Guidelines for Trade-Studies for Comparison of Liquid Salt and Helium Intermediate Coolants for the NGNP

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This report reviews the major issues and phenomena that should be considered in trade studies to compare the use of liquid salts and helium as intermediate coolants for the production of hydrogen using heat from high-temperature modular helium reactors.

Because the capital cost of the intermediate heat transport system is small compared to the total cost of the NGNP reactor and hydrogen plant, it affects the economics of hydrogen production in two primary ways, one through the efficiency of hydrogen production (which determines the amount of hydrogen that can be produced for a given total investment in the plant), and in the technical risk of successfully developing, licensing and deploying the NGNP.

In general, if the technical issues for the liquid salt intermediate loop can be resolved, liquid salts would be expected to provide higher hydrogen production efficiency for the same reactor outlet temperature, because the intermediate and process heat exchangers can operate with higher effectiveness and smaller temperature drops, recirculated power for pumping the intermediate coolant is lower, and the hydrogen production efficiency can be higher due to the ability to operate the thermal dissociation process at an optimal pressure rather than pressure balancing with the primary coolant.

For both the liquid salt and the helium primary coolants, to meet NGNP schedule goals it is expected that the intermediate heat exchanger (IHX) must be constructed from available ASME code qualified metal alloys. The high-temperature process heat exchangers for sulfuric acid decomposition will be fabricated from silicon carbide composites, which will not be subject to creep but which are vulnerable to brittle failure at relatively low stresses. The IHX must operate at sufficiently high temperatures (850 to 950°C) that creep will place important constraints on the IHX design and lifetime for any candidate IHX material.

For the helium intermediate loop option, it is expected that the IHX will operate in pressure balance between the primary and intermediate loop helium, primarily because recirculating power would be prohibitive if the intermediate helium operated at significantly lower pressures. The challenges in IHX design for the helium-to-helium system include designing the heat exchangers to achieve relatively high effectiveness and low log-mean temperature difference, and to accommodate thermal and pressure transients that can be expected to occur during reactor operation.

For the liquid-salt intermediate loop option, while in principal the IHX could operate in pressure balance, in practice it is expected that the IHX will be designed to accommodate the pressure difference between the primary helium coolant and the optimal hydrogen process pressure.

Extensive experience is available with liquid salt corrosion with the specially developed alloy Hastelloy N, which is is known to provide excellent corrosion performance. However, Hastelloy N is only ASME code qualified up to 704°C. For the NGNP intermediate loop IHX and hot leg that would operate above this temperature, Hastelloy N could only be used as a corrosion resistant cladding for a higher-temperature alloy like Alloy 800H or Hastelloy X, that are code qualified for use at temperatures relevant to the NGNP intermediate loop.

Figure 1 shows an example of a diffusion-bonded Heatric heat exchanger design that could be adapted to use with Alloy 800H plates, with Hastelloy N cladding and offset strip fin plates. However, this configuration would not be capable of operating with large pressure differentials without the Hastelloy N lining the liquid salt channels collapsing from creep deformation.

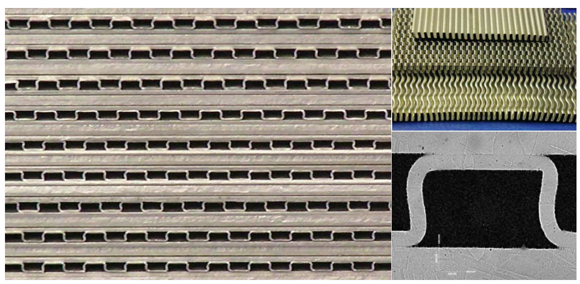

Fig. 1 Diffusion bonded formed plate heat exchanger (FPHE) fabricated by Heatric.

In general, if creep deformation of the IHX liquid salt channels is to be limited to a low rate, and approach like that shown in Fig. 2 may be required, where the compressive stresses around the liquid salt channels is minimized by making the flow channels relatively small. In this case, however, it is likely less practical to apply a protective cladding to this metal, and therefore the salt have acceptable corrosion rates when coupled to an ASME code qualified high temperature alloy.

Thus a key viability issue for the liquid salt intermediate loop is to demonstrate acceptable corrosion rates between a liquid salt one or more ASME code qualified high temperature alloys. Initial experiments at the Univ. of Wisconsin have shown relatively high corrosion rates between flinak and Alloy 800H. This issue for Alloy 800H might be mitigated by using active chemistry control, or using a magnesium chloride ($MgCl_2$) based salt with active metal redox control using magnesium metal. Alternatively, other high temperature alloys may provide acceptable corrosion performance.

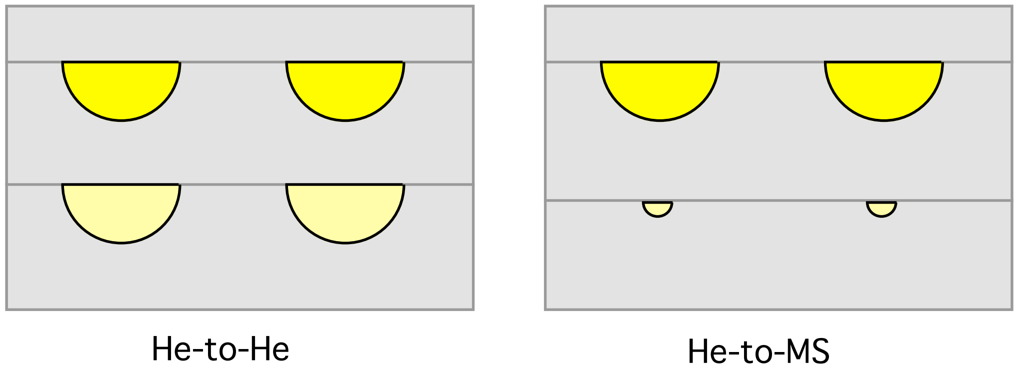

Fig. 2 Comparison of conventional Heatric heat exchanger configurations, showing a design option with small liquid salt flow channels to reduce compressive stresses and limit creep deformation rates.

Trade studies between liquid salts and helium must consider a large number of parameters, and make selections before sufficient information is available to fully understand how these different parameters should be weighted. As noted above, the final selection must be one between performance (efficiency of hydrogen production for a given reactor outlet temperature) versus technical risk. In general, there will be tradeoffs also between performance and technical risk, because in general reducing the reactor outlet temperature reduces the performance, but also reduces the risk.

Consistent comparisons of performance and risk

Because technical risk arises from many sources, it is recommended that trade studies comparing liquid salt and helium intermediate fluids be performed at two or three net hydrogen production efficiency levels, corresponding to different reactor outlet temperatures for liquid salts and helium. In general, for equivalent hydrogen production efficiency, corrected for recirculating power, liquid salt loops can be expected to require lower reactor outlet temperatures than helium. For each hydrogen production efficiency level, sources of technical risk can be listed and rank-ordered for each fluid, and top sources of risk compared. Likewise, by comparing how risks change as the hydrogen production efficiency changes, the sensitivity of the hydrogen production economics to technical risk can also be assessed for each intermediate coolant option.