1

NASA TM-78,448

NASA-TM-78448

Parametric Performance Of A Spiral-Artery, Liquid-Trap-Diode Heat Pipe

Richard J. Williams

October 1977

NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

PARAMETRIC PERFORMANCE OF A SPIRAL-ARTERY,

LIQUID-TRAP-DIODE HEAT PIPE

Richard J. Williams*

Ames Research Center

SUMMARY

This report describes a series of parametric investigations to determine the effect of various fluid charges on the performance of a 0.635-cm-diam (.25 in) spiral-artery, liquid-trap diode in both the forward and reverse modes. Specific parameters such as forward- and reverse-mode conductances, shutdown times and energies, and recovery to forward-mode operation, are evaluated for ethane as a working fluid in the temperature range 170 K to 220 K.

Results indicate that the heat pipe will not reliably start up in the forward mode. However, startup can be initiated when preceded by a diode reversal. Also included are data which show the susceptibility of the diode to fluid charge and tilt. The optimum fluid charge was found to be 2.67 g, and transport capability at this charge was in excess of 1200 W-cm at 200 K. The diode in the reverse mode exhibited a rapid shutdown (within 9 min) with a shutdown energy of 1150 J (0.32 Wh).

INTRODUCTION

Extensive studies have been carried out on both active and passive heat pipes for fine temperature control aboard spacecraft. However, many applications exist where the ability of the heat pipe to conduct heat efficiently in one direction, and to shut off in the reverse direction, is of primary importance. Such heat pipes are described as thermal diodes (refs. 1,2). These thermal diodes are attractive for use in the cryogenic temperature range. In the near future a large number of cryogenic payloads are due to be flown. In one proposed application (ref. 3), diode heat pipes are used to extract heat from a low-temperature sensor, such as an infrared detector, and to thermally disconnect the sensor to prevent overheating should the radiator be exposed to a sudden high external heat flux. Using this concept, low-temperature cooling can be provided in low subsolar Earth orbits where radiator cooling was never before considered possible.

This paper presents the parametric results of tests on one such diode concept: the liquid trap (ref. 4). The liquid-trap concept employs a

---

*National Research Council, Resident Research Associate.

reservoir situated at the normal evaporator end of the pipe which does not communicate with the wick. In normal operation the trap contains no liquid, and the diode performs as a normal heat pipe. During reverse-mode operation the trap becomes the cold end of the pipe, and condensation of the working fluid occurs inside the trap. The wick is thus depleted of working fluid, and a rapid reduction of transport capability results until all the fluid is condensed in the trap. Throughput is then limited to conduction heat transfer along the heat pipe wall and wick.

Both arterial wicks and axial grooves (ref. 5) are suitable for this type of diode. Axial grooves, while more reliable, are inferior in transport capacity to similarly sized arterial wicks. At present the axial grooves have only been tested with aluminum which results in a higher reverse-mode conductance over a stainless steel diode.

The following sections cover the diode design, the effect of fluid inventory, and tilt or attitude angle. They also describe various anomalies in the behavior of the liquid-trap diode.

DIODE CONSTRUCTION AND TEST SETUP

The fabricated diode consisted of four sections: an evaporator, a transport section, a condenser, and a liquid trap. The wick was a spiral artery formed by wrapping 250-mesh stainless steel screen and 0.04-cm-diam spacers on a mandrel (see fig. 1).

A transition section at the evaporator end of the pipe is integral with a cylindrical reservoir having an inner core of aluminum channel. Detailed design of the pipe is summarized below in table 1.

No liquid communication, i.e., no capillary connection, was provided between the reservoir and spiral artery. Liquid communication between artery and pipe wall was achieved with three scroll-type webs of 250-mesh screen equally spaced in the condenser and evaporator only. Circumferential grooves (63/cm) were used in the evaporator and condenser sections and standoffs were provided on the artery for support in the unblocked transport section.

Three aluminum masses were attached to the heat pipe: an evaporator mass of 0.163 kg to simulate a detector block, a reservoir mass of 0.423 kg, and a condenser mass of 1.063 kg for ease of mounting the heat pipe assembly to a liquid nitrogen (LN_2) sink. Strip heaters were fixed to the reservoir and evaporator blocks to simulate forward-mode heat loads, while rod heaters in the condenser block controlled the forward-mode temperature and elevated condenser temperature during diode reversal.

The locations of the instrumentation used to monitor the temperature of the heat pipe are shown in figure 2. The rod heaters together with thermocouple number 19 are connected to a unit which provides temperature control for the condenser liquid nitrogen sink. Once assembled, the diode

TABLE 1.- HEAT PIPE DESIGN DATA

Design parameter		
Length, cm		
Evaporator	10.160	4"
Transport	28.257	11.125"
Condenser	30.48	12"
Reservoir	15.56	6.125"
Transition	1.524	0.6"
Charge tube	4.445	1.75"
Inactive sections	2.540	1.0"
Effective	48.57	19.12"
Diameter, cm		
Pipe OD	.635	0.25"
Pipe ID	.493	0.194"
Artery OD	.300	0.118"
Solid tunnel OD	.051	0.02"
Reservoir OD	1.588	0.625"
Charge tube OD	.318	0.125"
Other pertinent design information includes:		
Pipe: 304 - 1/8 HD stainless steel		
Screening: 250-mesh 304 stainless steel		
Circumferential grooves: 63/cm (160/in.)		
Reservoir: 6061 Aluminum laminates 0.239 cm thick with 0.127 cm wide × 0.127 cm deep axial machined grooves. Core machined to 1.448 cm OD for press fit into 304 - 1/8 HD stainless steel cylindrical shell		

package was wrapped in approximately 15 layers of multilayer insulation (MLI) before being inserted in the vacuum chamber. All testing was performed in this vacuum chamber, which had no provision for cooling of the walls.

PERFORMANCE TESTS

Low-temperature thermal performance tests were carried out with ethane in both the forward and reverse modes of operation. Using the physical dimensions and the permeability of the wick structure, the diode's theoretical fluid charge was calculated, and tests were performed with four separate filling conditions. These fluid charges were: 3.08, 2.85, 2.67, and 2.53 g which correspond to 115, 106, 100, and 95% of theoretical charge at 200 K. These charges were preprocessed in a separate stainless steel cylinder by a freeze/thaw process before being introduced to the diode heat pipe. This process was required because initially a great deal of trouble was encountered which was apparently due to the impurity of the ethane working fluid as received from the supplier.

Forward-mode tests were performed at various levels of tilt (evaporator above condenser); reverse-mode tests were conducted in a horizontal attitude.

PARAMETRIC RESULTS FOR FORWARD MODE

With the heat pipe containing the 3.08-g charge (115% theoretical), the temperature controller was adjusted to give a nominal operating temperature of 180 K, and with the heat pipe horizontal, forward-mode tests were carried out. These initial tests attempted to start up the heat pipe directly in the forward mode by adding 3 W to the evaporator, allowing the pipe to thermally stabilize, and then increasing the heat inputs in increments up to the burnout condition. Burnout in this case was defined as the evaporator temperature (thermocouple no. 14) being 10 K or more above the transport section. Using this method of startup the pipe burned out at 10 W (fig. 3), the theoretical prediction being in excess of 28 W at 200 K. Repeating this procedure with 1.2-cm reflux tilt produced similar results (fig. 4). This premature burnout was probably due to the inability of the wick structure to completely prime by capillary action alone. To completely prime the wick, a pressure or Clapeyron priming technique (ref. 6) was employed which will now be described.

1. The heat pipe was first isothermalized at 165 K with no heat input.

2. The set point of the temperature controller was increased to 180 K causing the condenser temperature to rise by approximately 1 K/min and making the diode perform a heat piping action in the reverse mode, condensing fluid in the normal evaporator and thus ensuring that sufficient fluid was available in the evaporator when heat was applied.

3. As the condenser temperature approached 180 K, 3 W were applied to the normal evaporator.

If the wick was unprimed at this time, it would have contained saturated vapor and some liquid at a pressure corresponding to the liquid temperature. When the heat load was applied, the pressure of this vapor was less than that of the main vapor space since any liquid leaving the condenser does so at a subcooled temperature relative to the main vapor space. This difference in pressures was sufficient to cause liquid to flow into the wick and completely fill it. This pressure, or Clapeyron, priming technique, is a very powerful priming mechanism when compared with capillary forces, particularly for fluid with high saturation pressures. For example, with ethane at 200 K, a temperature difference of only 0.015 K is sufficient to provide a liquid pressure head of 2.5 cm. It is therefore possible in a 1-g situation to prime wicks which could not be primed by surface tension forces alone.

Once the heat pipe had stabilized at 3 W, the forward-mode tests were repeated as before. These results are shown in figure 5. As can be seen, the heat pipe was isothermal up to the entrance of the condenser for heat inputs up to 21 W indicating a full heat piping action, with burnout occurring at 25 W. The temperature gradient in the condenser was probably due to the excess fluid charge which formed a liquid slug at the far end of the condenser and rendered it inactive. However, calculations indicate a blocked length of only 10.5 cm in the condenser vapor space for this amount of excess charge. Therefore, the excess fluid was probably priming across the small vapor space in other parts of the condenser, and blocking off the area downstream. Further tests were run with the pipe level using this Clapeyron startup procedure at a temperature approximately 20 K below the first case. These results are shown in figure 6. In this case, the heat input was taken directly from 3 W to 15 W. The temperature drop across the condenser in this case at 15 W was only 3 K as opposed to nearly 6 K for the previous higher temperature case. This can be attributed to the higher liquid density of ethane at the lower temperature producing a smaller excess volume of liquid.

Several further tests were undertaken with this fluid charge at various levels of tilt. Figure 7 shows the 2-cm tilt case. Apart from the higher temperature drop across the condenser, there is little difference between this case and the horizontal condition. In fact, this trend continues for higher values of tilt (figs. 8 and 9).

In all of these cases, the thermocouples in the transport section read approximately 1 K to 2 K above both the evaporator and condenser thermocouples. Additional thermocouples were taped to the outside of the heat pipe in the transport section, and the reading from these thermocouples substantiated those of the original spot-welded thermocouples. A test performed with three times the normal amount of insulation, the maximum feasible with the present test setup, still produced the high transport section temperatures.

At present this phenomenon cannot be satisfactorily explained and precludes any reasonable estimates being made of the individual evaporator and condenser coefficients. Later in the report, overall coefficients from this device will be compared with those from other systems.

After completing these tests, the diode was removed from the thermal vacuum chamber, and a small amount of working fluid bled from the heat pipe into a vacuum. This reduced the fluid charge to 2.85 g (106% of theoretical at 200 K).

Figure 10 shows the results for this fluid charge with the pipe horizontal. As can be seen, the temperature profile of the heat pipe was nearly isothermal up to 15 W. However, as the heat input was increased, the gradient across the condenser increased. From the data it appears that at least half the condenser (15 cm) is blocked at 25 W. The amount of liquid required to fill this volume is 0.7 g or approximately 25% of the present charge.

This was unlikely, as small reductions in working fluid charge from the 100% condition cause a drastic reduction in transport capacity (see later section on 96% theoretical charge). Again the liquid was probably priming across the vapor space, blocking off large portions of the condenser. The temperature at the end of the condenser as the heat input was increased above 25 W can be seen to decrease (fig. 10). This would indicate some slug of liquid in the condenser being isolated from the active part of the condenser, and being subcooled by the liquid nitrogen in the condenser block.

The 2- and 3-cm tilt test results of figures 11 and 12 are similar in trend to the results for the horizontal pipe and the earlier tests at these tilts with the larger fluid charges. For heat inputs above 20 W, a gradient of up to 1.5 K was observed to develop between the top and bottom of the pipe which became even greater near burnout. This condition was probably due to the hydrostatic pressure difference across the pipe's diameter (25.6 $N \cdot m^{-2}$) and would not occur, of course, in a zero-g environment.

Initial tests with the 2.67 g charge (100% theoretical) and a horizontal pipe produced a burnout at 20 W. In figure 13 notice that the temperature at the end of the condenser at this heat input has dropped by 3 K. This may have produced a "pressure depriming" process, whereby the temperature, and thus the pressure, of the condenser drops below that of the artery. This pressure difference causes an excessive amount of liquid to be drawn out of the artery, thus depriming it and resulting in a premature burnout. The two tilt tests at 2 and 3 cm (figs. 14 and 15) produced better results, with burnout not occurring until 28 W. In these cases, the temperature drop across the condenser was at most 2 K which would indicate that the heat pipe was operating with a near optimum fluid charge. Again, high temperatures in the transport section were evident for all values of tilt.

The final value of fluid charge tested was 2.53 g (95% theoretical at 200 K). These results are shown in figures 16 and 17. Figure 15 shows the results for a nominal no-load operating temperature of 180 K. Burnout occurred at 10 W. The temperature profile was isothermal indicating no liquid blockage. Increasing the set point to 210 K had the effect of postponing the burnout until 12.5 W. This was simply due to the smaller fluid charge required for satisfactory operation at this higher temperature.

