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FABRICATION AND EVALUATION OF CHEMICALLY VAPOR DEPOSITED TUNGSTEN HEAT PIPE

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ABSTRACT

A network of lithium-filled tungsten heat pipes is being considered as a method of heat extraction from high temperature nuclear reactors. The need for material purity and shape versatility in these applications dictates the use of chemically vapor deposited (CVD) tungsten. Adaptability of CVD tungsten to complex heat pipe designs is shown. Deposition and welding techniques are described. Operation of two lithium-filled CVD tungsten heat pipes above 1800° K is discussed.

INTRODUCTION

The basis for the design of these heat pipes is a high temperature, fast reactor concept as applied to space power systems, for example, by Breitwieser and Lantz (ref. 1). This concept advocates modularity of all subsystems for a significant improvement in reliability allowing for the failure of a number of individual subsystem components without compromising the total system effectiveness. Here we will be concerned with only the component heat pipes which make up the primary reactor coolant system. Figure 1 shows a diagram of a section of the proposed reactor with its primary coolant heat pipes and the secondary heat pipe system. The design of the cross flow, heat pipe heat exchanger requires a transition in cross section of the reactor coolant heat pipes from circular in the core to rectangular in the heat exchanger.

In a one megawatt reactor each reactor heat pipe would carry approximately 2.5 kilowatts at a design temperature of 1800° K. These reactor pipe walls must be chemically compatible with nuclear fuel for periods in excess of 10,000 hours. Early work on reaction of nuclear fuels with refractory metals indicates acceptable long term stability in tungsten systems even in the case of carbon rich UC fuel (ref. 2). An important consideration in wall material selection is oxygen induced corrosion which can occur in lithium systems. Based on the experiences of Busse et al. (ref. 3) with niobium, tantalum, and tungsten-based wall materials, tungsten demonstrates the least corrosion susceptibility. An additional practical factor in materials selection is adequate, reproducible room temperature strength of the components since, in system fabrication, these pipes must be handled and then assembled in large numbers into the core.

Based on these considerations, chemically vapor deposited fluoride tungsten was selected for the intended application.

HEAT PIPE FABRICATION

The components of a typical reactor heat pipe are shown in Figure 2. The CVD tungsten heat pipe shell is open only at the rectangular end (condenser) through which the wick and the lithium charge is inserted. The wicks shown here are made by swaging tungsten screen to shape, but autoclaved wicks and

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internal channels have also been used. Cylindrical screening (accumulators) in the condenser serve to keep excess lithium off of the heat transfer surfaces. After the wicks are inserted, the rectangular end plate is welded to the end of the CVD shell. After the lithium charge is inserted, the pipe is evacuated and sealed by welding the circular W-Re fill plug to the end plate.

Thus far seven CVD heat pipe shells, similar to that shown in figure 2, have been deposited onto molybdenum mandrels by Fansteel, San Fernando Laboratories. Initially the deposits were made using standard production methods developed for tubular sections. The mandrels were suspended from the rectangular end and the reactants flowed axially from the circular end. This deposition arrangement resulted in irregularities in the first two pipe shells deposited. Here a fold was grown into the transition fillet between the cylindrical and rectangular sections as shown in the diagram in figure 3. This type of fold was eliminated in subsequent pipes by enlarging the fillet radius from 0.15 cm to 0.38 cm (fig. 4). A related deposition problem was encountered in the fabrication of the rectangular condenser section of a channel walled pipe (fig. 2). In pipes of this type the condenser wick consists solely of axial channels, .03 cm x .03 cm, grown into the inside wall of the condenser. As shown in figure 5, axial voids existed in the pipe wall. This type of defect was eliminated in the next channel wall pipe by reducing the deposition rate, thereby allowing a void free deposit as shown in figure 6.

Following deposition the external pipe wall was ground to size with mandrels in place. The best results were obtained by diamond grinding, removing less than .002 in. per pass. Molybdenum mandrels were selectively etched out using a nitric and sulfuric acid water solution in most cases. Solutions of nitric and hydrochloric acid used on two pipes produced visible etching of the tungsten wall material after the time necessary to remove the mandrel.

