PROGRESS IN CONSTRUCTION OF A V-4CR-4TI THERMAL CONVECTION LOOP AND TEST FACILITY – 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

The objective of this project is to operate a flowing Li experiment to test the Li compatibility in a thermal gradient 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. The experiment is planned to start in February of 2007 and run for 1,000h at 700°C.

SUMMARY

A test loop made of stainless steel (SS) was fabricated and tested in the vacuum chamber to establish the test procedures, condition the refractory metal furnaces and identify potential problems. The vacuum system, furnaces and cold-leg preheating system performed well. At ~550°C peak temperature, a thermal gradient of ~175°C was achieved with a Li velocity of ~4 cm/s. The major problem identified was temperature measurement. This issue is being addressed by increasing the number of thermal wells from one to four in the V-4Cr-4Ti loop. Fabrication of the V-4Cr-4Ti loop has begun. Two-layer (Y_2O_3/V) coatings on V-4Cr-4Ti substrates have been fabricated and will be placed in the hot and cold legs of the loop along with uncoated specimens.

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 have shown 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. Ideally, a monometallic loop with relatively high purity Li and V specimens is needed to clarify the range of results found for V alloys in Li and preparations for a flowing Li thermal convection loop experiment are currently underway. The current plan is to run the loop for 1000h with a maximum temperature of 700°C beginning in February 2007. The loop will be destructively evaluated after the test with characterization completed later in 2007.

Results and Discussion

Stainless steel test loop. A vacuum of ~10^{-5} Pa is needed to run a high temperature V-4Cr-4Ti loop to avoid excessive oxygen uptake, and concomitant embrittlement, by the vanadium alloy tubing during the

