Design and Fabrication of Molten Salt Loop for Material Corrosion and Salt Chemistry Control

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Introduction

Today, molten salt is generating a larger interest among the nuclear community where it can be effectively used either as a fuel carrier or primary coolant in fission as well as fusion system. Even though both chloride and fluoride salts exhibit good heat transfer properties, chloride salts can interfere with the nuclear chain reaction due to its high absorption cross section and production of long lived radionuclides in the form of Cl-36, thus making fluoride salt as a more preferable option. But it also needs to be noted, the application of chloride salt is now extending into other areas like solar energy and pyro-processing of spent nuclear fuel [1], thus making it necessary to perform studies to investigate the corrosion phenomenon of these type of salts on different alloys at high temperatures and in well-defined flow conditions.

This study will mainly involve characterizing the molten salt-alloy interaction under controlled temperature and velocity conditions. Furthermore, the hydrodynamic factors affecting the corrosion kinetics will also be investigated and countermeasures will be suggested for the development of advanced materials.

Salt Chemistry and Details

The salt used for this study will be NaCl-$MgCl_2$ with eutectic melting temperature of 445^{0}C. The thermodynamic properties for the salt mixtures containing $MgCl_2$ are determined from the experimental works carried out in the past which is provided in the following Table I.

Table I. Thermodynamic properties of NaCl (58)-$MgCl_2$ (42) salt [2].

Details	T (^{0}C)	Value
Density	700	1.9422 g/cc
Ht. Cap.	700	0.258 Cal/g-^{0}C
Viscosity	700	0.1151 cP
Vap. Pr.	900	< 2mm of Hg

A proper entrance length was also selected to ensure the flow is fully developed before making contact with the test section. These hydrodynamic parameters are important in analyzing the corrosion phenomenon occurring at material interface. With turbulent flow, large eddies or patches will be created which will disturb the flow pattern across the test section thus enhancing diffusion at the material surface and initiating Flow Accelerated Corrosion (FAC) at an even faster rate.

Salt Purification Technique

Unlike fluoride salts, the corrosion in chloride salts is mostly dominated by the presence of impurities in the form of O,

H^+ and OH^- ions [3]. In this study, a combination of chemical and electrolytic processes will be used to purify the salt mixture as detailed below [4],

First, the required amount of salt mixture will be heated to 200^0C in the auxiliary tank to remove the moisture content. At this temperature, the water will either flash out or vaporize which will then be vented out from the system. This process will continue till no significant rise in pressure is observed. It also needs to be noted that some water will react with $MgCl_2$ due to its hygroscopic nature to form oxide and hydro-oxide precipitates in the form of Magnesium-Oxide (MgO) and Magnesium Hydroxy Chloride (MgOHCl). The reactions here are reversible and in equilibrium and can be controlled by adjusting the concentration of products (i.e. HCl). To remove these O_2 bearing impurities (i.e. MgO and MgOHCl), the melted salt will then be sparged by Ar-HCl mixture for atleast 2 to 3 hours. This will reverse the reaction by converting MgO and MgOHCl back to $MgCl_2$ with H_2O as the byproduct which will vaporize and eventually be vented out from the system. Furthermore, any additional presence of these impurities will be removed using the electrolytic cell comprising of carbon filled electrodes, as it would not be a feasible option to use excess HCl gas since it can cause severe attack on the granular structure of the component material. By applying the direct current across the electrodes, the MgO and MgOHCl will be destroyed by its attraction towards anode and all the off-gases released during this process will then be vented out and collected in separate containers by continuously sparging the system with Ar gas for atleast 5 to 6 hours.

