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Project Deliverable 7.3: Mid-term report on dissemination activities

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1 Executive *summary*

The present deliverable describes the Dissemination Activities of NEWSOL project until the end of month 21.

The dissemination plan (Deliverable 7.2) distinguishes between the dissemination for peer groups and dissemination for other target groups [1, 2].

An important pillar of the Dissemination Plan is the Advisory Board. The Advisory Board is foreseen in the DoA [3] and in section 3 the interactions with the Advisory Board are reported.

The dissemination for peer groups is presented in section 4, consisting of the listing of the project partners participation in conferences and dissemination events. The project partners participated in 7 conferences, with 5 oral presentations and 2 posters. Other presentations are already foreseen and have abstracts accepted, namely for the Solar Paces Conference.

The dissemination activities which are part of the communication plan (Deliverable 7.2) are described in section 5.

The present deliverable has, as annexes, the reports of the project partners of their dissemination and communication activities performed.

2 Introduction

The present deliverable reports the dissemination activities performed until the end of month 21 of the project. These activities are part of the "Dissemination Plan" as described in Deliverable D7.2

These activities follow the guidance given in reference [1] and in tutorial videos of Horizon 2020 [2]. According to this guidance, it is important to distinguish the objectives of dissemination of project results from those on communication of project results.

Dissemination of project results is focused on peer-to-peer information, namely through communications in congresses and publications in peer reviewed journals.

Communication of project results is focused on different target groups, which are:

- Public decision-makers;
- Other companies working or interested in joining this field;
- Technicians working in the CSP sector;
- Science, technology and engineering students;
- General public.

Communication for the above target groups is done using the website of the project (http://www.newsol.uevora.pt) but also through workshops, communication with the media, and other suitable tools.

The interactions with the Advisory Board are presented in section 3. The details of performed actions related with the dissemination plan are presented in section 4, while those regarding the activities related with the communication plan are presented in section 5.

3 Advisory Board

According to D1.1 [6], the project Advisory Board is formed by:

- Luis Crespo (ESTELA)
- Frank Dinter (Ustellenbosch)
- Eduardo Zarza (PSA)
- Christopher Richter (SolarPACES)
- Mikel Sojo (ACC Energia)

During this period the main interaction with the Advisory Board occurred:

i) .in the 3rd General Assembly Meeting (30th January 2018), where Frank Dinter was present and made a presentation “STE Market World-wide”.

ii) in the IPES (Portuguese Institute of Solar Energy) symposium – Solar Concetration and the Future – which took place in Évora, Portugal, during the days 24th and 25th of September 2018 and where Luis Crespo participated and presented a communication “A Vision from the solar concentration industry” and discussed the advances of NewSOL.

4 Dissemination plan

4.1 Conference communications

During the first 21 months of the project partners have participated in several conferences where communications were made related to the work performed within NEWSOL Project.

In Table 1 these participations are listed. Annex I and II include the reports of these participations as submitted to LNEG, WP Leader.

Table 1: Dissemination activities – communications in Conferences and dissemination events.

Partner	Date	Event	Location	Description	See
DLR	14th to 17th May 2017	2nd Green & Sustainable Chemistry Conference	Berlin, Germany	Poster presentation (“Advanced studies on thermal stability and alteration of molten nitrate salts used as heat storage media”)	Annex Ia)
AIMEN	29th May 2017	9th Workshop: Case Studies, Strategies, Model, and Tools	Dublin, Ireland	Power point “Case study: Monitoring in CSP molten salt tanks and modules”	Annex II
CSIC	23rd-24th October 2017	GUATEMALA IV Congreso Centroamericano de Nanotecnología y II Congreso deNanotecnología y Tecnologías Futuras para el Desarrollo Sostenible	Guatemala	Slide on NewSol project.	Annex II
ACC Industrial	30th January	3rd General Assembly NewSol	Setubal, Portugal	Oral Presentation by Miguel Barro “STE plants: a customer perspective”	Annex II
LNEG	1st February 2018	Symposium Newsol	Évora, Portugal	Oral Presentation by Teresa Diamantino and Carlos Nogueira, “Molten Salts in CSP: Materials and Corrosion”	Annex II
CSIC	5th to 6th March 2018	V Congreso Iberoamericano de Hormigón Autocompactante y Hormigones Especiales (V Congresso Ibero-americano sobre Betão Auto-compactável e Betões Especiais) http://hac2018.hac-bac.webs.upv.es/index.html	Valencia, Spain	Abstract Submited and accepted ("Influencia de aditivos orgánicos en las propiedades reológicas de pastas de cemento de aluminato de calcio", Marta Roig-Flores, Marta Palacios, María Martínez-Urbanos, y María Cruz Alonso)	Annex Ia)

DLR	13th to 15th March 2018	12th International Renewable Energy Storage Conference (IRES)	Düsseldorf, Germany	Oral Presentation (“Molten salt chemistry in nitrate salt storage systems: Linking experiments and modeling”)	
LNEG	24th april 2018	V Encontro Dia Mundial da Sensibilização para a Corrosão: Energias Renováveis, Materiais e Durabilidade	Lisboa, Portugal	Oral Presentation by Teresa Diamantino “A corrosão e a proteção dos materiais nos sistemas solares térmicos sem e com concentração”	Annex II
LNEG	14-18 May 2018	Intercorr 2018	São Paulo, Brasil	Oral Presentation; “Energias renováveis: corrosão e proteção de materiais”	Annex Ia)
LNEG	17 – 21 June 2018	ECOS 2018 - 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems	Guimarães, Portugal	Oral presentation and full paper in Conference Proceedings: F. Pedrosa, T. Marcelo, C.A. Nogueira, A. Gomes and T. Diamantino, Molten nitrate salts containing lithium as thermal energy storage media: a short review, ECOS 2018 - 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (Proc.), Guimarães, Portugal, 17-22 June, Univ. Minho, Guimarães, Portugal, 2018, 12 pp. (ISBN: 978-972-99596-4-6)	Annex Ia)

Table 2: Dissemination activities – communications in Conferences in coming months.

Partner	Date	Event	Location	Description	see
DLR	*2-6 Oct*	*SolarPaces conference 2018*	*Casablanca (Marrocco)*	*Abstract submitted and accepted for poster presentation (Dehydration and thermal stability of a ternary nitrate salt mixture in upscaling experiments, Veronika Sötz, Alexander Bonk und Thomas Bauer)*	*Annex Ib)*
CSIC/UEvora	*2-6 Oct*	*SolarPaces conference 2018*	*Casablanca (Marrocco)*	*Abstract submitted and accepted for poster presentation (Compatibility Tests Between High Temperature Concrete and Molten Salts to be Used for a Thermal Energy Storage)*	*Annex Ib)*

The participation in International Conferences will continue for the next two years. Table 1 lists the main events foreseen for 2019/2020 period. This list is only a guidance to the project partners and not a list of mandatory participation with communications in these conferences.

Table 3: Conferences foreseen for 2019 and 2020.

Date	Conference	Website	Location
4th to the 7th of November 2019	Solar World Congress 2019, SWC 2019	https://www.ises.org/what-we-do/events/solar-world-congress	Santiago, Chile
To be announced in October 2018	SolarPACES 2019	www.solarpaces.com	To be announced in October 2018

This list will be continuously updated and the participations reported in the deliverable:

- D7.7 – Final report on dissemination activities.

4.2 Peer reviewed journals

It is foreseen in the DoA the submission of work to journals with peer review. It is also foreseen to do it as Golden Open Access for 3 publications. Other publications can be available through Green Open Access whenever deemed necessary and suitable.

In Deliverable D7.7 – Final report on dissemination activities, all the papers submitted will be listed.

In the publication of results, partners shall conform to clause 9.4 of the Consortium Agreement [4].

4.3 Participation in relevant standardisation committees

Another important aspect of the dissemination plan is the presentation of project results that are relevant as pre-standardisation work.

The consortium already identified as a relevant standardisation committee the IEC TC 117- Solar thermal electric plants, which is presently developing a technical specification entitled "Solar thermal electric plants – Part 2-1: Thermal energy storage systems – Characterization of active, sensible systems for direct and indirect configurations"

Table 5 lists the countries of the project partners, which are following this standardisations committee activity.

Table 5: Partner countries participating in IEC TC 117.

Country	Membership (O- observer; P- participating)
Denmark	O-Member
Germany	P-Member
Italy	P-Member
Portugal	P-Member
Spain	P-Member (Secretariat)
Switzerland	P-Member

The document in preparation is expected to be presented for approval to the TC 117 General Meeting that will take place in November in Beijing.

5 Communication plan

5.1 Target groups and actions foreseen

The target groups of the communication plan were already listed in the introduction and are:

- Public decision-makers;
- Companies working with CSP and materials for CSP or interested in joining this field;
- Technicians working in the CSP sector;
- Science, technology and engineering students;
- General public.

In order to reach these different target groups, the project uses different tools. These tools are described below.

5.1.1 Communication material pack

The communication material pack envisaged in Deliverable D7.2 is:

- Project leaflet;
- Project poster;
- Video

Until the month 21 the material produced is listed in Table 6.

Table 6**: Comunication material produced**

type	Number (if applicable)	Used in:
Roll-Up	1	Ex: NewSol Symposium, UEvora, 1th February 2018, IPES Symposium, UEvora, 24th and 25th September 2018
Roll-Up	2	NewSol Symposium, UEvora, 1th February 2018, IPES Symposium, UEvora, 24th and 25th September 2018
Poster	1 "NewSOL Project"	IPES Symposium, UEvora, 24th and 25th September 2018
Poster	2 "Armazenamento Energia Térmico a Alta Temperatura em Módulo de Betão"	CIES Conference, March 25-29, Mexico, 2018

5.1.2 Project Workshops

Until month21 one event was organized, namely, The Newsol Symposium, 1st February 2018 fully dedicated to Newsol project. The Symposium agenda and photos are in Annex III. The number of participants was 50.

Another event with a strong involvement of Newsol partners is the 4th Symposium IPES (Portuguese Institute of Solar Energy). The agenda can be seen in http://www.ipes.pt/ipes/programa/ and photos are in Annex III. The number of participants was 60.

5.1.3 Project website

The project website is described in the Deliverable D7.1 [5]. The website is also one of the tools of the communication plan.
The project website is now operational with two language versions: English and Portuguese and can be accessed as: http://www.newsol.uevora.pt (English) or http://www.newsol.uevora.pt/pt-pt/ (Portuguese).

Using Google Analytics toll we can analyse the visualizations of the web site for a period of one year (19-09-2017 to 19-09-2018). The total number of users in this period was 642 and in Fig. 1 we see their distribution by city world-wide.

Fig. 1: Number of users per city (period of one year).

The distribution of users on monthly totals is given in Fig. 2. It is possible to see that users were growing steadily until July 2018. August and September have fewer visualizations but this may be due to the vacation period.

Fig. 2: total number of users per month (period of one year).

5.2 News via website and other media (e.g. Twitter)

Another important tool to communicate project results are the news that will be made public through the Website (see reference [5]) and also through the social networks, e.g. Twitter.

Communication to Media will be done by answering to requests of interviews as well as publication of press releases at least twice per year. All contacts with the Media shall be reported to LNEG, WP7 Leader, for inclusion on the deliverables D7.3 and D7.7. Plus, partners are invited to distribute the information to their workers, so it can be spread using their own communication channels.

A report shall be delivered to LNEG, WP7, Leader, by the partner communicating in this way with the media. The Template in Annex IV shall be used.

It is expect that the use of these communication tools will be more intense in the second half of the project.

6 References

1. "Communicating EU research and innovation guidance for project participants", Version 1.0, 25th September 2014, http://ec.europa.eu/research/participants/data/ref/h2020/other/gm/h2020-guide-comm_en.pdf, Accessed 13th march 2017
2. "What is Science Communication? - The EU Guide to Science Communication", EU Science & Innovation videos available at https://www.youtube.com/watch?v=4E8rXg3Nv7U , Accessed 13th march 2017
3. DoA - Description of the Action, NewSol Project, Grant Agreement n.720985
4. Consortium agreement - NEWSOL - NEW StOrage Latent and sensible concept for high efficient CSP plants, coupled to the Grant Agreement nº 720985
5. M. João Carvalho, NewSol -Project Deliverable 7.1 - Project visual identity and web-site,
6. Luís Guerreiro and Diogo Canavarro, NewSol -Project Deliverable 1.1 - Project Handbook, Rev.1, 28-02-2017
7. M. João Carvalho, NewSol- project Deliverable 7.2 – Disseminiation Plan

Annex Ia) – Reports on dissemination activities until 30th September 2018

WP7 – Task 7.4.1 – Report on dissemination activity

Partner name: DLR

Partcipant(s): Alexander Bonk

Event: 2nd Green & Sustainable Chemistry Conference

Location: Berlin

Date: 14. – 17.05.2017

Type of presentation: poster presentation

Reference to be used for the work (e.g. Proceedings; DOI (if applicable), …): ---

The communication presented (power point, poster or written communication) shall be included in this annex: ---

WP7 – Task 7.4.1 – Report on dissemination activity

Partner name: CSIC

Partcipant(s): Maria Cruz Alonso, Marta Roig

Event: V Congreso Iberoamericano de Hormigón Autocompactante y Hormigones Especiales (V Congresso Ibero-americano sobre Betão Auto-compactável e Betões Especiais)

Location: Valencia (Spain)

Date: 5-6 March 2018

Type of presentation: Oral presentation

Reference to be used for the work (e.g. Proceedings; DOI (if applicable), …):

DOI: http://dx.doi.org/10.4995/HAC2018.2018.8274

ISBN: 978-84-9048-591-0

The communication presented (power point, poster or written communication) shall be included in this annex.

PDF of the final paper attached. Basic info:

> **Influencia de aditivos orgánicos en las propiedades reológicas de pastas de cemento de aluminato de calcio.** M. Roig -Flores, M. Palacios, M. Martínez-Urbanos y M. C. Alonso. V Congreso Iberoamericano de Hormigón Autocompactante y Hormigones Especiales 2018, Valencia, 5-6 March

Influencia de aditivos orgánicos en las propiedades reológicas de pastas de cemento de aluminato de calcio

Marta Roig-Flores [(1)], Marta Palacios [(1)], María Martínez-Urbanos [(1)] y María Cruz Alonso [(1)]

[(1)] Instituto Eduardo Torroja de Ciencias de la Construcción, Consejo Superior de Investigaciones Científicas (CSIC), Madrid, España.

DOI: http://dx.doi.org/10.4995/HAC2018.2018.7226

RESUMEN

El cemento de aluminato de calcio (CAC) es un tipo de cemento utilizado en elementos constructivos que necesitan propiedades refractarias, debido a su resistencia a elevadas temperaturas. Sin embargo, este tipo de cemento presenta diversas dificultades para su puesta en obra debido a su fraguado rápido y la dificultad para obtener trabajabilidades elevadas con relaciones agua/cemento bajas. Este trabajo realiza un análisis de la reología obtenida al utilizar distintas familias de aditivos con CAC, incluyendo superplastificantes basados en policarboxilato, vinílicos, naftalenos o lignosulfonatos, así como aditivos retardadores como ácido cítrico y gluconato. Además, se estudia la influencia de la presencia de cenizas volantes y escorias de alto horno como adiciones minerales. Para ello se ha calculado el esfuerzo de cizalla umbral de pastas con aditivos a partir de los valores de escurrimiento a lo largo del tiempo. Los resultados muestran la elevada compatibilidad de los aditivos tipo lignosulfonato y de los retardadores manteniéndose la fluidez hasta 90 minutos tras el inicio de la hidratación. Finalmente, la adición conjunta de aditivos basados en lignosulfonato y policarboxilato ha permitido obtener una fluidez óptima de los sistemas de CAC.

PALABRAS CLAVE: cemento de aluminato de calcio, superplastificantes, retardadores, reología, esfuerzo de cizalla umbral

1.- INTRODUCCIÓN

Las estructuras de hormigón generalmente trabajan a temperatura ambiente, pero para ciertas aplicaciones como hormigones refractarios pueden necesitar resistir temperaturas entre 500 y 2000°C. En la construcción de dichos hormigones, se precisa la utilización de cementos específicos, áridos estables a alta temperatura, así como una granulometría adecuada para obtener una estructura densa y resistente en su conjunto. Respecto al diseño de la pasta de cemento para estas aplicaciones, las principales estrategias propuestas en la literatura incluyen el uso de cemento Portland con adiciones y el uso de cemento de aluminato de calcio [1].

El cemento Portland (OPC) se hidrata formando como productos principales silicato cálcico hidratado (C-S-H) e hidróxido cálcico (portlandita - CH). Es conocido que el C-S-H y CH se descomponen a temperaturas superiores a 100°C y 400°C, respectivamente [2]. La deshidratación del CH conduce a la formación de óxido de calcio, el cual se rehidrata con facilidad a temperatura ambiente, formando de nuevo portlandita (mayoritariamente), aunque también puede formar nuevo C-S-H. Estas reacciones son de carácter expansivo y producen fisuración y descomposición en la pasta de cemento [1,2]. Los cementos con adiciones generan mayor proporción de geles C-S-H y menos portlandita [3] por lo que reducen dichas reacciones expansivas [1,3].

Debido a las limitaciones del OPC, otra estrategia para conseguir hormigones refractarios es el uso de cemento de aluminato de calcio (CAC). Este cemento tiene como compuestos mayoritarios aluminatos y óxidos de silicio o de hierro, con poco contenido en cal. Los compuestos producidos tras la hidratación son aluminatos cálcicos hidratados (CAH_{10} y C_2AH_8) e hidróxido de aluminio (AH_3). Los dos primeros compuestos son químicamente inestables y sufren una conversión a compuestos más estables C_3AH_6 y AH_3. Esta conversión se produce a distintas velocidades según la temperatura y humedad ambientes. A temperaturas normales, este proceso puede llevar años, a 40°C puede producirse en días y a 70°C en pocas horas [5]. Este proceso es irreversible y produce una pérdida de resistencia e incremento de porosidad, por lo que para su uso en una construcción las propiedades a considerar en el diseño son las que se obtienen tras este proceso de conversión [1,5]. Respecto a su comportamiento a altas temperaturas, los compuestos CAH_{10} y AH_3 se empiezan a deshidratar a temperaturas de 300°C, y entre 400 y 500°C se encuentran completamente deshidratados. Este proceso no es reversible, y por tanto el CAC tras la deshidratación es más estable que el OPC [1].

A pesar de sus ventajas para aplicaciones refractarias, el uso de CAC en obra se enfrenta a dos dificultades principales [5]: la dificultad de obtener un hormigón trabajable a bajas relaciones agua/cemento (recomendadas para minimizar la conversión) y el fraguado rápido del CAC lo que dificulta su puesta en obra. Además, los superplastificantes más comunes están diseñados para su uso con OPC, por lo que en general no son eficientes en sistemas de cemento CAC, independientemente de la relación carboxilato/éter [6,7]. Otros estudios muestran que, cuanto menos aniónicos son los PCE, más potencia de dispersión tienen con CAC [8], al contrario que con OPC. Dichos aditivos se adsorben sobre la superficie de las partículas de cemento ejerciendo una repulsión de tipo estérico, responsable del incremento de la fluidez. El hormigón fresco se puede considerar una suspensión de alta concentración, por lo que utilizando parámetros físicos de viscosidad y esfuerzo de cizalla se puede cuantificar la fluidez del material [9]. Asimismo, las medidas de escurrimiento se pueden relacionar directamente con el esfuerzo de cizalla umbral [10-12], parámetro para el que se ha propuesto la expresión en la Ecuación (1), ajustada para valores de escurrimiento altos y bajos [10].

$$\tau_0 = \frac{225 g \rho V^2}{128\pi^2 R^5 (1 + \frac{225}{128\pi}\sqrt{3} V R^{-3})} - \lambda \frac{R^2}{V} \quad (1)$$

Donde τ_0 es el esfuerzo de cizalla umbral, g es la constante gravitacional, ρ es la densidad de la muestra, V el volumen, λ a una constante ajustada en 0.005, y R es el radio de escurrimiento.

En este trabajo se analiza la compatibilidad entre un cemento de aluminato de calcio y distintos aditivos, así como su capacidad para mantener la fluidez, estudiando la reología de la pasta utilizando como parámetro el esfuerzo de cizalla umbral.

2.- MATERIALES Y METODOLOGÍA

2.1.- Composición de la mezcla

La Tabla 1 muestra los aditivos utilizados en este estudio. Las cantidades estudiadas de los aditivos están expresadas en porcentaje de su fracción seca. Para ello se ha calculado experimentalmente la fracción seca de todos los aditivos comerciales. Los rangos estudiados de contenido de aditivo se comprenden entre 0.1 y 0.4% sobre el peso del cemento, expresados en su fracción seca.

Tabla 1. Lista de aditivos utilizados, tipología y fracción seca

Código	Familia	Tipo	Fracción seca
PCE1	Éter de policarboxilato	Superplastificante líquido	40%
PCE2	Éter de policarboxilato	Superplastificante líquido	40%
PCE3	Éter de policarboxilato	Superplastificante líquido	40%
V	Vinílico	Superplastificante líquido	25%
N	Naftaleno	Superplastificante líquido	40%
LS1	Lignosulfonato	Superplastificante líquido	33%
LS2	Lignosulfonato	Superplastificante líquido	25%
PAA	Ácido poliacrílico	Plastificante líquido	50%
RET1	Ácido Cítrico	Retardante sólido	100%
RET2	Gluconato	Retardante líquido	25%

Los aditivos elegidos para el estudio incluyen, éter de policarboxilato (PCE), que son los aditivos más extendidos actualmente; un aditivo vinílico; un naftaleno y dos lignosulfonatos, que fueron de los primeros fluidificantes utilizados en hormigón. Además, también se ha estudiado la influencia de ácido poliacrílico, debido a su similitud con la cadena principal de los policarboxilatos [13]. Finalmente, se estudió el efecto de dos retardadores de fraguado, ácido cítrico y otro basado en gluconatos.

Sobre una selección de aditivos, se ha analizado su compatibilidad con cementos en los que se ha sustituido el 30% de su contenido por adiciones (escoria de horno alto y cenizas volantes).

2.2.- Metodología experimental

Para el mezclado de las pastas se ha utilizado una amasadora automática C0086 Proeti. Las dosificaciones se prepararon considerando 1200 g de cemento y 360 g de líquido, que incluye el agua y el aditivo (relación agua/cemento 0.30).

