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PERFORMANCE EVALUATION OF AN EVAPORATIVE WATER-RECOVERY SUBSYSTEM UTILIZING AN AUTOMATIC FEED CONTROL

by John B. Hall, Jr.

Langley Research Center
Hampton, Va. 23365

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16. Abstract

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The effects of urine collection and pretreatment on the quality of the recovered water were evaluated, and the degradation in subsystem performance with urine-solid buildup in the wicks was determined. Maximum wick life as determined by the capacity of the wick to retain urine solids was 36 days/man/pound of wick material (79 days/man/kilogram of wick material) for the urine and flush water processed.

The feasibility of utilizing an automatic control for batch feeding liquid wastes into the evaporator to minimize crew attention to the subsystem was demonstrated.

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SUMMARY

A performance evaluation has been conducted of an evaporative water-recovery subsystem designed to recover potable water from liquid wastes on long-duration manned space missions. The evaluation included four wick-life tests over a range of operating conditions. Process rates of 0.60 to 2.60 lb/hr (0.272 to 1.180 kg/hr) were obtained for various combinations of evaporator air-inlet temperature, condenser air-outlet temperature, and a subsystem average air-flow rate of approximately 37 ft^3/min (1.048 m^3/min). A total of 729.6 pounds (331 kilograms) of urine and flush water was processed with a recovery efficiency of virtually 100 percent.

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INTRODUCTION

Water-recovery subsystems will be required for long-duration space missions to collect waste water within the spacecraft, efficiently process this water, and return it to the crew as potable water. In addition to producing potable water, these subsystems should have automatic process controls to minimize crew attention during operation.

One water-recovery subsystem that has been under development for the past several years is a closed-cycle evaporative unit that utilizes a wick evaporator in a heated airstream. This subsystem has been operated during a number of integrated system tests of the integrated life support system at the Langley Research Center. (See ref. 1.) Operation, however, was generally at a single set of operating conditions without the aid of automatic process controls.

In order to obtain additional data on the operational capability of this water-recovery subsystem and to determine the feasibility of an automatic liquid-waste-feed control system, a bench-test program was conducted. This program was primarily directed at better defining the chemical and physical quality of the recovered water since the feasibility of the unit to produce microbiologically acceptable water had been demonstrated and is reported in reference 2. This report presents the data obtained from the test program in which four wicks were tested over a range of subsystem-operating conditions. By using the potability criteria specified in reference 3 as a guideline, selected chemical and physical analyses were made of the processed water to give an estimate of its quality. This report includes these data together with the performance characteristics of the liquid-waste-feed control system.

SUBSYSTEM DESCRIPTION

A schematic drawing of the evaporative, water-recovery subsystem used in this investigation is shown in figure 1. Basically, the subsystem is composed of three circuits: one each for the urine and flush water, air, and processed water. Included in the schematic are components used to accomplish the automatic-feed-control function.

In the urine and flush water circuit, waste water (urine and flush water) that has been chemically treated to fix the ammonia and retard the growth of micro-organisms is collected and transferred to the supply tank. When waste water is required in the wick, a solenoid valve is either manually or automatically actuated for sufficient duration to allow the desired quantity of liquid to flow into the wick evaporator and saturate the wick.

In the air circuit, air at about 37 ft^3/min (1.048 m^3/min) is forced through a closed loop by an electrically driven fan. The air passes through an electrically heated heat exchanger, where it is heated to increase its moisture-absorption capacity prior to passing through the saturated wick. Water is evaporated as the air flows through the wick. The nearly saturated air then passes through a charcoal filter for odor control and a condensing heat exchanger, where the water vapor is condensed. Water droplets are blown off the condenser, entrained by the airstream, and transferred to an air-driven centrifugal air-water separator rotating at about 4250 rpm. The water is separated from the airstream, and the air then returns to the fan for recirculation through the closed air loop.

In the processed-water circuit, the air-water separator pumps the processed water through a final charcoal filter into an accumulator tank. When the tank is filled to the desired level, the recovered water is automatically expelled into the storage tank.