As mentioned earlier, individual evaporator and condenser coefficients cannot be calculated due to the high transport section temperatures. However, overall coefficients can be calculated and compared with existing data. Table 2 shows this comparison for horizontal heat pipes.

$$U = \frac{\dot{Q}}{A(\Delta T)}$$

where

$\dot{Q}$ = heat input

A = condenser area + evaporator area

ΔT = (average evaporator temperature) - (average condenser temperature)

TABLE 2.- COMPARISON OF OVERALL HEAT TRANSFER COEFFICIENTS FOR VARIOUS HEAT PIPES

Heat pipe	U $(W \cdot m^{-2} \cdot K^{-1})$
Axial groove (ref. 5)	855
Liquid-blockage diode[a]	723
Graded-porosity slab wick (ref. 8)	377
Liquid-trap diode	953

[a]Private communication, J. Alario, Grumman Aerospace Corp., April 1977.

For tilts up to 3 cm, the overall coefficients decrease by only 10%. However, with the overcharged liquid-trap diode, the coefficients were reduced by as much as 30%. This is due to the thicker layer of liquid present in the evaporator with larger temperature difference across this layer, and the smaller effective condenser area due to the excess liquid slug.

Finally, in figure 18 a heat flux vs tilt curve for the 100% charge is presented showing both experimental results and the theoretical prediction of the heat pipe's performance at 200 K. In general, the larger than theoretical values of throughput are characteristic of heat pipes operated in a tilted mode. The results of tests on a liquid-blockage diode with a similar wick structure (ref. 7) is shown for comparison.

STARTUP BEHAVIOR

As was stated earlier, direct startup of the heat-pipe diode in the forward mode after cooldown from ambient, and recovery after a burnout condition have presented difficulties. This is believed to be due to high fluid resistance sections in the wick structure (e.g., artery to web interface) making it difficult for the wick to prime by capillary action alone. Reliable startup was induced in all of the foregoing tests by using the diode reversal pressure-priming (Clapeyron-priming) technique previously described. In separate tests carried out in an attempt to prime the diode wick, a small amount of heat (2 W to 2-1/2 W) was applied to the evaporator, and the heat pipe left in this condition for several hours. The heat input was then increased to 15 W (fig. 19) which resulted in a burnout. Therefore, it appears that the forces which resist the priming of the heat pipe wick cannot be overcome with a "heat soak" procedure such as this. The only reliable startup procedure is the pressure or Clapeyron technique.

REVERSE-MODE TEST RESULTS

The reverse-mode test results for the various fluid charges are very similar; therefore, only the results for the 2.67-g charge (100% theoretical) will be presented, and comments relating to this charge also refer to the other fluid charges.

Two types of reversal tests were undertaken. Once steady-state forward-mode operation was established, evaporator power was either turned off or left on at a low wattage. The magnitude of evaporator power determined the rise in evaporator temperature during reversal.

Figure 20 shows the diode temperatures during reversal. At time zero, power was removed from the evaporator heater and approximately 150 W applied to the condenser block, with no reduction of liquid nitrogen flow. After 5 min the pipe began to dry out, and the condenser rose in temperature above the rest of the pipe. Complete shutdown was achieved after approximately 9 min. Shutdown time is defined as the time at which the rate of increase in temperature of the liquid trap becomes a minimum. This time is somewhat uncertain as the position of the minimum rate of increase in temperature is somewhat arbitrary (see table 3).

TABLE 3.- VARIATION OF TRAP TEMPERATURE WITH TIME

Trap temp., K	Time, min	ΔT, K	Trap temp., K	Time, min	ΔT, K
192.9	0		196.2	10	0.2
193.3	1	0.4	196.3	11	0.1
194.1	2	0.8	196.5	12	0.2
194.7	3	0.6	196.6	13	0.1
195.0	4	0.3	196.7	14	0.1
195.2	5	0.2	196.8	15	0.1
195.5	6	0.3	196.9	16	0.1
195.7	7	0.2	197.0	17	0.1
195.9	8	0.2	197.1	18	0.1
196.0	9	0.1			

The shutdown energy Q_{sd} can also be obtained from this table and is defined as:

$$Q_{sd} = MC_p(T_o - T_{sd}) - \dot{Q}\tau$$

where

MC_p = thermal capacitance of trap and aluminum block

T_o = temperature of trap at start of reversal

T_{sd} = temperature of trap at complete shutdown

$\dot{Q}$ = evaporator power

τ = shutdown time

If the shutdown time was chosen to be 9 min, this produces a calculated shutdown energy of 1150 J (0.32 Wh). If a time of 11 min was chosen, Q_{sd} = 1261 J, and a time of 13 min produces Q_{sd} = 1372 J. The latent heat energy stored in the 2.67 g charge at 200 K was 1228 J; therefore, the 9-min shutdown time was probably the correct figure. Figure 21 shows the continuous response of the condenser and liquid trap for the same conditions. The reverse heat flow through the heat pipe was equal to the time derivative of the evaporator/trap temperature history multiplied by its heat capacity. This gives a reverse-mode heat leak of 0.844 W, a reverse-mode conductance of 0.037 W/K, and a turndown ratio (forward- to reverse-mode conductance) of 243:1.

Several reverse-mode tests were performed without removing evaporator power during reversal. Figure 22 shows a "reverse and recover" test where the evaporator heater was left on with 1.5 W, with no power being applied to the trap. The figure shows that 1.5 W of evaporator power produces an increase in evaporator temperature of 24 K/h.

For the value of thermal capacitance represented by this size of evaporator block, the rate of increase in temperature would probably not be satisfactory if a detector were being cooled, the maximum desirable temperature increase being on the order of 10 K in an hour. The other factor evident from this test was that a condenser temperature cooldown rate of 1.5 K/min was too fast for a recovery to forward-mode operation, i.e., the condenser temperature keeps decreasing and evaporator temperature keeps increasing without the coupling effect of heat piping action taking effect.

Leaving the evaporator heater on during reversal has the effect of retarding the shutdown process. The forward-mode heat piping action has to be overcome and reversed before shutdown can commence. This was evidenced in slightly longer shutdown times.

Figures 23 and 24 show an attempt to recover the diode to forward-mode operation after a reversal. The figure shows that with a condenser cooldown rate of 1 K/min, the evaporator temperature rate of increase (with a heat input of 0.3 W) could be arrested and reversed. The full diode temperature profiles are shown in figure 23. It is thought that if the evaporator and trap were thermally coupled, their temperatures would be nearly equal after, as well as before, reversal. Figure 23 also shows that the diode does not fully return to isothermal conditions, the transport section remaining higher in temperature. The heat pipe after the reversal and recovery is able to transport 3 W, but burns out at 15 W, which again is indicative of a partially primed system.

Finally, a strip-chart recording of the performance of the diode in a reverse and recover operation is shown in figure 25. By adjusting the heater power levels in proportion to their areas, the evaporator and trap temperatures were made to track one another. The main points of interest in this graph are centered around the crossover point between the decreasing condenser and increasing evaporator and trap temperatures.

The evaporator temperature can be seen to decrease momentarily, and then continue to increase for an additional 10 min while the trap temperature decreases with slight fluctuations during this period. These slight fluctuations may be due to the boiling action taking place inside the liquid trap. The theoretical time taken to evaporate the fluid charge is approximately equal to the time taken between the point when the condenser temperature drops below the evaporator/trap temperature, and the inflection points in the evaporator and trap temperature profiles.

After the inflection point, the trap temperature increases at a uniform rate consistent with its steady heat input of 0.9 W. (It is thought that if trap and evaporator were thermally coupled they would track one another without the use of auxiliary heat inputs.) The condenser and evaporator temperatures continue to decrease in parallel until the temperature controller takes over and produces stable conditions. The average temperature differences between evaporator and condenser at this point were 1.3 K; the transport section was 4.1 K above the evaporator temperature. This strip chart also emphasizes the difficulty in determining the shutdown time as the change in slope of the liquid-trap temperature profile is not easily discernable.

CONCLUSIONS

1. The spiral-artery heat pipe diode is a high-heat transport device capable of carrying in excess of 1215 W-cm in a horizontal attitude with ethane as a working fluid at 200 K.

2. The heat pipe would not reliably start up in the forward mode, i.e., start up after cooldown from ambient, after burnout or start up after several hours at a low heat input. However, reliable startup can be initiated when preceded by a diode reversal accompanied by a pressure or Clapeyron priming technique.

3. The performance of the pipe was very susceptible to fluid inventory. In an overcharged condition, the excess fluid would apparently prime across the vapor space and block large portions of the condenser. If the pipe was undercharged, its ability to transport heat was drastically reduced; for example, an undercharge of 5% reduced its heat carrying capacity by over 50%. The near optimum charge was found to be 2.67 g, the charge predicted by theory.

4. The diode would rapidly shut down with any reversal of the normal temperature gradient as no auxiliary energy was required for shutdown. However, the determination of shutdown energy can only be considered an estimate due to the inability to accurately measure the shutdown time. The measured shutdown times and energies were 9 min and 1150 J (0.32 Wh), respectively.

5. The condenser cooldown rate during recovery had to be 1 K/min or less in order to allow the reinitiation of heat pipe action.

6. There was a finite delay time after the condenser temperature dropped below the evaporator temperature before it started to decrease. This delay was equivalent to the time taken to evaporate all the working fluid in the trap.

7. The detector or evaporator load had to be kept to 0.3 W or below for this size of evaporator block so that the rise in evaporator temperature could be kept within reasonable bounds during reversal. For this situation, therefore, it appears unnecessary to use a high-performance heat pipe such as this at only 1.2% (0.3/25) of its capacity.

8. The liquid-trap diode would not directly recover to forward-mode operation after a burnout or a reversal. Therefore, it cannot at this moment be considered as a viable passive cryogenic heat-transfer device.

this particular heat pipe?!

Problems with this heat pipe seem related more to its inability to prime than anything else. If heat pipe had primed, conclusions would have been different.

REFERENCES

1. Kosson, R.; and Swerdling, B.: Design, Fabrication and Testing of a Thermal Diode. NASA CR 114526, Nov. 1972.

2. Quadrini, J.; and Kosson, R.: Design, Fabrication and Testing of a Cryogenic Thermal Diode. NASA CR 137616, Dec. 1974.

3. Wright, J. P.; Swanson, R. L.; and Trucks, H.: Design and Analysis of a 175 K Diode Heat Pipe Radiator System. Seventh Intersociety Conference on Environmental Systems, San Francisco, California, 1977.

4. Kirkpatrick, J. P.: Variable Conductance Heat Pipes — From the Laboratory to Space. First International Heat Pipe Conference, Stuttgart, Federal Republic of Germany, 1973.

5. Brennan, P. J.; and Groll, M.: Application of Axial Grooves to Cryogenic Heat Pipe Technology. Second International Heat Pipe Conference, Bologna, Italy, 1976, p. 183.

6. Kosson, R.; Hembach, R.; and Edelstein, F.: A Tunnel Wick 100,000 Watt-Inch Heat Pipe. AIAA Paper 72-273, April 1972.

7. Quadrini, J.; and McCreight, C. R.: Development of a Thermal Diode for Cryogenic Applications. AIAA Paper 77-192, Jan. 1977.

8. Groll, M.; Pittman, R. B.; and Eninger, J. E.: Parametric Performance of Circumferentially Grooved Heat Pipes with Graded-Porosity Slab Wicks at Cryogenic Temperatures. Second International Heat Pipe Conference, Bologna, Italy, 1976, p. 63.

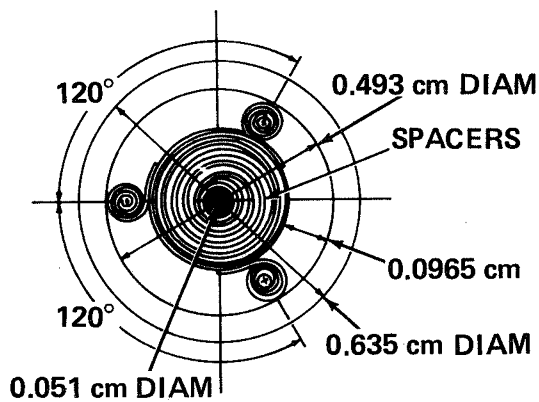

Figure 1.- Wick geometry.