En el proceso de mezclado, el aditivo se incorporó inicialmente al agua de amasado (si el aditivo se encontraba en estado sólido se disolvió primero) y, posteriormente se añadió el cemento. El proceso de amasado consistió en: 1) amasado rápido a 275 ± 5 rpm durante 90 segundos, 2) reposo durante 30 segundos, y 3) amasado rápido durante 90 segundos. Se determinó el valor de escurrimiento a los 5, 15, 60 y 90 minutos desde el contacto del cemento con el agua. A dichos tiempos, se amasó la pasta correspondiente con un agitador Heidolph RZR2020 a 800 rpm durante 1 minuto, previamente a la medida de escurrimiento.

Para el estudio del escurrimiento se utilizó un tubo de PVC de diámetro interior de 4.7 cm, siguiendo un diseño basado en la literatura [10,14]. Como superficie para realizar el ensayo se utilizó una placa de vidrio. Antes del ensayo de escurrimiento, se humedecieron tubo y placa con un paño húmedo. A los tiempos correspondientes, se rellenó el tubo con la pasta de cemento, se dejó reposar durante 1 minuto y se levantó el tubo. A partir del valor de escurrimiento se calculó el esfuerzo de cizalla umbral de acuerdo a la Ecuación (1).

3.- RESULTADOS Y DISCUSIÓN

3.1.- Compatibilidad del CAC con tipo de aditivo

La Figura 1, muestra el esfuerzo de cizalla umbral (τ_0) inicial de las pastas aditivadas, 5 minutos después de entrar en contacto el cemento y el agua, donde los valores más bajos de esfuerzo de cizalla umbral se corresponden con las mezclas de mayor fluidez. Los resultados obtenidos indican que los aditivos de la familia de los lignosulfonatos son los más efectivos, ya que obtienen mayor fluidez inicial para contenidos por debajo de 0,20% sobre el peso del cemento. Además, dosificaciones mayores conducen a la segregación de las pastas y elevados retrasos de los procesos reactivos (fraguado). Por otra parte, tanto el PAA como el aditivo vinílico obtienen valores inferiores de esfuerzo de cizalla umbral, comparando con los lignosulfonatos, para cantidades superiores a 0,30%, pero presentan una tendencia a la segregación. Los PCE estudiados mostraron resultados muy similares al aditivo vinílico. Finalmente, el aditivo tipo naftaleno no tuvo efecto en la fluidez, incluso para contenidos de 0,40 y 0,80 %.

Las Figuras 2-4, muestran la evolución del esfuerzo de cizalla umbral de las pastas aditivadas para los tiempos analizados (hasta 90 minutos).

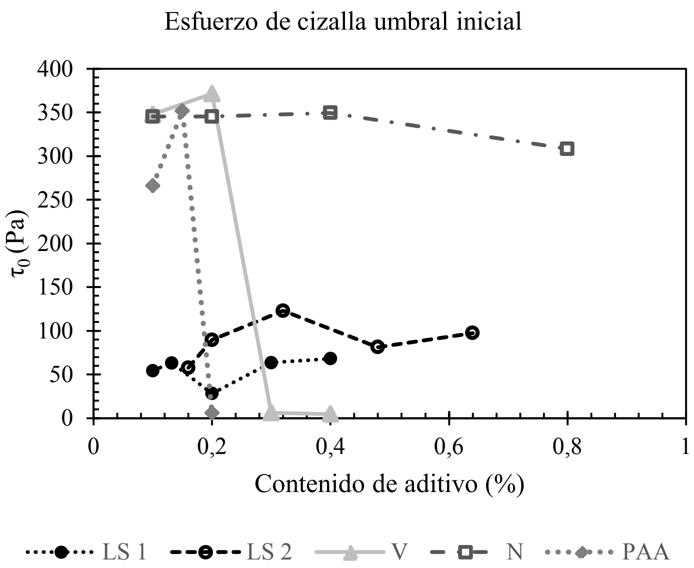

Figura 1. Esfuerzo de cizalla umbral inicial para 5 plastificantes utilizados

En la Figura 2 se muestra la evolución de τ_0 obtenida para los dos aditivos lignosulfonatos estudiados. Para contenidos superiores a 0,20% ambos aditivos empeoran la fluidez inicial y retrasan considerablemente el fraguado, por lo que se han representado los resultados para dosificaciones por debajo de 0,30% sobre el peso de cemento. Los resultados óptimos se obtuvieron para contenidos entre 0,16 y 0,20%, manteniendo la fluidez 60 minutos y con ligeras pérdidas a los 90 minutos.

En cuanto al aditivo vinílico estudiado (Fig. 3 izquierda), el aditivo mostró una adsorción muy rápida, con alta fluidez inicial para contenidos de 0,3 y 0,4%, pero que se perdía en los primeros 15 minutos. Además, en esos casos la mezcla resultó más propensa a la segregación. El aditivo naftaleno utilizado no incrementó la fluidez de la pasta en los contenidos estudiados en ningún caso (Fig. 3 derecha), comportamiento que también ha sido reportado en la literatura [5].

Los PCE analizados en este estudio mostraron un comportamiento similar a los vinílicos: para contenidos bajos no tienen efecto y para porcentajes mayores tienen un efecto muy elevado, induciendo a la segregación de la pasta. Sin embargo, dicha fluidez se pierde inmediatamente (tras los primeros 15 minutos), lo que está de acuerdo con los resultados indicados en la literatura [6,7]. A este respecto, la literatura indica la posible intercalación del aditivo en la estructura laminar del principal producto de reacción como causa de la pérdida de fluidez [8]. Otros trabajos indican que estos aditivos son muy efectivos y se pueden conseguir propiedades de autocompactabilidad para relaciones agua/cemento de 0.38, aunque confirman la tendencia al sangrado y a la segregación [5].

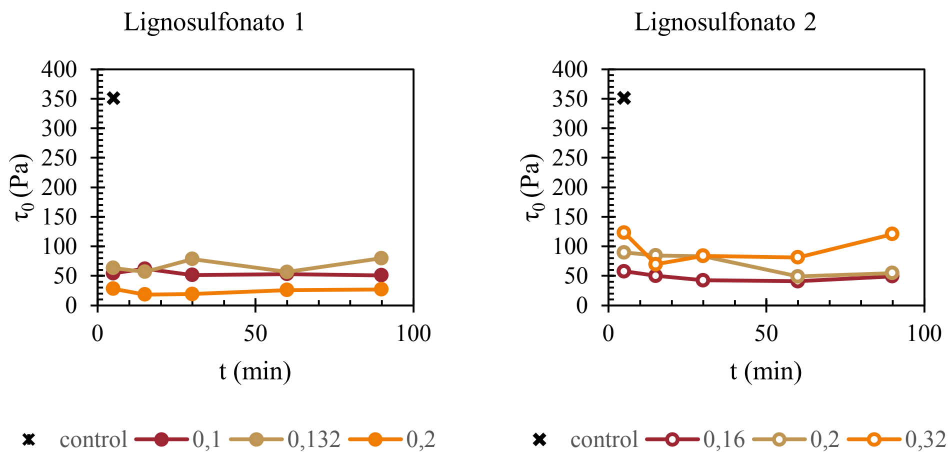

Figura 2. Evolución del esfuerzo de cizalla umbral para los lignosulfonatos

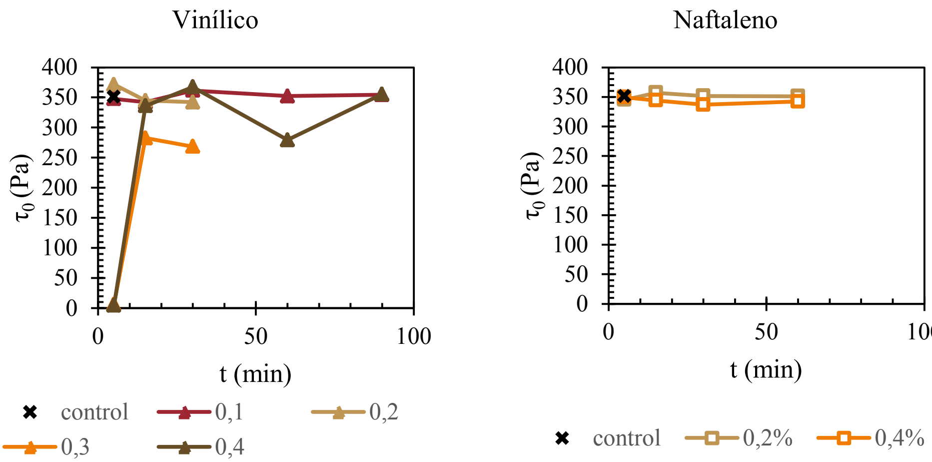

Figura 3. Evolución del esfuerzo de cizalla umbral para el vinílico y el naftaleno

Respecto al comportamiento del PAA con el CAC (Fig. 4 izquierda), en contenido 0,1% muestra la fluidez obtenida es muy baja y se pierde tras 30 minutos. Sin embargo, al aumentar el contenido a 0,15 tarda unos minutos en aumentar la fluidez y, a los 30 minutos, obtiene la misma fluidez que en un contenido del 0,2%. Esto indica que el comportamiento del PAA es poco estable para un rango muy cercano de contenidos. En cuanto a los retardadores (Fig. 4 derecha), tanto el ácido cítrico como el derivado del gluconato conducen a significativas reducciones del esfuerzo umbral, especialmente en el caso del gluconato.

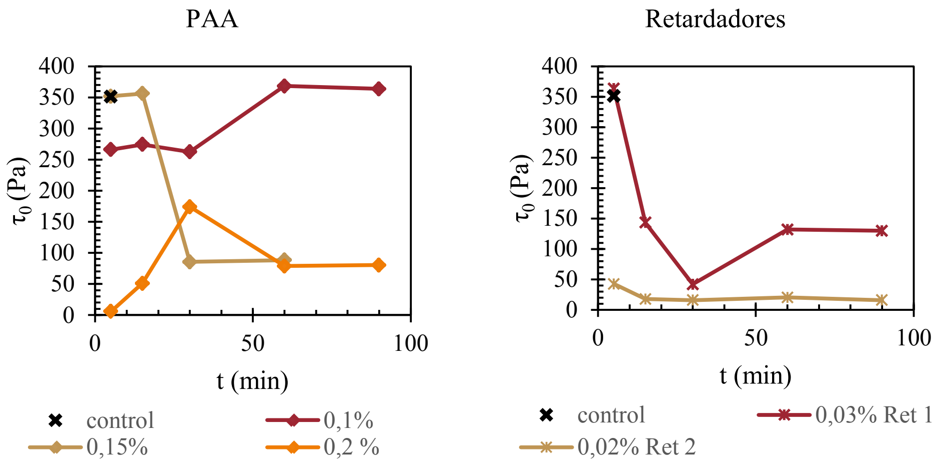

Figura 4. Evolución del esfuerzo de cizalla umbral para el PAA y los retardadores

3.2.- Influencia del tipo de adición mineral al CAC

Respecto al efecto de las adiciones minerales en la fluidez de la pasta, sin aditivos, la Figura 4 (izquierda) muestra que la escoria de alto horno y la ceniza volante 1 aumentaron la fluidez, mientras que la ceniza volante 2 no cambió la fluidez notablemente respecto al control.

Los mejores resultados en términos de reología son los correspondientes a los lignosulfonatos. Con objeto de incrementar la fluidez inducida por los aditivos basados en lignosulfonato, se estudió la influencia del empleo simultáneo de éstos con aditivos basados en policarboxilato. Al incorporar un 0.15% de aditivo lignosulfonato 1 y un 0.025% del PCE2, se obtuvo como diámetro inicial 180 mm, que comparados con el valor obtenido al utilizar únicamente el lignosulfonato 1 en un contenido del 0.132%, supone un incremento del 111%. Esta combinación mejora el comportamiento de ambos aditivos, ya proporciona una elevada fluidez inicial sin segregación y permite mantener la fluidez durante 90 minutos, algo que no ocurría al utilizar los aditivos por separado.

En pastas de CAC con adición de escoria de alto horno, la reología obtenida es similar a las correspondientes pastas sin escoria, mientras que la adición de cenizas volantes induce una reducción de la fluidez. Esto indicaría una menor afinidad de estos aditivos con las cenizas en comparación con las escorias.

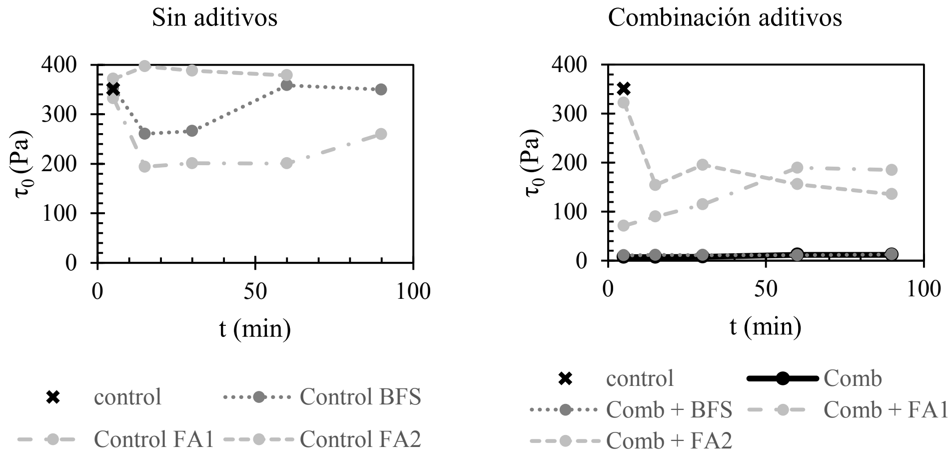

Figura 5. Evolución del esfuerzo de cizalla umbral para cemento con adiciones sin aditivos (izquierda) y con la combinación óptima de aditivos.

4.- CONCLUSIONES

En este estudio se ha analizado la influencia de diversos aditivos sobre la reología de pastas de cemento aluminoso durante 90 minutos. A partir de los resultados obtenidos se puede concluir:

- Los aditivos tipo lignosulfonato muestran una mayor compatibilidad con los cementos CAC, seguidos de los retardadores. Estos aditivos son los que permiten una mayor fluidez inicial sin que se produzcan indicios de segregación.
- Los aditivos PCE y vinílicos presentan un comportamiento similar. Dichos aditivos inducen los mayores incrementos de la fluidez a tiempos iniciales, a dosificaciones a las normalmente utilizadas en sistemas de cemento Portland. Sin embargo, dicha fluidez se pierde inmediatamente, confirmado la incompatibilidad de los cementos CAC con ambos aditivos superplastificantes.
- La combinación de aditivos tipo PCE con aditivos basados en lignosulfonato, permiten obtener la mayor fluidez inicial, conservándose ésta a lo largo del tiempo. Dicha mezcla de aditivos ha mostrado ser también compatible con cementos combinados con adición de escoria de alto horno.
- Dos de las adiciones minerales estudiadas mejoran ligeramente la fluidez cuando no se utilizan plastificantes. Al utilizar la combinación de aditivos plastificantes, la pasta con escoria de alto horno obtuvo la misma fluidez que la pasta de CAC sólo, sin embargo, las pastas con cenizas volantes obtuvieron notablemente menos fluidez, indicando menor afinidad de estos aditivos con las cenizas.

AGRADECIMIENTOS

Los autores agradecen al proyecto NewSOL H2020-IA-NMBP-17-2016 (project ID: 720985) la financiación recibida, así como a las empresas Cementos Molins S.A., Cementos Tudela Veguín y Secil Companhia Geral de Cal e Cimento, por el suministro de material y las discusiones técnicas.

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WP7 – Task 7.4.1 – Report on dissemination activity

Partner name: DLR

Partcipant(s): Veronika Soetz, Alexander Bonk, Thomas Bauer

Event: 12th International Renewable Energy Storage Conference (IRES)

Location: Düsseldorf, Germany

Date: 13.-15.03.2018

Type of presentation: oral presentation

Reference to be used for the work (e.g. Proceedings; DOI (if applicable), …): ---

The communication presented (power point, poster or written communication) shall be included in this annex: ---

WP7 – Task 7.4.1 – Report on dissemination activity

Partner name: LNEG

Partcipant(s): Teresa C. Diamantino

Event: Intercorr 2018

Location: São Paulo; Brasil

Date: 14-18 May 2018

Type of presentation: Plenary

Reference to be used for the work (e.g. Proceedings; DOI (if applicable), http://www.abraco.org.br/intercorr2018/conferencias-plenarias.php

The communication presented (power point, poster or written communication) shall be included in this annex.

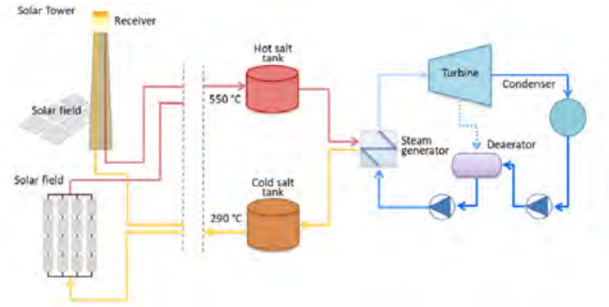



ENERGIAS RENOVÁVEIS: CORROSÃO E PROTEÇÃO DE MATERIAIS

Teresa Cunha Diamantino
teresa.diamantino@lneg.pt

REPÚBLICA PORTUGUESA

Esquema simplificado de uma central CSP



Magdalena Walczak et al. Renewable and Sustainable Energy Reviews 86 (2018) 22–44
https://doi.org/10.1016/j.rser.2018.01.010

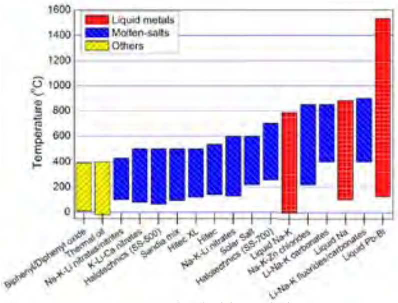
Armazenamento Térmico de energia – Sais fundidos

https://bigdishsolar.com/

Armazenamento térmico de energia – Sais fundidos

Gamas de temperatura de fusão / funcionamento dos fluidos de transferência de calor (HTF)

Elevadas temperaturas são necessárias para aumentar a eficiência do Sistema CSP. Os sais fundidos continuam a ser os candidatos mais promissores para atingir temperaturas até aos 800ºC.

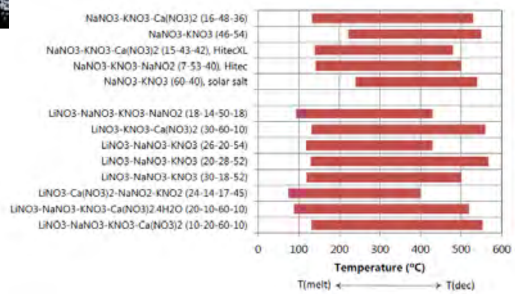


K. Vignarooban et al. Applied Energy 146 (2015) 383–396

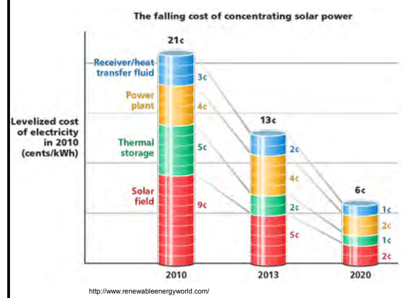
Baixo ponto de fusão
Elevado calor específico
Elevada condutividade térmica
Elevado ponto de ebulição
Baixa pressão de valor
Baixo viscosidade
Baixa reatividade
Baixo custo
Disponibilidade económica
Baixa Corrosividade

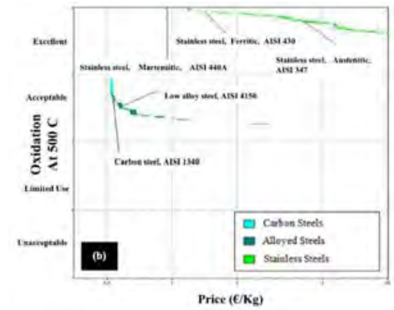
Gamas de temperatura de fusão / funcionamento dos fluidos de transferência de calor (HTF)

CALOR SENSÍVEL



Pedrosa *et al* ECOS 2018

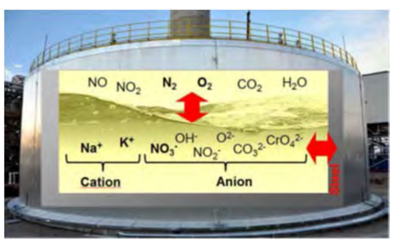


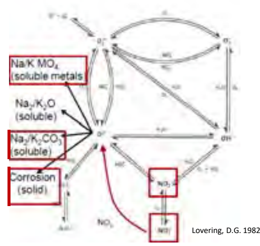


ELEVADA EFICIÊNCIA E DURABILIDADE
BAIXO CUSTO

F.J. Ruiz-Cabañas et al.Solar Energy Materials & Solar Cells 163 (2017) 134–147

Armazenamento de energia – Sais fundidos





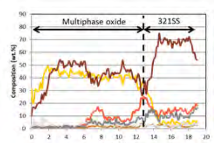
Lovering, D.G. 1982

Estabilidade dos materiais metálicos em contacto com os HTF é um parâmetro crucial para a longevidade dos sistemas CSP.

Que materiais metálicos e quais os tempos de vida

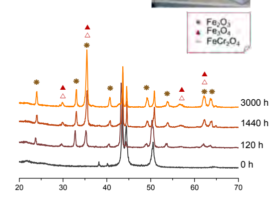
Sais fundidos e a Corrosão

SS 321H



XRD

SEM/EDS



Poucos dados estão disponíveis sobre a degradação dos materiais estruturais tendo em conta as análises de falha.