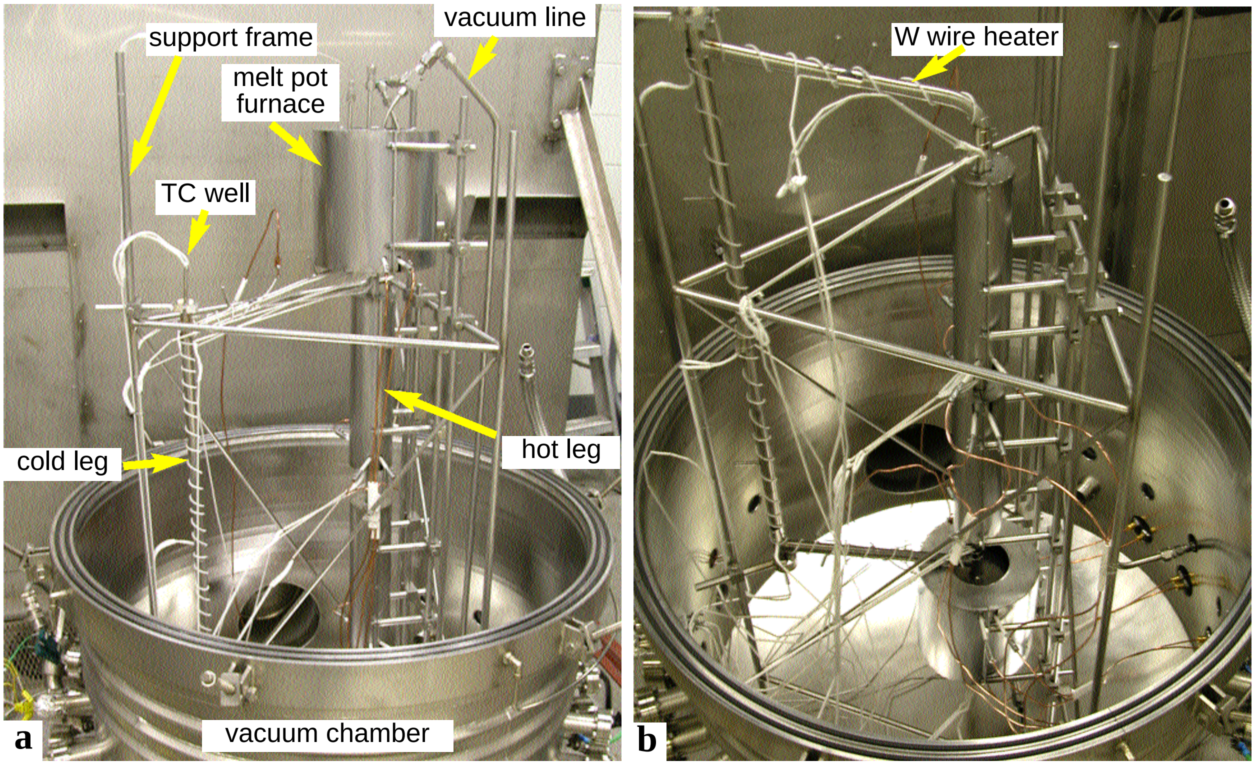

Figure 1. Photographs of (a) the SS loop in the vacuum chamber before bakeout, (b) the inverted SS loop ready for dumping the Li back into the pot.

experiment.[13] To test the planned procedure for running a loop in a vacuum chamber, a type 316 SS loop (~1m tall) was fabricated using the same design as developed for the V-4Cr-4Ti loop. A SS frame was built to hold the loop, 3 Mo wire heating element furnaces (2 hot leg, 1 melt pot) and 17 thermocouples (15 type K, 2 type S), Figure 1a. Each thermocouple (TC) was held in contact with the outside of the tube surface using SS foil and wire. Control and over temperature TCs were used on each furnace and at various locations around the loop. One thermal well was located at the top of the cold leg, Figure 1a, with the tip of the well touching the flowing Li. The chamber was baked out at 150°C for 24h prior to testing the furnaces. (For the V-4Cr-4Ti loop, the bakeout duration will be increased to ~48h to improve the vacuum.) The Li was loaded as sticks into the melt pot before it was welded shut. The Li loading of the loop was accomplished by heating the melt pot (Figure 1a) above the Li melting temperature. A ~3m long W wire with alumina beads was used to heat the cold leg to ~250°C using ~6A to prevent Li from freezing in the cold leg during the filling process. The hot leg furnaces were heated to 600°C before the furnace around the melt pot was turned on. There was some indication (TC variations) of Li melting into the loop when the pot temperature reached >180°C. The loop appeared to fill completely when the pot reached ~360°C.

Lithium flow was maintained for ~48h while the system performance was evaluated. Figure 2 shows the measured temperatures and various estimates of the temperature profile. There was a large, unexpected difference between the TC in the thermal well (TC13) and the TC on the outside of the adjacent tubing (TC10). This was most likely due to a short in the outside TC wire observed on completion of the test. Also, there was a large difference (20-30°C) between the pair of type K and type S thermocouples located at the top and bottom of the hot leg (e.g. TC7 and TC16 in Figure 2). Some of these differences can be attributed to the poor heat conduction in the vacuum and the relatively low thermal conductivity of SS. The differences likely would have been reduced as the system temperature was increased. However, the

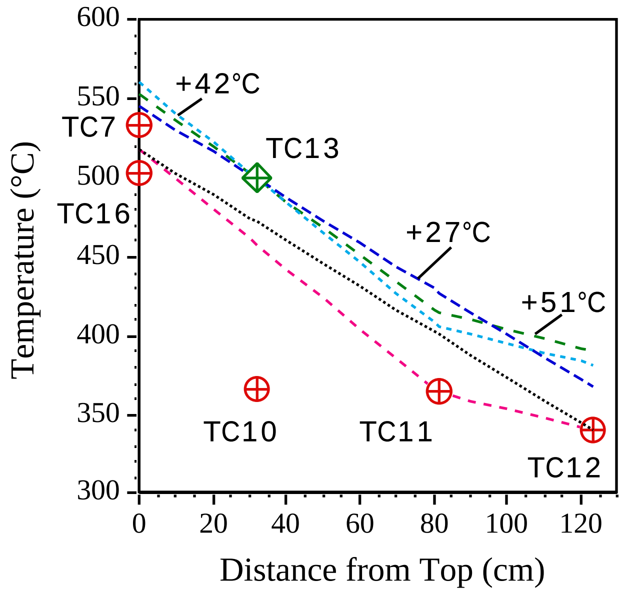

Figure 2. Temperature versus location plot for steady-state loop operation. TC7 and 16 were at the top of the hot leg and TC 10, 11 and 12 were at the top middle and bottom of the cold leg. The measured temperatures are plotted along with several estimates of the profile to estimate the maximum Li temperature.

temperature was not increased above the profile shown in Figure 2 because of the uncertainty of the maximum Li temperature. Because of the TC differences observed and the lack of other thermal wells, the measurement of the Li temperature was not adequate and will be corrected on the V-4Cr-4Ti loop by increasing the number of thermal wells to four (top and bottom of both hot and cold legs).