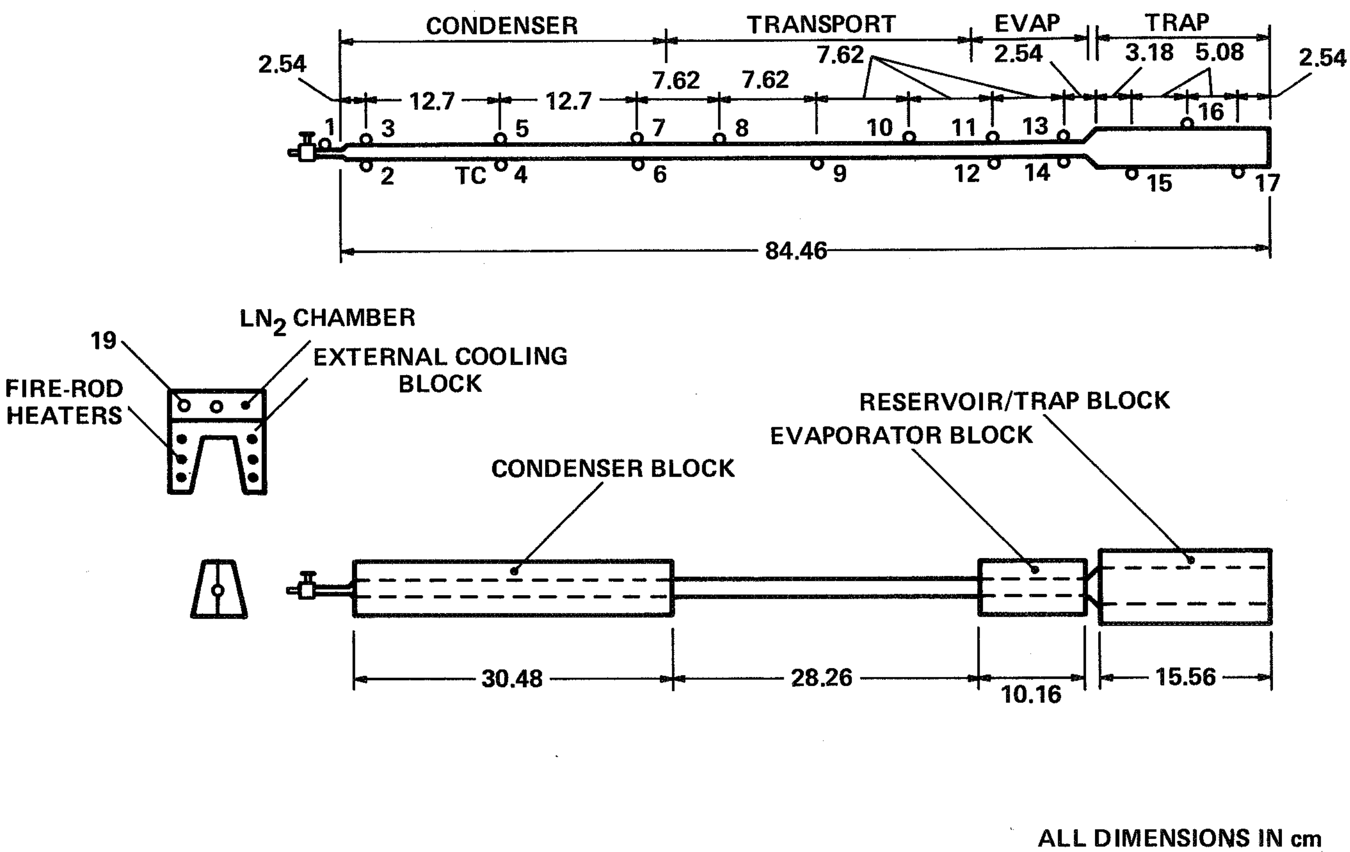

Figure 2.- Instrumentation of heat pipe diode.

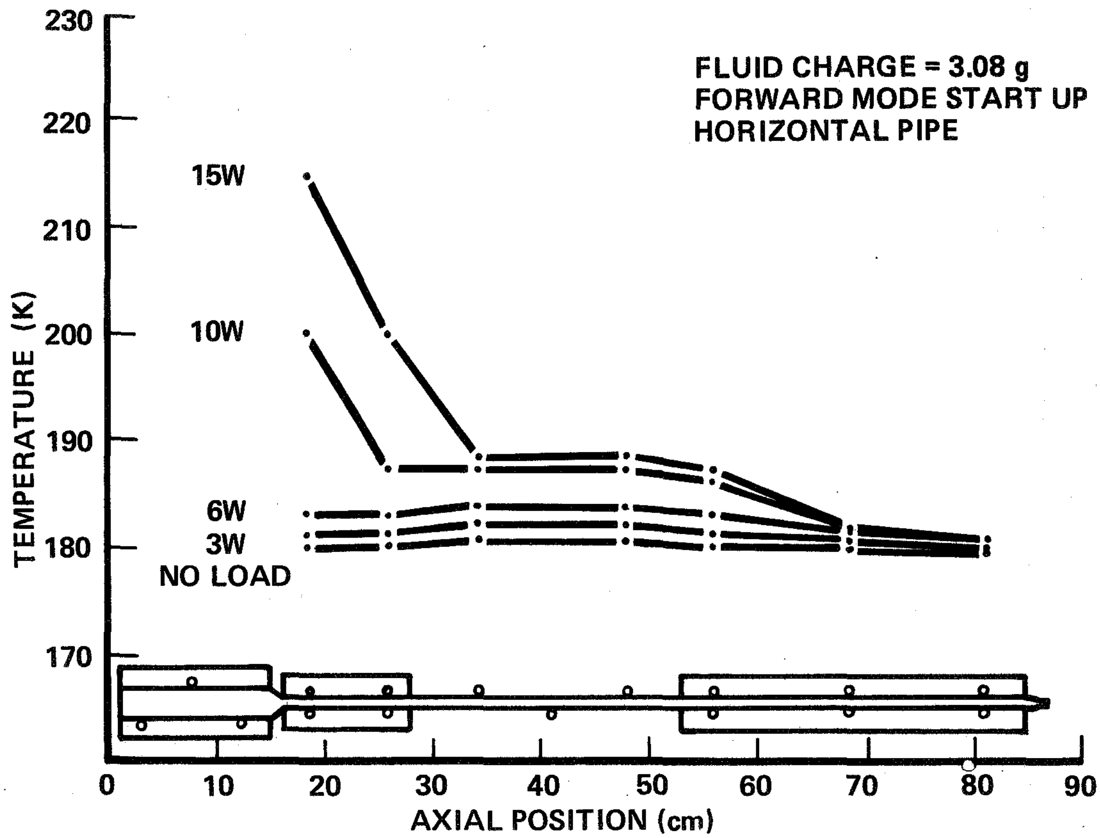

Figure 3.- Forward mode temperature profiles.

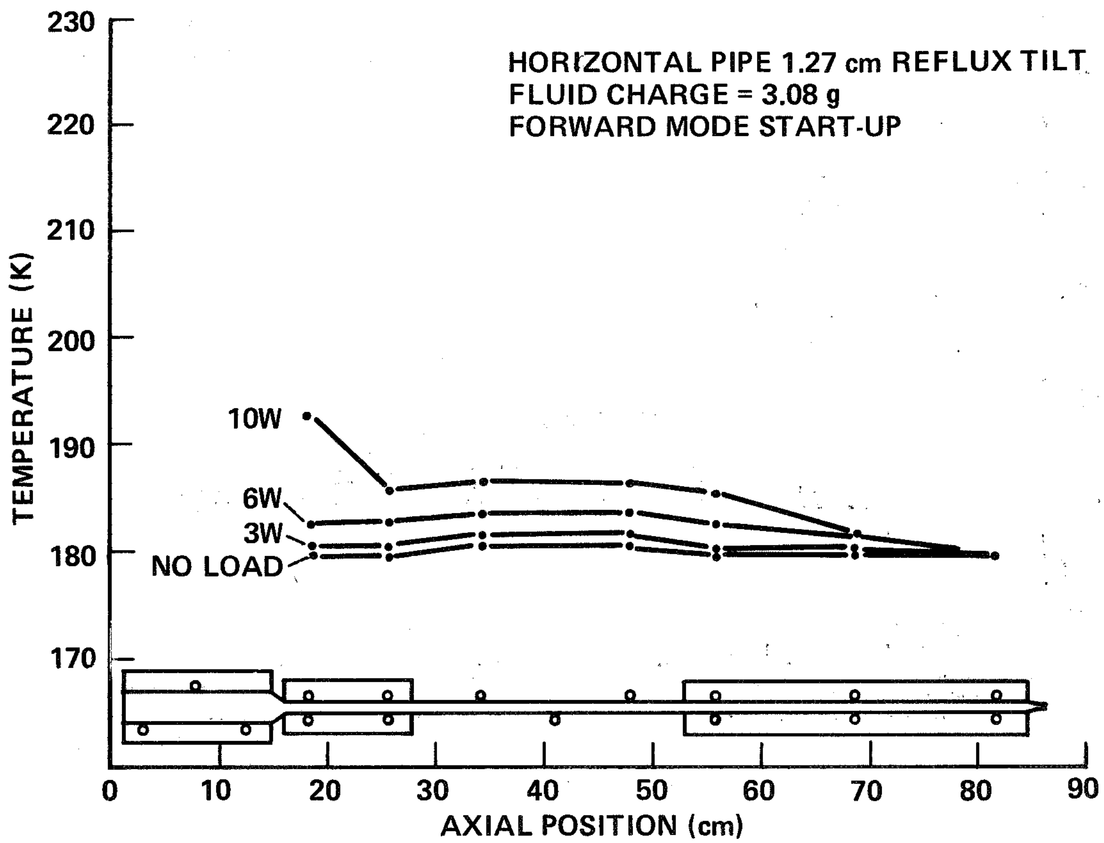

Figure 4.- Forward mode temperature profiles, reflux tilt.

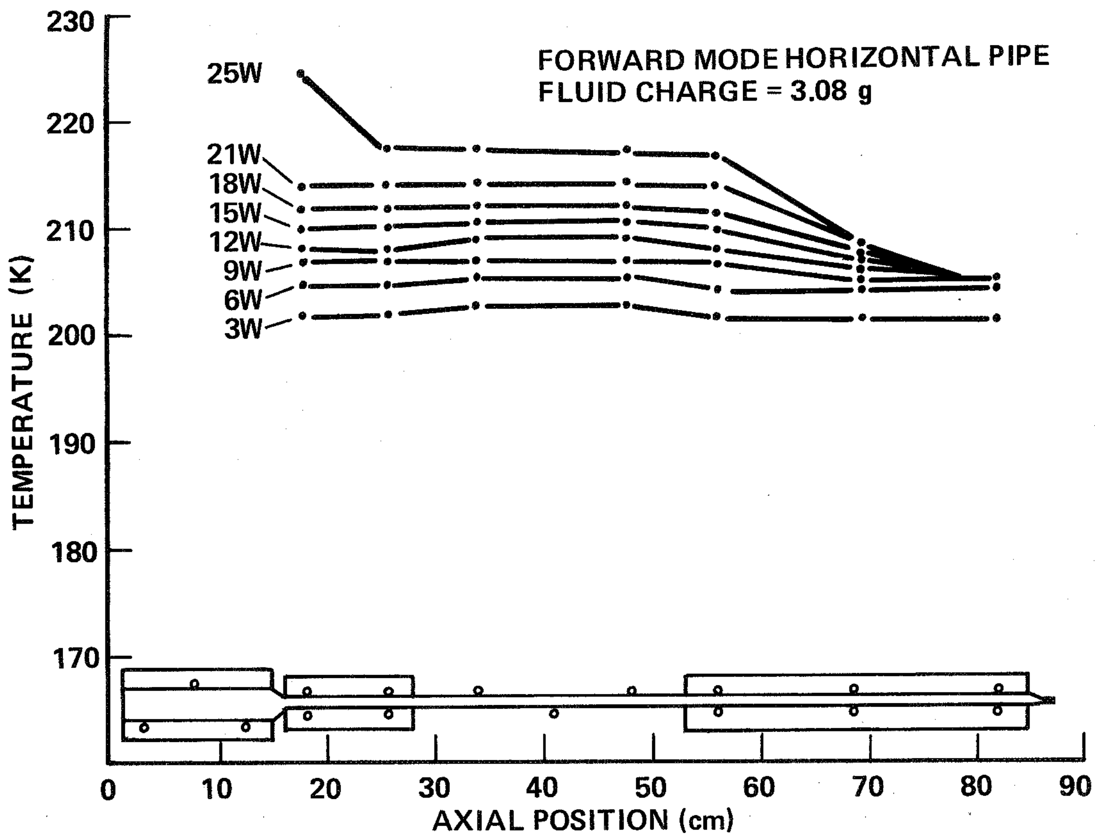

Figure 5.- Temperature profiles, Clapeyron priming at 200 K.