EVALUATION OF MATERIALS AND FABRICATION TECHNIQUES

One circular section from a surplus pipe was used to test the room temperature strength of a typical specimen. A beam bending test of the sample after a 1400° K anneal for 10 minutes indicated a 100 ksi ultimate wall stress and an elastic modulus of 42×10^6 psi. These values agree with values obtained elsewhere (ref. 4), and the material strength has proven adequate in room temperature handling and assembly operations on other pipes.

In developing a procedure for joining the W-26 Re rectangular end plate to the pipe shell, three welding techniques were investigated; electron beam (E.B.) welding, T.I.G. welding with a W-26 Re filler and T.I.G. welding without filler. The geometry and mass of the mating pieces produced unsatisfactory welds using E.B. welding. Even though T.I.G. welding parameters are less controllable, T.I.G. welding consistently yielded good welds. For the first pipe constructed, W-26 Re filler was used in T.I.G. welding. Micrographs of some sample filler welds as seen in figure 7 show voids at the filler interface thought to be from the filler material itself. The filler was eliminated in subsequent welding in favor of flowing the W-Re end plate material directly into the CVD tungsten wall. Both types of T.I.G. welding have proven acceptable in heat cycling and in pipe operation up to 1900° K. The pipe is sealed by E.B. welding the circular W-26 Re fill plug onto the W-26 Re end plate. The weld symmetry and identical materials involved in this design posed no unusual welding problems.

HEAT PIPE OPERATION

The smooth wall heat pipe (fig. 2) was first operated using R.F. heating. Poor coupling between the pipe and the R.F. coil prevented operation above 1200° K. Subsequently the pipe was operated up to 1900° K using electron bombardment (E.B.) heating. During normal startup the evaporator rises to about 1100° K leaving the remainder of the pipe temporarily near room temperature. As the pipe starts the line of temperature transition (front) moves towards the condenser end until the entire pipe is at about 1100° K. The location of the front is easily visible due to the large axial temperature gradient which can be as high as 400° K/cm during a normal startup. This condition introduces large thermal strains in the pipe wall. During the seventh startup of the first pipe, the evaporator was overheated causing a temperature gradient about double the normal value. This abnormal temperature gradient was apparently responsible for a crack at the grown-in fold at the transition fillet described earlier.

During initial R.F. tests of the channel wall pipe, better coil design allowed operation up to 1900° K as seen in figure 8. At these conditions the bare condenser was rejecting about 1400 watts. In order to increase the heat rejection capability of the condenser it was necessary to extend the heat rejection area by the use of fins seen bolted to the condenser in figure 9. These three tantalum fins are capable of increasing the heat rejection of the pipe to 3000 watts. Assembly of the fins onto the pipe represents the most severe room temperature handling condition imposed.

Life tests on the channel wall pipe are being conducted using E.B. heating. Heat throughput for this pipe as measured by a water cooled calorimeter is plotted in figure 10 as a function of temperature. This heat throughput is now limited by the thermal resistance between the condenser walls and the fins to 2100 watts at 1800° K. The heat flux as shown in figure 10 in kilowatts/cm^2 is based on the vapor flow area of the evaporator.

This channel wall pipe with the attached fins has thus far withstood 18 startups from room temperature to over 1800° K. Up to this time the pipe has accumulated over 2500 hours operating time above 1800° K and the life test is continuing.

CONCLUSIONS

The feasibility of using CVD tungsten as a heat pipe shell material has been demonstrated in light of the design criteria dictated by a proposed high temperature fast reactor concept. Some problems associated with deposition of complex shapes were overcome in the early stages of the program. Life testing of a lithium-filled CVD tungsten heat pipe over 2500 hours serves to reaffirm previous results showing corrosion resistance of lithium-tungsten systems. Tungsten wall material and welds have demonstrated the ability to withstand thermal stresses due to 400° K/cm axial temperature gradients encountered in startup. Room temperature strength tests and experience in handling pipes during assembly indicates that it is feasible to produce and assemble large networks of pipes into a heat pipe cooling system.

