OPERATION OF A V-4CR-4TI THERMAL CONVECTION LOOP WITH Li AT 700°C—ORNL Loop Team: B. A. Pint, S. J. Pawel, M. Howell, J. L. Moser, G. Garner, M. Santella, P. F. Tortorelli, and J. R. DiStefano (Oak Ridge National Laboratory)

OBJECTIVE

Conduct an experiment with Li in a thermal gradient to determine the compatibility of V-4Cr-4Ti and a multi-layer electrically-insulating coating needed to reduce the magneto hydrodynamic (MHD) force in the first wall of a lithium cooled blanket.

SUMMARY

The loop experiment ran for 2,355h from March to June 2007 with a maximum temperature of 700°±10°C and was stopped due to an unplanned power outage. After initial heating, the vacuum system ran at $<1x10^{-5}$ Pa, well below the level where significant oxidation of V-4Cr-4Ti is expected. Temperature control and monitoring was an issue and somewhat unusual temperature gradients were observed. Characterization of the exposed material will be conducted after the loop is drained and the specimens are removed in October 2007.

PROGRESS AND STATUS

Introduction

A self-cooled lithium blanket concept is attractive for a fusion reactor because of lithium's tritium breeding capability and excellent heat transfer characteristics. Due to compatibility issues at >500°C, vanadium alloys[1] are the most likely structural materials for this concept. One of the critical issues for this, and any liquid-metal concept, is the need to reduce the pressure drop associated with the magneto hydrodynamic (MHD) force due to the high magnetic field in the reactor.[2,3] One solution to the MHD problem is to apply an electrically insulating coating to decouple the structural wall from the liquid metal.[4] The coating must be thin, durable and have a high electrical resistivity. It also must be almost crack-free to prevent shorting.[5,6] The current focus of the U.S. program on reducing the MHD pressure drop is on durable multi-layer coatings or a flow-channel insert.[7,8] Both of these solutions have been previously proposed;[4,9,10] however, little experimental verification has been conducted. Both concepts rely on excellent compatibility of a relatively thin V or V alloy layer to prevent Li from contacting and degrading the insulating ceramic layer. Initial capsule and in-situ testing of multi-layer coatings has shown some promising results.[11] However, a flowing Li test with a temperature gradient is needed to validate the compatibility of such thin layers. A brief summary of the vanadium-lithium compatibility literature[12] indicated a wide range of results with no systematic study of the effects or relative importance of alloying elements and Li impurities. To examine compatibility in a flowing system, a monometallic V-4Cr-4Ti thermal convection loop with V-4Cr-4Ti specimens was designed, constructed and operated with relatively high purity Li for 2,355 h and a maximum operating temperature of ~700°C. A previous report[13] described the construction of the loop and the test specimens, while this report describes the operation. The loop will be drained and opened and the specimens characterized after October 1, 2007.

Results and Discussion

The V-4Cr-4Ti loop and 20 thermocouples (TC) were assembled in the vacuum chamber and the loop and fill tank (containing Li sticks) were evacuated with a roughing pump. The vacuum chamber was then closed and baked out for 48h at 150°C. A base vacuum of $<1x10^{-5}$ Pa was achieved with a vacuum gauge located on the chamber wall opposite the vacuum pump. On February 21, 2007, the furnaces were turned on and slowly heated to maintain the pressure in the $\sim 2x10^{-4}$ Pa range. A W wire with ceramic beads was

used to heat the cold leg to ~250°C. On February 22, 2007, an unsuccessful attempt was made to start flow in the loop. The Li melted in the tank and appeared to fill the loop. However, based on the various TC readings, there was concern that there was insufficient Li in the system or a Li leak. The furnaces were shut down and, after the system had cooled to room temperature, the chamber was opened. No Li leak was detected. An x-ray of the top of the loop showed that the hot leg was not filled to the top of the saddle. (Although with thermal expansion, there may have been sufficient Li to fill the loop at 700°C.) As a precaution, additional liquid Li was added to the tank from a heated secondary pot using pressurized He. The loop and tank were then closed and evacuated. The vacuum chamber was then closed and given a second 48h bake out at 150°C. A base vacuum of 8×10^{-6} Pa was achieved.

On March 7, 2007, the furnaces and W wire were again heated to melt the Li and begin operation. During this attempt, the upper and lower hot leg furnaces were heated to 950° and 890°C (60°C higher than the previous attempt) and flow was achieved at 5:40pm. The temperature at the top of the hot leg stabilized at 700°C by 6:15pm. This was considered the start of operation. During heating, the chamber pressure spiked into the 10^{-4} Pa range and a large pressure spike was observed when flow began and the top leg heated to >600°C for the first time. Within 100h of operation, the vacuum chamber pressure was below 1×10^{-4} Pa, Figure 1. Within 400h of operation, the pressure had dropped into the desired 10^{-5} Pa range and remained there for the rest of the operating period.