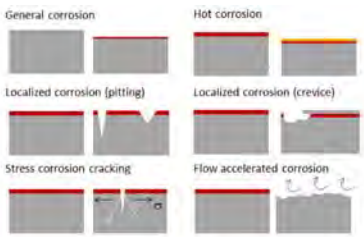
Outros estudos de corrosão são necessários para obter o conhecimento sobre os mecanismos de degradação com diferentes sais fundidos para as instalações CSP nomeadamente:

- Ensaios de corrosão dinâmicos
- Ensaios electroquímicos
- Ensaios mecânicos (fatiga e de corrosão sob tensão)

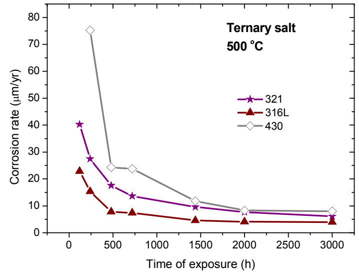
A. Gomes et al. 2016 doi:10.18086/eurosun.2016.03.12 Available at http://proceedings.ises.org

Sais fundidos e a Corrosão

Aços carbono e aços de baixa liga
Aços inoxidáveis
Ligas de níquel



Resumo dos mecanismos de corrosão identificados nas ligas metálicas expostas aos sais fundidos



Energias Renováveis: Materiais e a Durabilidade, uma Investigação Interdisciplinar

MUITO OBRIGADA PELA ATENÇÃO

teresa.diamantino@lneg.pt

LNEG

www.lneg.pt

Agradecimento especial a todos os colegas do Laboratório de Materiais e Revestimentos (LMR) e do Laboratório de Energia Solar (LES) do LNEG

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FCT COMPETE 2020 PORTUGAL 2020

Project STAGE-STE - Scientific and Technological Alliance for Guaranteeing the European excellence in Concentrating Solar Thermal energy (7FP) (2014-2018) GA 609837

Funded by the European Union

NEWSOL New Storage Latent and Sensible Concept for High Efficient CSP Plants. H2020 project, GA No. 720985

República Portuguesa

WP7 – Task 7.4.1 – Report on dissemination activity

Partner name: LNEG

Participant(s): Carlos Nogueira

Event: ECOS 2018 - 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems

Location: Guimarães, Portugal

Date: 17 – 21 June 2018

Type of presentation: Oral presentation and full paper in the Proceedings Book

Reference to be used for the work (e.g. Proceedings; DOI (if applicable), …):

F. Pedrosa, T. Marcelo, C.A. Nogueira, A. Gomes and T. Diamantino, Molten nitrate salts containing lithium as thermal energy storage media: a short review, ECOS 2018 - 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (Proc.), Guimarães, Portugal, 17-22 June, Univ. Minho, Guimarães, Portugal, 2018, 12 pp. (ISBN: 978-972-99596-4-6)

The communication presented (power point, poster or written communication) shall be included in this annex.

ECOS 2018

Proceedings of the

31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems

June 17th to 21st 2018 - Guimarães, Portugal

Organized by University of Minho

Publication Title
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ISBN: 978-972-99596-4-6

ECOS 2018 INTERNATIONAL Conference:

Proceedings of the 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, June 17 to 21, 2018, Guimarães, Portugal; [Support: Electronic] [Format: PDF / PDF/A]

Annex Ib) – Reports on future dissemination activities

WP7 – Task 7.4.1 – Report on dissemination activity

Partner name: DLR

Partcipant(s): Veronika Soetz, Alexander Bonk, Thomas Bauer

Event: SolarPaces conference

Location: Casablanca (Morocco)

Date: 02.-06.10.2018

Type of presentation: poster presentation

WP7 – Task 7.4.1 – Report on dissemination activity

Partner name: UEvora and CSIC

Participants(s):

- UEvora: F. Felizardo, L. Guerreiro and M. Collares-Pereira
- CSIC: M. C. Alonso and M. Roig-Flores

Event: SolarPACES conference 2018 http://www.solarpaces-conference.org/home.html

Location: Casablanca, Morocco

Date: October 02 - 05, 2018

Type of presentation: Oral presentation

Reference to be used for the work (e.g. Proceedings; DOI (if applicable), …): additional information will be provided after the conference

The communication presented (power point, poster or written communication) shall be included in this annex.

PDF of the final manuscript attached. Basic info:

> **Compatibility Tests Between High Temperature Concrete and Molten Salts to be Used for a Thermal Energy Storage,** F. Felizardo, L. Guerreiro, M. Roig-Flores, M. C. Alonso and M. Collares-Pereira, SolarPACES conference 2018, Casablanca, October 02 - 05

Compatibility Tests Between High Temperature Concrete and Molten Salts to be Used for a Thermal Energy Storage

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Abstract. Solar Energy is an abundant resource and can be stored for use at any time of the day. One of the most efficient methods of storage is the thermal process at high temperature (> 400 ºC) usual for solar concentrators using molten salts stored in two tanks. In order to reduce total storage costs, an alternative solution would be to store in a solid medium using concrete with thermal properties optimized as a storage medium. The present paper focuses on performing a compatibility evaluation, by analyzing at a laboratory scale, small concrete cubes uncoated and concrete cubes covered with protective refractory coatings that were put in contact with molten salts subject to a heating cycle up to 500ºC. In this investigation, thermal cycles between 290 ºC and 500 ºC were tested by placing cubic samples (40x40x40 cm) in a bath with a ternary mixture of molten salts in a furnace to simulate loading and unloading cycles The results show that a good concrete mix (suitable binder, suitable aggregates, admixtures) is critical for good thermal performance and adequate durability.

INTRODUCTION

With the increasing share of renewable energies for the production of electricity, cost-effective, efficient and clean energy storage solution need to be further developed. Among various solar energy technologies, concentrated solar power (CSP) is attractive considering the high efficiency, operating cost and scale-up potential [1]. Within the strong efforts that are made to decrease the cost of CSP produced electricity, new solutions are proposed to replace the conventional molten salt two-tank system [2].

With cost reduction in mind, a new storage system with low-cost materials like concrete could be suitable in case it proves to be compatible and durable with the energy storage fluid used, in this case molten salts of K.Na and Ca. Factors such as the mechanical strength of the mixture when submerged and subject to temperature cycles, as well as its stability when placed in direct contact with molten salts under high temperatures cycles at high temperatures have been analysed.

According to existing literature, Alonso et al. [3] conducted tests to evaluate a new cement-based blend that could conduct and store heat at high temperatures with thermal cycling in the range of 290 to 550 ° C, making it ideal for a thermal storage system in solar thermal power plants. The authors proposed to develop and analyze samples of calcium aluminate cement (CAC), containing 40% alumina, mixed with blast furnace slag (BFS) to control any risk of early conversion and to improve thermal performance at high temperatures. Long-term performance was however not investigated.

Investigation about the contact between concrete mixtures and molten salts was developed by Emerson et al. [4]. The work was based on the evaluation of selected mixtures with different binder and aggregate types (sandstone, limestone and syenite) for which they performed a series of tests at high temperature. The number of mixtures investigated was 26. In a first test, these mixtures were pooled and tested in a molten salt bath at 585 °C for 500 hours. The samples were also exposed to 30 thermal cycles between 300 °C and 585 °C when submerged in molten salt. A separate batch was subjected to drying cycles with forced air circulation for 30 times between 300 °C and 600 °C.

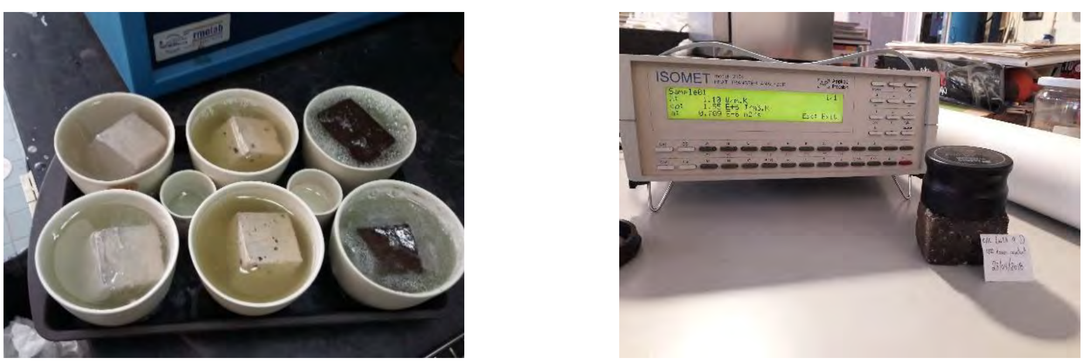
MATERIALS AND METHOD

The molten salt under investigation is a ternary mixture of K-Na-Ca Nitrates recently developed but not used yet in commercial applications. It has a low melting point (131°C). It has a volumetric heat capacity of 1.8 $MJ \cdot m^{-3} \cdot K^{-1}$, a thermal conductivity of 0.5 $W \cdot m^{-1} \cdot K^{-1}$ and a density 2.21 $kg.m^{-3}$ at 200°C. At 500°C has a volumetric heat capacity of 1.4 $MJ \cdot m^{-3} \cdot K^{-1}$, a thermal conductivity of 0.44 $W \cdot m^{-1} \cdot K^{-1}$ and a density of 1.89 $kg \cdot m^{-3}$. The concrete under study is a concrete with selected aggregates (size < 4mm) divided into two batches as in Table 1. The experimental work consisted in putting in contact molten salts with concrete samples (50×40×40 mm) after 28 days curing. The first batch has 6 aggregate combinations (siliceous, limestone, basalt, calcium aluminate synthetic sand, Sao Domingos slag) and was meant to be a preliminary study of 300 h to select the best aggregate for a deeper investigation. Batch two had 36 samples and the contact period was extended to 1500 h (Table 1). Additionally, two refractory materials were tested as protective layers. Six concrete cubes were placed into a molten salt bath and put in the oven, including two crucibles with only molten salt as references (Figure 1). In the first batch, the thermal conditions consisted of a constant temperature at 290°C and for the second batch thermal cycles changing the temperature between 290 ºC and 500 ºC every work day. The goal was to measure and evaluate changes in the thermal properties of the concrete and to understand if there is degradation of those properties with time.

TABLE 1. Experimental program description.

Batch	Number samples	Contact with molten salts	Protection Layer
1	18 with 6 aggregate combinations	300 h	• Uncoated • Coated with refractory paint • Coated with alumina mortar
2	36 with 1 aggregate combination	1500 h	• Uncoated • Coated with refractory paint • Coated with alumina mortar

The thermal properties of concrete were measured after 28 days curing, and later after 1000h and 1500h in contact with molten salts, using a portable measurement equipment ISOMET 2104 equipped with a surface probe (Fig. 1-b).



a) b)

FIGURE 1. a) Bath of concrete samples and molten salts references in crucibles. b) Thermal measurement after 1000 hours of contact with molten salts.

The use of protective layers for concrete mixes may represent an important step in this research in order to improve the stability of materials at high temperature and in direct contact with molten salts.

Materials that exhibit resistance to high temperature and extreme environments have already been developed and are available on the market. However, coatings that resist a heat-treated process of exposure to high temperature and in contact with molten salts are not yet known at present, for this reason, the study performed was a challenge. Some properties under consideration for the protective layers are the ability to withstand high temperature, resistance to contact with molten salts, resistance to thermal cycling and compatibility with a cementitious matrix.

After a pre-selection of possible commercial products, two products for testing were selected. One zircon based paint and one high alumina content refractory mortar. The selected products have characteristics such as a bulk density of 1800 kg/m^3 for the zircon paint and 2500 kg/m^3 for the vitset mortar. Some characteristics of these products are, for example, the grain size (in the case of zircon paint it is less than 0.1 mm, while in the vitset it is less than 0.5 mm). The method of application of the selected coatings, is displayed in Figure 2, for the case of zircon paint (Fig. 2-a) the application is done using a brush, in the case of vitset mortar, it is done with a spatula.

a) b)

FIGURE 2. a) Application of the paint with a brush. b) Application of the mortar with a spatula.

After application and drying, the zircon paint presented small cracks, while the refractory mortar had visually no defects. Therefore, the vitset mortar is the preferred material for the detailed interaction tests, additionally the paint shows a smoother surface due to its much easier application for the size of the samples.

The thickness of the samples was measured (Figure 3) before and after applying the protective layer (coatings), the measurement of the thickness was made three times (1,2 and 3) in the same face (faces A, B and C) (Fig. 3-b).

a) b)

FIGURE 3. a) Measure of the thickness of the cubes before the application of the coating. b) Three directions of the measurements performed on the prisms.

Table 2, presents the individual thicknesses, before and after paint and mortar application respectively showing an average thickness of 0.32 mm for the zircon paint and 1.85 mm for the vitset mortar.

TABLE 2. Measure of the thickness before and after applying the coatings.

BEFORE COATING										
SAMPLE		Dimension A (mm)			Dimension B (mm)			Dimension C (mm)		
	Cube	**h_{A1}**	**h_{A2}**	**h_{A3}**	**h_{B1}**	**h_{B2}**	**h_{B3}**	**h_{C1}**	**h_{C2}**	**h_{C3}**
Uncoated	1	40.52	40.43	40.31	40.50	40.27	40.44	51.05	51.10	51.30
	7	39.85	40.07	40.81	40.22	40.14	40.13	51.08	51.19	51.15
Zircon Paint	17	41.18	40.98	40.89	40.54	40.22	40.28	50.87	51.00	51.25
	23	41.87	41.87	42.39	40.22	40.33	40.29	51.43	51.21	51.33
Vitset Mortar	35	40.36	40.11	40.01	40.95	41.04	41.13	51.07	51.19	51.35
	36	40.12	40.13	40.13	41.42	41.43	41.44	50.83	51.44	51.34

AFTER COATING										
SAMPLE		Dimension A (mm)			Dimension B (mm)			Dimension C (mm)		
	Cube	**h_{A1}**	**h_{A2}**	**h_{A3}**	**h_{B1}**	**h_{B2}**	**h_{B3}**	**h_{C1}**	**h_{C2}**	**h_{C3}**
Uncoated	1	=	=	=	=	=	=	=	=	=
	7	=	=	=	=	=	=	=	=	=
Zircon Paint	17	42.61	42.12	42.25	40.88	41.30	40.89	51.78	51.95	51.83
	23	42.48	42.19	42.32	40.74	40.76	40.62	51.46	51.43	51.98
Vitset Mortar	35	43.69	43.57	43.47	42.57	42.98	52.85	53.48	54.65	54.64
	36	42.58	42.96	42.84	45.16	44.07	53.50	53.69	52.82	52.82

RESULTS AND DISCUSSION

The parameters in evaluation were the surface degradation of the uncoated and coated samples, changes in the thermal properties, and pore size distribution of the concrete mix at different depths, to analyze the penetration of the molten salt.

After a contact of 300 hours at a constant temperature of 290 ºC no visible cracks were detected. Nevertheless, the molten salt penetration was confirmed due to the mass of the sample increased in all cases between 9 and 18% of the initial mass before the contact. After a contact of 1500 hours and 32 temperature cycles performed, uncoated concrete samples had no visible cracks to the naked eye, while those coated with the refractory paint showed degradation of the paint in some areas and those coated with the alumina mortar were intact.

Figure 4 to Figure 6 present images taken in two surfaces of the three areas (A, B and C) measured, showing a visual registration of the degradation. Figure 4 shows a sample cube without coating that suffered thermal cycles of 290 to 500°C during 1500h in contact with a ternary mixture. Its visual appearance of the surface A and C shows only slight degradation of the surface, but no visible cracks.

a) b) c)

FIGURE 4. Visual appearance of an uncoated cube after 1500 hours in contact with the molten salts in surface A, B and C.

The surface degradation of coated samples is important to evaluate the protection layer. The cube sample 23 coating with the zircon paint has been analyzed after the thermal cycles for 1500h in contact with a ternary mixture of molten salt. Its visual appearance shows clear degradation of the coating (Figure 5), especially in surface A and C. The same analysis was performed for samples coated with vitset mortar, after suffering the abovementioned cycling conditions. The results (Figure 6) show good integrity of the mortar but with a slight start of cracking in some faces.

a) b) c)

FIGURE 5. Visual appearance of the cube sample 23 coated with zircon paint after 1500 hours in contact with the molten salts in surface A, B and C.

a) b) c)

FIGURE 6. Visual appearance of the cube sample 35 coated with vitset mortar after 1500 hours in contact with the molten salts in surface A, B and C.

The surface degradation of the samples with zircon paint were calculated and are as high as 30% of the exposed surface. The process followed is summarized in Figure 7. The degraded area was selected as the area with a specific color range (Adobe Photoshop CS6 feature), using as reference the concrete color. This area was colored in red for clarity, and this area was evaluated (in pixels) and compared with the number of pixels in the whole section.

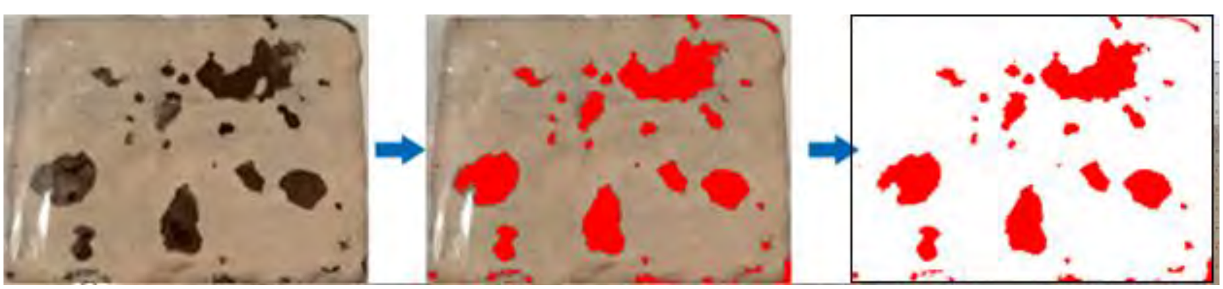


FIGURE 7. Image processing for the evaluation of the percentage of area degraded from surface "A" exposed to molten salt.

The values of the amount of surface where the coating disappeared calculated with this method are:

- Zircon Paint A: 17.2% - Surface area 20 cm^2
- Zircon Paint B: 1.7% - Surface area 16 cm^2
- Zircon Paint C: 28.4% - Surface area 20 cm^2
- Vitset A, B, C, no visual degradation (0%)

Thermo-physical measurements reveal a slight increase of thermal conductivity (λ) after 300 hours contact at constant temperature of 290 °C, possibly related to an internal deposition of the salts, and a very slight decrease after the 1500 hours contact with thermal cycles (Table 3). Specific heat values obtained before and after the contact are maintained fairly constant around $1.5 \cdot 10^6$ $Jm^{-3}K^{-1}$.

TABLE 3. Thermal conductivity measured before and after temperature cycles.

Batch	Thermal conductivity range before contact	Thermal conductivity range 300 hours	Thermal conductivity range 1500 hours
1	$\lambda \in [0.88 – 1.98]$ $W \cdot m^{-1} \cdot K^{-1}$	$\lambda \in [0.89 – 2.14]$ $W \cdot m^{-1} \cdot K^{-1}$	-
2	$\lambda \in [1.08 – 1.53]$ $W \cdot m^{-1} \cdot K^{-1}$	-	$\lambda \in [0.88 – 1.15]$ $W \cdot m^{-1} \cdot K^{-1}$

In order to evaluate this penetration capacity, one sample that was never in contact with molten salts neither thermal cycles (7) was used as a reference. From the samples that suffered thermal cycles and contact with the molten salts, two positions were compared, one in the external part of the sample (where higher penetration was expected) and another in the interior of the sample, at a distance of approximately 2 cm from the surface. Using this method, the presence of pores will indicate the effectiveness of the coating.

The results obtained when using zircon paint and vitset mortar are displayed in Figure 9 and Figure 10, respectively, showing that for the external points, after the contact all the pores were completely filled by the molten salt, despite the presence of the coating. However, in the interior of the sample, vitset mortar achieved certain protection of the concrete, which can be deduced by the presence of pores of the size over 25 µm. The pore size distribution indicates that finer pores will be completely filled.