Two SiC heaters were located on the bottom leg of the loop to provide a “hot spot” test. The heaters were fully energized and the increase in temperature was tracked around half of the loop to measure the Li velocity. Some of these data are shown in Figure 3, which indicated a velocity of ~3.9 cm/s. The hot spot system worked better than expected and will be included in the V-4Cr-4Ti loop

V-4Cr-4Ti loop construction. The V-4Cr-4Ti tubing (19mm OD, 1.6mm wall thickness) has been cut and machined to size and welded, Figure 4a. All of the parts, including the inside of the tubing were acid ($60H_2O$-$30HNO_3$-10%HF) cleaned, acetone wiped and air dried prior to welding. Figure 4b shows a closeup of the nipple at the bottom of the cold leg. This will be cut off to connect a gas line for dumping the loop. Figure 4c shows one of the four thermal wells, also made from V-4Cr-4Ti. The top, bottom and side of the melt pot have been made and the side seam welded, Figure 4d. The only part of the system not made from V-4Cr-4Ti are the five 6.4mm tubes into the top of the melt pot (2 thermal wells, 1 for evacuating the loop and 2 used during dumping the loop). Due to lack of appropriate sized V-4Cr-4Ti tubing, Nb-1Zr tubing was used. The Nb-1Zr should not be in contact with Li during the flowing test and should therefore not affect the results.

To test the quality of the V-4Cr-4Ti tubing, a capsule was made by welding ends onto a length of tubing. Three SS-3 type V-4Cr-4Ti specimens were placed in the capsule. It contained Li for 1000h at 800°C with no leaking observed. The post-exposure Li chemistry has not been checked.

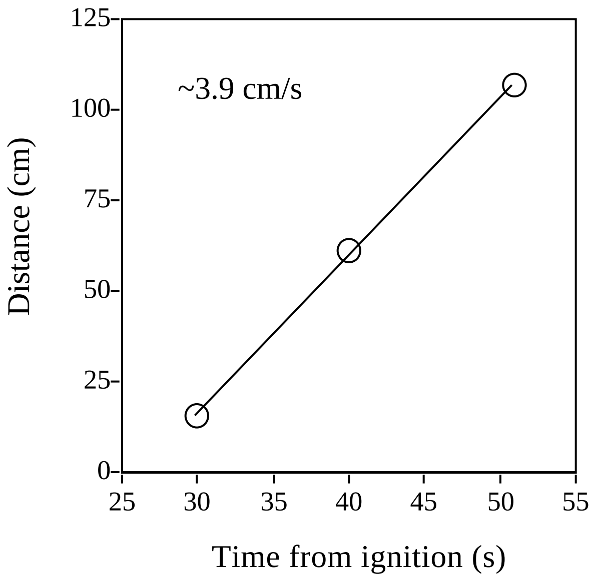

Figure 3. Time versus distance plot for one of the hot spot tests to determine the Li velocity with a peak temperature of 550°C and a 175°C gradient.

Compatibility specimens. As discussed in the previous report,[14] various V-4Cr-4Ti specimens will be used in the specimen chains in the hot and cold leg of the loop. Figure 5a shows a picture of a segment of the specimen chain which includes spacers (with a width similar to the tube ID), SS-3 type tensile specimens and the two layer MHD coating specimen (with a temporary protective covering). The pieces are connected with V-4Cr-4Ti wire. A typical coated specimen is shown in Figure 5b. The central area (arrow) has a ~10µm thick Y_2O_3 coating which is covered by ~10µm of vanadium (central square area). Both coatings were made by physical vapor deposition at Lawrence Livermore National Laboratory. Two batches of coatings were made. The second batch did not produce an optimal composition. One