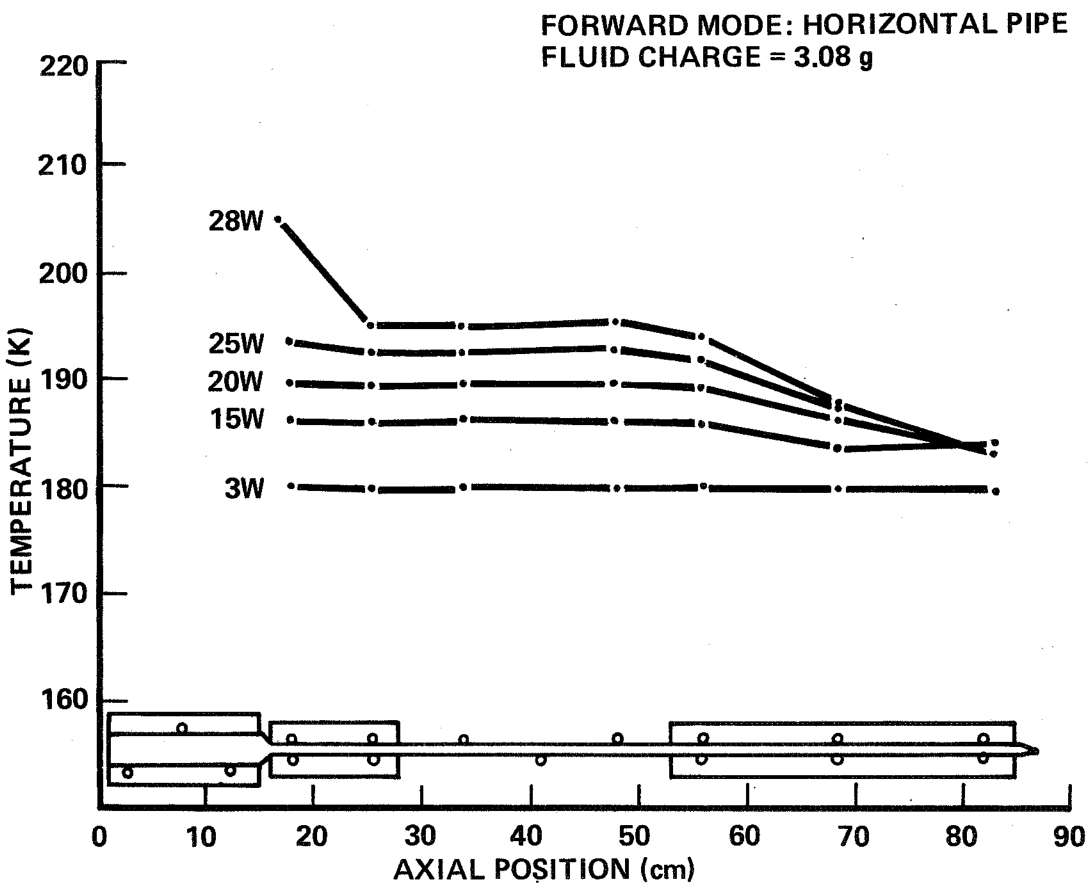

Figure 6.- Temperature profiles, Clapeyron priming at 180 K.

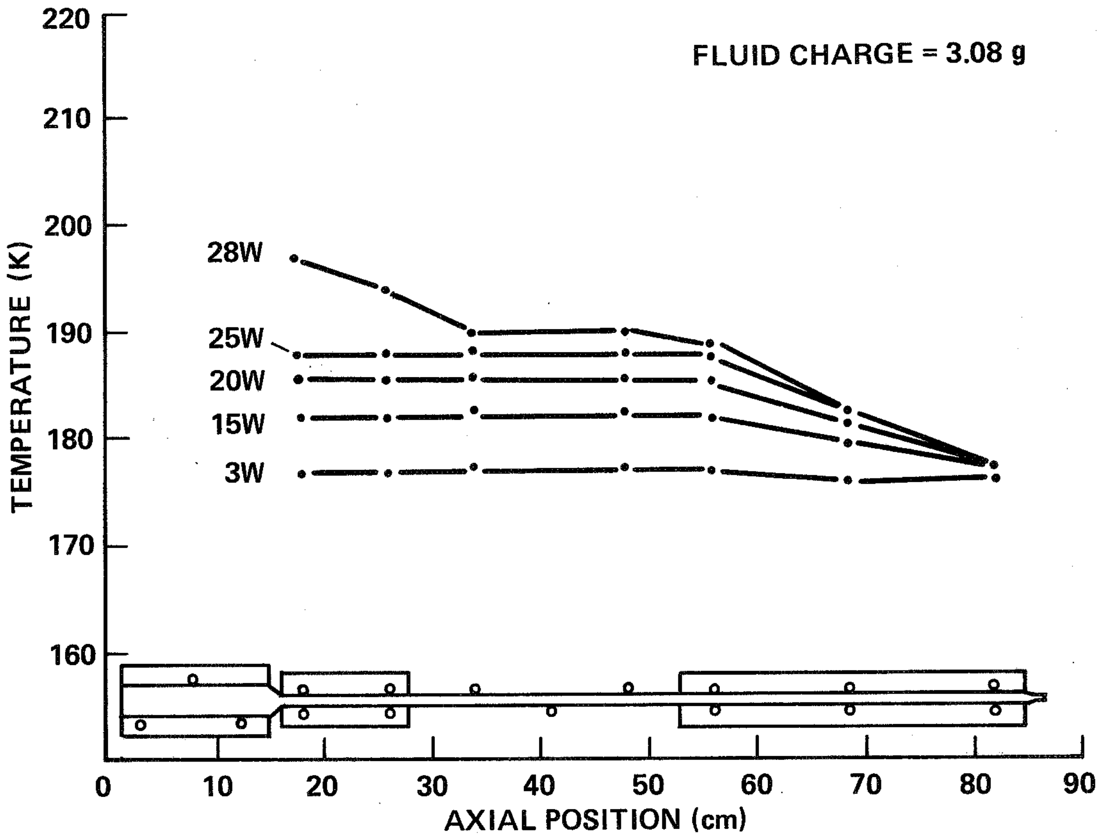

Figure 7.- Forward mode temperature profiles, 2 cm tilt.

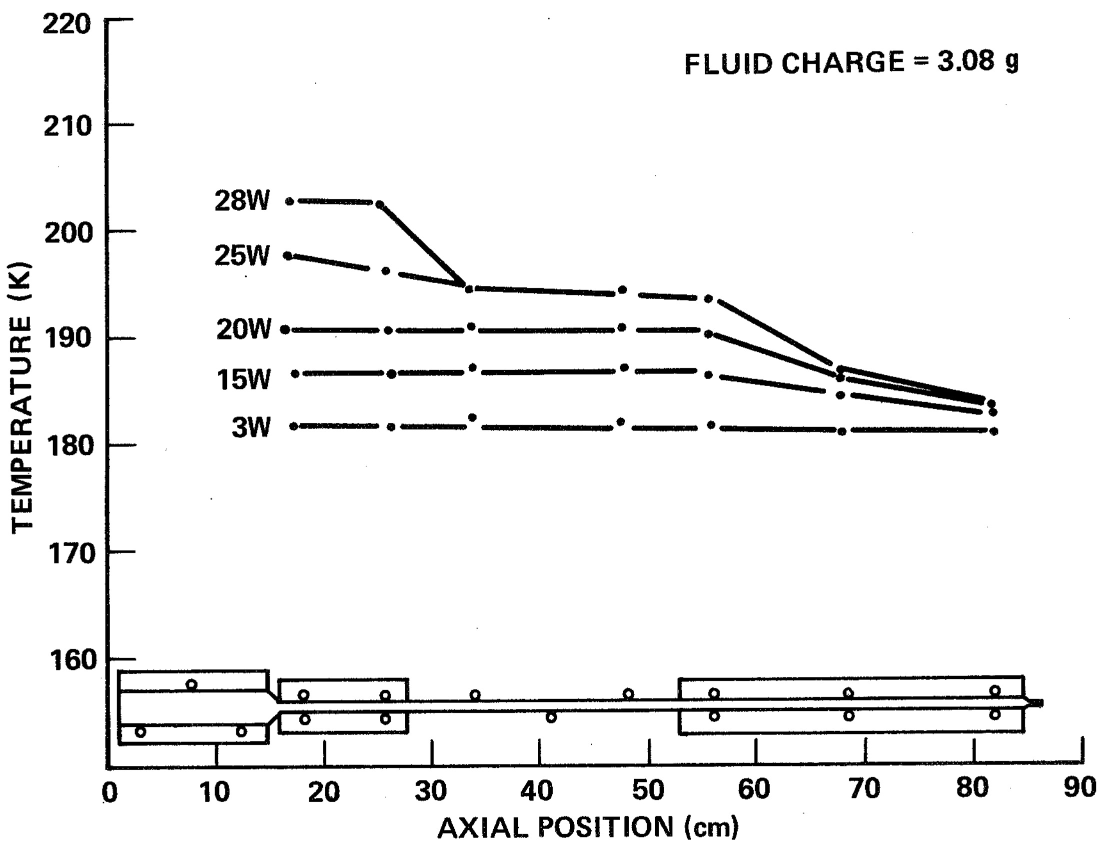

Figure 8.- Forward mode temperature profiles, 3.2 cm tilt.

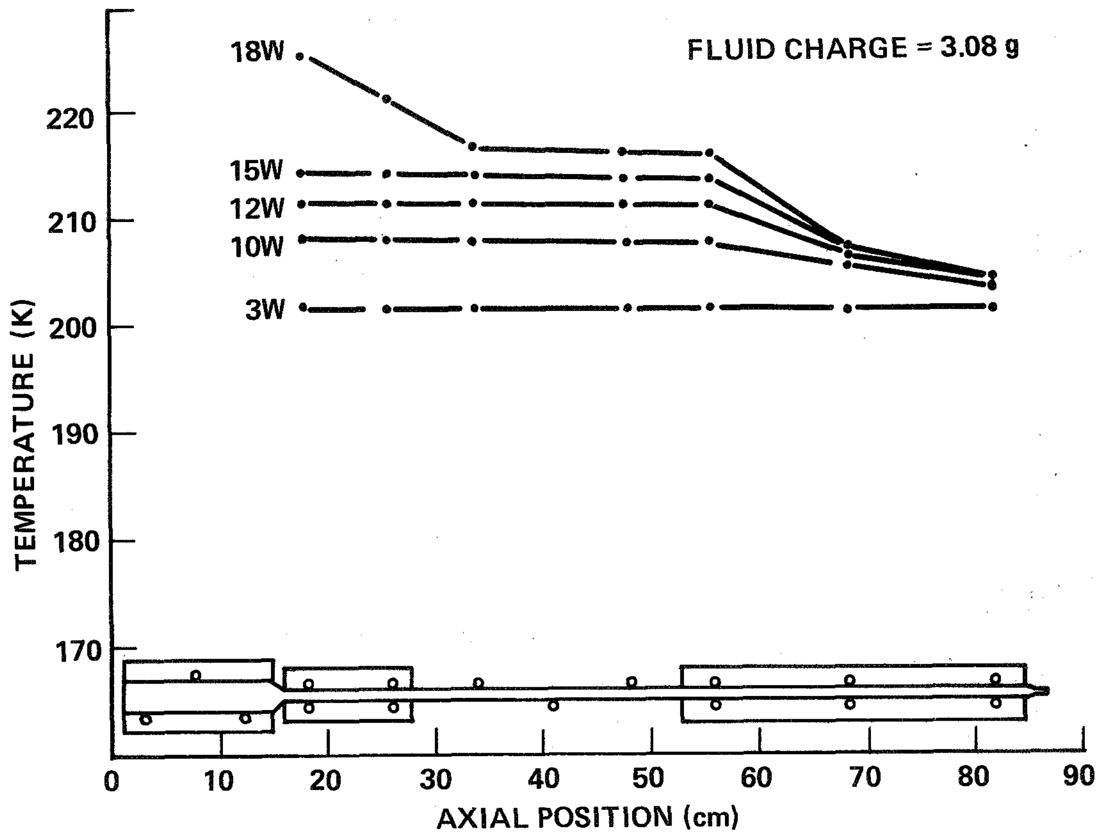

Figure 9.- Forward mode temperature profiles, 6 cm tilt.

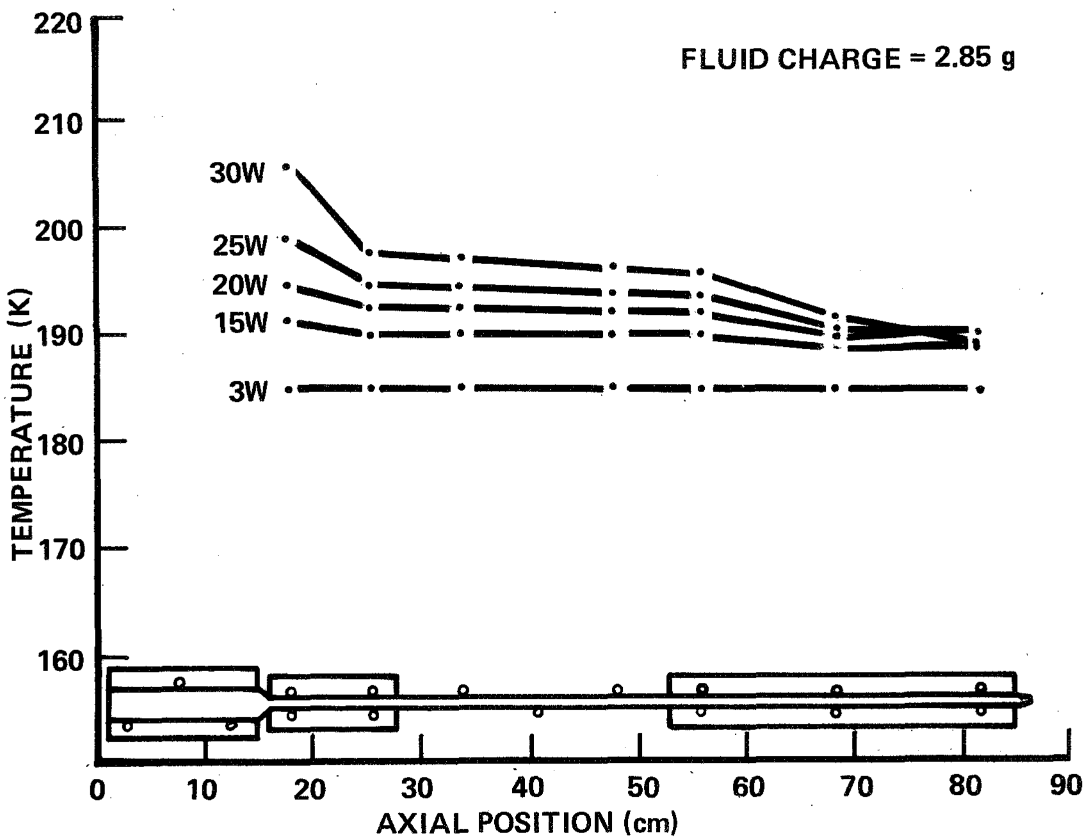

Figure 10.- Forward mode temperature profiles, horizontal pipe.