Experimental Setup

A high temperature forced circulation Molten Salt Loop (MSL) is designed and will be built at the Virginia Tech University to study the flow induced corrosion effects on special alloys like Inconel 600, Inconel 800 and Hastelloy-N. The MSL is designed for high temperature applications with ratings of 730^0C and capabilities of generating flow velocity upto 2 m/s. For the corrosion experiments, the system will be operated at 15 psi pressure, 700^0C temperature and 2 m/s flow velocity, thus replicating the MSR conditions. As shown in Fig. 1, the system consists of a storage tank which houses a 3-HP submersible pump with capabilities of generating 25 to 30 gpm flow rate. The auxiliary tank is used to melt, purify and control the salt mixture chemistry before being transferred to the storage tank for the corrosion experiments. The tank and pipe thickness are calculated and checked with high safety margin against mechanical properties of austenitic stainless steel at 750^0C. Furthermore, an allowance of 5 mm is also considered owing to the corrosive nature of chloride salts. All the wetted parts in the system are constructed of material SS316. The system is also provided with ceramic heater mantles for the tanks and several heating clamps positioned at different locations along the system to maintain it above the salt crystallization temperature and prevent freeze zones. Furthermore, the flow velocity is monitored using an externally mounted ultrasonic flowmeter. The instrumentations are controlled using the control panel with inbuilt data logging capabilities.

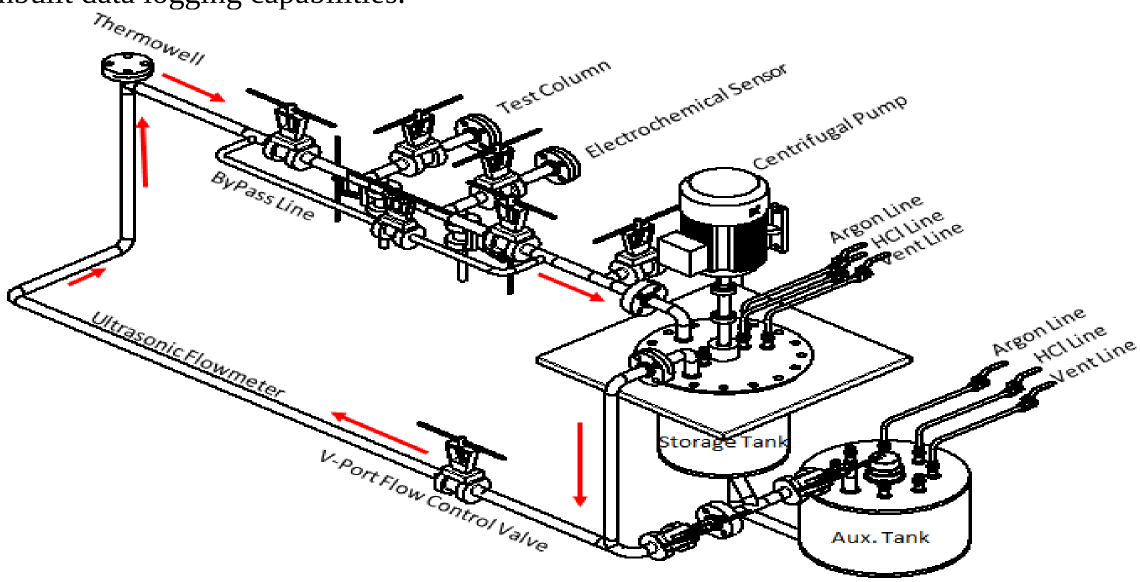

Fig. 1: A 3D layout of molten salt loop.

At present, the system is in fabrication, but post completion atleast three long duration corrosion tests are planned to be conducted for 3 months each for special alloys like Inconel 600, Inconel 800 and Hastelloy N. During these tests, salt mixture will be collected post purification and post corrosion test from the sampling port and will be analyzed for its composition using the Inductively Coupled Plasma (ICP) technique. Furthermore, the alloy surface will also be analyzed for the total weight loss and the film will be characterized for its thickness and composition using the X-ray Photoelectron Spectroscopy (XPS). Also, the morphology of the sample will be studied using the Scanning Electron Microscopy (SEM) to understand the chromium depletion in the grain as well as along the grain boundaries.

References

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