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# Comparative environmental assessment of two materials suited to central tower CSP technology

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ABSTRACT

Compatibility of containment materials with molten salt thermal storage media is a significant technical challenge for Concentrating Solar Power plants. Metal alloys in contact with molten salt must have a specific behavior, mechanical properties and resistance to degradation processes that allow them to operate at temperatures above 500 °C, being both respectful to the environment.

Firstly, this study presents two types of specific materials to operate at raised temperatures in Concentrating Solar Power plants, particularly the central tower technology. The materials are AISI 347H stainless steel and the Ni-based alloy HRSA INCONEL 617. Then, a Life Cycle Assessment shows the influence and contribution to different impact categories from the elements that compose both metals, demonstrating that materials that provide better mechanical properties could have environmental shortcomings.

This paper aims to contribute to an improved understanding of the environmental implications of these materials and which is the best choice in terms of sustainability. The results showed better environmental behavior in the AISI 347H case against INCONEL 617.

## 1. Introduction

In response to global economic growth, energy consumption has been increased. And the emissions of this circumstance have substantially contributed to the worldwide problem so called Global Warming (McGlade and Ekins, 2015). In this regard, renewables are clean and inexhaustible energy sources and the best option to address the $CO_2$ emission reduction. In recent years, International Renewable Energy Agency (IRENA) statistics showed (IEA, 2013) the exponential increase in clean energies generation. As an example of this, the power installed showed a 20.8% net growth from 2012 to 2013. Among renewables, solar energy is the most abundant resource and its use is the most promising solution to achieve this goal (Yan, 2015). Furthermore, among solar technologies, Concentrating Solar Power (CSP) is becoming an increasingly important electricity source. CSP capacity worldwide has grown to around 5 GW, much of this capacity installed in the last decade (Gauché et al., 2017). The most representative CSP developments are the parabolic trough collector (Daabo et al., 2016) and central tower receiver (Salomé et al., 2013). Both technologies can incorporate Thermal Energy Storage (TES) composed by nitrate molten salts. TES allow the continuous operation for the plant in nocturnal cycles or when there is not solar radiation available and this is the main advantage of CSP in comparison to other renewables.

One of the main concerns in CSP plant design is the material working conditions. Materials operating under high temperatures conditions are usually alloys steels. The combination of different factors such as the material composition, their life cycle, availability and the economic are essential for the viability of the plant. (Turchi et al., 2015). On one hand, the materials used in central tower CSP plants in contact with molten nitrate salts are low alloy carbon steels ($T \leq 400$ °C), Cr-Mo stainless steels with Cr content up to 9% ($T \leq 500$ °C), Cr or Cr-Ni stainless steels with alloys such as Mo, Nb, Ti ($T \leq 570$ °C) and Ni- base alloys such INCONEL or HASTELOY type ($T \leq 650$ °C) (Bauer et al. 2013). On the other hand, the majority of TES fluids are alkali nitrate molten salts. These molten salts are in contact with its metallic containing materials. This contact could cause corrosion phenomena in which the molten salts are the electrolyte (El Gharbi et al. 2011; De Miguel et al. 2016). Subsequently, the impurities contained in the industrial alkali nitrate molten salts (around 0.3 wt% chlorides) increase these corrosion processes between molten salts and steels Fabrizi, 2006.

Corrosion phenomena is one cause of the shortening materials life time. Therefore, corrosion phenomena in CSP is becoming an important issue and many authors studied the corrosion resistance of several

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metals in contact with molten salts. In the solar tower development Solar Two Plant in Daggett, (California), the A516 low-alloy carbon steel is used in those parts which are in contact with molten salts and which operate in low temperatures (240 °C), such as the cold molten salt tank. And those parts in contact with molten salt which operate at high temperatures (565 °C) are composed by an austenitic stainless steel (AISI 304 type, with 18% Cr and 8% Ni content). In this case, corrosion by cracking was observed in those pipes which were in contact with nitrate molten salt at high temperatures (Goods et al., 1994). García-Martín et al., 2017 evaluated the corrosion resistance of the austenitic stainless steels AISI 304 and AISI 316 and the results showed good behavior up to 550 °C Likewise, oxides layers were observed in the AISI 316 stainless steel receptor tubes (Moore et al., 2000). A thermo-resistant alloy Ni-based (HRSA INCONEL 625) also was evaluated and it was observed the formation of adherent oxides thin layers (Bradshaw and Goods, 2001). Moreover, Tzvetkoff and Gencheva, 2003 studied different Ni alloy types in contact to nitrate molten salts and the results showed dissolution processes of passivation.