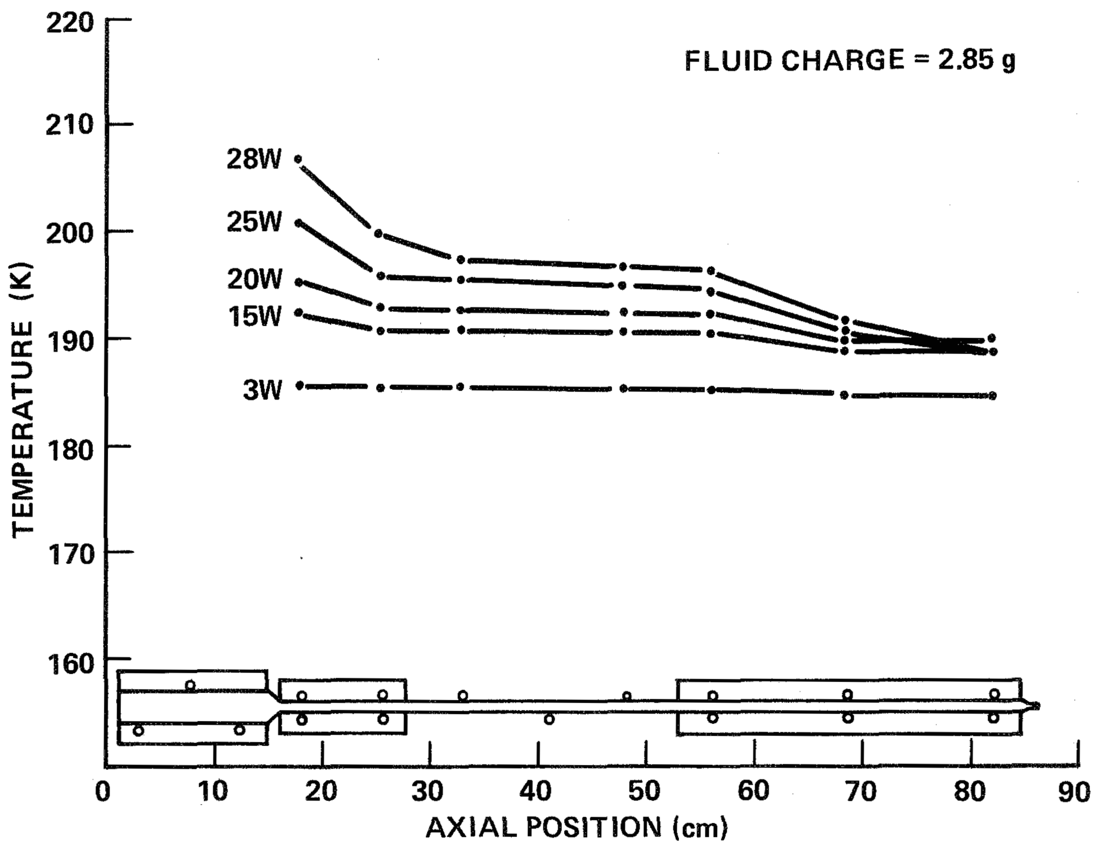

Figure 11.- Forward mode temperature profiles, 2 cm tilt.

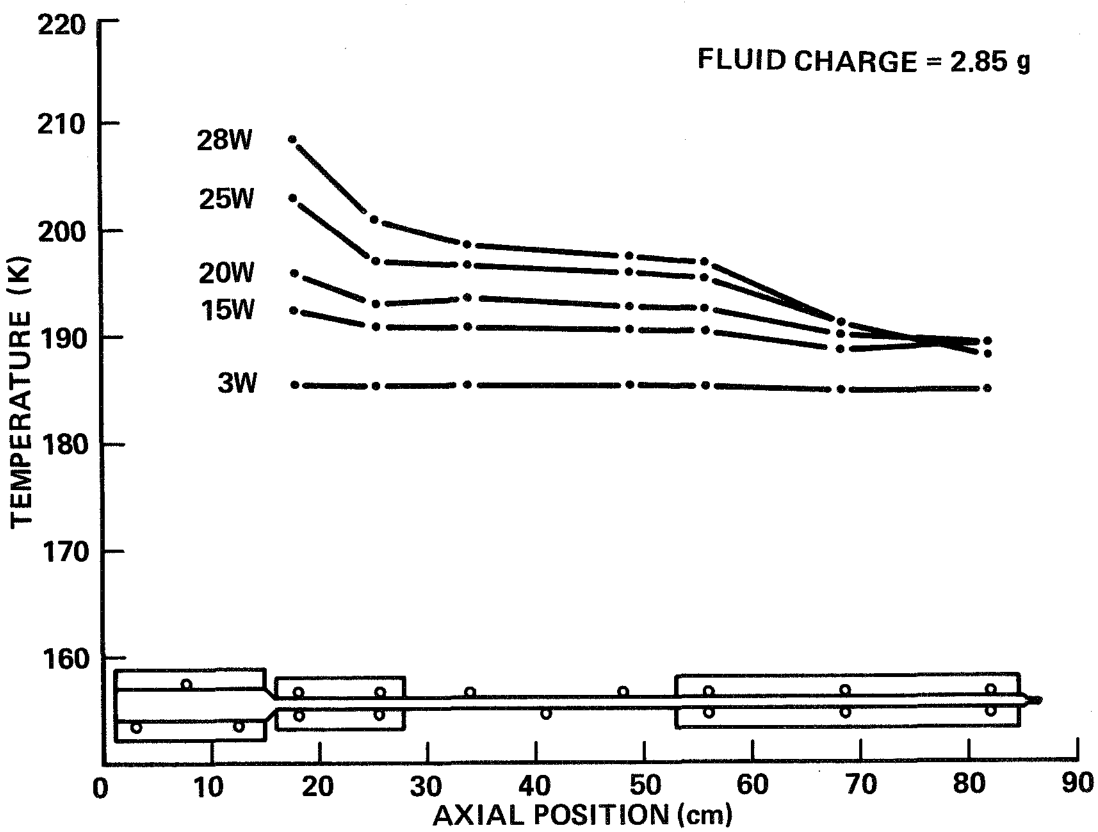

Figure 12.- Forward mode temperature profiles, 3 cm tilt.

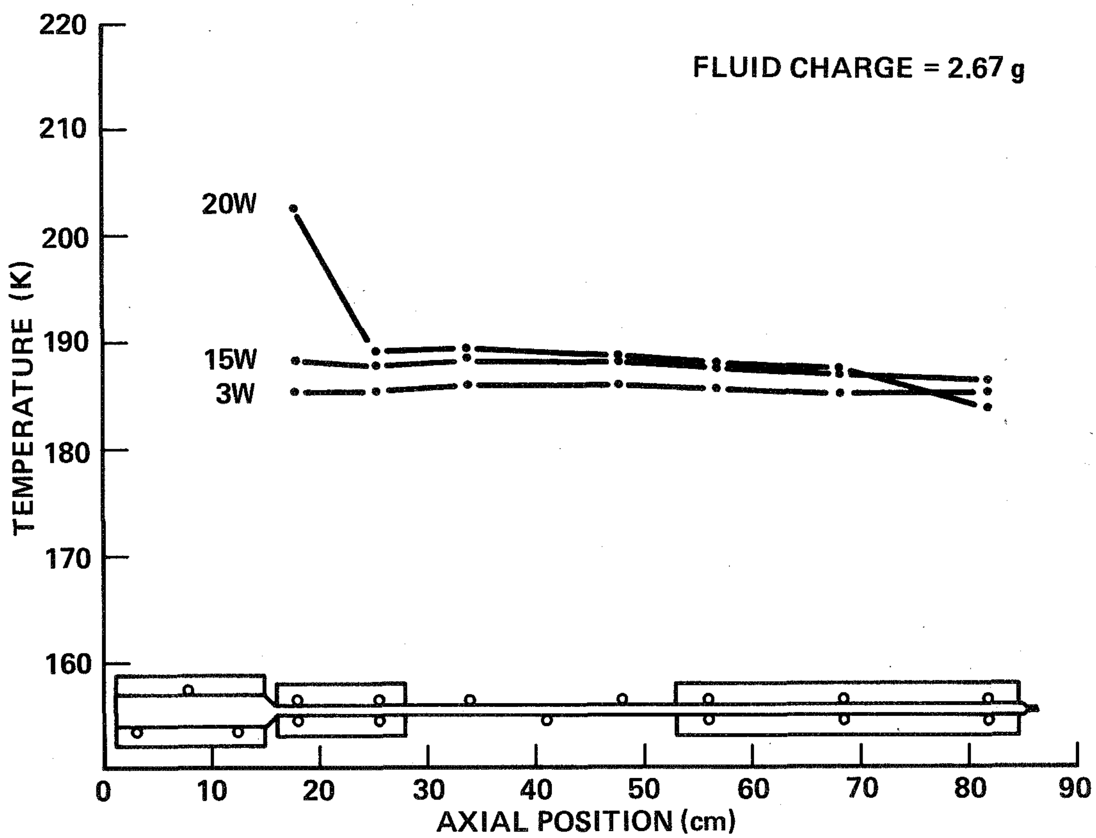

Figure 13.- Forward mode temperature profiles, horizontal pipe.

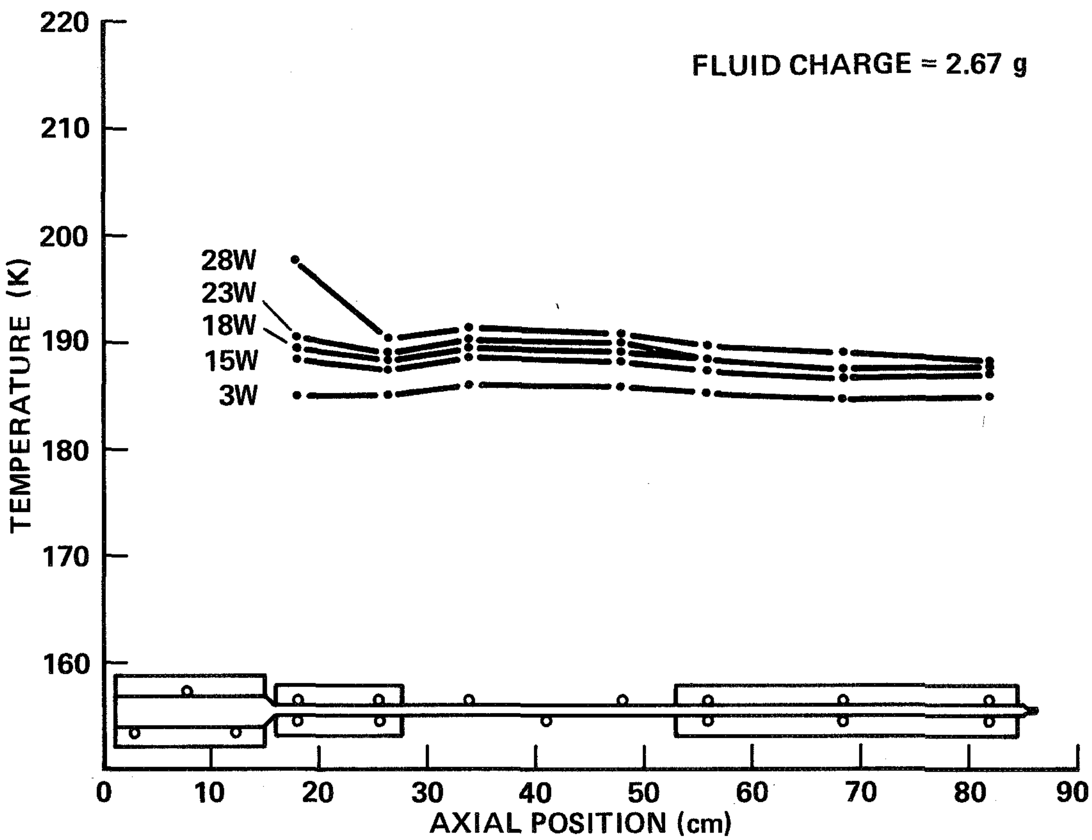

Figure 14.- Forward mode temperature profiles, 2 cm tilt.