The automatic-feed technique utilizes a finite quantity of processed water as the means for controlling the amount of waste water fed into the wick evaporator. Initially,

the wick evaporator is filled to the desired quantity with pretreated urine and flush water. As this water is processed, it is pumped by the air-water separator into the accumulator tank. As the accumulator tank fills, a piston-rod assembly moves until the upper microswitch (fig. 1) is actuated; and the three solenoid valves are thus energized. Nitrogen pressure is applied to the vent side of the piston; this pressure forces the piston in the opposite direction. Concurrently, the recovered water is expelled from the accumulator tank into the storage tank, and waste water is forced into the evaporator. When the piston bottoms, the lower microswitch is actuated, and the solenoid valves are deenergized. The nitrogen pressure is relieved from the vent side of the piston, and the flow of waste and recovered waters is terminated. The quantity of waste water that is fed into the evaporator while the accumulator tank is being emptied is controlled by the adjustment of the two throttling valves. The quantity of recovered water collected prior to feeding the waste water into the evaporator is controlled by the position of the upper microswitch.

TEST SETUP AND INSTRUMENTATION

A view of the test setup is shown in figure 2. Cooling for the condensing heat exchanger was supplied by a closed fluid loop. The cooling fluid was 25 percent (by volume) aqueous propylene glycol.

The power consumption of the air-circuit heat exchanger was monitored by a wattmeter connected across one phase of the 208 volt, 400 cps (400 hertz), three-phase input.

Six iron-constantan thermocouples, located as shown in figure 1, were used to determine operating temperatures. The outputs from the thermocouples were monitored on a strip-chart recorder.

A conductivity sensor was located in the processed-water circuit to give an indication of water quality. Subsequent to the tests, chemical analyses were made to further define recovered-water quality.

The quantity of the urine and flush water in the wick was determined from the output of three strain-gage load cells mounted under the wick evaporator. The load cells were electrically connected in parallel and were continuously monitored on a strip-chart recorder.

WICK-LIFE TESTS

Four wick-life tests were performed by using the test conditions shown in table I. Two wick configurations were used during these tests. The life of a wick was considered expended when either the measured properties of the recovered water exceeded the limits

given in reference 3 or the process rate of the urine and flush water became less than 0.70 lb/hr (0.318 kg/hr). This process rate was considered to be a minimum for a four-man crew.

Wick Configurations

Wick configuration 1, shown in figure 3, was used for tests 1, 2, and 3. The wicking material was rayon felt matte, which was 0.2 inch (0.508 cm) thick and weighed 1.06 lb/yd^2 (0.576 kg/m^2). The filler material, which allowed air to pass through the wick, was 0.25-inch- (0.635-cm-) thick urethane foam with 10 pores per linear inch (3.94 pores per linear cm). Thirty-two pieces each of the wicking and filler material were required to fabricate the wick core.

The wick core was installed in a housing fabricated from poly[ethylene terephthalate] plastic film, 0.015 inch (0.0381 cm) thick. The end cones and tubes were fabricated from 0.001-inch- (0.00254-cm-) and 0.005-inch- (0.0127-cm-) thick plastic film, respectively. Rubber connections were provided on the end tubes to allow flexible connections between the wick and the air circuit.

A stainless-steel manifold was installed on the top of the wick core to distribute the waste water into the wick. Details of the manifold are shown in figure 4. Wick configuration 1, including the manifold, weighed 2.33 pounds (1.06 kilograms).

Wick configuration 2 was used for test 4. The wick-core materials and dimensions were the same as those used in wick configuration 1. The wick was modified for side loading in a stationary, stainless-steel holder, as shown in figure 5. The top of the wick-holder structure served as the waste-water manifold. This manifold consisted of two plates spaced 0.125 inch (0.318 cm) apart with 0.03-inch-diameter (0.0762-cm) holes perforated in the bottom plate. The manifold allowed a more even distribution of waste water within the wick. Wick configuration 2, excluding the holder, weighed 1.87 pounds (0.85 kilogram).

Charcoal Filters

Two charcoal filters were provided in the subsystem to aid in odor control. These filters contained Barnebey-Cheney type HE charcoal. Charcoal capacities of the air-stream and processed-water filters were 2.25 pounds (1.02 kilograms) and 0.25 pound (0.113 kilogram), respectively.

Waste-Water Mixture and Collection Methods

The waste-water mixture processed in the subsystem simulated the daily accumulation, 16.8 pounds (7.62 kilograms), provided by a four-man crew in a closed environment.

