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LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Quarterly Status Report on the
Space Electric Power R and D Program
for the Period Ending January 31, 1968
Part I

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Printed in the United States of America. Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

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Report distributed: February 21, 1968

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HEAT PIPE SYSTEMS

High Performance Heat Pipe-Vertical

Some results have been obtained with a system which was operated in a manner different from the usual heat pipe. This system is 2.3-cm o.d. x 315-cm long, and the layer of screen which contacts the vapor passage has a pore size of 1000 μ . The remainder of the liquid return network consists of screen of finer mesh. The system was operated vertically and heat was added to a zone just above a rather large pool of sodium located in the bottom of the pipe. Liquid was wicked from the pool into the evaporator section.

Heat addition and heat removal rates were increased in steps at a constant temperature. With each step, more liquid was required in the screen structure throughout the pipe so that more condensate could be returned to the evaporator with the available liquid head. As long as the flow of vapor did not interfere with the return of liquid, the pool diminished by a fixed amount when a proportionate power change was made. When the level in the pool dropped while operating at constant power, it was evident that a heat transfer limit had been reached. After this, the pool disappeared and the evaporator overheated.

The heat transfer limits as a function of temperature obtained with this system are given in Table 1.

Table 1. Vertical Heat Pipe Performance

<u>Temp., °C</u>	<u>Heat Transfer Limit, W</u>
650	3200
700	4450
750	6000
800	7800
850	10,000

The product of the vapor density and square of the vapor velocity is nearly constant at each limit. Thus the limit performance of the system appears to depend on the dynamic pressure. Vapor and liquid move in opposite directions in the heat pipe and the phases can interact to limit heat

transfer. Sometimes sufficient liquid cannot return to the evaporator because it is torn from the surface of the wick and entrained in the moving vapor. This type of an "entrainment" limit is being investigated in more detail.

Heat Pipe Flow Simulation Experiment

A quantitative knowledge of the distribution of pressure in the vapor of heat pipes is essential for the understanding and eventual improvement of these devices to their full heat transport capabilities. Under conditions encountered in high-performance heat pipes, this pressure distribution cannot as yet be deduced reliably from theory. The purpose of the heat pipe flow simulation experiment is to obtain this information. It will consist of a porous cylindrical tube 2 m long and 10 cm diam through which a liquid will be introduced and removed appropriately from a multichamber tank surrounding the tube. Flow patterns will be examined by observation of dye streams through windows in the ends of the tube. If the nature of these patterns permit, flow velocity distributions (from which pressure distribution can be deduced) will be measured using a precise laser Doppler technique recently developed elsewhere.

Two recent heat pipe developments modify the outlook for this experiment as originally conceived. It now appears that it is both feasible and desirable to operate heat pipes at relatively high subsonic Mach number. The possibility of using a compressible gas instead of a liquid in the experiment in order to simulate these new conditions must be assessed. In addition, there are now strong theoretical indications that boundary layer separation occurs in the condenser of a heat pipe. If this is so, the usefulness of the laser Doppler technique is not certain.

The equipment required for the flow simulation experiment is being assembled and fabrication of the tank is almost complete.

The Effect of Vibration on Heat Pipe Performance

A water heat pipe was operated while being subjected to typical sinusoidal and random vibrations, such as might be encountered by a

satellite during the missile launch period, to investigate the effects of vibration on heat pipe performance. The heat pipe used for this test was a 12 in. x $\frac{3}{4}$ in. o.d. stainless steel tube lined with three layers of 100-mesh screen; it contained 7.5 g of water. Heat was supplied by a copper clad electric heater wound around one end of the pipe and soldered in place with pure tin. Temperatures were measured by 12 thermocouples spaced along the length of the pipe with six along the top surface and six underneath. A 12-point recorder was used to record the temperature.

The facility for the experiment was a Ling Electronics vibration exciter with a power amplifier of 90-kW output and an 80-filter automatic control console for random vibration inputs. Vibration tests were made with the heat pipe at two different temperatures, 60° and 90°C. The sinusoidal sweep was made from 5 to 2000 cps at a rate of 3 min/octave with input forms up to 12 g's. Random vibrations were applied for a period of 4 min.