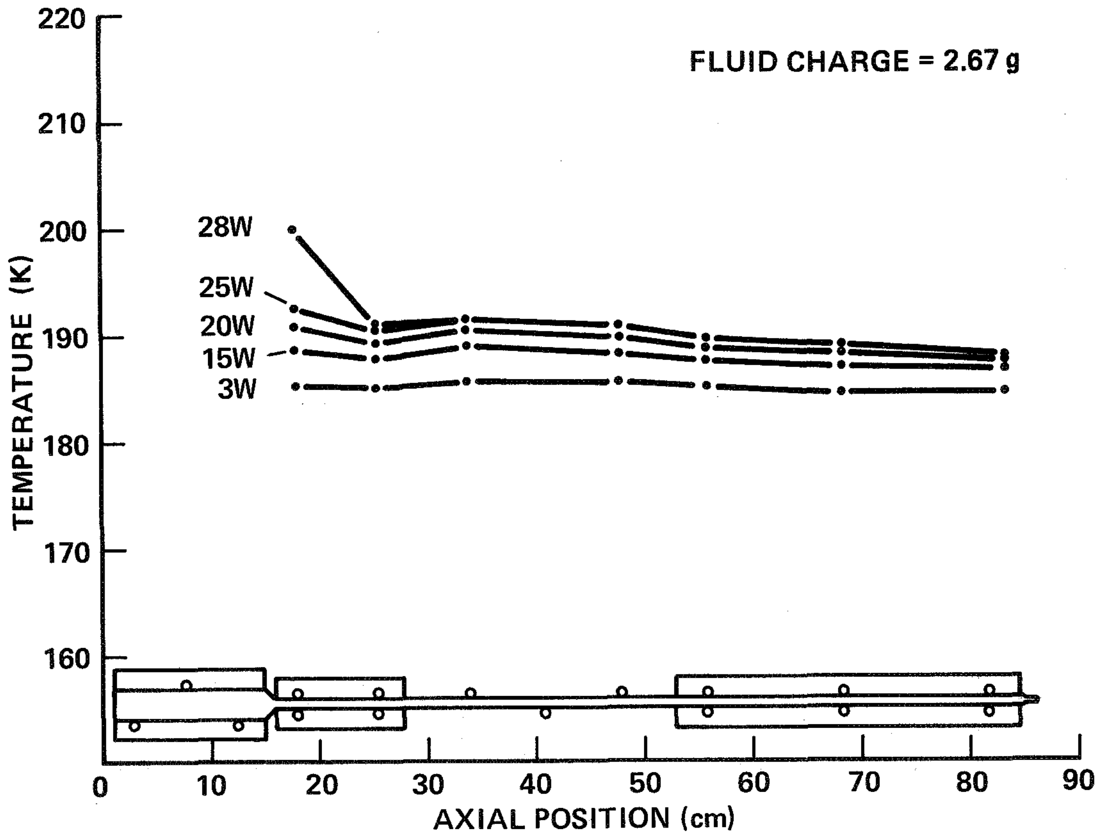

Figure 15.- Forward mode temperature profiles, 3 cm tilt.

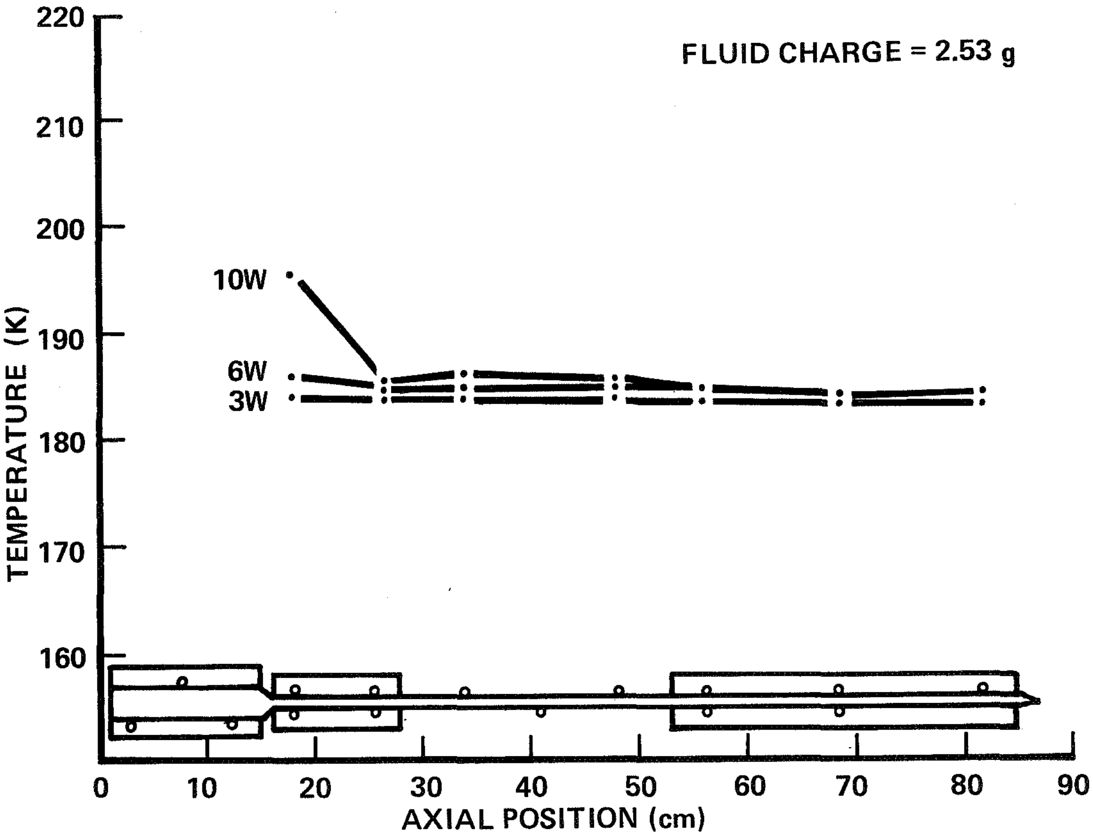

Figure 16.- Forward mode temperature profiles, horizontal pipe at 183 K.

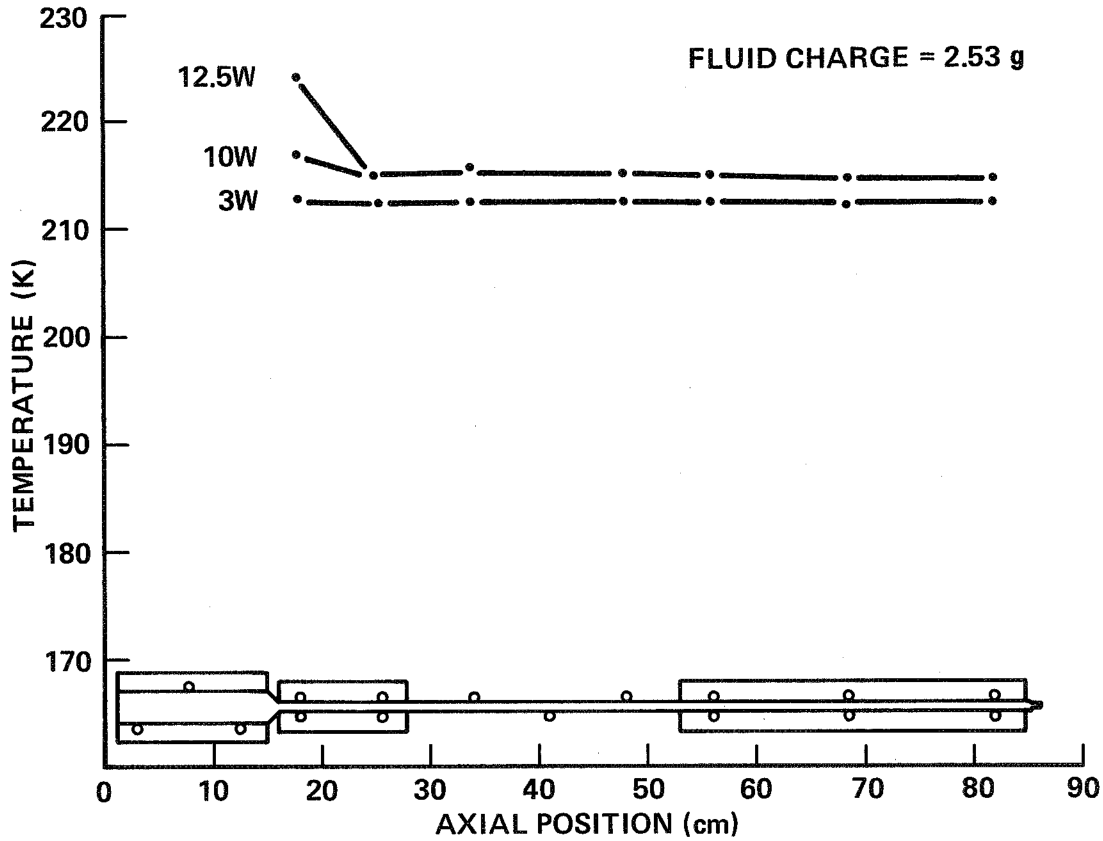

Figure 17.- Forward mode temperature profiles, horizontal pipe at 203 K.

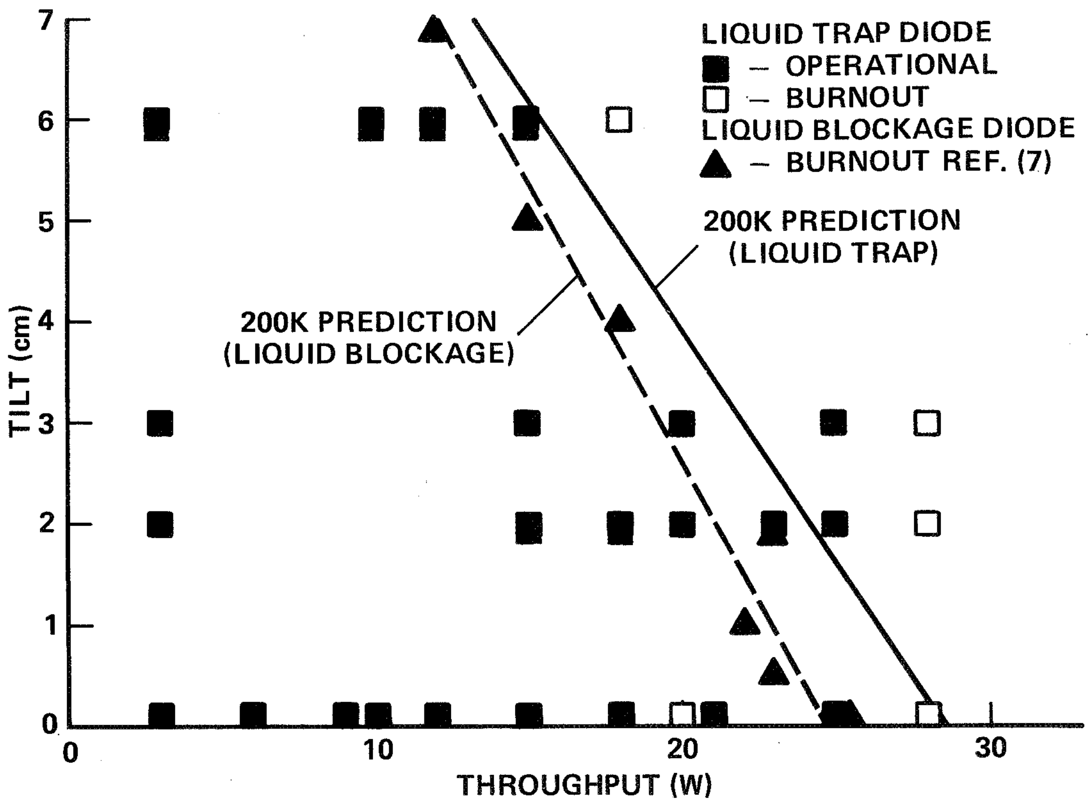

Figure 18.- Forward mode throughput characteristics.