The temperature difference between the top of the hot leg and the bottoms of the cold leg and hot leg was unexpectedly high, Figure 1. The maximum temperature difference began at ~340°C and increased to almost 400°C during the first ~1250h. There is no apparent reason for the observed cooling of the bottom of the loop. A change in the heat transfer rate in the system does not appear likely. The ~700°C maximum loop temperature was controlled based on the TC in the thermal well at the top of the hot leg. After some initial adjustments of the furnace controller set point, the system operated with no set point changes until ~800h, Figure 2. A hot spot test conducted during this period indicated the Li velocity was ~2cm/s,

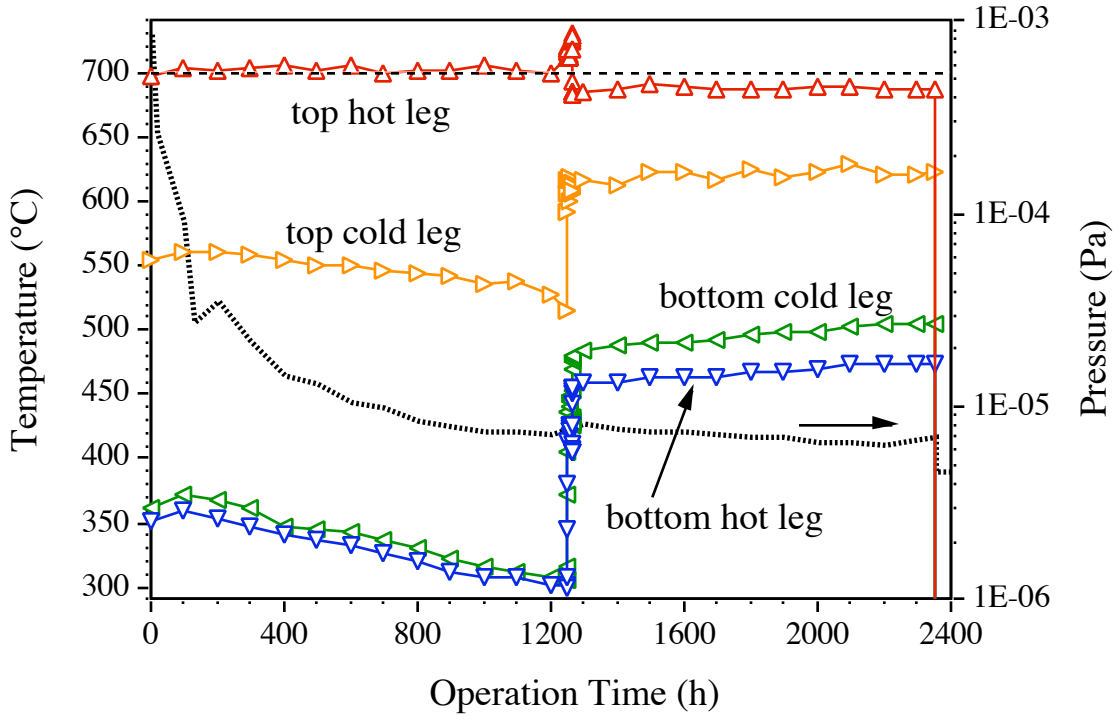

Figure 1. Temperatures in loop thermal wells and chamber pressure as a function of operation time for the V-4Cr-4Ti loop experiment.