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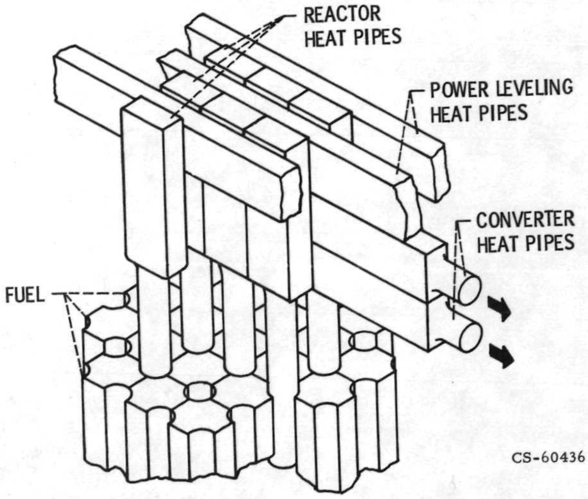

Figure 1. - Cross flow heat exchanger.

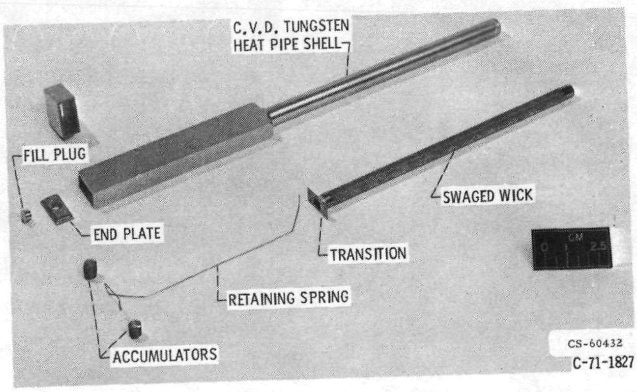

Figure 2. - Channel wall tungsten pipe.

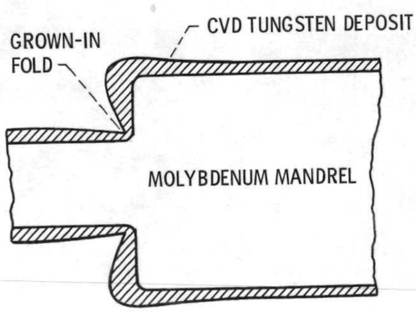

Figure 3. - Small transition fillet.

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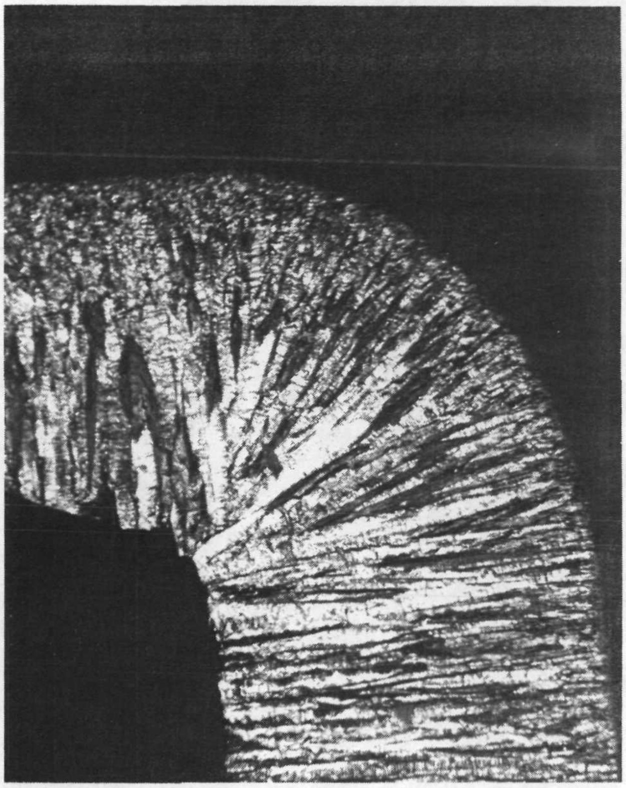

Figure 4. - Large transition fillet.

