Molten chloride salt TES for next-generation CSP plants: R&D Progress in corrosion control and process upscaling

Dr. Wenjin Ding[1], **Dipl.-Ing. Ralf Hoffmann**[1], **Dr. Thomas Bauer**[2]

[1]Institute of Engineering Thermodynamics in Stuttgart, German Aerospace Center (DLR). Pfaffenwaldring 38-40, 70569 Stuttgart, Germany.

[2]Institute of Engineering Thermodynamics in Cologne, DLR. Linder Höhe, 51147 Cologne, Germany.

*Correspondence: Dr. Wenjin Ding, Wenjin.ding@dlr.de

Keywords: Concentrating solar power (CSP), Thermal energy storage (TES), Fe-based alloys, Corrosion control system (CCS), Molten chloride loop.

Abstract:

Next-generation concentrating solar power (CSP) plants with operating temperatures higher than 700°C need advanced high-temperature thermal energy storage (TES) systems and power cycles (e.g., supercritical CO_2 Brayton power cycle) for a higher energy conversion efficiency (>50%) and lower levelized cost of electricity (LCOE) [1]. The next-generation molten salt TES technology based on chlorides is such a promising high-temperature TES technology under R&D by many research groups [2], since compared to other TES technologies like solid particles, its replacement to the molten nitrate TES in the state-of-the-art CSP plants can keep the current CSP system design and the key components (e.g., molten salt pump, salt receiver, etc.) as much as possible [1].

Progress in corrosion control of molten chlorides

$MgCl_2$-KCl-NaCl is a promising candidate of such high-temperature TES materials due to its low material costs (<0.35 USD/kg) and excellent thermophysical properties (e.g., high thermal stability >1000°C) [1]. However, the most commercial Fe-Cr-Ni alloys (all the Fe-based alloys) have unacceptably high corrosion rates in unpurified or not properly purified molten chlorides at temperatures higher than 700°C [2]. In theory, purification with Mg metal can reduce the redox potential (i.e., corrosivity) of the molten $MgCl_2$-KCl-NaCl and thus the corrosion rates of Fe-based alloys to acceptable low levels (target of DOE: <30 µm/year [3]) at temperatures higher than 700°C [4]. Using affordable alloys such as Fe-based (Fe: ≥50 wt.%) alloys as the main structural materials for the chloride-based TES system is the key to ensuring its cost competitiveness (CAPEX: 27 USD/kWh_{th}) [4]. Under corrosion control with Mg salt purification and corrosion inhibition, our group has achieved that the corrosion rates of SS310 and In 800H in molten $MgCl_2$-KCl-NaCl at 700°C are lower than 15 µm/year [4], while P91 also has the corrosion rate of lower than 15 µm/year in molten $MgCl_2$-KCl-NaCl at 500°C [5]. The corrosion immersion tests up to 2000 h were carried out under static conditions in lab scale. The corrosion rates were determined with mass loss and SEM-EDX microstructural analysis methods.

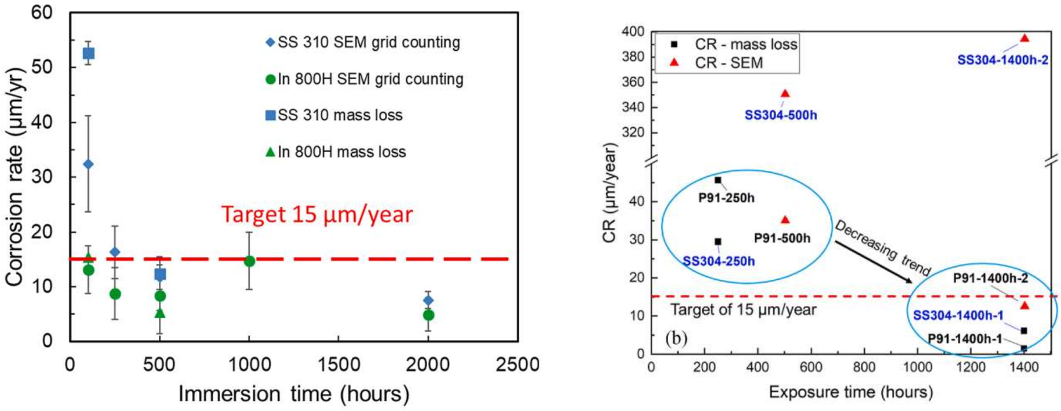

Fig. 1: Achieved low corrosion rates (<15 µm/year) of Fe-based alloys in molten $MgCl_2$-KCl-NaCl: for hot tank at 700°C (left [4]) and for cold tank at 500°C (right [5]).