At equilibrium, the heat pipe operated isothermally within 2°C at both temperatures. When vibration was applied, the operation was slightly improved and was isothermal within 1°C. These results indicate that sinusoidal and random vibrations, within the spectrum tested, are not detrimental to heat pipe performance. Complete details of this experiment are described in LA-3798-MS.

Phenyl Ether Life Test

An effort is being made to find a heat pipe fluid which has an operating range between that of water and the liquid metals, namely, 200°-300°C, for heat rejection devices in thermoelectric systems. The choice of fluids for this range is limited to organic compounds and although their properties are not ideal for use in heat pipes they should be suitable for transferring moderate heat fluxes. Many organic compounds decompose or fractionate at temperatures which preclude their use as heat pipe fluids, and so any fluid being considered must be tested for stability at the operating temperature.

One fluid which has a suitable boiling point for the desired operating range is phenyl ether and a life test is now being conducted to determine its stability at 300°C. The heat pipe used for the test is a 12-in. by 1 $\frac{1}{4}$ -in. o.d. stainless steel tube with a $\frac{5}{8}$ -in. o.d. reentrant tube 6 in. long which contains the heater. The inner surface of the outer tube and the outer surface of the reentrant tube are lined with three layers of 100-mesh screen and connected at the heater end with a screen bridge to form the capillary wick structure. The heat pipe contains 30 cm³ of phenyl ether. Heat input to the pipe is provided by an electric cartridge heater inserted into the reentrant tube (Fig. 1). Temperatures are measured with 10 chromel-alumel thermocouples spot-welded along the length of the pipe.

The heat pipe was placed in a metal box filled with vermiculite for insulation, with the heater end slightly elevated so that liquid return would be by capillary action. Adjustment of the temperature is made by a powerstat controlling the power input to the heater.

To date the heat pipe has been operating continuously for over 1300 h at 300°C. So far the phenyl ether appears to be stable as the pipe is isothermal within 3°C over its entire length, just as it was at the start of the test. If decomposition or fractionation occurred a gas pocket would develop at the condenser end and a temperature gradient would result. It is planned to continue the test as long as the phenyl ether remains stable.

Heat Input Fluxes to Water Heat Pipes with Various Wick Structures

A study is being made to determine the maximum heat flux which can be put into water heat pipes when different wick structures are used. As water has a very low thermal conductivity, the type of structure and material used for the wick in the evaporator section are important factors governing the amount of heat which can be transferred into a heat pipe system.

In this study, three different wick structures are being evaluated: annulus, screen, and grooves. Three heat pipes, 12-in. long and $\frac{3}{4}$ -in. o.d. were

Fig. 1. Life test heat pipe.

Fig. 2. Heat input to various wick structures.

constructed each with a different wick structure and loaded with distilled water. In order to provide a uniform heat input flux, copper sleeves were soldered to the evaporator zone with pure tin and the heater elements were wound on these sleeves. The copper sleeves were $1\frac{1}{4}$ -in. long and $\frac{1}{8}$ -in. thick and were cut in half in an axial direction to provide gaps for mounting thermocouples (Fig. 2).

The annulus structure was formed by wrapping five layers of 100-mesh stainless steel screen on a copper mandrel; the mandrel was inserted in a copper tube and the assembly drawn through a die to compress the screen thickness from 0.050 to 0.030 in. The outer copper tube was then dissolved off and a narrow strip of screen was wound on each end of the screen cylinder to build up the diameter to the i.d. of the heat pipe tube. This assembly was inserted into the tube and the latter was drawn down to a diameter which would form a concentric annular space of 0.015 in. between the heat pipe wall and the compressed screen cylinder. The copper mandrel was then dissolved away and end caps were welded on.

A screen wick structure was built into a pipe by rolling three layers of 100-mesh screen into a cylinder and inserting it into the pipe. A steel ball was then forced through the pipe to compress the screen against the wall.

The groove wick structure was formed by milling grooves 0.010 in. wide by 0.030 in. deep in a flat sheet. This sheet was then rolled into a cylinder with the grooves in an axial direction and seam-welded to form the heat pipe.

