HEAT EXCHANGER CONSIDERATIONS FOR A SPACE MOLTEN SALT REACTOR. J. Flanders[1], M. Eades[2], T. Blue[3] and X. Sun[4], [1234]The Ohio State University, [1]Flanders.17@osu.edu, [2]Eades.15@osu.edu, [3]Blue.1@osu.edu, [4]Sun.200@osu.edu.

Introduction: Research at the Ohio State University under the *NASA Ralph Steckler Space Grant Colonization Research and Technology Development Opportunity* has identified molten salt reactors as a potentially appealing technology for high power, high temperature space fission systems. Here, the design aspect of the heat exchangers is discussed.

Central to the molten salt reactor concept is the use of fissile material dissolved in a molten salt liquid medium (such as LiF-BeF2-UF4) as both fuel and coolant. In a traditional solid fuel reactor, the fuel is affixed to the core and the heat is removed by a separate coolant. A molten salt reactor functions differently; the fuel is constantly circulating through the reactor core and the heat exchanger. From the heat exchanger, a power conversion system converts the heat to electricity. To promote cycle efficiency, heat exchanger must achieve as high an effectiveness as possible.

Design Considerations: Before selection of heat exchanger types can proceed, one must first consider the specifics of the power cycle being used. A closed Brayton cycle with a helium working fluid has been selected. The full power conversion system can be seen in Figure 1. The fuel is a mixture of LiF - UF_4 and acts as the primary coolant in the loop. Liquid lithium was chosen as a the coolant for the secondary loop on the basis of high thermal conductivity (~55 W/m-K at 1000˚C), high boiling temperature (1615 K at 1 atm) and because lithium has been shown to be an acceptable coolant in radiation enviroments. The lithium is enriched Li-7 to minimize the He-4 and H-3 produced in the secondary loop from the (n, α) reaction in Li-6. [1] Although Li-7 would be an expensive coolant, no other liquid metals that matched our criteria possess a stable isotope with which neutrons hardly react. The mass reduction of a compact system with liquid metals would help counteract this cost during launch.

Heat rejection. To decrease the pressure losses in the helium loop, a fourth loop consisting of elemental lithium is used to transport heat to the radiator setup, which consists of heat pipes at descending temperatures. One end of each heat pipe enters the lithium loop to allow direct contact with the lithium. This lithium does not need to be enriched Li-7 because it is not located within the radiation field.

Figures of merit. The figures of merit for heat exchangers for molten salt reactors with space applications differ from terrestrial solid fueled reactors. The biggest difference is that with a liquid fuel, the delayed neutron fraction that is produced in the core is a major contributor to controllability. The result is that returning the fuel to the core as fast as possible becomes very important. The size and weight of the heat exchanger is also extremely important for space applications, due to the cost per unit mass of transporting material out of Earth’s gravitational influence; this is especially true for the size of the primary heat exchanger, as its size affects the solid angle required for radiation shielding. The final figure of merit is the pressure drop. A lower pressure drop requires less pumping power and, in the case of the helium loop, where a pressure drop results in extractable enthalpy being lost, a higher cycle efficiency is obtained.

Material considerations. Few materials exist that can withstand a very high temperature, corrosive salt, high fast neutron flux environment. Refractory alloys such as molybdenum, rhenium, and tantalum have