Progress in process upscaling

To upscale the chloride-based molten salt TES technology, a test facility named MOCTEF with a molten salt pump and two salt tanks (max. 50 kg salt) has been designed and is under construction at DLR. Fig. 2 shows its 3D model. The designed max. test temperature of MOCTEF is 750°C. The salt purification tank is used to do salt purification experiments for develop and optimize the salt purification process, while the pumped loop is used to do corrosion tests under dynamic conditions close to real conditions for structural materials selection and upscaling of a corrosion control system (CCS) developed by DLR. The CCS system containing the corrosion monitoring (e.g., electrochemical corrosive impurity monitoring using CV method) and mitigation (in-situ salt purification using electrolysis or Mg) parts is integrated into the molten salt loop to control the corrosivity of molten $MgCl_2$-KCl-NaCl [4], [6], i.e., the selected high-temperature Fe-based alloys for tests have the corrosion rates of <30 µm/year in the molten $MgCl_2$-KCl-NaCl under pumped dynamic conditions at >700°C.

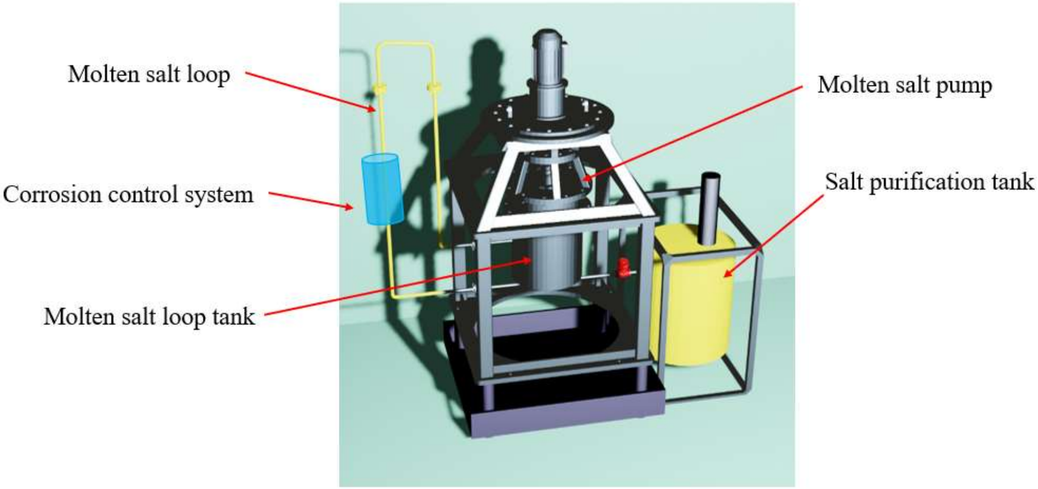

Fig. 2: Molten chloride Test Facility (MOCTEF) of DLR

Acknowledgment

The work is performed under the DLR basic funding from German Federal Ministry for Economic Affairs and Climate Action (BMWK).

References

[1] W. Ding, T. Bauer, Progress in research and development of molten chloride salt technology for next generation concentrated solar power plants, Engineering 7(3), 334-347 (2021). doi: https://doi.org/10.1016/j.eng.2020.06.027.
[2] C. Turchi, S. Gage, J. Martinek et al. 2021. CSP Gen3: Liquid-Phase Pathway to SunShot. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-79323. https://www.nrel.gov/docs/fy21osti/79323.pdf.
[3] B.L. Garcia-Diaz, L. Olson, M. Martinez-Rodriguez, et al., High temperature electrochemical engineering and clean energy systems. J.S.C. Acad. Sci. 2016;14(1):4. https://scholarcommons.sc.edu/jscas/vol14/iss1/4/.
[4] Q. Gong, T. Bauer, W. Ding, et al., Molten chloride salt technology for next-generation CSP plants: Compatibility of Fe-based alloys with purified molten $MgCl_2$-KCl-NaCl salt at 700° C, Applied Energy 324, 119708 (2022). doi: https://doi.org/10.1016/j.apenergy.2022.119708.
[5] Q. Gong, T. Bauer, W. Ding, et al., Molten chloride salt technology for next-generation CSP plants: Selection of cold tank structural material utilizing corrosion control at 500° C, SOLMAT, 253, 112233 (2023). doi: https://doi.org/10.1016/j.solmat.2023.112233.
[6] C. Villada, W. Ding, T. Bauer, et al., Engineering molten MgCl2–KCl–NaCl salt for high-temperature thermal energy storage: Review on salt properties and corrosion control strategies, SOLMAT, 232, 111344 (2021). doi: https://doi.org/10.1016/j.solmat.2021.111344.