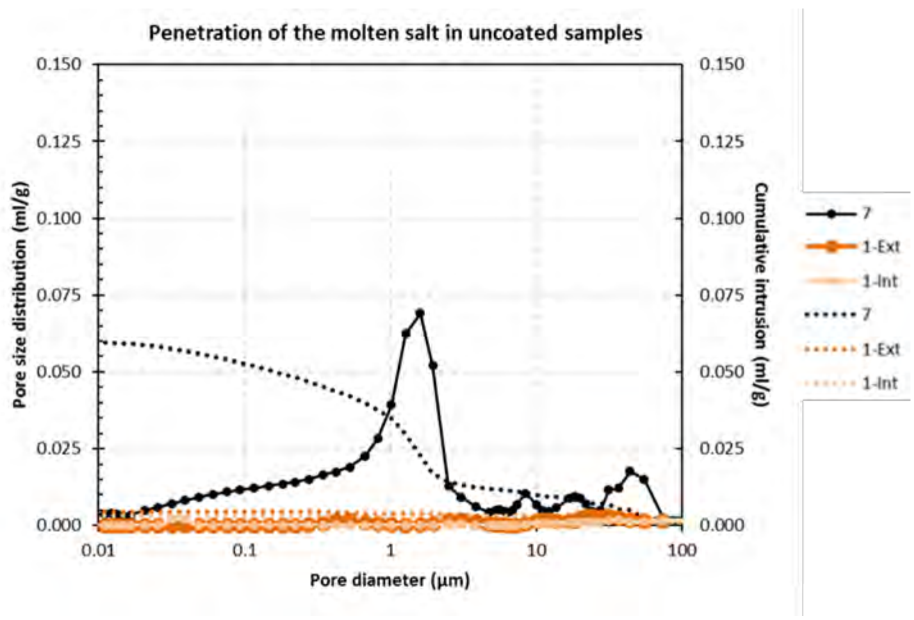


FIGURE 8. Pore size distribution for a reference concrete sample (7) and two zones of a sample after suffering the contact with ternary mixture after 1500 hours. (<u>note</u>: *solid lines show the pore size distribution curves, principal axis, and dashed lines cumulative intrusion curve, secondary axis*)

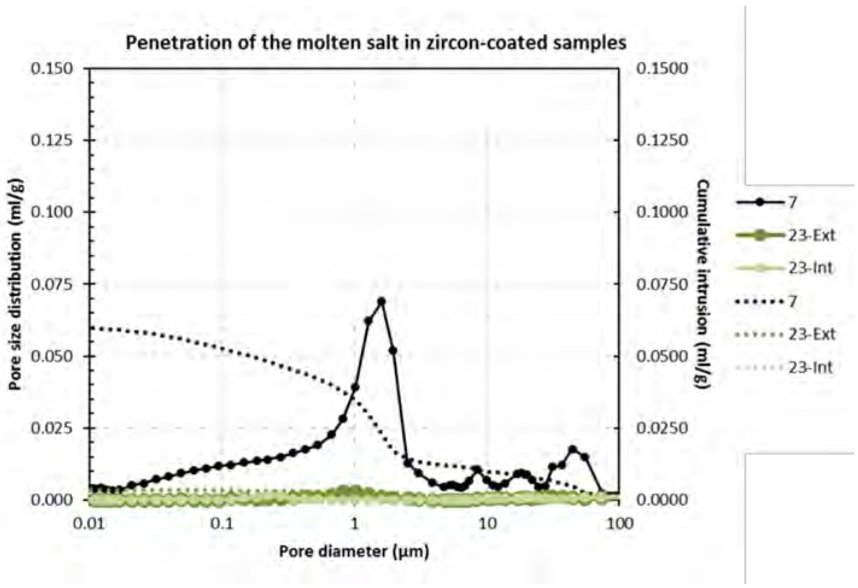


FIGURE 9. Pore size distribution for a reference concrete sample (7) and two zones of a sample coated with zircon paint after interacting with Ternary mixture under thermal cycles for 1500 hours. (note: solid lines show the pore size distribution curves, principal axis, and dashed lines cumulative intrusion curve, secondary axis)

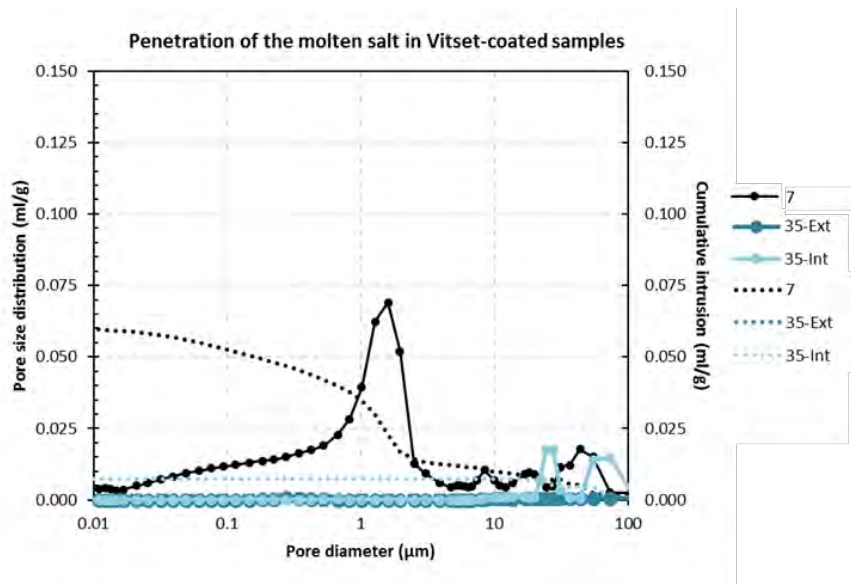


FIGURE 10. Pore size distribution for a reference concrete sample (7) and two zones of a sample coated with vitset mortar after interacting with Ternary mixture under thermal cycles for 1500 hours. (note: solid lines show the pore size distribution curves, principal axis, and dashed lines cumulative intrusion curve, secondary axis)

Table 4 shows the values of total pore area and porosity values obtained for the reference sample, showing the characteristic porosity of this concrete mix and the values obtained after the interaction with the molten salt, either for uncoated or coated samples. The porosity values obtained show that the external points have very low porosity after the interaction with the salt, demonstrating its penetration. However, when analyzing points at 2 cm of the surface ("Internal points"), the results indicate that the vitset mortar is able to reduce and delay the penetration of the molten salt to the interior of the concrete.

TABLE 4. Total pore area and porosity values obtained for the different samples after the interaction with the molten salts for uncoated and coated samples at external and internal points.

Sample type	Total Pore Area (m²/g)	Porosity (%)		
Reference	1.416	14.9582		
	External point		Internal point	
	Total Pore Area (m²/g)	Porosity (%)	Total Pore Area (m²/g)	Porosity (%)
Uncoated	0.008	1.3078	0.043	0.9719
Zircon coated	0.016	1.0064	0.011	0.6601
Vitset coated	0.003	0.5243	0.001	2.1298

Results presented indicate that the alumina mortar showed better resistance (2.1298% of porosity) than the zircon paint, being able to delay the penetration of the molten salts to the interior of concrete. However, and according to analysis [3], since the salt was able to penetrate inside the concrete to some extent, to guarantee concrete durability for a long-term direct contact, it will be necessary to protect it with a different coating or another protection method, such as a steel liner.

These are preliminary results of on-going work within an extensive Project on Materials for Energy Storage [5] and thus further results are expected in the framework of the project.

CONCLUSIONS

These are preliminary results of on-going work within the NewSol Project on Materials for Energy Storage. From the results, it is possible to conclude that the concrete samples analyzed have a slight change (less than 10%) in their thermal properties after being in contact for 1500 h with molten salts. Up to now, concrete shows a good resistance to thermal cycles and is stable when in contact with molten-salts. The thermal measurements result show that the decrease in thermal conductivity produced in those samples coated with the refractory mortar are higher than in the uncoated and coated samples with the paint. Heat capacity shows very little changes after the interaction tests, meaning there are no significant changes on the thermal performance of the samples.

Along to this investigation made to the samples with and without coating a first conclusion is that to guarantee a long-term durability of the concrete in direct contact with the salts, it needs to be protected with a coating or another protection method. The sample without coating after the thermal cycles only shows a slight degradation of the surface, however with time it is expected that crack formation will increase. The coated sample with alumina mortar showed better resistance than the zircon paint, which was demonstrated by the absence of surface degradation of the vitset mortar, and the reduction of the penetration of molten salts in the interior of the concrete sample as seen in the increase of porosity values for depths of around 2 centimeters. Even though these protective layers would improve the long-term behavior and durability of the system, in both cases the molten salt is able to penetrate inside the concrete matrix. For this reason, further research is needed to find a completely effective protective layer. For the time being, an alternative (steel lining) is a possible option.

ACKNOWLEDGEMENTS

Research work was supported by the European Commission, program H2020, Project Newsol (Project ID: 720985) [5].

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5. Website, Project Newsol, "www.newsol.uevora.pt," [Online]. [Accessed August 2018].

Annex II – Presentations made on events considered relevant for the presentation of the project and project results, not included in dissemination activities.

Partner name: CSIC

Partcipant(s): Maria Cruz Alonso

Event: GUATEMALA IV Congreso Centroamericano de Nanotecnología y II Congreso de Nanotecnología y Tecnologías Futuras para el Desarrollo Sostenible

Location: Guatemala

Date: 23-24 October 2017

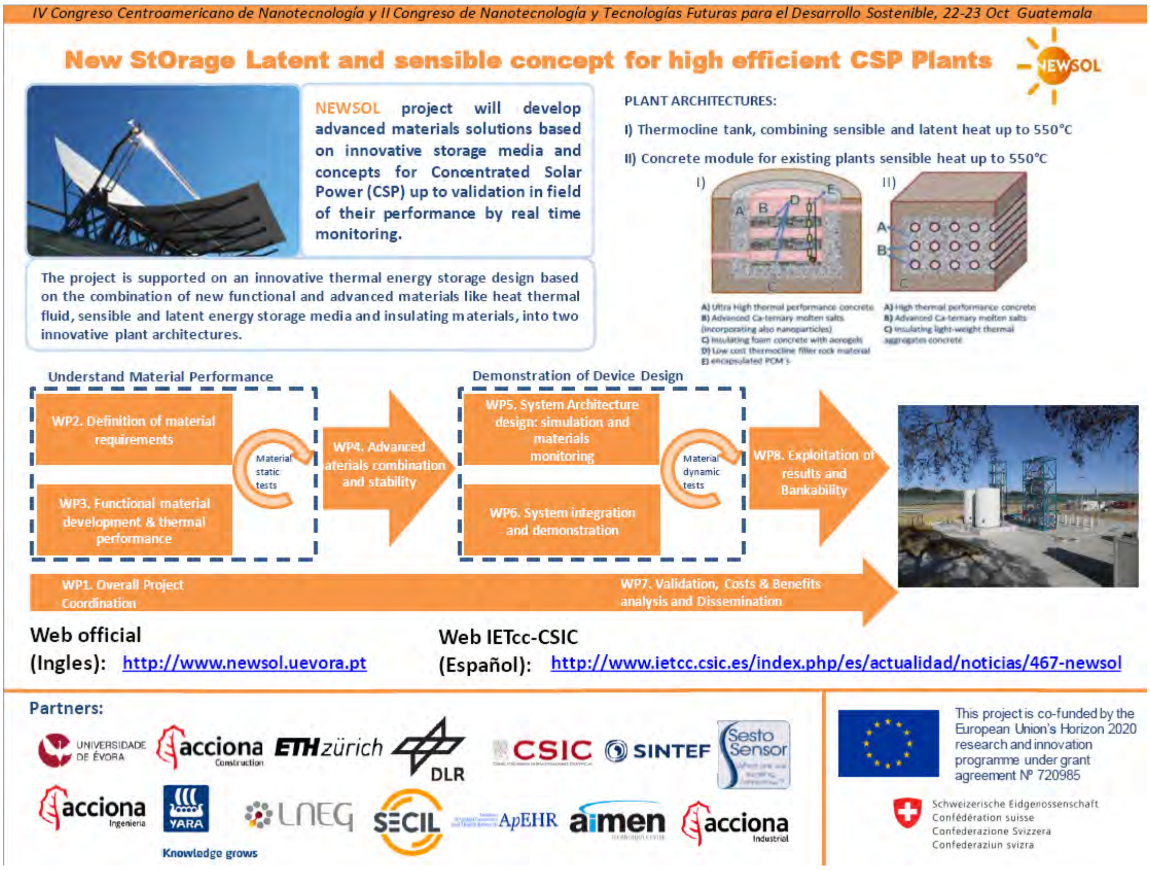
Target group: Centro American researchers and professionals from the nanotechnology and future technologies fields.

Number of participants:

Type of presentation (NEWSOL power point; Other results of project presentation):

In the annex, include the power point presentation if different the NEWSOL power point presentation.

Slide included in a broader presentation. The slide of Newsol is attached in the next page.



IV Congreso Centroamericano de Nanotecnología y II Congreso de Nanotecnología y Tecnologías Futuras para el Desarrollo Sostenible, 22-23 Oct Guatemala
New StOrage Latent and sensible concept for high efficient CSP Plants
NEWSOL project will develop advanced materials solutions based on innovative storage media and concepts for Concentrated Solar Power (CSP) up to validation in field of their performance by real time monitoring.
The project is supported on an innovative thermal energy storage design based on the combination of new functional and advanced materials like heat thermal fluid, sensible and latent energy storage media and insulating materials, into two innovative plant architectures.
PLANT ARCHITECTURES:
I) Thermocline tank, combining sensible and latent heat up to 550°C
II) Concrete module for existing plants sensible heat up to 550°C
Understand Material Performance
Demonstration of Device Design
WP2. Definition of material requirements
WP3. Functional material development & thermal performance
Material static tests
WP4. Advanced materials combination and stability
WP5. System Architecture design: simulation and materials monitoring
WP6. System integration and demonstration
Material dynamic tests
WP8. Exploitation of results and Bankability
WP1. Overall Project Coordination
WP7. Validation, Costs & Benefits analysis and Dissemination
Web official (Ingles): http://www.newsol.uevora.pt
Web IETcc-CSIC (Español): http://www.ietcc.csic.es/index.php/es/actualidad/noticias/467-newsol
Partners:
This project is co-funded by the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 720985
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

WP7 – Task 7.4.2 – Report on presentation of project and project results on relevant events.

Partner name: AIMEN

Partcipant(s): Ander Zornoza

Event: 9th Workshop: Case Studies, Strategies, Model, and Tools

Location: Dublin (Ireland)

Date: 29.05.2017

Target group: Members of COST action TU 1402 "Quantifying the value of structural health monitoring"

Number of participants: 40

Type of presentation (NEWSOL power point; Other results of project presentation): power point and fact sheet

In the annex, include the power point presentation if different the NEWSOL power point presentation.

Proceedings of the 9th Workshop, Dublin, Ireland, May 29 and 30, 2017.

COST Action TU1402: Quantifying the Value of Structural Health Monitoring

Editors: Jochen Köhler, Sebastian Thöns, October 2017

Case Study Fact Sheet No. WG4-8

Solar Molten Salt Concrete thermocline tank Monitoring: Introduction and preliminary framework for VoI analysis implementation

Dr. Ander Zornoza, Robotics and control R&D unit, Aimen technology center

I. Scope of the fact sheet

This fact sheet is presenting the working progress on a case study. It summarizes the character and context of the study and highlights the major steps and challenges for the implementation of a value of information assessment. Furthermore, outlook on further developments of the case study are given.

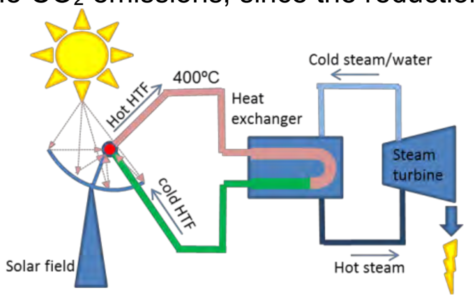
II. Abstract

Efficient thermal energy storage is one of the main challenges to help the widespread adoption of Centralized Solar Power (CSP). Currently we are working in and advanced solution, a solar molten salt concrete thermocline tank, to increase the efficiency and reduce the cost of thermal storage in CSP. To assure the performance of the tank and its structural integrity a monitoring system, based on fiber optic sensors is being developed and in order to quantify the value of this monitoring system a Value of Information (VoI) analysis is proposed as a case study. In this document, the preliminary framework for VoI analysis implementation is set.

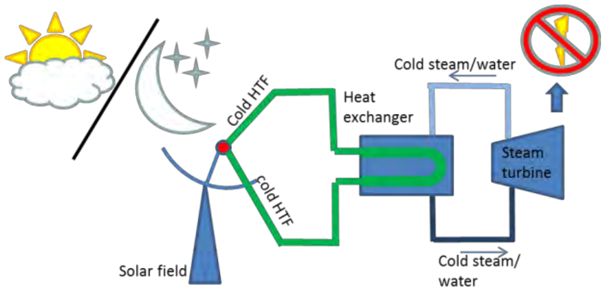
III. Description of the case study

i. Introduction to thermal energy storage in CSP

To address the global challenges such as clean energy, climate change and sustainable development, there is a strong need for development of advanced energy technologies. Concentrating solar power (CSP) plants have grown considerably worldwide since 2010 as a clean renewable energy source. In fact, it is solar energy, one of the most suited to be the energy of the 21st century[1,2], where CSP's is about to play a major role in the Global Energy Mix, as it is expected to increase from 4GW in 2014 to 1000GW in 2050. This transition will have a big impact in lowering the CO_2 emissions, since the reduction is estimated at 2.1Gton[1].



(a)



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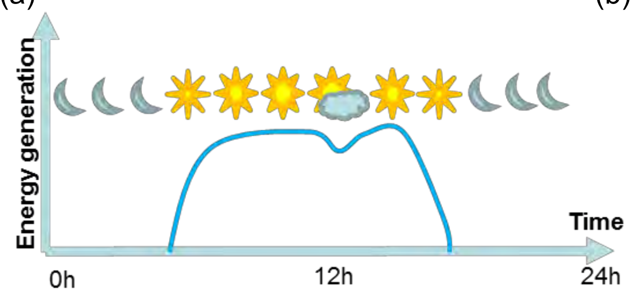
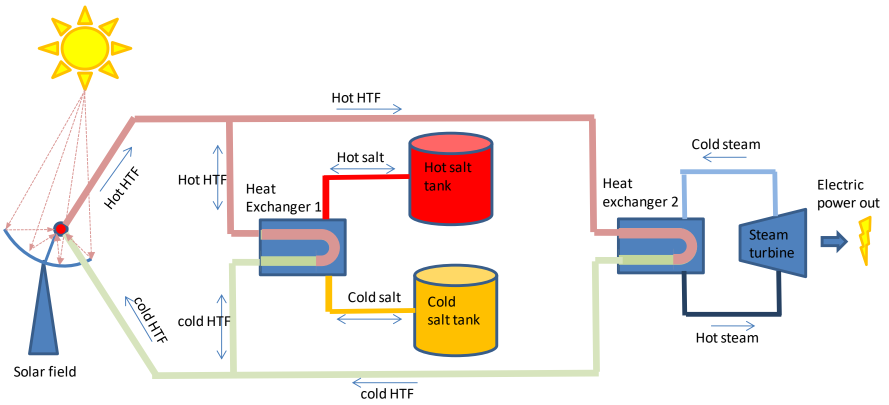
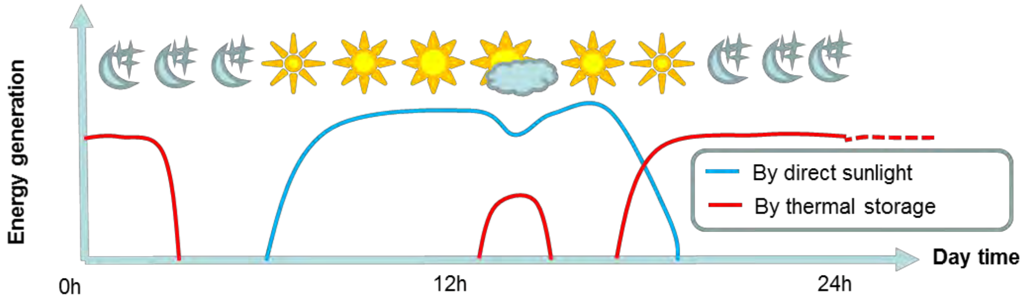


(c)

Figure 1: Schematic of a CSP using HTF (a) with sunlight (b) without sunlight (c) and energy generation throughout the day.



(a)



(b)

Figure 2: (a) Schematic of a CSP using SMS (b) and energy generation throughout the day.

Although the technical benefits from CSP in the energy challenge field are evident, the service life of actual CSP infra-structures are widely questioned, given that the durability of functional materials used to operate in the severe conditions are far from the optimized ratio of Efficiency/Durability/Cost. One solution to overcome this limitation is to use thermal storage materials. These materials should keep temperature levels that guarantee the working regime of heat exchange and turbines. Therefore, the solar resource intermittency is eliminated, by increasing the performance of the turbines due to constant steam production. Solar molten salts (SMS), composed of KNO_3 and $NaNO_3$, have been proven as a solution for this matter, since they can keep a plant working during a complete night[3]. SMS are however very corrosive and have high melting temperature (usually above 200ºC depending on the mixture used), they can operate currently up to 600ºC. CSP plants can use SMS in two different architectures. It can be used as an intermediate fluid just to store heat and oil as the main heat transfer fluid (HTF) or as the only HTF fluid. In figure 1 a parabolic trough solar facility is explained using SMS as intermediate fluid and oil as main HTF. The HTF is heated in the receiver with daylight and then diverted, toward two heat exchangers. In the heat exchanger, cold SMS, (at 300ºC) coming from the cold salt tank is heated up to 385ºC and sent to the hot salt tank. The cold HTF is sent back to the solar field to be heated. In heat exchanger 2, the heat is transferred to the steam, so the HTF is cooled down while the steam is heated up. The cold HTF is sent back to the solar field and mixed up with the cold HTF coming from heat exchanger 1. When the system is discharged (i.e. at night) the SMS and HTF flow in the opposite direction in heat exchanger 1. Therefore, the heat is transferred back to the HTF from the SMS. The hot HTF is sent to heat exchanger 2, where saturated steam is generated, allowing the generation of power in the turbine even at nighttime. In the case of using SMS as the only HTF, the salt is sent to the solar field from the cold tank at daytime to collect heat from the solar parabolic through colletors (or a solar concentrating tower). After heating, the hot SMS, at about 550ºC, is sent to the hot molten salt tank, where it is stored until it is directed to the heat exchanger. It is in the heat exchanger where the heat from the SMS is transferred to the steam, so, the SMS gives away energy coming down to a temperature around 300ºCwhile the steam is heated up. The hot steam heads to the steam turbine, where the electrical energy is generated. The steam is then sent to the turbine, cooled down after the turbine, and directed to the heat exchanger again in a cyclic operation. The cold salt after exiting the heat exchanger, is stored in the cold salt tank before being returned to the tower for heating again. If enough hot SMS is stored, the plant may operate during nighttime, reducing intermittency of CSP generation, since the salt in the hot salt tank can remain several hours hot enough to keep the plant running. When oil is used as HTFs the temperature at which the steam is heated is lower, so the efficiency of the plant is lower. However, when HTF and SMS are simultaneously used there is a great advantage: if a problem occurs with the SMS heat storage system, the plant can continue running, although only at daytime. As we have already discussed, SMS are at high temperatures and are very corrosive, having a big impact in the long-term stability of the materials used in the storage tanks and pipelines. Therefore, care must be taken while choosing the materials and design of the tanks, heat exchangers and pipelines. Especially since they must withstand the high temperatures of the salt and avoid corrosion. Also, note that SMS salt should not solidify, which could be specially harmfull for the pipelines, so they must be kept well above their melting point, >290ºC. Therefore, they impose several limitations coming from their high temperature and corrosive nature, which make their deployment and application a challenge[3].

ii. Advanced SMS tanks

Currently, SMS tanks are made of steel and must be carefully insulated to avoid any heat loss. Also, the current configurations need the deployment of two tanks: one for hot SMS and another one for cold SMS storage and great volumes of SMS. Therefore, a lot of research effort is conducted to optimize de Efficiency/Durability/Cost in the SMS storage tanks. Currently, in NEWSOL project[4], a solution based in novel materials for tank heat storage, advanced SMS, insulating materials, filler materials within the tank and advanced monitoring systems is being developed and demonstrated in a novel configuration: the thermocline tank. Figure 3 shows a CSP plant running only on SMS as HTF and storage fluid and the thermocline tank. The SMS, after heated in the solar field, is stored in the thermocline tank. The hot SMS, from the top of the tank is directed to the heat exchanger, where the steam is heated. Note the power block is the same as in the two-tank configuration. The cold SMS is then directed to the thermocline tank, where it is stored until is heated in the solar field again. Note that the SMS input and output to and from the tank are at different levels in the figure. This is to ensure that the fluid with different temperatures are placed at different parts of the tank to reduce heat transfer between them and isolate one from another. So, in the thermocline tank a vertical temperature gradient is observed, with an abrupt change in temperature between the hot and cold salt, called the thermocline. Therefore, when the tank is fully charged, the tank will be filled with hot SMS only, and when it is discharged, only cold SMS will be inside the tank. This way a lower volume of SMS is needed and a single tank is needed for storage, reducing the cost of the system. The design consists of a single thermocline tank with concrete walls, instead of the classic 2–tank system with steel walls, containing filler materials inside the tank for sensible heat storage from 290ºC up to 550ºC. The new thermocline concrete tank will take advantage of the thermocline effect to combine both, the hot and the cold molten salt in the same tank by separating them through a thin layer of a high-temperature gradient. This thermocline tank will be filled with low cost solid filler materials that displace the more expensive molten salts and act as the primary thermal storage medium. These filler materials will be arranged in several layers along the tank height.