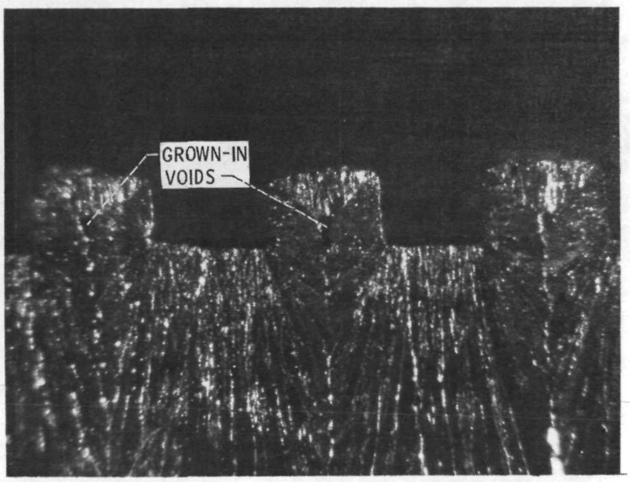

Figure 5. - Voids grown in at normal deposition rates.

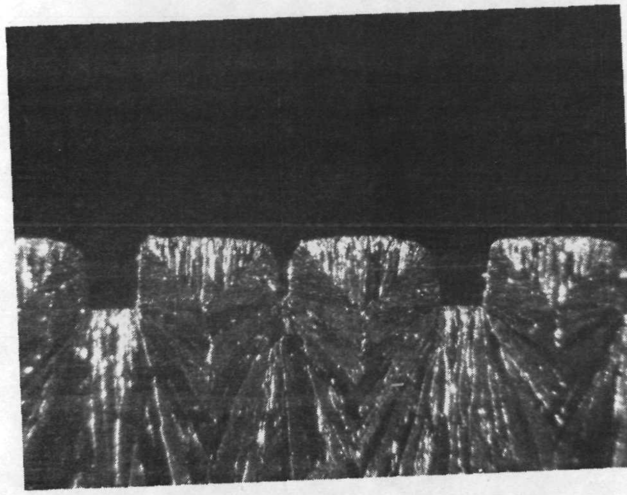

Figure 6. - Solid deposition at low deposition rates.

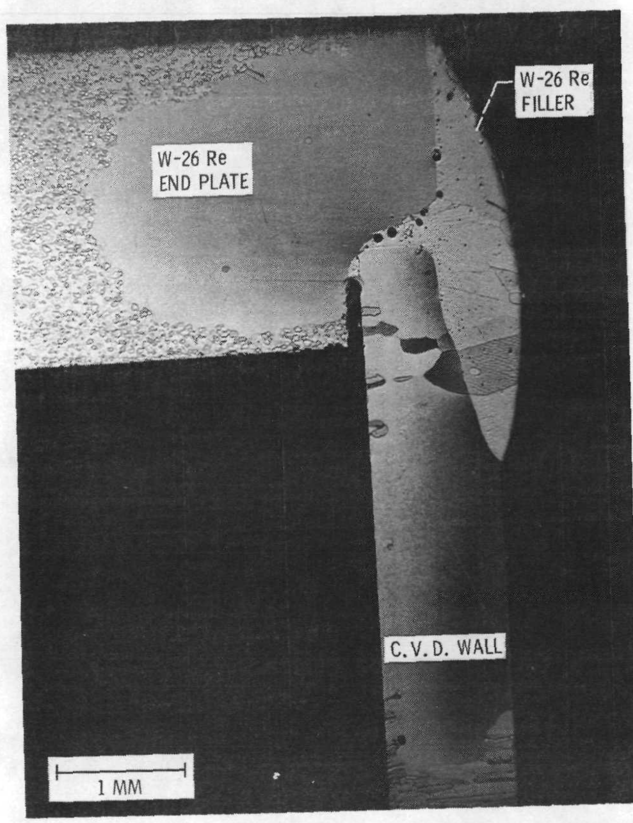

Figure 7. - Sample end plate welds.