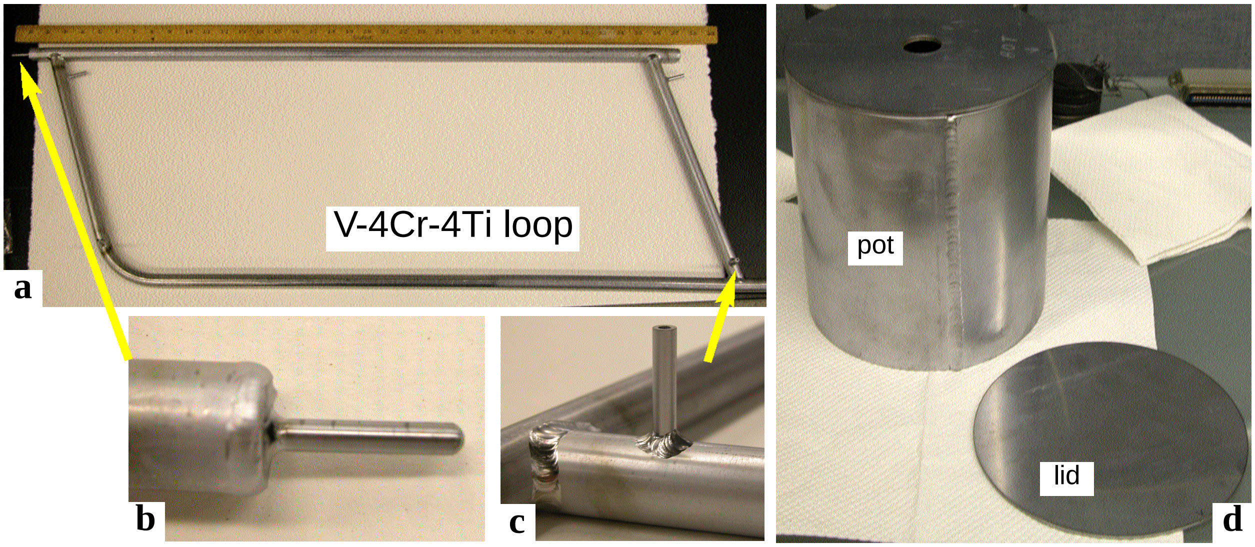

Figure 4. Photographs of (a) the V-4Cr-4Ti loop with closeups of (b) the cold leg nipple and (c) the thermal well at the top of the hot leg and (d) the melt pot and lid before the lid connections were fabricated.

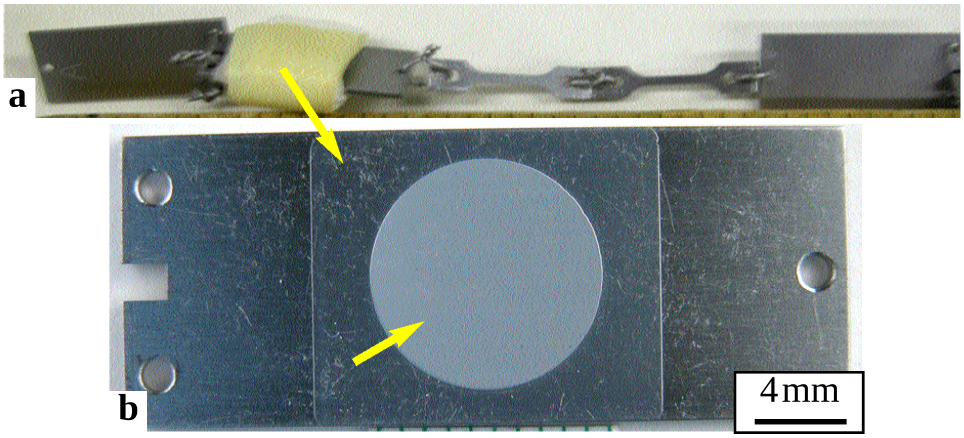

Figure 5. Photograph of examples of V-4Cr-4Ti tab and SS-3 tensile specimens prepared for the loop experiment. The circle (arrow) gives an indication of the PVD oxide (Y_2O_3 or Er_2O_3) coatings that will be applied to some specimens and then overcoated with 10µm of vanadium.

specimen from each batch will be held for characterization. The specimens from the second batch will be placed in the cooler sections of the loop while the coatings with higher quality Y_2O_3 will be placed in the hottest sections of the loop where degradation would be most likely. Post-exposure characterization of the thin V outer layer on these coatings will be one of the critical evaluations for determining compatibility.

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