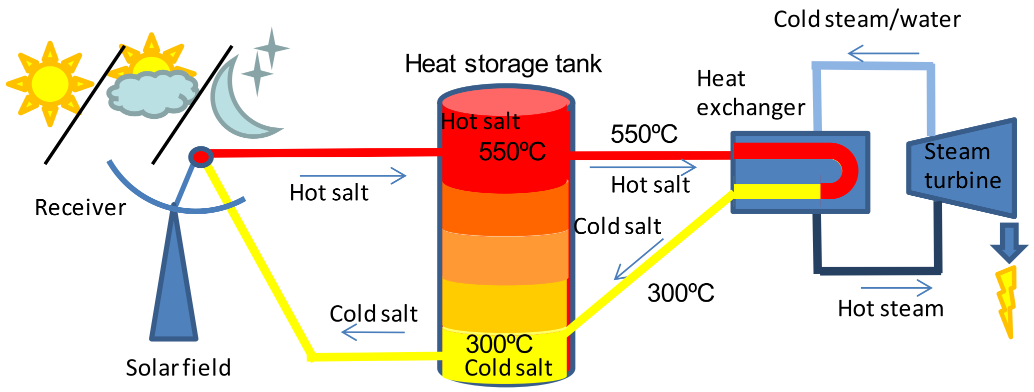


Figure 3: Thermocline SMS tank configuration on a CSP

iii. Monitoring system and sensors for molten advanced SMS concrete tanks

A solution to help widespread the adoption of SMS technology and thermocline concrete tanks, alongside with their benefits, is predictive maintenance of the storage tanks. Measuring and storing temperature data of the salt or the structural health of the tank is an important input and the sensing technologies applied are the key element for feasible and stable measurements. The most widely employed transducers are thermocouples for temperature monitoring, strain gages for strain monitoring and embedded or surface-bonded piezoelectric sensors for vibrations or acoustic emission (AE). However, these technologies present serious drawbacks for monitoring large structures at high temperature or corrosive environments. Thermocouples and strain gages are hard to multiplex and are subject to electric and magnetic disturbances. In the case of piezoelectric sensors, they lose the piezoelectric effect above temperature of Curie (300ºC) and exhibit degradation due to thermal cycling[5]. Furthermore, they do not offer very good multiplexing capacities, and resistance to corrosion.

Fiber optic sensors (FOS) are a promising alternative, since they can measure strain, temperature, vibrations, AE… and their properties make them well suited for applications in harsh environments such as CSPs[6]. Also, they are completely passive, so no power source is needed in the communication channel or sensor itself. Also, they are immune to electric and magnetic fields. The diameter of the cladding of the fiber is near 125um, so they are very small in size and light in weight. Furthermore, FOS can be easily multiplexed, so a complete CSP plant could be monitored with a simple optical network, especially in the case of Fiber Bragg Grattings (FBG)[7]. Some applications have been studied using commercial FOS in SMS, however they have been discarded, mainly because the packaging used for the sensor protection is corroded by the SMS[7]. A solution based on FBGs was presented by Grandal et al.[8], where a corrosion resistant package was employed to protect the FBG sensor from the salt and the temperature between 290 and 550ºC was monitored. In NEWSOL this solution will be further developed[4] for monitoring at different locations of the tank within two scopes: (1) structural health monitoring of the tank and (2) assessment of thermal performance of the system. So, the monitoring system for the thermocline tank will consist on a fiber optic sensor network that will monitor input and outlet temperatures of salt, molten salt temperature, concrete wall temperature, lateral wall temperature, base concrete temperature, cover temperature. Therefore, there will be two main groups of sensors: embedded sensors in the different concrete layers and temperature sensors immersed in molten salt. The sensors embedded in concrete layers will measure temperature and strain. The output of this monitoring system will consist on temperatures and strain in the different materials, structural parts and locations where the sensors are placed or embedded. So, the VoI analysis while rely in the information provided by this monitoring system.

IV. Implementation of a VoI analysis

As it has been explained, the information provided by monitoring system developed for the tank will assess the structural health and the thermal performance of the system. Therefore, the VoI analysis will be indicated for both cases from now on when necessary, and in section V the necessary simplifications will be discussed.

i) Decision maker
The decision maker will be the power plant operator, usually a private company.

j) Regulative constraints
In the case of the concrete SMS thermocline tank developed regulatory constraints are neglected, since the actual tank to be monitored is a demonstrator to proof the concept of the technology and material performance to a TRL level[9] equivalent of 7.

k) System temporal and spatial boundaries
A predesign of the demonstrator tank has already been performed, - However, since the tank will be built in 2019 and some of the material solutions have not been completely developed yet, changes may be made to obtain the final design. Also note that the tank will operate during a three-month period, from September 2019 to January 2019, so the conclusions will be only available after this time.

l) Events of interest and the corresponding representation
Structural health:

- crack is generated or growing: the apparition of cracks is an event that must be detected and evaluated, since it can be an indicator for spalling or excessive load.
- thermal stress of materials is detected: Thermal stress can undermine properties of the materials and risk the structural health of the system.
- mechanical load is a given value: when applied loads are higher than the ultimate loads the structure was designed for, the structural integrity of the system is endangered.

Thermal performance:

- temperature of the SMS at inlet or outlet is a given value: the temperature at inlets and outlets of the tank is an important parameter to estimate the charge and discharge rate of the tank.
- The temperature gradients on tank depth is at a given height: will indicate the volume and place of hot and cold salt.
- The tank is charged with a given capacity.
- The electrical power demand is at a given value

m) Event consequences
Structural health:

- bad performance of the thermocline tank;
- collapse of the tank;
- No thermal energy stored;
- no electrical power generation

Thermal performance:

- More/less efficient energy generation;
- Energy cost decrease/increase

n) Indicators (to observe)
Structural health:
- Loads, strains and cracks in the concrete
- Temperature in materials and positions

Thermal performance:
- Current stored thermal energy in the tank
- Electricity demand (not by monitoring system)
- Sun radiation (not by monitoring system)

o) Decision alternatives – monitoring and/or inspection options
- Cracks can also be detected by visual inspection but only if the cracks are in the outer part of the concrete tank, or if in the inner part during an outage (planned or emergency) and the tank is empty.
- Temperatures can also be measured with thermocouples but only at some given locations.

p) Decision alternatives – other measures, repair, replacement, etc.
Structural health:
- Do nothing
- Repair
- Replace

Thermal performance:
- do nothing
- charge tank at a given rate
- discharge tank at a given rate

V. Critical appraisal, necessary simplifications

The case study presented offers the possibility to perform a previous analysis and a model and to check it with a demonstrator and at the current state and timeline there is still room for changes that may ease the VoI analysis[8]. However, note that the demonstrator tank will not be constructed until September 2019, so the case study related to COST action TU1402 will not be completed until the action is already over. However, the first part, with the previous analysis and model should be ready before COST action TU1402 is finished.
Being the tank constructed a demonstrator that will not be connected to a real CSP plant, there are some constraints related to the thermal performance VoI analysis. Only some tests will be run during the operation of the tank, and these tests may not be indicative of the actual performance of a real tank. Also, there are factors related to energy generation cost that may change during the timeline of the project that would affect the VoI analysis related to thermal performance. So, from now on we will concentrate only in the structural part and we will leave the thermal performance VoI analysis as a future work.

VI. Further steps and resources required

Within the NEWSOL project[4], where the main developments of material solutions and monitoring system are developed and the tank is constructed. So, the following timeline is set:
June 2017 – framework to start project.
- From this moment on the monitoring system will be developed. This is already taking place in AIMEN under the author of this fact sheet's coordination. This task will finish in December 2019.

- The model that will allow VoI analysis will be set. Here collaboration from the cost network will be necessary, since the main strength of AIMEN is on monitoring system evaluation as a tool for SHM, but not so much in SHM and VoI. A STSM could help with this part. This could take place during the first semester of 2018.
- Preliminary VoI analysis. Fall 2018.

January 2019 – Monitoring system developed and tested in lab demonstrator
September 2019 – Tank and module operating
January 2020 – Evaluation after 3 month of tank operating. Re-evaluate VoI.

VII. Summary and conclusion

The VoI flowchart for concrete SMS thermocline tanks monitoring system is presented in figure 6. Note that although the thermal performance related VoI has been discarded, it is still shown (in grey) for completeness.

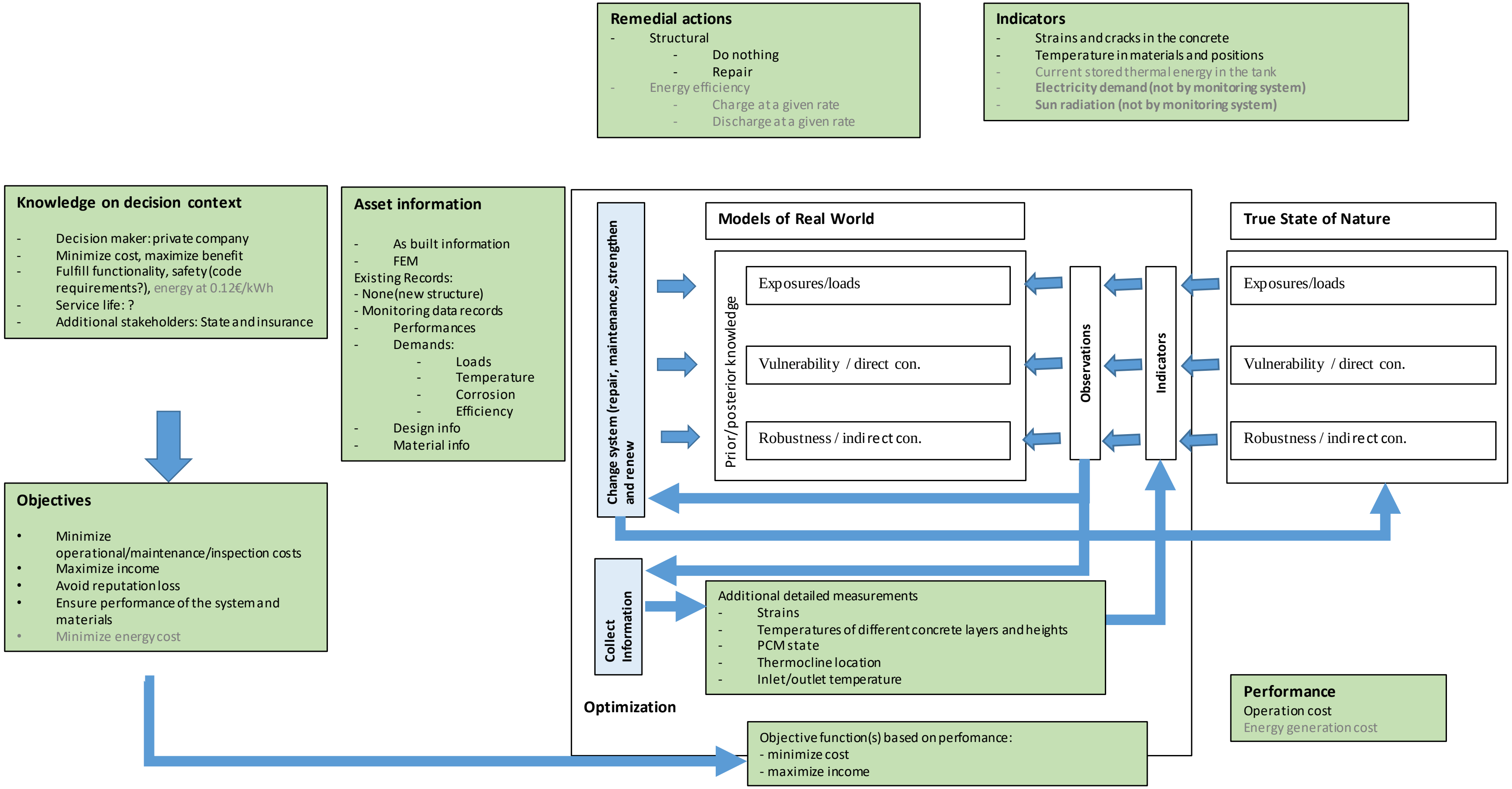


Figure 6: FlowChart for SMS concrete thermocline tanks.

Contact information

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Acknowledgements

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 720985, project NEWSOL.

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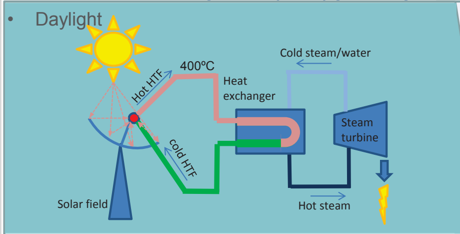
2. ESTELA. Solar Thermal Electricity. Strategic Research Agenda 2020-2025, (2012).
3. S. Kuravi, J. Trahan, D.Y. Goswami, M. M. Rahman, E.K. Stefanakos, "Thermal energy storage technologies and systems for concentrating solar power plants", Progress in Energy and Combustion Science, Vol. 39 (4), pp. 285-319, August 2013.
4. http://www.newsol.uevora.pt/
5. Santos J.L. and Farahi F., [Handbook of Optical Sensors], CRC Press (2014).
6. S.J. Mihailov, "Fiber Bragg Grating Sensors for Harsh Environments", Sensors, vol. 12, pp. 1898-1918, 2012.
7. Gill D., Kolb W., Briggs R., "An Evaluation of Pressure Measurement Technology and Operating Performance Using Sandia's Molten Salt Test Loop". Proceedings of the SolarPACES 2013 International Conference, Energy Procedia, Volume 49, 2014, Pages 800–809 (2013).
8. T. Grandal, Sergio Fraga and Ander Zornoza, "Solar molten salt temperature monitoring with fiber optic sensors", accepted for publication at Advanced Photonics congress, Control Number: 2526009, 2016, Vancouver (Canada).
9. HORIZON 2020 – WORK PROGRAMME, General Annex G: "Technology readiness levels".

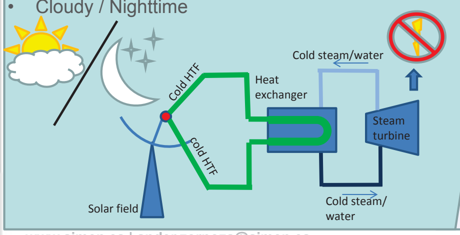
Concentrated solar power (CSP) plant operation work without storage

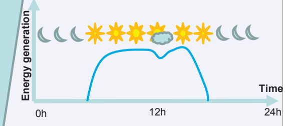
- Daylight



- Solar thermal energy is converted into electric energy
- Max HTF temperature near **400ºC**
- Energy generation through the day without storage

- Cloudy / Nighttime



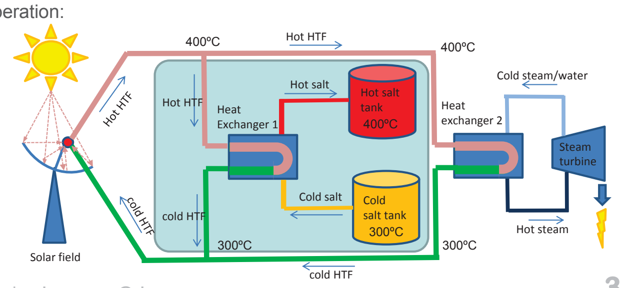


No sunlight, no power

CSP with thermal storage

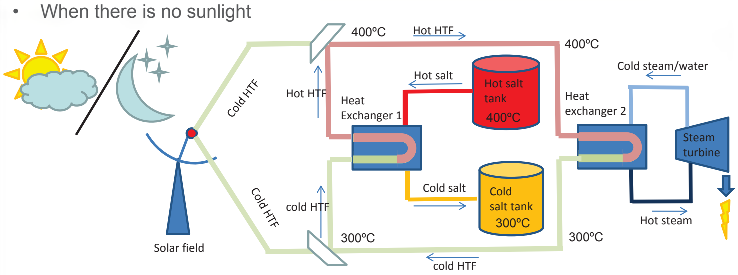
- **Thermal energy (heat) is stored by heating molten salt**
- Molten salt composition: **KNO_3+$NaNO_3$**
- A **new heat exchanger** (between HTF and Molten salt) and two Molten salt tanks are needed
- Molten salt can store temperature but it is **highly corrosive and cannot solidify** (melting temperature 280ºC)

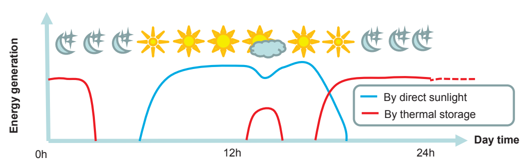
Daylight operation:



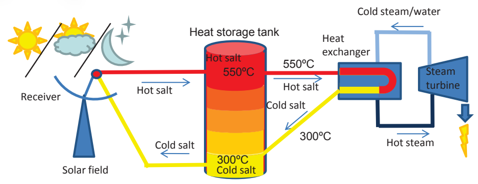
CSP with thermal storage

- When there is no sunlight

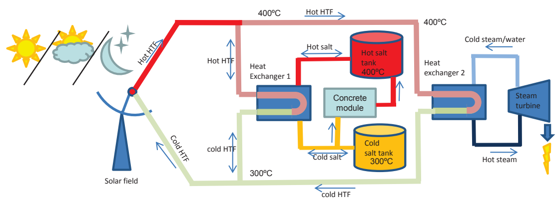




New Plant concept

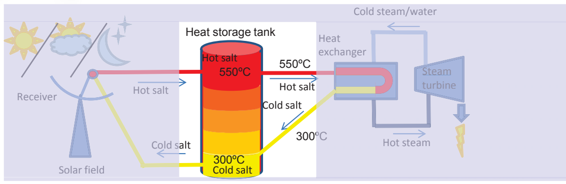


Existing Plant concept

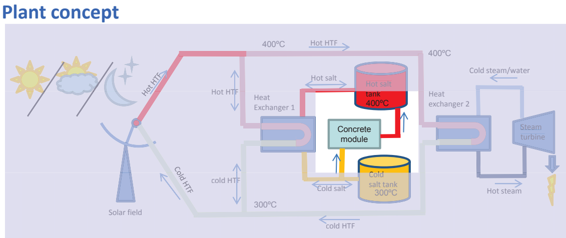


Monitoring in CSP molten salt tanks and modules

New Plant concept



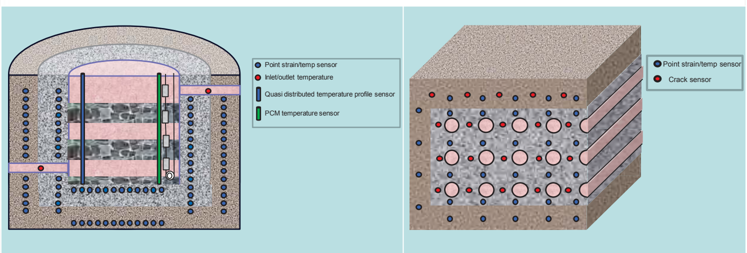
Existing Plant concept



Monitoring in CSP molten salt tanks and modules

Objective

- Assessment of thermal performance of materials
  - Increase energy efficiency of the system
- Structural health monitoring of the tank and concrete module
  - Increase safety of the structure



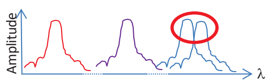
Monitoring in CSP molten salt tanks and modules

NewSOL solution

- **High temperatures and high corrosion** → **NEED MONITORING TECHNOLOGY**
- Due to monitoring requirements of CSP plants, need for:
  - **Multiplexing**
  - Good performance at **high temperatures** (550ºC) → **Fiber optic sensors**
  - **Withstand** Molten salt **corrosion**

Monitoring system development for concrete made heat storage systems in CSP

- Molten salt temperature profile in tank depth (packaged FBG arrays and distributed sensors)
- Concrete embedded temperature/strain sensors (FBG and distributed)
- Fiber optic network design
- Interrogator development



A. Zornoza, T. Grandal, and S. fraga, "Solar molten salt temperature monitoring with fiber optic sensors," in Advanced Photonics 2016 (IPR, NOMA, Sensors, Networks, SPPCom, SOF), OSA Technical Digest (online) (Optical Society of America, 2016), paper SeM4D.5.

Approach for implementing formal VoI analysis

- KPI's defined for monitoring technology are set to help VoI analysis

KPI	Description	Clarification/Internal comments	Target values
Number of sensors multiplexed	Number of sensors multiplexed by combination of wavelength division and time division multiplexing	To estimate the number of sensors to be multiplexed and interrogated using a single interrogator, to minimize instrumentation cost	500
Temperature and strain sensors reliability	$RF = \frac{NS - US - BQS}{NS} \cdot 100\%$ where: RF = Reliability Factor. NS = Number of Sensors. BQS = Number of sensors providing bad quality measurements. US = unavailable sensor	To estimate the number of sensor operating long term after three month test period of the demonstrator	80%
Savings due to the monitoring system under operation of the demonstrator tank	$\Sigma = Structural + Efficiency = \sum \lvert CNM_S - CWM_S \rvert + \sum \lvert CNM_E - CWM_E \rvert$ where: Structural =Savings related to Structural monitoring Efficiency =Savings related to Energy Efficiency event monitoring CNMS =Cost of Structural event with No Monitoring CWMS =Cost of Structural event With Monitoring CNMEE =Cost of energy generation event with No Monitoring CNMEE =Cost of energy generation event With Monitoring	To calculate the savings due to efficiency improvement and structural health provided by the monitoring system on the demonstrator tank and module during 3 month operation	>0

Current status

- **June 2017 –** framework to start project
- **January 2019 –** Monitoring system developed and tested in lab demonstrator
- **September 2019** – Tank and module operating
- **January 2020** – Evaluation after 3 month of tank operating

Open questions

- VoI is not only related to Structural performance – Energy efficiency and material performance too

Potential to use synergies with other case study proposals

- ?