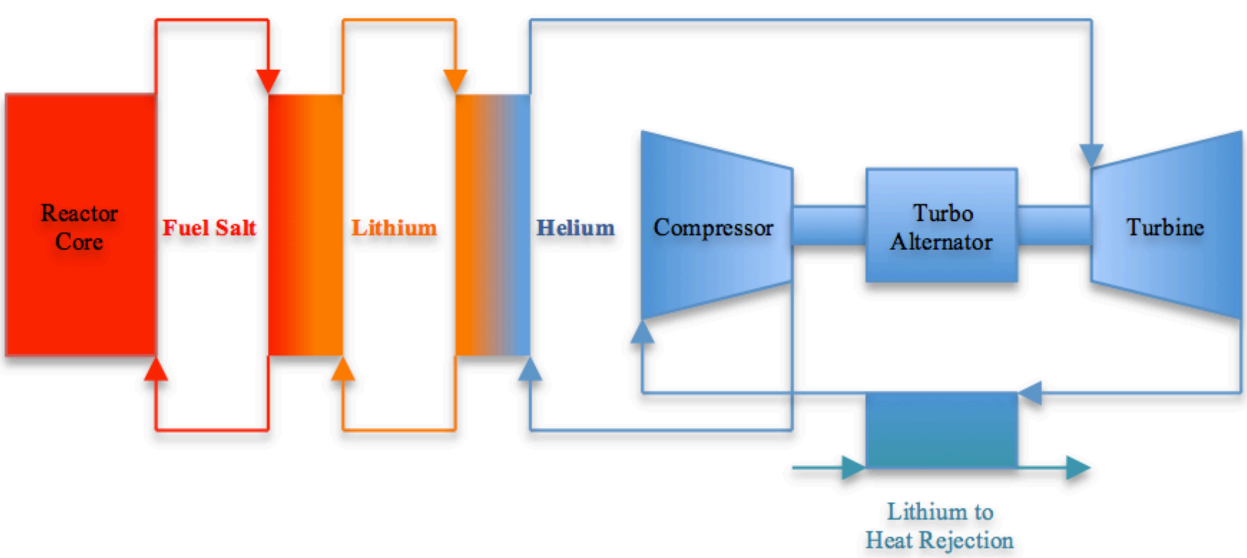

Figure 1: Power Conversion System for a Space Molten Salt Reactor

been shown to handle such temperatures and are acceptable in a fluoride salt environment, provided O_2 is not present, which is the case for this reactor. This makes them ideal material choices for the primary, secondary and tertiary coolant loops. Where temperatures below 1150 K exist, such as in the Brayton cold leg and the heat rejection loop, nickel superalloys would be acceptable materials. [3]

Heat Exchanger Selection: For the secondary lithium to helium heat exchanger, an offset fin strip heat exchanger was selected. For liquid to gas heat transfer, offset fin strip heat exchangers have been shown to be very effective at producing a small compact design. [4] The calculations performed were generated in MATLAB using numerical correlations developed by Joshi and Webb. [5] For a 2 MWt heat exchanger, the length was calculated to be just below 0.5 m and a cross sectional face of only 100 cm^2 was calculated, all while maintaining a helium pressure drop of less than 20 kPa.

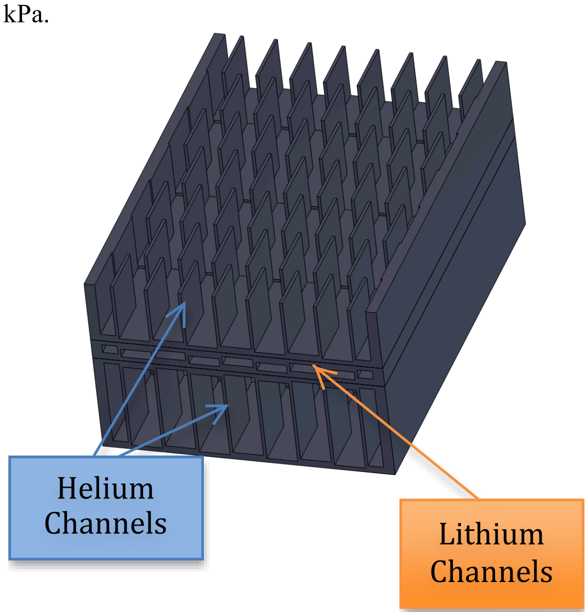

Figure 2: Offset Fin Strip Compact Heat Exchanger Model

For the primary heat exchanger, it was found that a tube in shell heat exchanger was able to return the fuel salt to the core in a shorter amount of time than an offset fin strip heat exchanger. With the fuel salt being rather ineffective for heat transfer, having a thermal conductivity of 0.4 W/m-K and a viscosity of 16.9 cP, to keep the pressure drop below 1 MPa, which is still unfavorably high, the flow velocity had to be kept below 0.15 m/s. This resulted in poor convective heat transfer and a heat exchanger approximately 8 m long, resulting in 53 second fuel salt residency within the heat exchanger. In terms of controllability, this is not a desirable solution; nearly all of the delayed neutrons will be emitted outside the core. With a tube in shell heat exchanger, and the fuel salt within the tubes, the fuel salt residency time in the heat exchanger was reduced to 7.9 seconds.

Scaling considerations. Under the scope of the Steckler grant, three power levels are to be considered: a 500 kWe reactor for surface power on the moon, a 3 MWe reactor for surface power on Mars, and a 15 MWe reactor for nuclear electric propulsion. It is therefore important to consider the effect of higher power on the heat exchanger figures of merit. In general, an increase in power will increase the mass flow rate of the heat exchanger, the pressure drop, and the size dimensions. The design should be optimized so that the pumping power to electrical output ratio decreases for higher power systems. Since the physical size of a molten salt reactor does not increase significantly, higher powers result in a shorter time spent by the salt in the core. This means that in order to obtain the same delayed neutron fraction in the core, the fuel must be returned more quickly for a higher power reactor. Generally, this increase in flow rate enhances heat transfer. Therefore, with an only slightly larger heat exchanger, the time spent within it can still be reduced.

Future Work: Currently, the primary and secondary heat exchangers have been designed for only the 500 kWe system. After an optimized solution for the heat rejection heat exchanger has been obtained, the process will be repeated for the two larger power systems. The design of an effective header for each heat exchanger inlet is also required to maintain accuracy. These calculations assume uniform flow distribution between channels, which must be ensured in the designed header in order to validate the assumption.

Because many of the calculations performed on the heat exchangers are based on empirical correlations, such as the Nusselt number correlations, it is important to verify that the designs are reasonably accurate. In order to validate the design, a CFD model using FLUENT will be created. In particular, the pressure drops of the helium loop need to be verified because they will directly affect the reactor thermal power through cycle efficiency.

References:

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