Cooling of the condenser section is accomplished by inserting the end of the heat pipe into a tank of water through a water-tight fitting. The amount of cooling can be controlled by varying the length of pipe inserted into the tank. The temperature of the water in the tank can also be varied by a cooling coil and immersion heaters. A micro-

phone clamped to the tank provides a means for listening to any boiling action which may occur in the evaporator.

The three water heat pipes have been operated at various power levels and preliminary data, shown in Fig. 2, indicate that a groove wick structure would provide the greatest input heat fluxes to the system. Relatively low heat inputs to both the annulus and screen structures resulted in very high temperatures at the heat input zone as compared with the rest of the heat pipe.

Additional tests are planned for the groove wick structure in an attempt to increase the heat transfer capacity of heat pipes using fluids of low thermal conductivity. These tests will include different groove sizes and nickel structures. Tests will also be made using phenyl ether instead of water.

Potassium Heat Pipe with Beryllium Liner

A compatibility test was conducted to determine if beryllium could withstand being subjected to circulating potassium at 750°C for more than 1000 h.

A heat pipe was constructed using Nb-1% Zr for the container material and three layers of 100-mesh Nb-1% Zr screen for the wick. Since the test was to determine the compatibility of beryllium with the working fluid of the pipe, a 0.040-in. thick beryllium liner was inserted into the heat pipe between the wick structure and the container wall. This liner fitted loosely, thereby allowing the potassium to fill the space between the liner and the container wall. The heat pipe was assembled in the TIG welding facility then fired to 1000°C for 2 h in a vacuum of $< 10^{-7}$ torr.

Sufficient potassium was vacuum distilled into the pipe to completely fill the wick structure and the void between the beryllium liner and Nb-1% Zr container. Upon completion of the distillation, the pipe was pinched closed under vacuum. Final cutoff and closure were made by TIG welding the pinched tube.

The heat pipe was wet-in at 625°C overnight, then placed in a Vac-Ion system with induction heating. It was operated at 750°C for a

period of 1208 h. The pipe was then cut apart and placed in butanol to dissolve the potassium. There was no residue in the potassium or wick structure of the pipe. This indicates that no mass transport occurred.

A section of the pipe was submitted to metallographic analysis for comparison with the beryllium as received. The results indicate there was no intergranular attack, alloying, or any other indications of interaction with the potassium.

Among the observed effects of firing beryllium to temperatures of 750°C and above for extended periods of time is that recrystallization of the beryllium liner takes place, in a matter of seconds, in the initial cleanup firing to 1000°C prior to distillation of potassium into the pipe. Considerable grain growth occurs when beryllium is held at a temperature of 750°C for more than 10 h. Hardness tests show that the beryllium is fully annealed.

Double Heat Pipe Diode

Recent experiments indicate that rhenium heat pipes may have long lives at high temperatures. Since rhenium is frequently used as an emitter surface in high-performance thermionic diodes, it appeared that a rhenium heat pipe might serve as a heat source for a diode and at the same time be the emitter surface. A prototype of such a diode has been designed, built, and operated (Fig. 3). A rhenium-lead heat pipe emitter is shown although this choice is arbitrary. The system incorporates a heat pipe collector and cesium adsorption reservoir in addition to the heat pipe emitter. For convenience, the prototype had a tantalum-lead emitter heat pipe of the same dimensions as the rhenium pipe. When the rhenium pipe becomes available it will be a simple matter to incorporate it into the assembly.

After about 70 h checking out operation at about 1400°C, the diode has been disassembled, preparatory to mounting the rhenium pipe. The experiment will continue when the pipe is installed and the cell reassembled.

THERMIONIC POWER SYSTEMS

The results obtained in the work on Thermionic Power Systems are classified and are described in the Space Electric Power Report, Part II, LA-3882-MS (Confidential).

PUBLICATIONS

"Heat-Pipe Performance in a Zero Gravity Field," J. Spacecraft Rockets, 4, 1556 (1967).

"The Effect of Vibration on Heat Pipe Performance," LA-3798.

"Capillary Insert for Heat Tubes and Process for Manufacturing such Inserts," U.S. Patent 3,305,005 (1967).

Fig. 3. Heat pipe thermionic diode.