Acknowledgements

NEWSOL

This Project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 720985

H2020 Grant Agreement Nº 720985
Start date of project: 01/01/2017
Duration of project: 42 months

HORIZON 2020

aimen
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WP7 – Task 7.4.2 – Report on presentation of project and project results on relevant events.

Partner name: Acciona Industrial

Partcipant(s): Miguel Barro

Event: 3rd General Assembly

Location: SECIL, Setubal hosted by Secil

Date: 30 th January

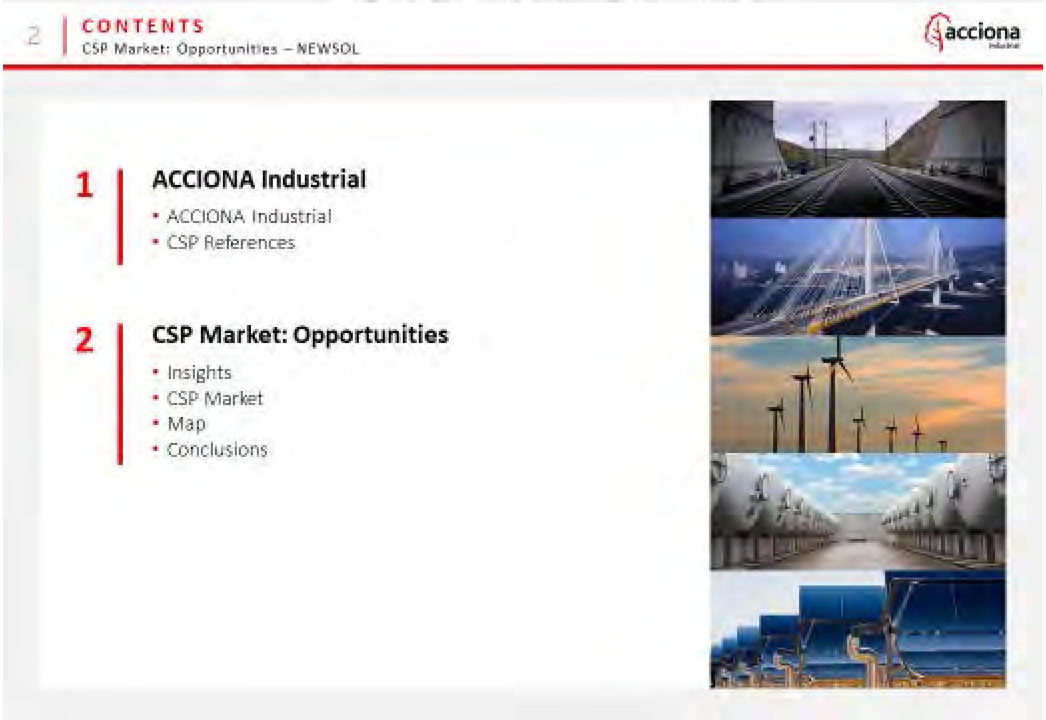
Target group:

- Public decision-makers
- Technicians working in the CSP sector
- Company workers
- Other companies working or interested in joining in this field
- Science, technology and engineering students.

Number of participants: 30

Type of presentation (NEWSOL power point):

NEWSOL
acciona
Industrial
STE Plants: a customer perspective
NEWSOL
Miguel Barro
ACCIONA Industrial
GA-3, 30th January 2018, Setúbal - Portugal



2
CONTENTS
CSP Market: Opportunities – NEWSOL
acciona
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ACCIONA Industrial
• ACCIONA Industrial
• CSP References
2
CSP Market: Opportunities
• Insights
• CSP Market
• Map
• Conclusions

3 | **OVERVIEW**
ACCIONA Industrial

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REFERENCE IN INDUSTRY AND POWER GENERATION

+€3.5 billion
Under tender or pending award until end 2016.

Specialist in Turnkey Projects
Integral management of industrial and generation projects under EPC agreements, as well as executing facilities projects.

Activity sectors
Thermal Power:
- Conventional thermal power plants
- Solar CSP
- Waste to Energy
- Biomass power plants.

Photovoltaic and Hydroelectric plants.

Oil & Gas.
- LNG terminals

Transmission Network & Substations

4 | **CONCENTRATED SOLAR POWER STATIONS REFERENCES**
ACCIONA Industrial

acciona

CSP references

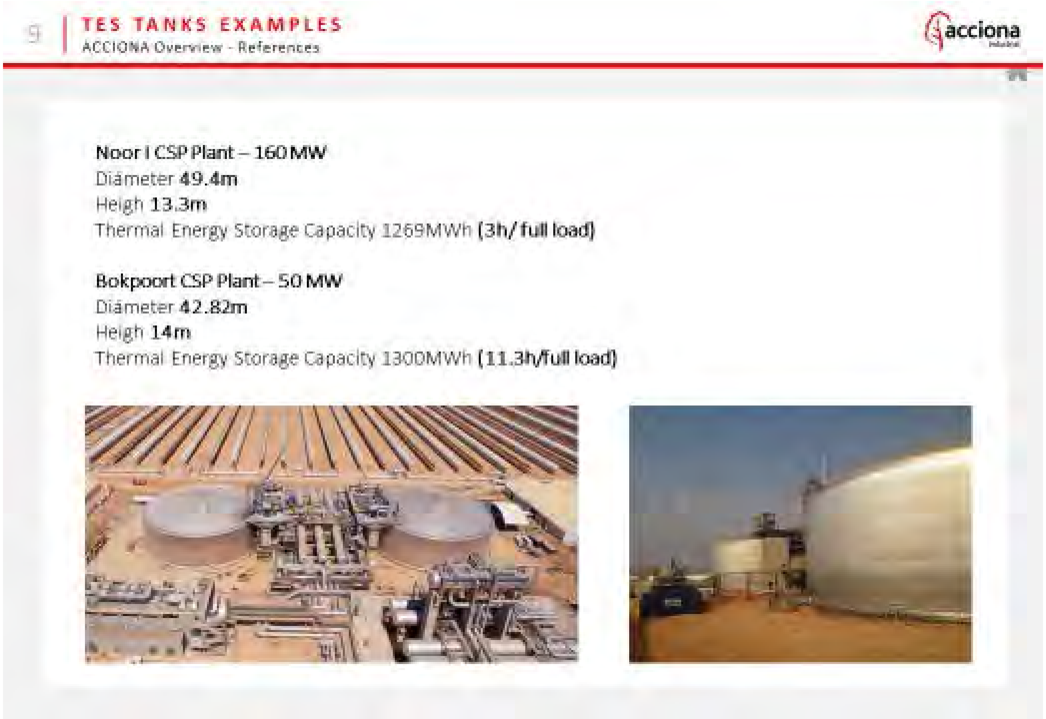
Projects	Location	Client	Value*	MW
Majadas	Caceres - Spain	ACCIONA Energía	265 MM USD	50
Alvarado I	Badajoz - Spain	ACCIONA Energía	-	50
Olivenza	Badajoz - Spain	IBEREOLICA	208 MM USD	50
Orellana	Badajoz - Spain	ACCIONA Energía	235 MM USD	50
Morón	Seville - Spain	IBEREOLICA	461 MM USD	50
Palma del Río I	Cordoba - Spain	ACCIONA Energía	-	50
Palma del Río II	Cordoba - Spain	ACCIONA Energía	274 MM USD	50
Nevada Solar One	USA	ACCIONA Energía	266 MM USD	64
Saguaro	USA	-	-	1
Ouarzazate	Morocco	ACWA Power	650 MM USD	160
Bokpoort	South Africa	ACWA Power	380 MM USD	50
Kathu	South Africa	ENGIE	650 MM USD	100
Redstone	South Africa	ACWA Power	650 MM USD	100
			TOTAL	825 MW

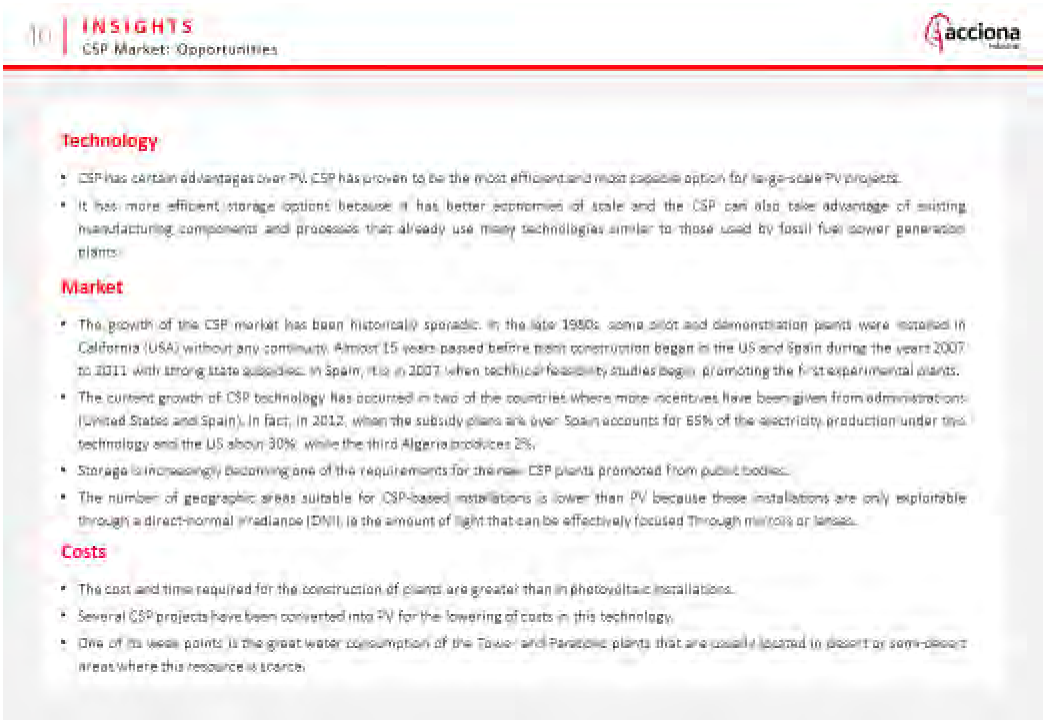

5
NOOR I SOLAR CSP PLANT
ACCIONA Overview - References
acciona
Noor I Solar CSP Plant
Ouarzazate, Morocco.
Capacity: 160 MW
Client: Acwa Power (Saudi Arabia)
Budget: 650 MM USD*
End Date: Feb 2016
Surface of the solar field 450 hectares
Equivalent in homes: 135,000
CO2 Emissions prevented: 240,000 Tn
Molten Salt Storage Capacity: 3 hours


6
BOKPOORT SOLAR CSP PLANT
ACCIONA Overview - References
acciona
Bokpoort Solar CSP Plant
Northern Cape, South Africa
Capacity: 50 MW
Client: Acwa Power (Saudi Arabia)
Budget: 380 MM USD*
End Date: March 2016
Equivalent in homes: 21,000
Mirrors: 136,000
Molten Salt Storage Capacity: 9.3 hours
Bokpoort has set a new African record (April, 26th 2016) for the continuous, round the clock supply of electricity.


7
KATHU SOLAR CSP PLANT
ACCIONA Overview - References
acciona
Kathu Solar CSP Plant
Northern Cape, South Africa
Capacity: 100 MW
Client: ENGIE
Budget: 650 MM USD*
Currently under construction
Molten Salt Storage Capacity: 4.5 hours


8
CONCENTRATED SOLAR POWER REDSTONE
ACCIONA Overview - References
acciona
Concentrated Solar Power Redstone
Kalahari Desert, South Africa
Capacity: 100 MW
Client: Acwa Power (Saudi Arabia)
Budget: 650 MM USD*
Early Works
Molten Salt Storage Capacity: 12 hours


9
TES TANKS EXAMPLES
ACCIONA Overview - References
acciona
Noor I CSP Plant – 160 MW
Diámeter 49.4m
Heigh 13.3m
Thermal Energy Storage Capacity 1269MWh (3h/ full load)
Bokpoort CSP Plant – 50 MW
Diámeter 42.82m
Heigh 14m
Thermal Energy Storage Capacity 1300MWh (11.3h/full load)


10
INSIGHTS
CSP Market: Opportunities
acciona
Technology
CSP has certain advantages over PV. CSP has proven to be the most efficient and most capable option for large-scale PV projects.
It has more efficient storage options because it has better economies of scale and the CSP can also take advantage of existing manufacturing components and processes that already use many technologies similar to those used by fossil fuel power generation plants.
Market
The growth of the CSP market has been historically sporadic. In the late 1980s, some pilot and demonstration plants were installed in California (USA) without any continuity. Almost 15 years passed before plant construction began in the US and Spain during the years 2007 to 2011 with strong state subsidies. In Spain, it is in 2007 when technical feasibility studies begin, promoting the first experimental plants.
The current growth of CSP technology has occurred in two of the countries where more incentives have been given from administrations (United States and Spain). In fact, in 2012, when the subsidy plans are over Spain accounts for 65% of the electricity production under this technology and the US about 30%, while the third Algeria produces 2%.
Storage is increasingly becoming one of the requirements for the new CSP plants promoted from public bodies.
The number of geographic areas suitable for CSP-based installations is lower than PV because these installations are only exploitable through a direct-normal irradiance (DNI), is the amount of light that can be effectively focused Through mirrors or lenses.
Costs
The cost and time required for the construction of plants are greater than in photovoltaic installations.
Several CSP projects have been converted into PV for the lowering of costs in this technology.
One of its weak points is the great water consumption of the Tower and Parabolic plants that are usually located in desert or semi-desert areas where this resource is scarce.

11 | **CSP MARKET**
CSP Market: Opportunities

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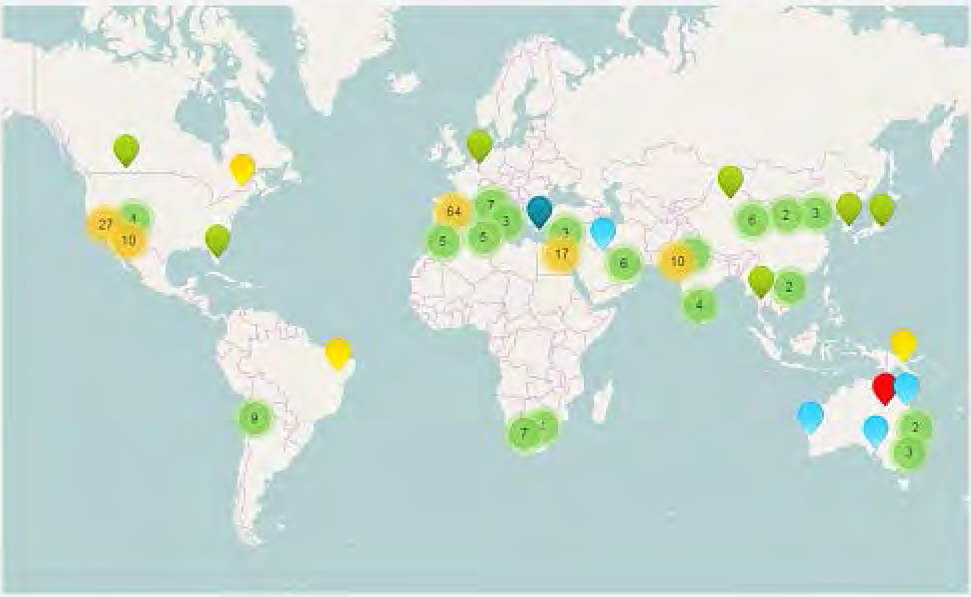
CSP Market January 2017

Project Country	Operational	Construction	In Development	Pre Development	Total (MW)
Argentina		250			250
Brazil	55				55
Chile		210	230	450	890
China	11	450	1149		1610
Egypt				100	100
Germany	5,17				5,17
Germany, Spain			33,8		33,8
India	103,5	314	150		567,5
Israel			373		373
Japan				400	400
Lebanon		50			50
Morocco	180		350	800	1330
Oman			200	1021	1221
South Africa	44	400	300		744
Spain	2101,8		329,3		2431,1
Turkey			330		330
Uganda	66				66
United Arab Emirates	100			1000	1100
United States	1111	1320	1490		3921
	3777,47	2994	4935,1	3771	15477,57

12 | **CSP MARKET MAP**
CSP Market: Opportunities

acciona



13 **CONCLUSIONS**
CSP Market: Opportunities

TES around the world

- Some 15 out of the 17 utility-scale projects under construction around the world include TES, according to the CSP Today Global Tracker;
- In China, 18 out of 20 projects being developed under the CSP demonstration program incorporate molten salt TES, according to the China National Solar Thermal Energy Alliance.
- Parabolic Trough developers are experimenting with molten salt HTF to increase operating temperatures and further technology advancements could narrow the advantage of tower-based storage systems. Chinese companies are now researching molten salt based parabolic trough plants and two out of seven parabolic trough plants under China's demonstration program will use molten salt as HTF. Tower plants using molten salts as heat transfer fluid (HTF) can operate up to 565 degrees Celsius. In contrast, parabolic trough plants, which currently use thermal oil HTF, are limited to temperatures below 385 degrees Celsius.

WP7 – Task 7.4.2 – Report on presentation of project and project results on relevant events.

Partner name: LNEG

Partcipant(s): Teresa C. Diamantino

Event: *"V Encontro Dia Mundial da Sensibilização para a Corrosão: Energias Renováveis Materiais e Durabilidade"*

Location: Lisbon; Portugal

Date: 24 april 2018

Target group:

Number of participants:

Type of presentation: power point

In the annex, include the power point presentation if different the NEWSOL power point presentation.

Attached

A Corrosão e a Proteção dos Materiais nos Sistemas Solares Térmicos Sem e Com Concentração

V Encontro Corrosão | Energias Renováveis Materiais e Durabilidade

República Portuguesa

Estrutura da Apresentação

Laboratório Nacional de Energia e Geologia e a aposta na **Energia Solar**

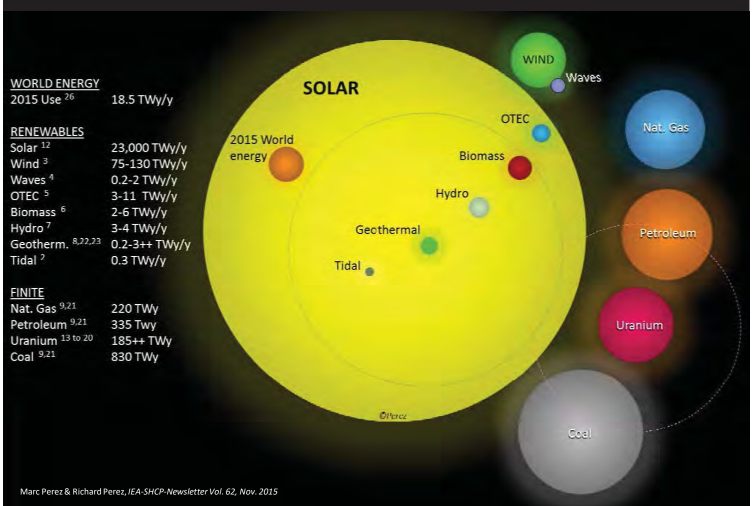
A Corrosividade Atmosférica e a Energia Solar Térmica

Corrosão e a Proteção dos Materiais:

- Em **Sistemas Solares Térmicos sem Concentração**
  - Inquéritos e visitas de inspeção
  - Durabilidade dos *Revestimentos Absorsores Solares*

- Em **Sistemas Solares Térmicos com Concentração**
  - Materiais usados nos *Reflectores*
  - Armazenamento Térmico de Energia
  - (*Materiais em contacto com sais fundidos*)

LNEG – Laboratório Nacional de Energia e Geologia



Marc Perez & Richard Perez, *IEA-SHCP-Newsletter Vol. 62, Nov. 2015*

Energia Solar

Colectores solares
PRODUÇÃO DE CALOR

Módulos fotovoltaicos
PRODUÇÃO DE ELECTRICIDADE

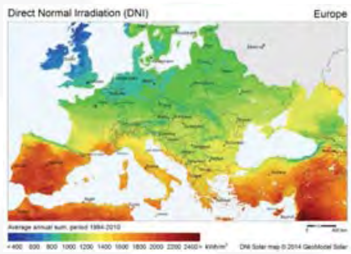
Calor de baixa temperatura (abaixo de 150°C) (pasteurização, esterilização, limpeza, secagem, lavagem, branqueamento, vaporização, decapagem, cozinhar)

Calor de média temperatura (150°C-400°C) (destilação, fusão de nitratos, tingimento, compressão)

Calor de alta temperatura (superior a 400°C) (processos de transformação de materiais)

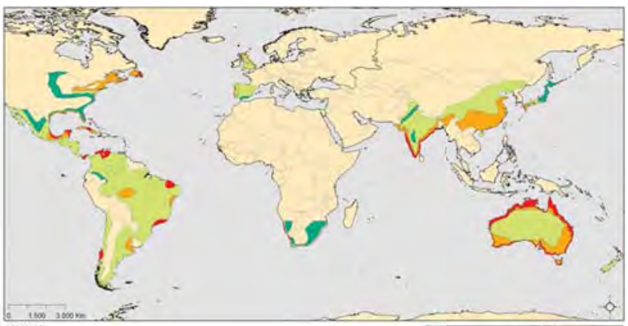
Solar Payback Project (https://www.solar-payback.com/)

100°C 200°C 300°C 400°C



K.Slamova et al.. *Photon. Energy.* 2(1), 2012 (http://dx.doi.org/10.1117/1.JPE.2.022003)

Dados de Corrosividade Atmosférica no Mundo



Legend

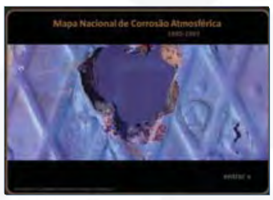
Extremely severe
Severe
Moderate
Mild
No data
Continent line
National border

