28	0.27	0.01	0.008	Balance
OCT	3	-	35	14	-	2	3	Balance
In 702	2.75-3.75	-	75	14-17	-	-	-	2

4. Results

4.1. Corrosion tests in nitrate salts

The gravimetric weight loss for the steels tested at 550°C during 1000 hours is shown in Figure 5. The OCT steel shows highest mass gain after 1000 hours of molten salt exposure, resulting in an irregular growth of mass, with different weight gains and losses. In contrast, In702 shows the best behaviour in this environment with a reduced mass gain.

Figure 5. Gravimetric corrosion curve in 30wt.%LiNO₃ + 57wt.%KNO₃ + 13wt.%NaNO₃ mixture at 550°C for 1000 hours of test

It is important to point out the weight gain in 304SS with a high corrosion tendency until 500 h of exposure and a change on this trend at the end of the experiment. To explain this behaviour, a micro-structural (superficial) study of the 304SS was performed using SEM (backscattered electron detectors). Figure 6 shows the superficial appearance of the sample after 500 and 1000 hours of exposure as well as the EDX analysis performed. The formed oxidation layer is very fragile, with several releasing zones, which explains the continuous fluctuations in the mass gain and the weight reduction at the end of the test.

Spectrum	O	Mg	Cr	Mn	Fe
Spectrum 1	32.56	4.08	3.02	2.04	58.39
Spectrum 2	22.39	7.99	2.55	2.63	64.44

Figure 6. Superficial image of 304SS at 500 h (left) and 1000 h (right) of test In702 (Figure 7 left) showed Al and Cr content explaining the best behaviour in the corrosive environment due to the formation of a protective scale. OCT (Figure 7 right) revealed higher oxygen content, according with the gravimetric corrosion weight gain.

Spectrum	O	Mg	Al	Cr	Ni
Spectrum 1	28.64	8.89	2.13	5.80	Balance

Spectrum	Al	O	Cr	Fe	Ca	Mg
Spectrum 1	0.57	32.44	1.23	Balance	5.64	5.63

Figure 7. Superficial image of In702 (left) and OCT (right) at 1000 h of test

The cross sectional study performed in 304SS confirms the spallation and the loss of weight at the end of the test. The scale is mainly composed by iron and oxygen.

Spectrum	O	Cr	Fe	Ni
A-2	12.65	1.73	78.80	1.42
A-4	16.36	1.63	69.45	0.93

Figure 8. Cross section image of 304SS at 1000 h of test

For the OCT steel, the transversal study shows a more compact corrosion layer composed by Al, O, Cr and Fe. This content in aluminium and chromium could form a protective barrier against corrosion over the time.

Spectrum	Al	O	Cr	Fe	Ni
A	1.61	9.51	3.3	Balance	0.25

Figure 9. Cross section image of OCT at 1000 h of test

As mentioned before, In702 showed the best corrosion behaviour in the ternary nitrate molten salt and no corrosion products were obtained at the end of test (Figure 7 left). XRD analyses were carried out in the steels at 1000 hours of immersion in order to obtain the corrosion and protective compounds formed in the steels surface. An example of the diffractogram obtained in the steels tested is shown in Figure 10. According with the gravimetric results, a protective layer composed by Al_2O_3 and NiCr_2O_4 was formed in the material surface.

Figure 10. XRD analysis of In702 at 1000 h of test

Table 2 shows the compounds detected in the XRD analysis carried out in the steels immersed in 30wt.% LiNO_3 + 57wt.% KNO_3 + 13wt.% NaNO_3 mixture at 550°C during 1000 hours.

Table 2. Corrosion products detected by XRD in 304SS, OCT and Inconel 702 immersed in 30wt% LiNO₃ + 57wt%KNO₃ + 13wt%NaNO₃ molten salt during 1000 hours

Molten salts	Material	Corrosion Products
30wt.% LiNO ₃ + 57wt.% KNO ₃ + 13wt.% NaNO ₃	304SS	LiFeO ₂ FeCr ₂ O ₄ Fe ₂ O ₃
	OCT	LiFeO ₂ Fe ₃ O ₄ MgO MgAl ₂ O ₄ Fe ₂ O ₃
	In702	NiO Al ₂ O ₃ NiCr ₂ O ₄

Corrosion products obtained are divided in protective compounds [13], as Al₂O₃, NiCr₂O₄, and FeCr₂O₄ (and the interaction with some impurities from the salt, MgAl₂O₄), and the unprotective layer, composed by oxidation products as Fe₂O₃, Fe₃O₄, MgO, and NiO. Some of these oxides can interact with decomposition products from the salt forming LiFeO₂, according the following reaction [24]:

4.2. Corrosion tests in carbonate salts:

The eutectic ternary carbonate salt 32wt.% Li₂CO₃ + 35wt.% K₂CO₃ + 33wt.% Na₂CO₃ was tested at 650°C in the same alloys, 304SS, In702, and OCT, during 1000 hours. The gravimetric curve obtained is shown in Figure 11.