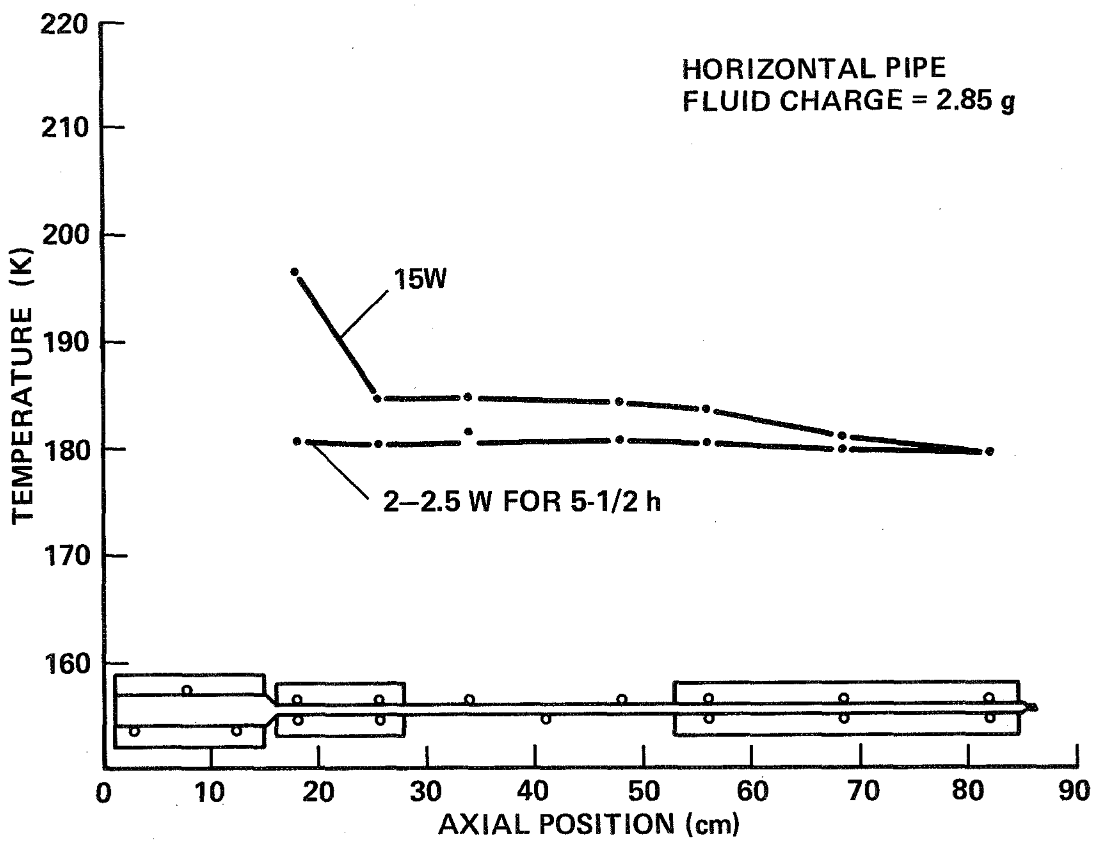

Figure 19.- Forward mode startup behavior.

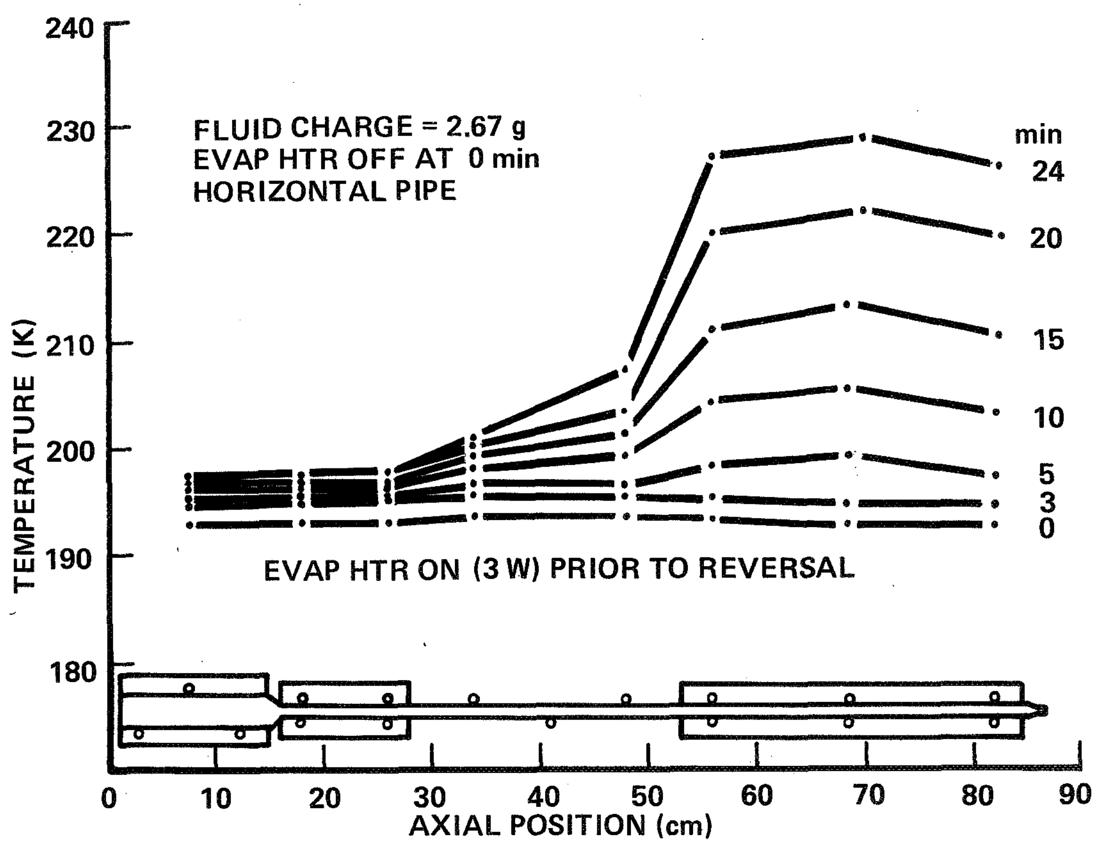

Figure 20.- Temperature profiles during reversal (evaporator heater off).

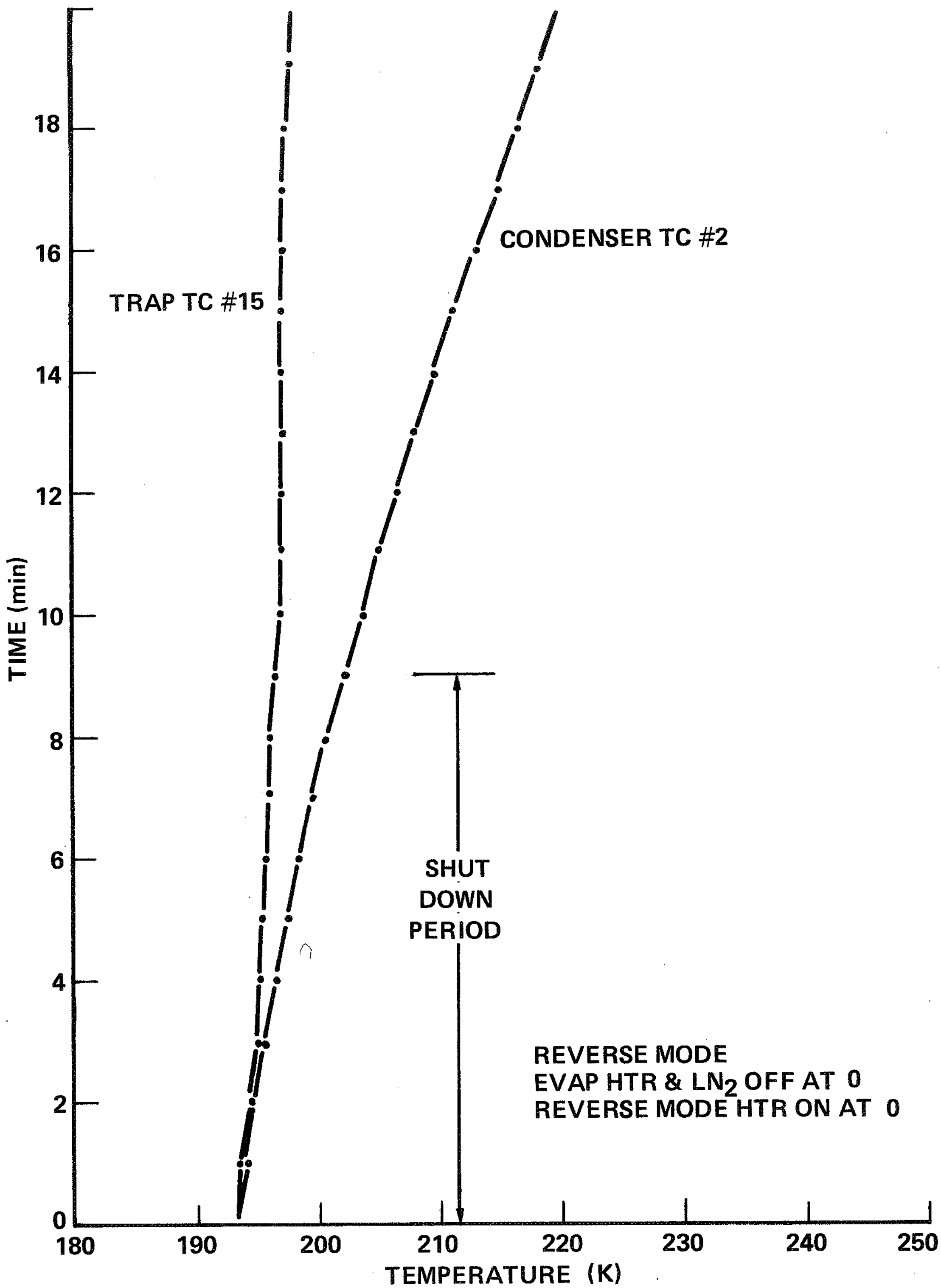

Figure 21.- Shutdown response of condenser and liquid trap.

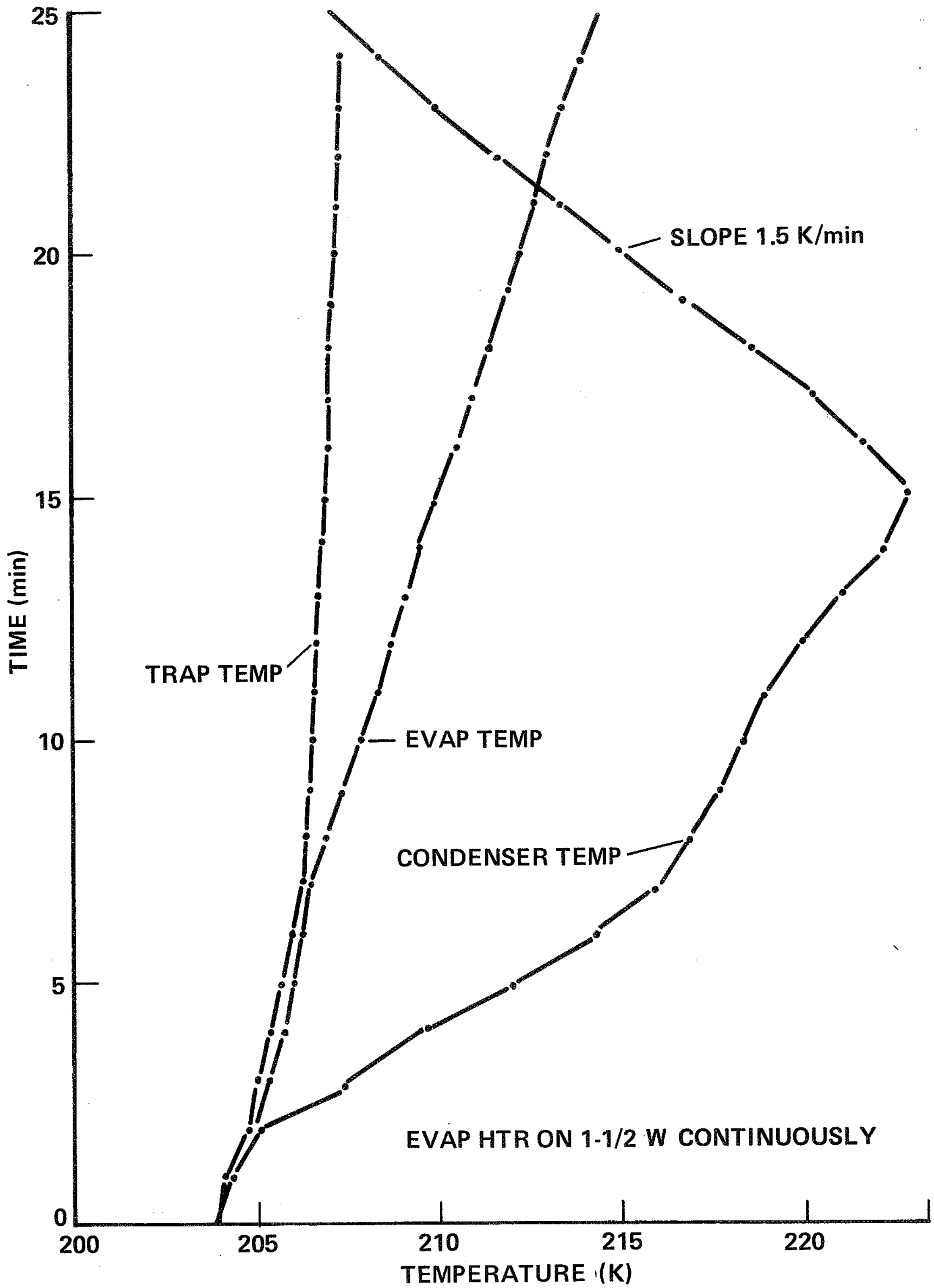

Figure 22.- Transient response during reversal and attempted recovery.