K.Slamova et al.. *Photon. Energy.* 2(1), 2012 (http://dx.doi.org/10.1117/1.JPE.2.022003)

Categorias de Corrosividade – Atlas de Corrosão Atmosférica

C1 very low corrosivity
C2 low corrosivity
C3 medium corrosivity
C4 high corrosivity
C5 very high corrosivity
CX extreme corrosivity
(ISO 9223: 2012)

Categoria corrosividade	Velocidades de corrosão (r_{corr}) dos metais				
	Unidades	Aço carbono	Zinco	Cobre	Alumínio
C1	g(m².a) µm/a	$r_{corr} \leq 10$ $r_{corr} \leq 1,3$	$r_{corr} \leq 0,7$ $r_{corr} \leq 0,1$	$r_{corr} \leq 0,9$ $r_{corr} \leq 0,1$	Desprezável -
C2	g(m².a) µm/a	$10 < r_{corr} \leq 200$ $1,3 < r_{corr} \leq 25$	$0,7 < r_{corr} \leq 5$ $0,1 < r_{corr} \leq 0,7$	$0,9 < r_{corr} \leq 5$ $0,1 < r_{corr} \leq 0,6$	$r_{corr} \leq 0,6$ -
C3	g(m².a) µm/a	$200 < r_{corr} \leq 400$ $25 < r_{corr} \leq 50$	$5 < r_{corr} \leq 15$ $0,7 < r_{corr} \leq 2,1$	$5 < r_{corr} \leq 12$ $0,6 < r_{corr} \leq 1,3$	$0,6 < r_{corr} \leq 2$ -
C4	g(m².a) µm/a	$400 < r_{corr} \leq 650$ $50 < r_{corr} \leq 80$	$15 < r_{corr} \leq 30$ $2,1 < r_{corr} \leq 4,2$	$12 < r_{corr} \leq 25$ $1,3 < r_{corr} \leq 2,8$	$2 < r_{corr} \leq 5$ -
C5	g(m².a) µm/a	$650 < r_{corr} \leq 1500$ $80 < r_{corr} \leq 200$	$30 < r_{corr} \leq 60$ $4,2 < r_{corr} \leq 8,4$	$25 < r_{corr} \leq 50$ $2,8 < r_{corr} \leq 5,6$	$5 < r_{corr} \leq 10$ -
CX	g(m².a) µm/a	$1500 < r_{corr} \leq 5500$ $200 < r_{corr} \leq 700$	$60 < r_{corr} \leq 180$ $8,4 < r_{corr} \leq 25$	$50 < r_{corr} \leq 90$ $5,6 < r_{corr} \leq 10$	$r_{corr} > 10$ -



http://geoportal.lneg.pt/

Durabilidade dos Materiais para a Energia Solar Térmica

DESAFIOS
Aumentar a eficiência e reduzir os custos de construção, operação e de manutenção (redução do LCOE)

Coletores Solares Térmicos

Coletores Planos

- Absorsor
- Caixa do colector
- Cobertura
- Fluido de Transferência de Calor
- Isolamento

Tubos de Vácuo

Coletores Concentradores Parabólicos Compostos - CPC

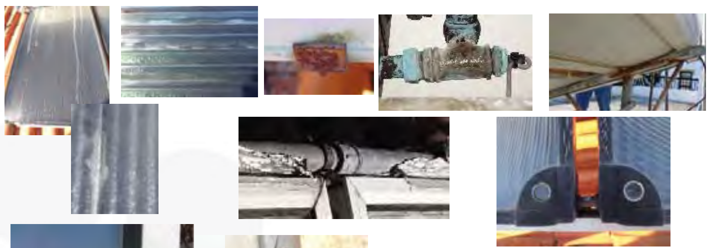
Inspeção e análise de falha em função da corrosividade ambiental

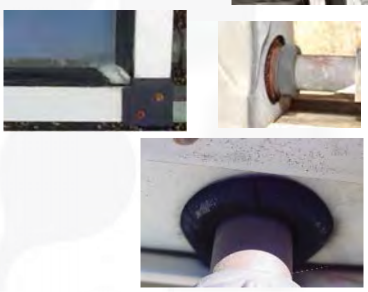
Inquérito e visitas de inspeção realizados às instalações existentes em Portugal de média e grande dimensão, com tempos similares de funcionamento (13-17 anos)

1) Identificar os danos existentes em coletores solares térmicos;
2) quais os componentes com maiores danos e
3) verificar se existe correlação entre o processo de degradação, a corrosividade ambiental de Portugal e a proximidade da orla marítima.

Diamantino et al. 2016. Corrosão e Protecção de Materiais, 35 (1) 15-20 (2016)
http://dx.medra.org/10.19228/j.cpm.2016.35.02

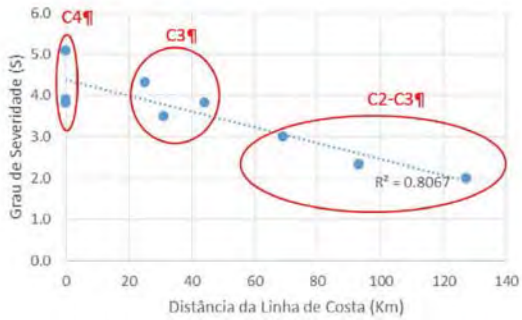
Grau de Severidade_ Instalações visitadas





Severidade (S)	Valor
Nenhum efeito no componente	1
Efeito menor no produto mas nenhum efeito no funcionamento no sistema	2-3
Risco de falha de funcionamento	4-6
Certeza de falha no funcionamento do produto	7-9
Falha que pode afetar a segurança	10

Inspeção e análise de falha em função da corrosividade ambiental



Correlação entre o grau de severidade e a distância da costa para as 9 instalações.

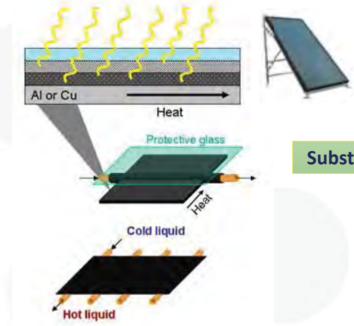
O desempenho dos colectores solares térmicos depende da durabilidade dos seus componentes, em particular da **superfície absorsora** e dos componentes elastoméricos, bem como do sistema de ventilação do colector.

Diamantino et al. 2016. Corrosão e Protecção de Materiais, 35 (1) 15-20 (2016)
http://dx.medra.org/10.19228/j.cpm.2016.35.02

LNEG

Absorsor

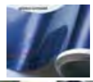
Absorção da energia radiante, transferindo-a sob a forma de calor para o fluído de transferência



Substrato metálico + **Revestimento**

Cu
Al

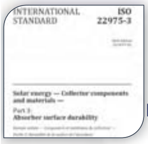
Limitações dos revestimentos PVD:
Durabilidade
Corrosão
Resistência à humidade e condensação
Custo
Complexas técnicas de produção
Resistência à riscagem



http://www.kemi.uu.se/research/inorganic-chemistry/research-areas/nanomaterials-from-solution/spectrally-selective-solar-heat-absorbers/

LNEG

Qualificação da Superfície Absorsora

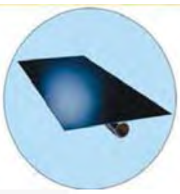


Resistência térmica

Resistência Humidade e Temperatura com condensação

Resistência atmosferas húmidas com dióxido de enxofre

ADERÊNCIA DO REVESTIMENTO
Pull-off (ISO 4624:2002)
Quadrícula (ISO 2409:2007)



PROPRIEDADES ÓTICAS
$\Delta\alpha_S$ = alteração do coeficiente absorção
$\Delta\varepsilon_T$ = alteração da emissividade

Corrosão e proteção anticorrosiva dos revestimentos

Superfície absorsora qualificada
=
Durabilidade superior a 25 anos

LNEG

Durabilidade das Superfícies Absorsoras

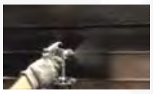
Estações Atmosféricas

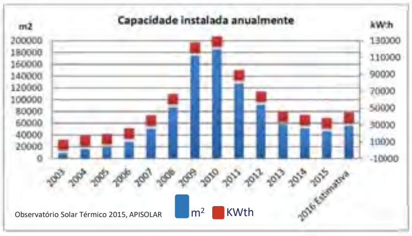
Estudos em Laboratório

Diamantino et al. Solar Energy Materials and Solar Cells, (2017) 166, 27-38
https://doi.org/10.1016/j.solmat.2017.03.004

LNEG

Durabilidade dos Materiais para a Energia Solar Térmica





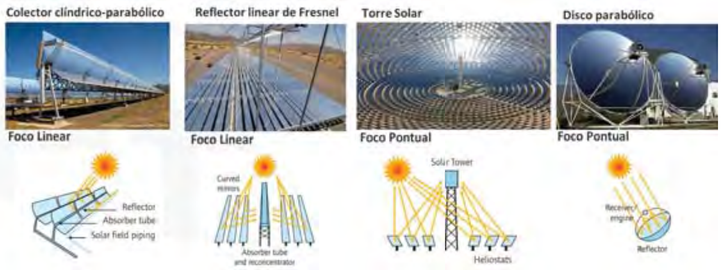
DESENVOLVIMENTO DE NOVOS PRODUTOS

NOVOS ENSAIOS E INFRAESTRUTURAS LABORATORIAIS

ESPECIFICAÇÃO DOS MATERIAIS

Tecnologias CSP

Energia Solar Termoeléctrica (STE)

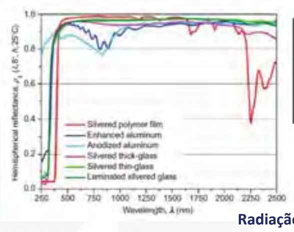


Luz Solar
↓ concentração
Calor ↔ Armazenamento térmico de energia
↓ Turbina
Electricidade

REFLECTORES

MATERIAIS METÁLICOS E HTF

Reflectores para CSP



Type of mirror	Solar hemispherical reflectance
Silvered thin-glass	0.94–0.96
Laminated silvered glass	0.95–0.96
Silvered thick-glass	0.94–0.95
Silvered polymer film	0.90–0.95
Aluminum	0.83–0.90

A. Fernández-García *et al.* Mirrors *in* The performance of CSP systems. Analysis, measurement and assessment. Peter Heller (Ed.) 2017

Radiação

Temperatura

Abrasão

Tensões mecânicas

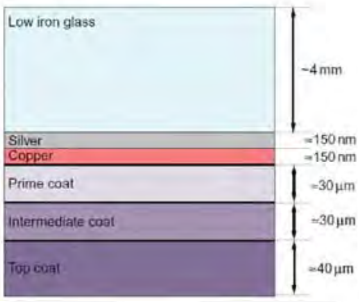
Poluentes atmosféricos

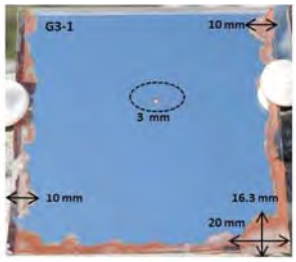
Poeiras atmosféricas

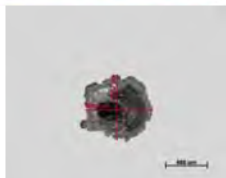
Humidade relativa

Reflectores para CSP

Reflectores de Vidro

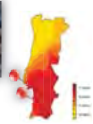


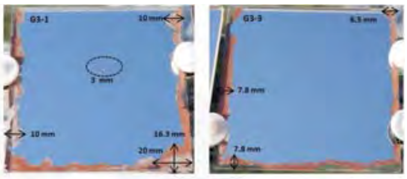




Reflectores para CSP

Reflectores vidro
(Sines – atmosfera corrosividade muito alta - extrema)





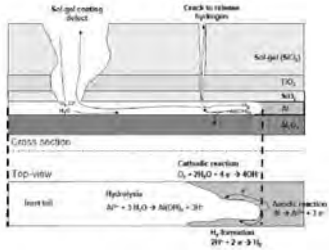
Máxima progressão da corrosão a partir das arestas **20 mm**;
Corrosão fora das arestas (Ø 3mm);
Descamação do revestimento orgânico a partir das arestas.

Reflectores vidro
(Lumiar_Lisboa – atmosfera corrosividade baixa - média)

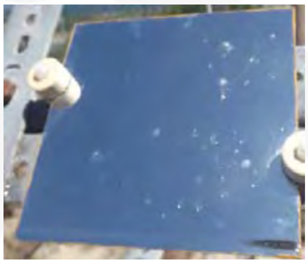
Máxima progressão da corrosão a partir das arestas **1 mm**;
Corrosão fora das arestas (<1 mm);
Descamação do revestimento orgânico a partir das arestas apenas na aresta superior

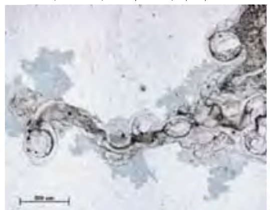
Reflectores para CSP

Reflectores de Alumínio



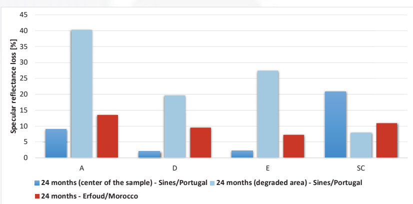
Sutter, F. and Wette, J. and Lopez-Martin, R. (2012) SolarPACES 2012





Reflectores para CSP

Erfoud_Marrocos **Sines_Portugal**



Diamantino et al. Eurocorr 2017

Micropicadas
Corrosão revestimento PVD
Corrosão por picadas

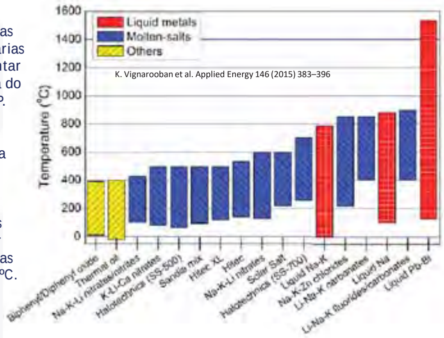
Armazenamento Térmico de energia – Sais fundidos

https://bigdishsolar.com/

Armazenamento térmico de energia – Sais fundidos

Gamas de temperatura de fusão / funcionamento dos fluidos de transferência de calor (HTF)

Elevadas temperaturas são necessárias para aumentar a eficiência do Sistema CSP. Os sais fundidos continuam a ser os candidatos mais promissores para atingir temperaturas até aos 800ºC.



Ponto de fusão

Calor específico

Condutividade térmica

Decomposição

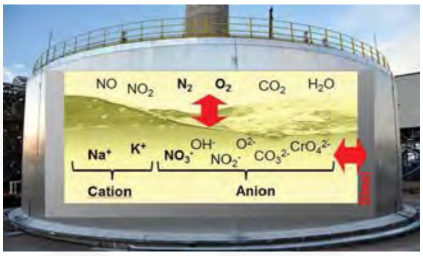
Degradação química

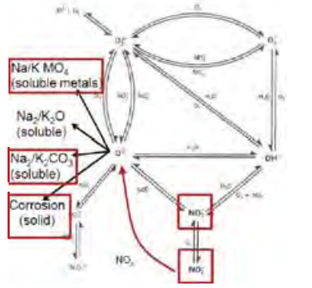
Densidade/viscosidade

Estabilidade ao longo do tempo

Corrosão

Armazenamento de energia – Sais fundidos





Estabilidade dos materiais metálicos em contacto com os HTF é um parâmetro crucial para a longevidade dos sistemas CSP.

Que materiais metálicos e quais os tempos de vida

Lovering, D.G. 1982

Sais fundidos e a Corrosão

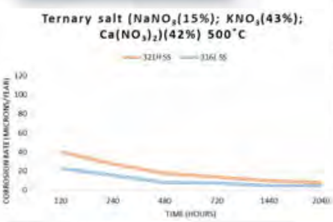
SAIS FUNDIDOS

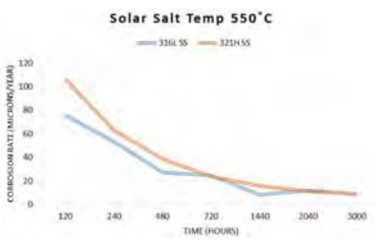
Sal solar (60% $NaNO_3$ + 40% KNO_3)

Sais ternários (Na, K, Ca)

Aços inoxidáveis austeníticos

Aços inoxidáveis ferríticos





A. Gomes etl al 2016
doi:10.18086/eurosun.2016.03.12 Available at
http://proceedings.ises.org

Raising Awareness About Corrosion and Corrosion Protection Around the World

THE WORLD CORROSION ORGANIZATION

Welcome to WCO – The World Corrosion Organization

April 24th is Corrosion Awareness Day

3 - 4% PIB

https://www.nace.org/uploadedFiles/Publications/ccsupp.pdf

MUITO
OBRIGADA PELA
ATENÇÃO

www.lneg.pt

Este trabalho teve o Apoio financeiro da FCT através dos projetos DURASOL (FCOMP-01-0124-FEDER-027507 (Ref. FCT RECI/EMS-ENE/0170/2012)) e LIFESOLAR POCI-01-0145-FEDER-016709 FCT (PTDC/EMS-ENE/0578/2014)

Project STAGE-STE - Scientific and Technological Alliance for Guaranteeing the European excellence in Concentrating Solar Thermal energy (7FP) (2014-2018) GA 609837

New Storage Latent and Sensible Concept for High Efficient CSP Plants.
H2020 project, GA No. 720985

Funded by the
European Union

WP7 – Task 7.4.2 – Report on presentation of project and project results on relevant events.

Partner name: LNEG

Partcipant(s): Teresa C. Diamantino and Carlos Nogueira

Event: Symposium NEWSOL

Location: Evora University, Portugal

Date: 1 February 2018

Type of presentation: Communication

Reference to be used for the work (e.g. Proceedings; DOI (if applicable), Symposium NEWSOL

The communication presented (power point, poster or written communication) shall be included in this annex.

Attached

Molten Salts in CSP: Materials and Corrosion

Teresa Diamantino, Carlos Nogueira,
Anabela Gomes, Fátima Pedrosa, Teresa Paiva, Teresa Marcelo

LNEG (Lisboa, Portugal)

SYMPOSIUM, 1 February 2018, University of Evora, Espirito Santo College

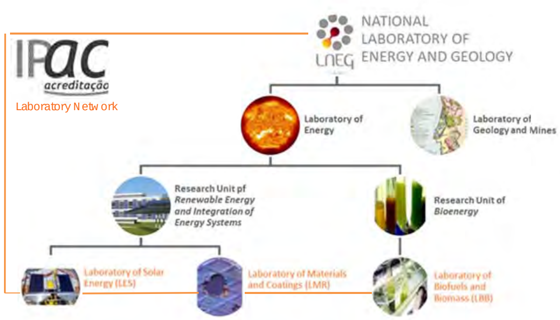
New Storage Latent and Sensible Concept for High Efficient CSP Plants

Funded by the European Union

H2020 project, GA No. 720985

Outline

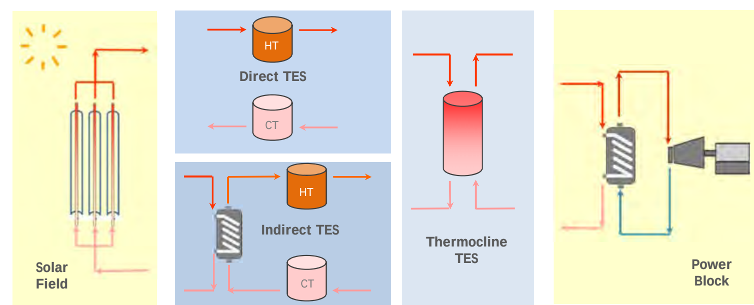
- LNEG short presentation
- Energy Storage and Molten Salts
- Molten Salts: properties and reactivity
- Thermal performance and stability
- What is corrosion and what is its impact?
- Steels and Corrosion
- Corrosion with molten salts



LNEG is an R&D institution oriented to meet the needs of society and business. We aim at a sustainable research in a sustainability frame through the generation of knowledge of our territory.

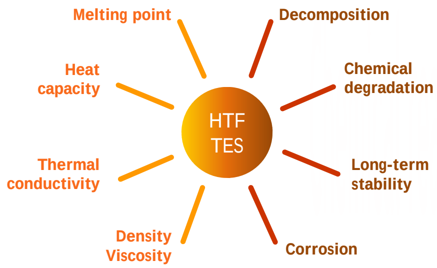
Energy Storage and Molten Salts

Sensible Thermal Storage with different arrangements in CSP applications



Energy Storage and Molten Salts

The design, development and validation of molten salts as HTF/TES is a complex task:



Alkali/alkaline-earth nitrate salts have been developed as good candidates for sensible-heat TES

Li, Na, K, Ca / NO_3 (NO_2)

- *Binary mixtures*
- *Ternary mixtures*
- *Quaternary mixtures*

Molten Salts: properties and reactivity

Nitrate-based molten salts have several physical-chemical properties, in line with the requirements for a Heat Transfer Fluid (HTF) and for Thermal Energy Storage (TES) media:

Property	Shall be:	Typical ranges for molten alkali nitrate mixtures
Melting point	Low, avoid freezing	T_{min} = 90 to 240ºC (20% above T_{melt})
Maximum temperature	High, depends on chemical stability/decomposition	T_{max} = 400 to 550ºC
Operating temperature range	High. Maximum heat transfer per unit mas/vol.	ΔT = 290 to 420ºC
Heat capacity	High. Maximum heat transfer per unit mass and per T degree.	Cp = 1.2-1.8 J g^{-1} K^{-1}
Density and viscosity	Adequate for improving transfer phenomena	ρ = 1.7-1.9 g cm^{-3} μ = 0.002-0.03 Pa·s

Molten Salts: properties and reactivity

Nitrate-based molten salts have several physical-chemical properties, in line with the requirements for a Heat Transfer Fluid (HTF) and for Thermal Energy Storage (TES) media:

Property	Shall be:	Typical ranges for molten alkali nitrate mixtures
Volumetric heat capacity	High. Maximum heat transfer per unit vol. and per T degree.	-
Thermal conductivity	High, improves heat transfer rate	-
Chemical stability	High. Low decomposition. Long long periods of operation (cold/hot cycles).	-
Materials compatibility	High. Avoid chemical interaction with construction materials. Minimize corrosion.	-

Molten Salts: properties and reactivity

Chemical Reactivity of the nitrate molten salts is a crucial issue:

- Decomposition;
- Interaction with the atmosphere;
- Interaction with the construction materials;
- Reactions induced by the presence of impurities (water, chlorides, …).