Figure 11. Gravimetric corrosion curve in 32%Li₂CO₃ +35%K₂CO₃ + 33%Na₂CO₃ mixture at 650°C for 1000 hours of test

The gravimetric weight gain is higher than that of nitrate molten salts. 304SS test only could be carried out until 500 hours of immersion, showing a severe corrosion spallation (Figure 12).

Figure 12. Corrosion observed in 304SS immersed in saline 32wt.% Li₂CO₃ + 35wt.% K₂CO₃ + 33wt.% Na₂CO₃ at 650°C after 500 hours of test

OCT showed the highest mass gain in contact with the carbonate molten salt studied. The superficial study revealed the formation of an unprotective scale with Mg-O-Fe content (Figure 13).

Spectrum	O	Mg	Fe
Spectrum 1	33.00	2.06	61.65
Spectrum 2	32.01	2.67	62.15

Figure 13. Superficial image of OCT immersed in 32wt.% Li_2CO_3 + 35wt.% K_2CO_3 + 33wt.% Na_2CO_3 mixture at 650°C during 1000 hours of test.

As in the previous case, In702 showed the best behaviour against corrosion and, in this case, a protective scale in the Ni base alloy surface, composed by Al-O-Ni, was formed (Figure 14).

Spectrum	O	Al	Fe	Ni
Spectrum 1	23.86	-	2.26	79.95
Spectrum 2	21.41	1.59	2.51	72.98

Figure 14. Superficial image of In702 immersed in 32wt.% Li_2CO_3 + 35wt.% K_2CO_3 + 33wt.% Na_2CO_3 mixture at 650°C during 1000 hours of test

The cross sectional study performed in OCT steel showed a thicker corrosion scale compared with the previous case in nitrate salts. Figure 15 shows the microstructure obtained and the EDS analysis (left) as well as a composition proposal of each scale (right), according the XRD performed in the samples and showed in Table 3.

Spectrum	Al	O	Cr	Fe	Ni	Li
A	1.45	18.09	22.53	29.39	24.53	-
B	1.09	19.56	7.85	16.45	53.19	-
C	3.5	20.44	1.71	12.49	35.81	5.32
D	1.27	21.64	-	17.82	5.62	9.78

Figure 15. Cross sectional image of OCT immersed in saline 32wt.% Li_2CO_3 + 35wt.% K_2CO_3 + 33wt.% Na_2CO_3 at 650°C during 1000 hours of test

The cross section study performed in In702 is shown in Figure 16. A compact scale was obtained at the end of the test, composed by Al, Cr, Ni and oxygen, mainly. Lithium element could be detected using Soft X-ray Emission Spectrometer (SXES) coupled to EDX detector.

Figure 16. Cross sectional image of In702 immersed in 32wt.% Li_2CO_3 + 35wt.% K_2CO_3 + 33wt.% Na_2CO_3 at 650°C during 1000 hours of test

The X-ray diffractogram obtained in In702 is shown in figure 17, confirming the protective compounds present in the protective scale formed.

Figure 17. XRD analysis of In702 immersed in 32wt.% Li_2CO_3 + 35wt.% K_2CO_3 + 33wt.% Na_2CO_3 at 1000 h of test

Table 3 shows the compounds detected in the XRD analysis carried out in the materials immersed in 32wt.% Li_2CO_3 + 35wt.% K_2CO_3 + 33wt.% Na_2CO_3 at 650°C after 1000 hours of test.

Table 3. Corrosion products detected by XRD in 304SS, OCT, and Inconel 702 immersed in 32wt% Li_2CO_3 + 35wt% K_2CO_3 + 33wt% Na_2CO_3 molten salt during 1000 hours

Molten salts	Material	Corrosion Products
32wt.% Li_2CO_3 + 35wt.% K_2CO_3 + 33wt.% Na_2CO_3	304SS	Fe_3O_4 Fe_2O_3 MgO CaCO_3
	OC-T	LiFeO_2 NiO Li_2O CaAl_2O_4
	In702	MgAlCrO_4 Al_2O_3 NiO

In this case, some corrosion products were obtained in the stainless steel (304SS) composed by hematite (Fe_2O_3) and magnetite (Fe_3O_4), and in the OCT steel, mainly composed by LiFeO_2 , NiO , and Li_2O . In this case a protective compound was detected (CaAl_2O_4), confirming the layer proposed in Figure 15.

The better behaviour obtained in In702 is due to the protective layers detected by XRD and composed by MgAlCrO_4 and Al_2O_3 . NiO was the oxide detected in this case at the end of the experiment.