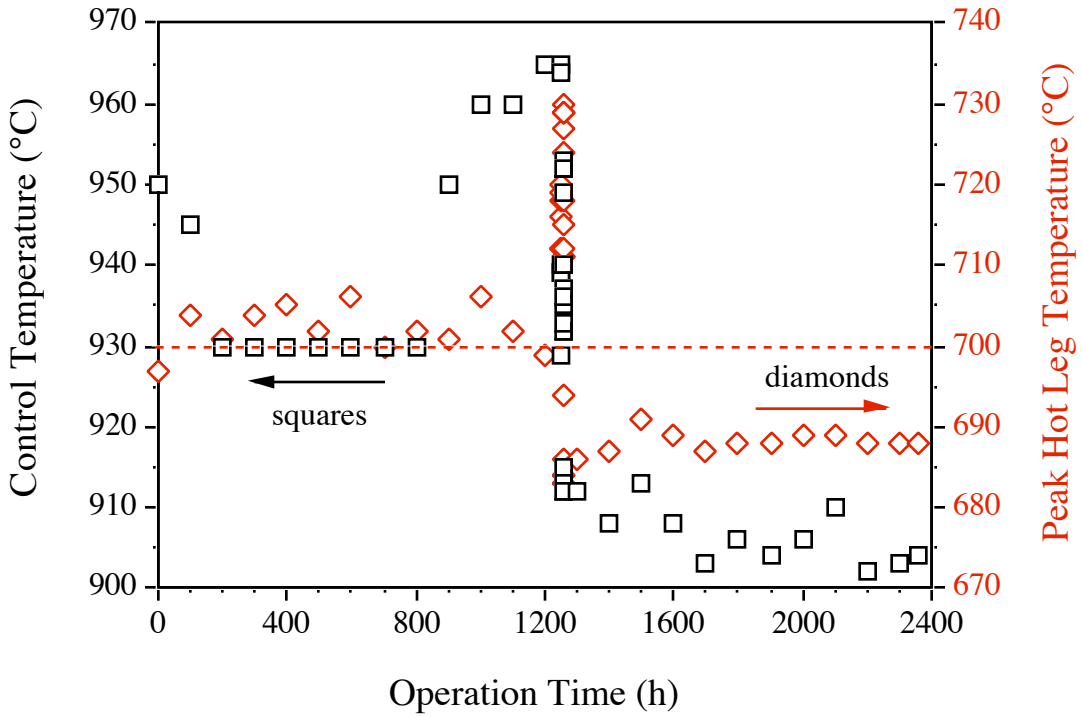

Figure 2. Comparison of temperature of the control TC in the furnace at the top of the hot leg to the TC temperature in the thermal well above that furnace that was used to control the maximum temperature in the loop.

somewhat slower than the 3-4cm/s measured in the stainless steel test loop at 550°C.[13] However, with the higher temperatures in this loop, it was more difficult to conduct the hot spot test as the hot spot temperature did not significantly increase the normal TC readings, especially in the hot leg. (Also, the hot spot was not moved from the bottom of the loop to the top of the loop where it would have worked more effectively.)

Figure 2 shows that after 800h it was necessary to increase the control point on the top furnace on the hot leg in order to keep the peak hot leg temperature at ~700°C. The furnace temperature was increased from 930°C to 965°C between 800h and 1200h. Between 1247 and 1262h of operation, the system underwent several unexplained excursions in temperature. There is no clear reason for these fluctuations which occurred over a weekend. No external change was evident in the vacuum system or furnaces. At ~1247.5h of operation, the cold leg began increasing in temperature with little change in the peak hot leg temperature, Figure 1. However, at 1260h the peak temperature increased to ~730°C for ~1h before dropping to ~690°C. At this point, the top furnace on the hot leg lost control and could no longer maintain its set point. The furnace control TC varied from 900-915°C during the remainder of the test instead of ±1°C observed during the first 1260h of operation, Figure 2. This is the reason why the maximum temperature was not maintained at 700°C during the final ~1100h of operation. It averaged ~688°C during this period. However, it is not clear what caused the furnace control problem. The furnace was still drawing current after the upset and was producing heat. Typical failures of resistively heated furnaces result in complete furnace failures due to element degradation or other problem. The furnace will be inspected when the chamber is opened.

The increase in temperature of the cold leg suggested that the Li velocity increased at this point. However, this could not be confirmed with the hot spot test. With the higher temperatures in the cold leg it was even more difficult to detect the effect of the hot spot on the local temperature. One test indicated that the Li

velocity had decreased to 0.6 cm/s but a lower velocity is not consistent with the observed temperature changes. A possible reason for the change is that the one (or both) of the specimen chains was restricting flow and that it moved, crept or broke during Li exposure. These possibilities cannot be evaluated until the loop is opened. For the remaining ~1100 h, the loop operated with a temperature gradient of 215-230°C which is much closer to the expected gradient for this temperature and loop geometry. A thunderstorm caused an interruption in plant-wide power at 9:49pm on June 13, 2007. The system shut down after 2,355.5 h of operation and was not restarted.

The two type S TCs did not indicate any degradation in the type K TCs during operation. One pair of S and K TCs located together at the bottom of the hot leg showed a difference of 8±1°C during the entire test. The other pair at the top of the hot leg showed a wider variation but it did not consistently change with time.

One conclusion from the operation of this loop is that the system may have benefited from a third furnace on the loop between the bottom of the cold leg and the bottom of the hot leg. Over this ~30cm segment, the Li was flowing upward ~9cm (compared to 84cm in the hot and cold vertical legs). This uphill segment would represent a slight drag on flow and may be the reason it was difficult to initially start flow in the system. Four TC thermal wells were included in the V-4Cr-4Ti loop based on the poor experience with only one thermal well in the SS loop [13] and they were critical to controlling and monitoring this loop. However, even more TC redundancy would have been beneficial. Extra TCs could have been included to ensure that spurious readings were not due to TC degradation or failure.

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