Examples of reactions *(M = Na,K,Li,…)*

$MNO_3 = MNO_2 + ½ O_2$ *(nitrite formation)*

$2 MNO_2 = M_2O + NO + NO_2$ *(oxide formation)*
and/or
$5 MNO_2 = M_2O + N_2 + 3 MNO_3$ *(oxide formation/ nitrate regeneration)*

$M_2O + CO_2 = M_2CO_3$ *(carbonation)*

Driven by:

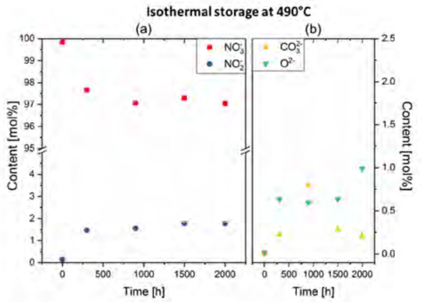
Thermodynamics:
$\Delta G (T,p) < 0$

Kinetics:
$v = k_0 \exp(-E_A/RT)\, C_i^n\, C_j^m\, p_u^v \ldots$

Thermal performance and stability

Long-term thermal stability tests - LiNaK-NO_3 mixture: chemical analysis

Analysis by:

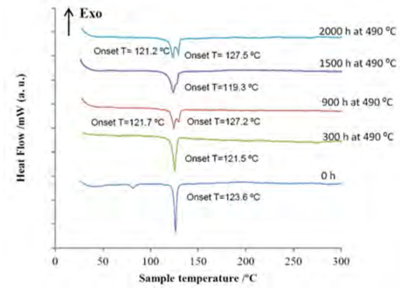


Conditions:
- Muffle furnace
- Air atmosphere
- Top-covered crucibles

Results:
- Nitrite formation (up to 1.8mol%), but seems to stabilize after 1500h
- Carbonate and oxide formation
- Oxide seems progressively increase (1 mol% after 2000 h)

Thermal performance and stability

Long-term thermal stability tests - LiNaK-NO_3 mixture: DTA-DSC heat flow curves



Experimental Conditions:

Stability tests:
- Muffle furnace
- Air atmosphere
- Top-covered crucibles

DTA-DSC analysis:
- Synthetic air

Results:
- Presence of two endothermic peaks after 900 h at 490ºC, revealing some decomposition of the salt (confirmed by chemical analysis).

SYMPOSIUM | 1 February 2018 | Univ. Évora | Presenting authors: Teresa Diamantino, Carlos Nogueira

What is corrosion and what are the impacts?

Physical interaction between a metal and its environment which results in changes of the metal's properties and which may lead to significant functional impairment of the metal, the environment or the technical system of which they form a part.

Corrosion is a naturally occurring phenomenon commonly defined as the deterioration of a material (usually a metal) that results from a chemical or electrochemical reaction with its environment

IUPAC INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

An irreversible interfacial reaction of a material (metal, ceramic, polymer) with its environment which results in consumption of the material or in dissolution into the material of a component of the environment.

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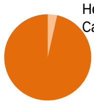
Corrosion Costs



How Much Can Be Saved?

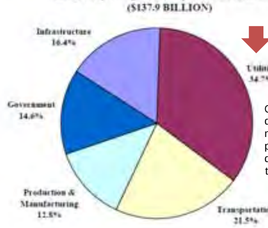
25-30%

Appropriate anticorrosive protection measures

1000-1400 million €

Direct costs
3.1% GDP
Gross Domestic Product

High impacts:
Economic
Environmental
Social



https://www.nace.org/uploadedFiles/Publications/ccsupp.pdf

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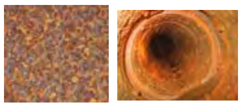
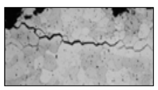
Corrosion types_Forms of Corrosion

UNIFORM



A chemical or electrochemical reaction which proceeds uniformly over the entire exposed surface or over a large area. The metal becomes thinner and fails.



MACROSCOPIC

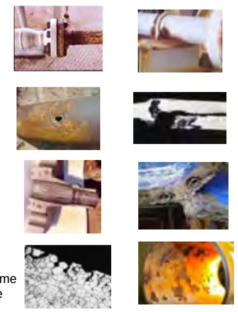
Galvanic
Crevice
Pitting
Erosion
Selective
Microbial

MICROSCOPIC

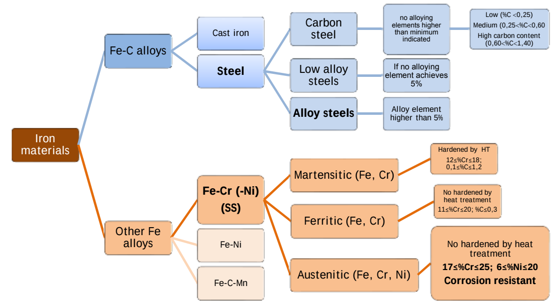
Stress (SCC)
Specific corrosive environment
Tensile stress

Intergranular
Impurities at the grain boundaries
Enrichment of the alloying elements
Depletion of some elements in the grain-boundary areas

LOCALIZED

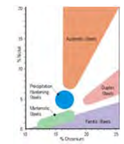


Steel Grades and Properties



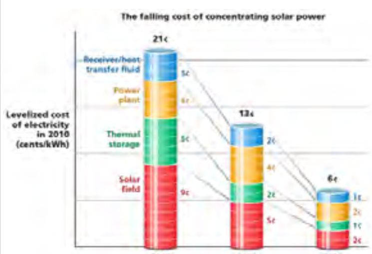
EN 10020

Al – 0,30%	Cu – 0,40
Bi – 0,10	Mn – 1,65
B – 0,0008	Mo – 0,08
Cr – 0,30	La Lanthanides (each one) – 0,1
Co – 0,30	



AISI	Alloy	Microstructure
200	Cr, Ni, Mn ou Ni	Austenitic
300	Cr, Ni	Austenitic
400	Only Cr	Ferritic and Martensitic
500	Low Cr (<12%)	Martensitic

Corrosion and Molten Salts

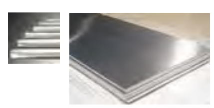


http://www.renewableenergyworld.com/

HIGH EFFICIENCY WITH LOW COST

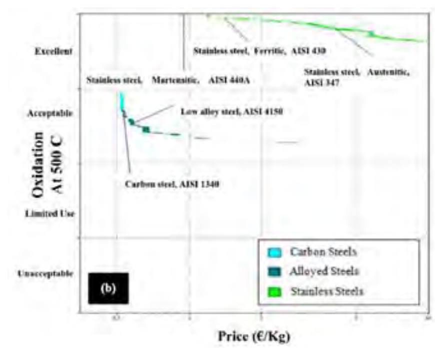
HTF is one of the most important components for overall performance and efficiency of CSP systems. And is one of the most important parameter for TES reductions costs.

Stability of the metallic materials while in contact with HTF is very important for the longevity of CSP systems.



what metallic materials and what is their life time

Corrosion and Molten Salts

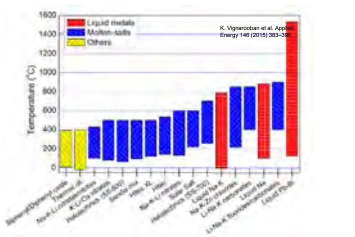


F.J. Ruiz-Cabañas et al.Solar Energy Materials & Solar Cells 163 (2017) 134–147

Corrosion and Molten Salts

OPERATING TEMPERATURE RANGE FOR VARIOUS HTFs

High operating temperature is necessary to improve efficiency in the CSP system and molten-salts are the most promising HTF candidates at high temperatures up to 800ºC.



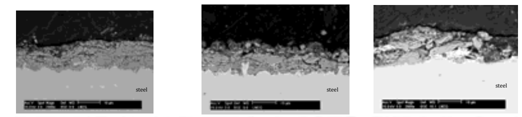
Corrosion issues are more significant in CSP plants operated with molten-salts compared to other HTFs, mainly because of the high operating temperatures.

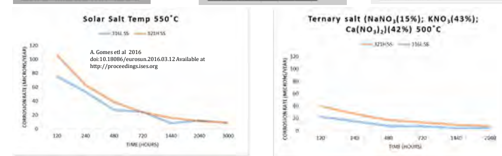
For reliable long-term application and in particular high temperatures (e.g. ≥500ºC) there is still a lack of knowledge about corrosion mechanisms and results and methodologies are inconsistent about steel corrosion rates in molten salts

Corrosion and Molten Salts

Molten salts:
Solar Salt
Ternary Salt (Na, K, Ca)

SS 347 SS 321H SS 316L

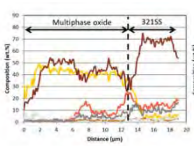


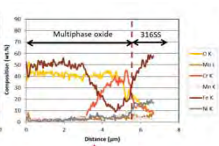


Solar salts is compatible with austenitic stainless steel with corrosion rate between 4-15μm/year.
Low alloy steels often reveal insufficient corrosion behavior.
A lower corrosion rate in ternary nitrate salts were obtained relatively to solar salt

Corrosion and Molten Salts

SS 321H

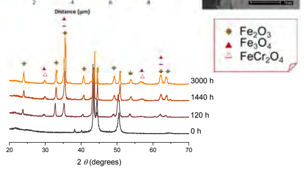




SS 316L

SEM/EDS

Few data is available of structural materials degradation based on failure analyses in commercial plants.
Other corrosion tests are necessary to gain insight the material degradation by new salts and with nitrate moltens salts for its use in CSP plants like:
- Dynamic corrosion tests
- Electrochemical techniques
- Mechanical testing (fatigue and stress corrosion cracking)



A. Gomes etl al 2016 doi:10.18086/eurosun.2016.03.12 Available at http://proceedings.ises.org

XRD

http://cspworld.org/cspworldmap

CHALLENGES FOR CSP GROWTH
Increasing efficiency and reducing construction costs, operation and maintenance (reduced LCOE)

Materials for CSP : an Interdisciplinary Research

www.lneg.pt

Thank you for your attention

Funded by the European Union

The project NEWSOL has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 720985

REPÚBLICA PORTUGUESA

Annex III – Report on project workshops

WP7 – Task 7.4.2 – Report on project workshops.

Partner name: UEvora

Event: Newsol Symposium

Location: University of Évora, Portugal

Date: 1st February 2018

Target group: Academic researches, students and solar energy community

Number of participants: 50

In annex include:

- **Agenda of Workshop: pdf in annex**
- **Power point presentations: Available if requested**
- **List of material delivered: Flyer in annex**
- **Photos of the event: In annex**
- **Videos of the event (if applicable): No video**

New Materials for High Temperature Applications in Solar Concentration

SYMPOSIUM **Pictures**

1st February 2018

University of Évora

Portugal

Additional Information: lguerreiro@uevora.pt

NEWSOL

Agenda

09:30 Reception of Participants

09:45 Start of Symposium and Welcome address

(Presentations shall take 10 to 15min each plus 5 min questions)

(Person to present will be announced at a later stage)

10:00 "CSP Plants Worldwide", (*to be confirmed*)

10:15 "Overview of Energy storage for CSP Plants", UEvora

10:30 "Sensible heat storage for CSP plants based on molten salts", DLR

10:50 "Concrete and cement innovations", SECIL

11:10 "Molten Salts in CSP: Materials and Corrosion", LNEG

11:30 "Durable Aluminum Reinforced Environmentally-friendly Concrete Construction", SINTEF

11:50 "Concrete application for Heat storage infrastructures: Concrete at high temperature", CSIC

12:10 "Use of Yara-MOST as Heat Storage and Transfer Liquid", Yara

12:30 "Challenges in Project Newsol", UEvora

12:45 "INPOWER Project: TES materials advances", Fertiberia

13:00 Lunch (free)

14:15 Departure from Evora to EMSP (by own means)

14:30 – 15:30 Visit to EMSP – Evora Molten Salt Platform (best by own means, a few places could be available)

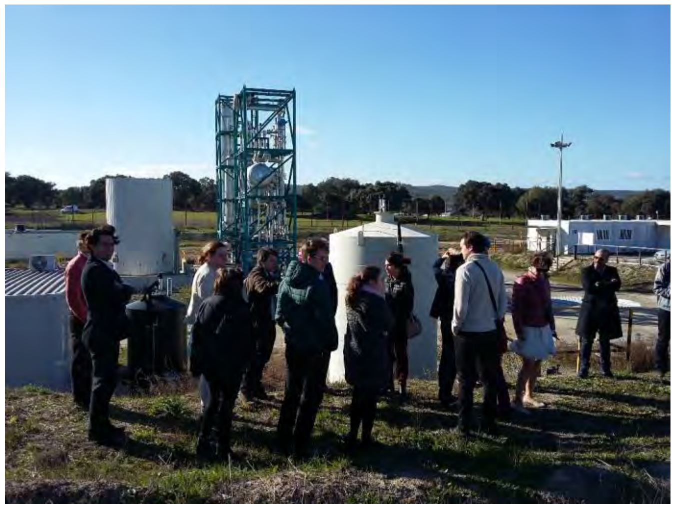
Symposium Presentations (01/02/2018)


CSIC
CONCRETE APPLICATION FOR HEAT
STORAGE INFRASTRUCTURES


UEvora


Fertiberia
THANK YOU FOR THE ATTENTION
IN POWER
RENEWABLE
ENERGIES CHAIR

Visit to EMSP – Evora Molten Salt Platform (01/02/2018)



Thermal Energy Storage and New materials Development

R&D Areas: Storage Technologies, new materials, system operation with new concepts

NEWSOL project is the main research project of UEvora in the TES (thermal energy storage) field. It addresses the specific challenge towards high efficiency solar energy harvesting by advanced materials solutions and architectures.

NEWSOL Objectives:

www.newsol.uevora.pt

- Single Thermocline Tank, (combining sensible and latent heat up to 550ºC);
- Concrete Thermal Storage for existing plants (sensible heat up to 550ºC).

Advanced materials:

- High thermal performance concrete and insulation;
- Molten Salts: new mixtures development and validation (including nanoparticles);
- Slag material validation and re-usage.

Relevant Impacts:

- Reduced LCOE towards 10-12cEuro/kWh via higher material performance;
- New design that enable a reduction of CAPEX and OPEX;
- Increase material understanding enabling long term performance;
- Deployment of high tech monitoring technologies included in the demo activities;
- Environmental significant benefit by means of re-usage of slag materials
- Through innovative materials, higher world penetration of European materials sector.

Demonstration Site:

Évora Molten Salt Platform (EMSP), 10km south of Evora is the demonstration site where prototypes resulting from NEWSOL project will be tested.

Partners

Universidade de Évora; SINTEF; ETH Zürich; acciona Ingeniería; CSIC; Sesto Sensor; LNEG; acciona Industrial; aimen; SECIL; ApEHR; YARA Knowledge grows; acciona Construcción; DLR

Links

www.estelasolar.org; www.irena.org; www.protermosolar.com; www.csp-world.com; www.csptoday.com

This project is co-funded by the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 720985

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Jan 2018

-

WP7 – Task 7.4.2 – Report on project workshops.

Partner name: UEvora

Event: Simpósio IPES

Location: University of Évora, Portugal

Date: 24th and 25th september 2018

Target group: Academic researches, students, energy police makers and general publicNumber of participants: 60

In annex include:

- **Agenda of Workshop: In annex**
- **Power point presentations: Available if requested**
- **List of material delivered: No**
- **Photos of the event: In annex**
- **Videos of the event (if applicable): No video**

IPES
INSTITUTO PORTUGUÊS DE ENERGIA SOLAR

4° Simpósio IPES: A Concentração Solar e o Futuro

Évora, 24/09/2018 e 25/09/2018

4th Symposium on Solar Energy – Solar Concentration and the Future
(Languages: Portuguese and English, without translation)
Visit to HPS-2 Parabolic Trough Solar Field, under construction at EMSP facilities

Location: PACT – Parque do Alentejo de Ciência e Tecnologia (38°32’57.35 N 7°54’40.33 W)

1st day – September 24th

9:00h – Opening session
Rector of the University of Évora – Prof. Ana Costa Freitas
Vogal Alentejo 2020 – Dr. Hélder Guerreiro
President of LNEG – Dr. Teresa Ponce de Leão
President of Estela – Dr. Luis Crespo
President of IPES – Prof. Manuel Collares Pereira

I – Solar Energy Concentration: The State of the art and the vision
9:30h A Vision from the solar concentration industry – Luís Crespo (President of ESTELA – European Solar Thermal Electricity Industrial Association)
10:15h Research and Development at European level, final conclusions of Project STAGE-STE – Julian Blanco (CIEMAT–PSA)
11:00h Coffee Break
11:30h CSP State of the Art and New Developments, the DLR vision – Klaus Hennecke (DLR)
12:00h CSP State of the Art and New Developments, the CENER vision – Marcelino Sanchez (CENER)
12:30h Linear Concentration Technology, Advances and New Opportunities – Manuel Collares Pereira and Diogo Canavarro (U. Évora – Renewable Energies Chair)
13:00h Lunch
14:30h Solar Fuels from thin air, where are We? – Dr. Alexander Muroyama (ETH – Zurich)
15:00h INSHIP Project – Pedro Horta (Fraunhofer ISE)

II – HPS-2 Parabolic Trough Concentrators and molten salts as Heat Transfer Fluid and for thermal energy storage
15:30h HPS2 – High Performance Solar 2 @ EMSP – Michael Wittmann (DLR)
15:45h Challenges and solutions for parabolic trough collectors using molten salt as HTF – Mark Schmitz (TSK-Flagsol)
16:00h Molten Salts as Heat Transfer Fluid and for thermal energy storage – Günter Doppelbauer (YARA)
16:15h From heat to steam (electricity) – Jaime Paucar (Steinmüller Engineering)
16:30h Heat Tracing – Purpose and Solutions in HPS2 – Peter Schmidt (Eltherm)

16:45h Coffee Break

III – Energy Storage: Alternative solutions
17:15h Project NEWSOL – Thermal energy storage, new concepts – Luís Guerreiro (U.

Évora – Renewable Energies Chair)
17:30h 2 Tanks vs 1 tank solution for thermal energy storage (Thermocline) – Thomas Fasquelle (U. Évora – Renewable Energies Chair)
17:45h Challenges in the electric mobility management – Filipe Lopes (EFACEC)
18:00h Direct Electricity Storage – Flowbatteries – Luis Fialho (U. Évora – Renewable Energies Chair)

2nd day – September 25th

IV– Solar Energy interfaces with technologies
09:30h SHIP Project | Demonstration of a holistic system of production, storage and direct supply of heat to industrial processes based on solar thermal energy – Ricardo Barbosa (INEGI)
09:45h Quasi-stationary CPC-type solar collectors for process heat aplications – Tiago Osório (U. Évora – Renewable Energies Chair)
10:00h Soiling in Solar Energy Conversion Technologies – Ricardo Conceição (U. Évora – Renewable Energies Chair)
10:15h ECMWF forecasts of DNI towards a more efficient management of concentrated solar thermal plants – Hugo G. Silva (U. Évora – Renewable Energies Chair)
10:30h Porous materials as volumetric solar thermal receivers in concentration systems – Germilly Barreto (U.Évora)
10:45h Measurement and analysis of Direct Normal Irradiance (DNI) in Southern Portugal – Afonso Cavaco (IPES)
11:00h Durability of CSP Materials – Teresa Diamantino (LNEG)
11:15h Coffee Break
11:45h Round Table – Solar Energy and the future of energy for a decarbed economy (Moderator: Manuel Collares Pereira)
12:30h Conclusions and End of the Symposium – Manuel Collares Pereira (IPES)

12:45h Lunch

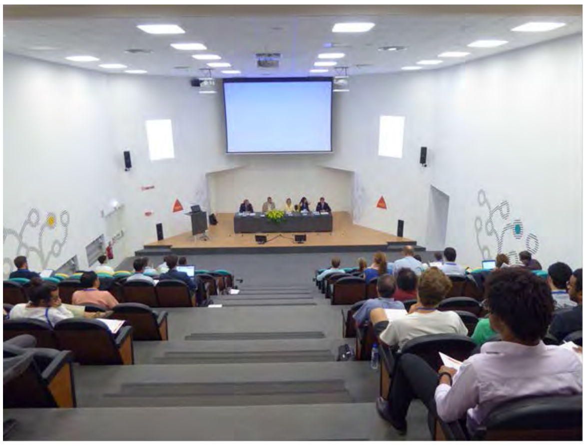
V – Technical Visits
14:30h Visit to Solar Field at EMSP (Évora Molten Salt Platform) – Herdade da Mitra, with the presence of the Minister for Scince and Technology, Professor Manuel Heitor

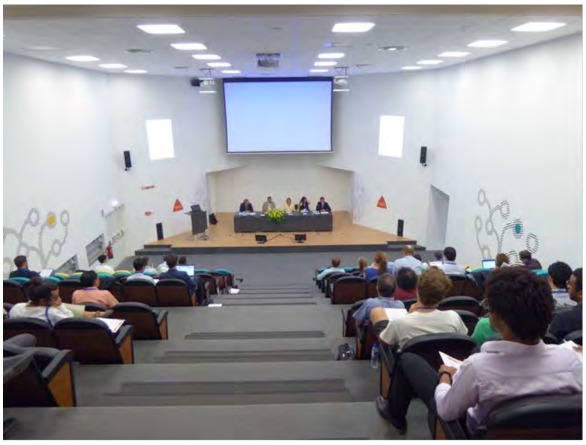
Brief presentation and words by

- Klaus Hennecke – Solar Energy Director, DLR (Köln)
- Manuel Collares Pereira – Chairman, Renewable Energies Chair – University of Évora, IPES
- Ana Costa Freitas – Rector, University of Évora
- Manuel Heitor – Minister for Science, Technology and Higher Education

15:00h Visit to the EMSP site: TSK – Flagsol Parabolic Trough Solar Field (Project HPS-2)
16:00h Visit to PECS – Solar Concentrator modules Testing Facility
17:00h Sunset get together

Photos of the event





Visit to Solar Field at EMSP (Évora Molten Salt Platform)