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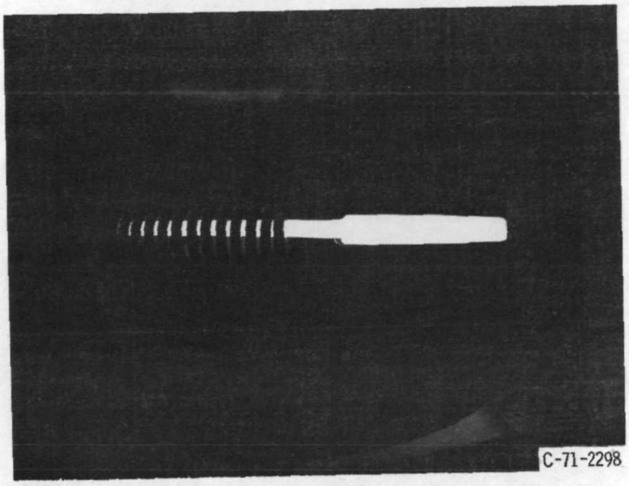

Figure 8. - Channeled heat pipe operating bare at 1900° K.

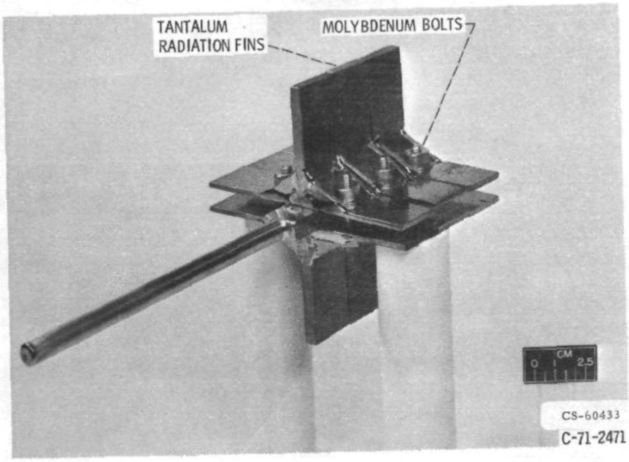

Figure 9. - Tungsten heat pipe with fins.

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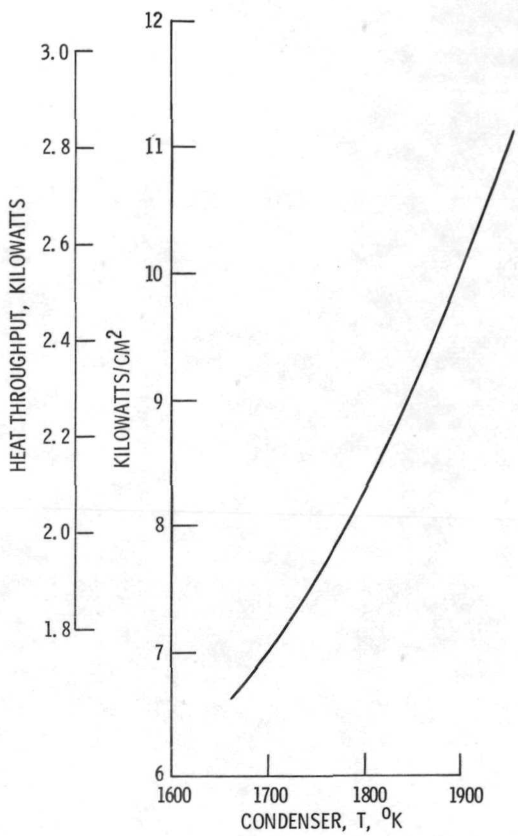

Figure 10. - Heat throughput for tungsten reactor heat pipe with three fins attached.