4.3. Corrosion tests in chloride salts

Taking into account the results obtained in carbonate salts, the corrosion study, on chloride molten salts at 750°C, was only performed in In702 since it was the alloy with a higher corrosion resistance. The gravimetric results obtained are shown in Figure 18.

Figure 18. Gravimetric corrosion curve in 45wt.% LiCl + 55wt.% KCl mixture at 750°C for 1000 hours of test

Gravimetric weight changes for In702 are higher than the results obtained in nitrates (figure 5) and carbonate (figure 11) molten salts. In order to establish the corrosion mechanism of this Ni base alloy immersed in chloride molten salts, some EIS tests have been developed during 100 hours. In this case, the Nyquist plots and their respective equivalent circuits are matching for a protective layer (Figure 19) model for In702 during 100 hours of test. Results of each electrochemical element are shown in Table 4.

Table 4. Electrochemical elements results for In702 in 45wt.% LiCl + 55wt.% KCl at 750°C

Time (h)	R_s (Ω -cm ²)	R_t (Ω - cm ²)	C_{dl} (Ω - s^{ndl-1})	n_{dl}	R_{ox} (Ω -cm ²)	C_{ox} (Ω - s^{nox-1})	n_{ox}
24	1.89	87.7	0.0068	0.98	26.02	0.007	0.56
100	1.85	3.3	0.0133	0.70	35.39	0.181	0.57

Figure 19. Nyquist diagrams for EIS study performed in saline 45wt.% LiCl + 55wt.% KCl at 750°C for 24 h (left) and 100 h (right) of test

The scale is considered as a capacitor and it is related with the double-layer capacitance at the scale/salt interface, represented by the equivalent circuit of Figure 19, where, C_{ox} represents the oxide capacitance and R_{ox} , the transfer resistance of ions in the scale [22].

The second loop at low frequencies is referred to the corrosion process controlled by ions transport in the material surface layer. Where, R_s represents the molten-salt (electrolyte) resistance and R_t is the electrochemical transfer resistance or polarization resistance of the tested material. C_{dl} is the double layer at the metal/salt interface and n_{dl}/n_{ox} represent respectively the constant phase element coefficient of the first and second capacitance loop [23]. In this case R_s values (electrolyte resistance) are reduced during the time so the electrical conductivity is increased as well as the salt corrosiveness.

Corrosion models were confirmed by SEM. These results are shown in Figure 20, where a protective barrier composed by Al and Cr was detected.

Figure 20. Cross section image and element mapping performed in In702 immersed in 45wt.% LiCl + 55wt.% KCl at 750°C for 100 h of test

Finally, gravimetric corrosion rates obtained in this work in nitrate, carbonate and chloride salts are summarised in Table 5. According to these results, Inconel 702 presented the best corrosion behaviour in the nitrate and carbonate molten salts tested but, according the results obtained in chloride molten salt, this material need to be operate with caution at temperatures above 700°C. For this control the EIS tool could be an interesting option, since corrosion mechanism can be controlled under operation as well as evaluate the wall thickness variation in the storage containers during the time.

Table 5. Overview of the corrosion rate obtained in the molten salt tested

Molten Salt	Alloy	Temperature (°C)	Corrosion Rate (µm/year)	Recommended
30% LiNO ₃ + 57% KNO ₃ + 13% NaNO ₃	OCT	550	5.95	Yes
30% LiNO ₃ + 57% KNO ₃ + 13% NaNO ₃	In702	550	1.97	Yes
30% LiNO ₃ + 57% KNO ₃ + 13% NaNO ₃	SS304SS	550	3.93	Yes
32% Li ₂ CO ₃ + 33% Na ₂ CO ₃ + 35% K ₂ CO ₃	OCT	650	213	No
32% Li ₂ CO ₃ + 33% Na ₂ CO ₃ + 35% K ₂ CO ₃	In702	650	39	Yes
45% LiCl + 55% KCl	In702	750	118.1	With caution

5. Conclusions

Molten salts act as the electrolyte in a corrosive system that attacks the metal containers. High operating temperature is necessary to improve efficiency in the CSP system and molten salts are the most promising TES materials at high temperatures. Different AFA steels were proposed as container and piping materials immersed in the most promising TES material for the new generation of CSP plants working at higher temperatures. In702 showed the best corrosion resistance in carbonates molten salts tested due to the protective layers formed, composed mainly by Al₂O₃ and NiCr₂O₄ and establish a start point for chloride molten salts assessment. The corrosion models were determined by electrochemical impedance spectroscopy, obtaining the formation of a protective scale during the first 100 hours of test. Nevertheless, further research is needed for long term corrosion tests in chloride molten salts and a corrosion mitigation plan for CSP plants working at higher temperatures must be performed.

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