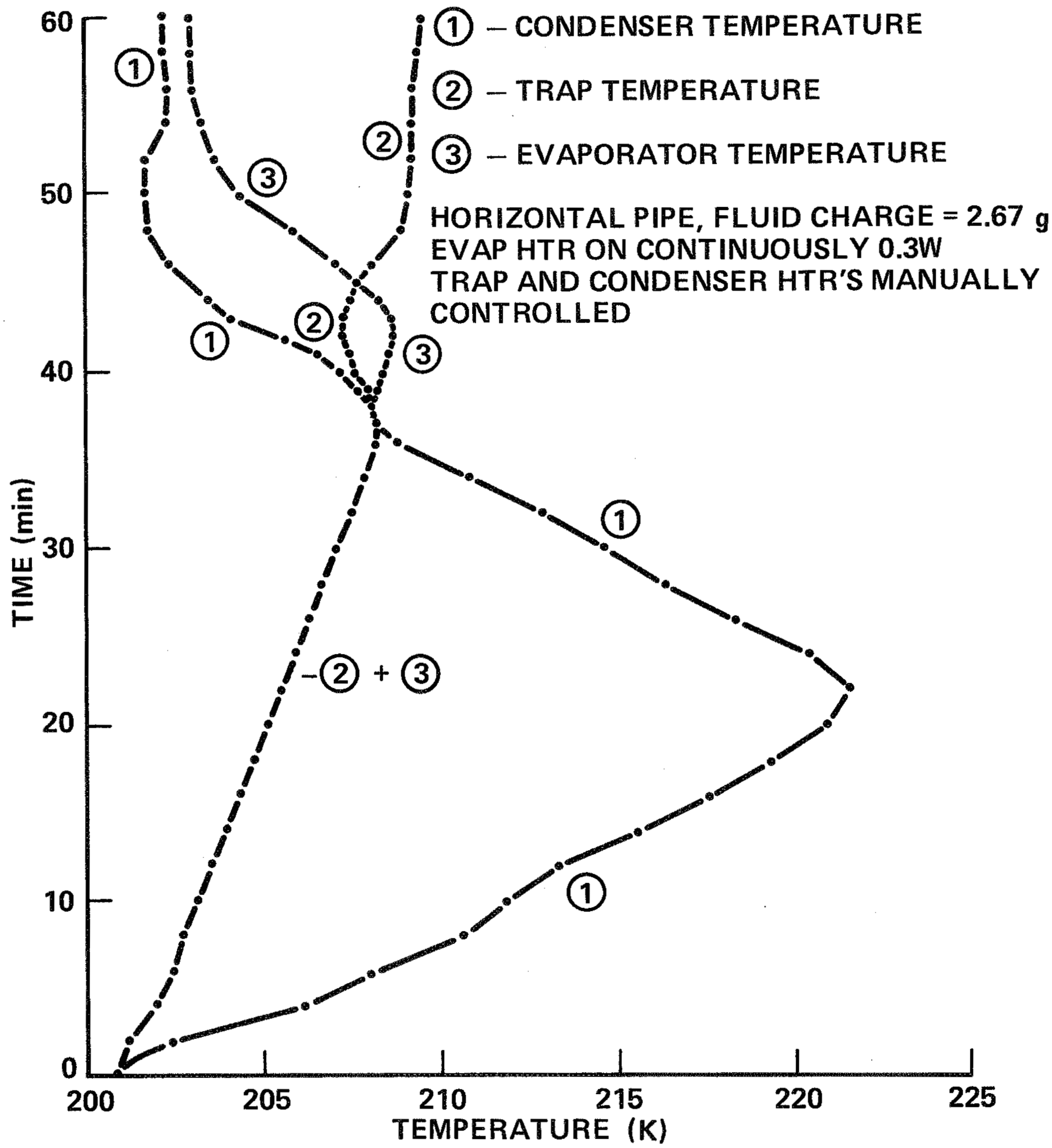

Figure 23.- Transient response during reversal and recovery.

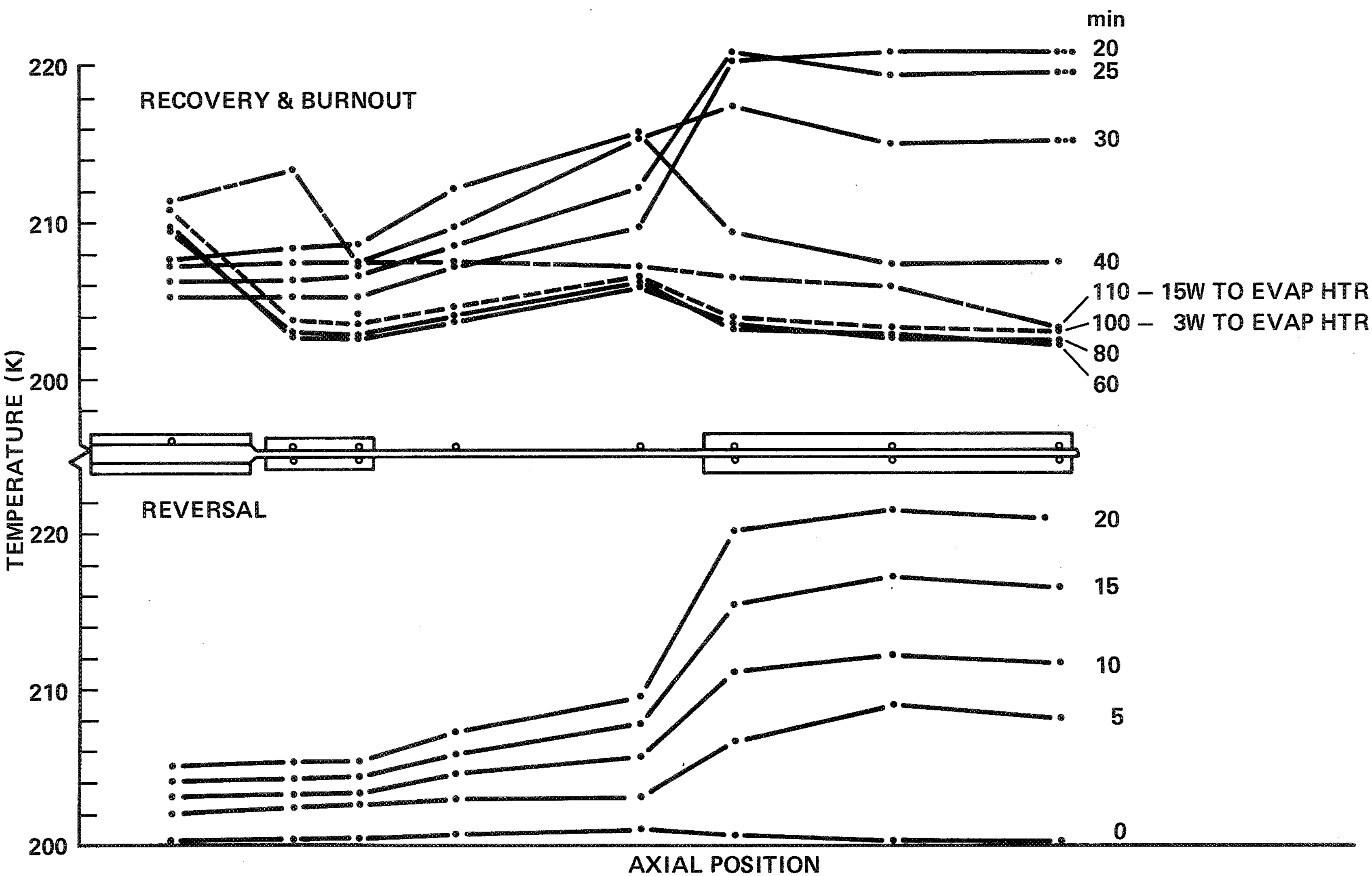

Figure 24.- Temperature profiles during reversal, recovery, and burnout.

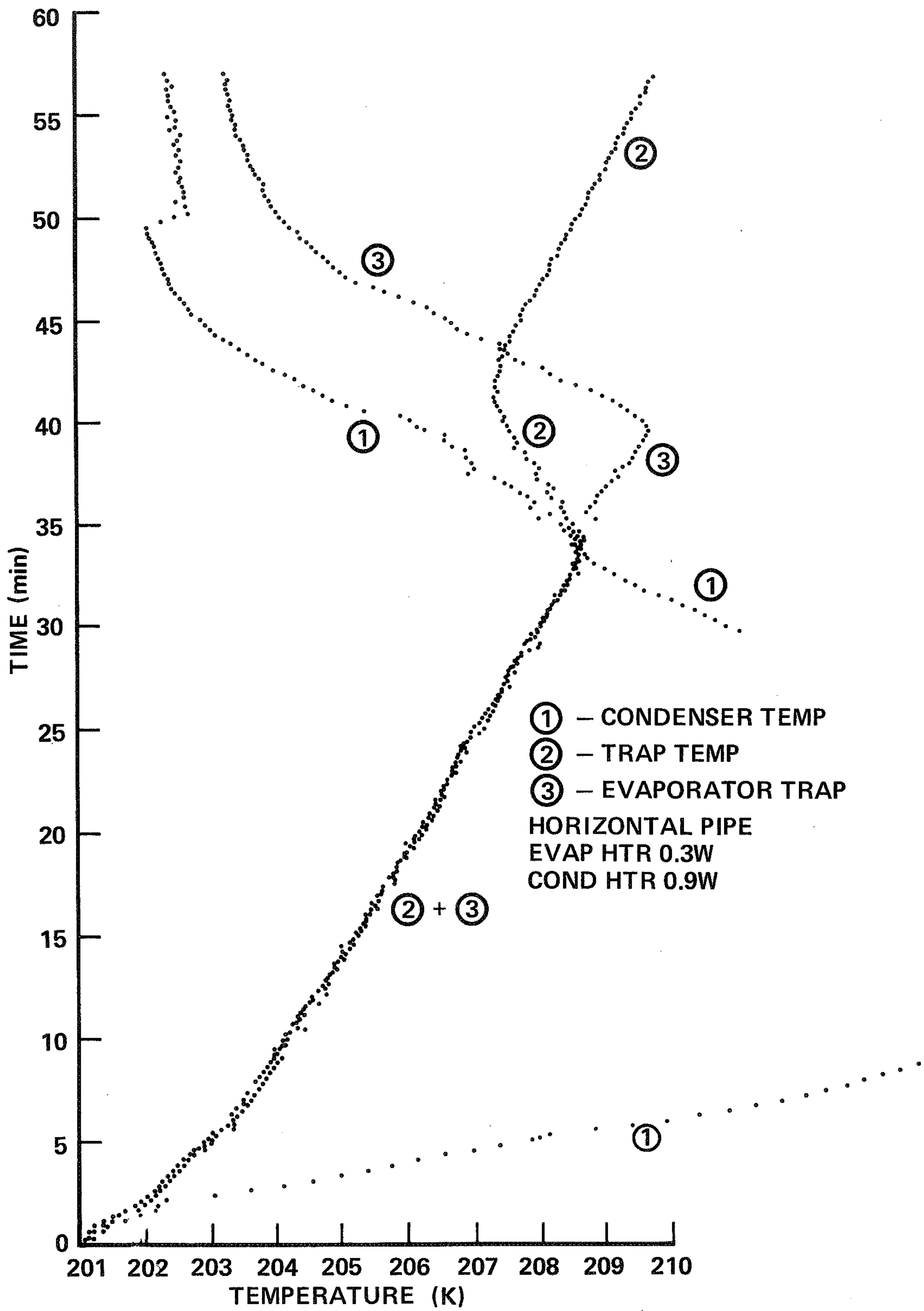

Figure 25.- Strip chart recording of reversal and recovery.

1. Report No. NASA TM-78,448	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PARAMETRIC PERFORMANCE OF A SPIRAL-ARTERY, LIQUID-TRAP-DIODE HEAT PIPE		5. Report Date
		6. Performing Organization Code
7. Author(s) Richard J. Williams*		8. Performing Organization Report No. A-7255
9. Performing Organization Name and Address NASA Ames Research Center Moffett Field, Calif. 94035		10. Work Unit No. 506-16-31
		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

*National Research Council, Resident Research Associate.

16. Abstract

This report describes a series of parametric investigations to determine the effect of various fluid charges on the performance of a 0.635-cm-diam spiral-artery, liquid-trap diode in both the forward and reverse modes. Specific parameters such as forward- and reverse-mode conductances, shutdown times and energies, and recovery to forward-mode operation, are evaluated for ethane as a working fluid in the temperature range 170 K to 220 K.

Results indicate that the heat pipe will not reliably start up in the forward mode. However, startup can be initiated when preceded by a diode reversal. Also included are data which show the susceptibility of the diode to fluid charge and tilt. The optimum fluid charge was found to be 2.67 g and transport capability at this charge was in excess of 1200 W-cm at 200 K. The diode in the reverse mode exhibited a rapid shutdown (within 9 min) with a shutdown energy of 1150 J (0.32 Wh).

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Cryogenic heat pipe Thermal diode	Unlimited STAR Category - 34

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	38	$4.00

*For sale by the National Technical Information Service, Springfield, Virginia 22161