In summary, scientific literature on steels and alloys in CSP plants showed the following issues:

- Possibility of using carbon steels in systems operating at temperatures up to 300 °C, such as pipes and low temperature molten salts storage tanks.
- High Cr-contain steels may be used in systems operating at temperatures close to 570 °C, such as pipes and high temperature molten salts storage tanks.
- It is advisable to use Ni base alloys in systems where temperatures are close to 650 °C such as the receiver or steam exchanger pipes.

Thus, among the different steels and alloys, there are some for specific application within the requirements CSP plants. So, when the operating conditions are not severe it is possible to use low-alloy carbon steels; which are low-cost materials. On the other hand, for those systems exposed to aggressive physic-chemical conditions, it is necessary to use materials which avoid the corrosion phenomena.

Taking into consideration the above-mentioned aspects and other authors recommendations (Moore et al., 2000 and Zavoico, 2001), this work focused on the environmental behavior of the well-known austenitic stainless steel AISI 347H type and the High Resistant Super Alloy (HRSA) INCONEL 617, in addition both alloys are suitable to be part of the central tower CSP plant systems in contact with high temperature molten salt nitrates. These materials were mainly developed to avoid corrosion phenomena in contact with nitrate molten salts (Bradshaw et al., 2002) providing high resistance and protection against corrosion phenomena at high temperatures (Yang et al. 2006).

In CSP developments, the environmental damages were identified mainly in the materials used in the large-scale projects power plant design. In fact, the material with the highest impact was steel followed by molten salt and synthetic oil (Ehtiwesh et al.,2016). It follows that the environmental impacts can be minimized with an appropriate material choice.

There are studies related to environmental assessment through the Life Cycle Assessment (LCA) techniques in CSP technology (Viebahn et al., 2009 and Lechón et al., 2008). However, the life cycle inventories of these works are addressed evaluating in a general way without specifying which steel grades are being assessed or which alloys are involved in every plant systems. Furthermore, the physic-chemical properties of different steels in contact with nitrate molten salts have been also studied (Moore et al., 2010). However, no evidence had been found in literature about the environmental behavior of INCONEL 617 or AISI 347H materials.

INCONEL 617 and AISI 347H steel are advanced materials because its technical properties improve the conventional ones used in CSP plants (Bradshaw et al., 2002) but their environmental behaviors have not been studied yet. For this reason, this study aims to give an environmental assessment for these two materials.

A detailed study of environmental aspects for steels and alloys used in plants with central tower CSP technology was necessary to cover the lack of these kind of works. To this end, this paper aimed to know which materials present better environmental performance. To address this, an evaluation is carried out using the LCA techniques. In this comparative LCA we examined the contribution of the chemicals components involved in each material to the final impact results. The results introduce the environmental aspect into the material choice as a new aspect as important as the technical issues in the CSP plant design.

## 2. Methodology

Life Cycle Assessment (LCA) is a widely recognized and accepted method. It is considered an appropriate technique in the analysis of environmental aspects in energy technologies (Davidsson et al., 2012) and the most complete tool to determinate all material impacts. Thus, to get firm conclusions on the environmental impact for both materials a comparative LCA was done.

The environmental assessment was carried out in accordance with the international standards ISO 14040 (ISO, 2006a) and 14044 (ISO, 2006b) which involve four steps:

1. Goal and scope.
2. Life Cycle Inventory.
3. Life Cycle Impact Assessment.
4. Interpretation.

### *2.1. Goal and scope*

In this stage, the description of the system, the evaluation method used and the purpose of the study must be defined.

The objective of this LCA was to compare the environmental impacts of two alloys which are suitable in central tower CSP technology. The main purpose was to determinate and quantify the incidence of the main impact categories. This fact allows deciding which material presents better environmental behavior. In addition, the hot spots of each alloy were identified highlighting the material components with the greatest impact on the environment.

The intended audience is the scientific community, with the purpose of increasing awareness about the importance of selecting material that protects the environment. Moreover, environmental assessment using the LCA technique will identify of solutions to make the choice respectful to the environment. The functional unit taken as reference in the study was 1 kg of material. Then, 1 kg of INCONEL 617 was evaluated against 1 kg of AISI 347H steel.

Fig. 1 shows the material manufacturing flows. The main stages in life cycle steel are the followings. (i) Production: This includes the complete production of stainless steel, from raw materials. (ii) Manufacturing: In this step, stainless steel is finished. (iii) Use stage. And, (iv)


**Fig. 1.** Steel Lifecycle. Source: http://www.jernkontoret.se/en/energy–environment/product-related-environmental-issues/, (2017).