The ratio of urine to flush water was 3.67 to 1 (by weight). The mixture was treated with a chromic acid solution recommended in reference 4; this mixture consisted (by weight) of 4.0 parts sulfuric acid (H_2SO_4), 4.08 parts distilled water, and 1.0 part chromium trioxide (CrO_3).

Urine was collected for tests 1 and 2 in an open empty container placed in the men's restroom at the beginning of each work day. No attempt was made to screen and control the urine donors. At the end of the day, the container with the collected urine was sealed and placed in a refrigerator at 40° F (4.4° C) until it was required for processing. Immediately prior to processing, distilled water was added to the urine to maintain a ratio of urine to flush water of 3.67 to 1. This mixture was pretreated with 4 milliliters (4 cm^3) of the chromic acid solution per liter (0.001 m^3) of urine.

Urine for tests 3 and 4 was collected in an open container initially containing 1 pound (0.454 kilogram) of distilled water and 20 milliliters (20 cm^3) of the chromic acid solution prior to placing the container in the men's room. No attempt was made to screen and control the urine donors. The collected urine was removed daily from the restroom and mixed with additional chromic acid solution to give 4 milliliters (4 cm^3) per liter (0.001 m^3) of urine. In addition, sufficient distilled water was added to maintain the ratio of urine to flush water of 3.67 to 1. The waste water was then stored in a refrigerator at 40° F (4.4° C) until required for processing. Prior to processing, additional chromic acid solution was added, as required, to reduce the pH of the waste water to 2. The quantity of the chromic acid solution used during these tests averaged 7.3 milliliters (7.3 cm^3) per liter (0.001 m^3) of urine.

Test Method

A clean wick and clean charcoal filters were installed in the unit prior to the start of each test. The wick was filled with 5.95 pounds (2.70 kilograms) of urine and flush water. Then the unit was started and operated for sufficient time to allow operating temperatures to stabilize. Adjustments were made to the automatic feed control to maintain the desired amount of waste water in the wick. The unit was then operated until the wick was expended. Operation was continuous except for shutdown for maintenance and repair. Manual operation was restricted to transferring the urine and flush water into the subsystem supply tank as it was required. Performance data were taken every 2 hours. Samples of the recovered water were taken at intervals during each test for chemical and physical analysis. The quantity of waste water in the wick and process rates were determined by correlating process time with the output of the load cells positioned under the wick.

RESULTS AND DISCUSSION

Table I gives a summary of the wick-life tests, and table II gives a summary of selected chemical and physical properties of the recovered water. Figure 6 shows subsystem process rates, and figures 7, 8, and 9 show chemical and physical properties of the recovered water as functions of solid concentrations (percent by weight) in the wick evaporators. The solid-concentration values are the ratios of accumulated solids to waste-mixture quantities in the wick evaporators. These quantities are mean values of the total-weight operating ranges shown in figures 10, 11, 12, and 13. Also shown in these figures are solid symbols which represent the amount of solids retained in the wicks after they were dried down. The dashed lines in figures 10, 11, 12, and 13 represent accumulated solids in the wicks assuming a linear solid buildup as the waste water was processed. This assumption was validated during test 4. (See fig. 13.) The values above and below the dashed lines represent the water and solid portions, respectively, of the total waste mixtures in the wick evaporators. Figures 14, 15, and 16 show wick-evaporator configurations after completion of wick-life tests.

Effect of Method of Urine Collection and Acid Pretreatment

The method of urine collection and acid pretreatment used for tests 1 and 2 was considered to yield the worst results. No attempt was made to control bacteria or the production of ammonia in the mixture until immediately prior to processing. During tests 3 and 4, partial control of bacteria and ammonia was maintained during collection and storage prior to processing. This control resulted in significant improvements in the chemical and physical properties of the recovered water as indicated in table II. The average conductivity and ammonia levels for tests 1 and 2 were both approximately six times greater than the averages for tests 3 and 4. The importance of pretreating the urine early with sufficient chromic acid solution to prevent the production of ammonia either by the bacterial enzyme decomposition of urea or the liberation of free ammonia from the urine during processing was indicated. When the concentration of ammonia in the recovered water reached approximately 40 parts per million (ppm), a noticeable odor was detected. Subsequent removal of the odor required the replacement of the wick and the charcoal filters, and cleaning of all plumbing and tankage with distilled water.

Waste-Water Process Rates

Waste-water process rates, as shown in figure 6, ranged from about 0.60 to 2.60 lb/hr (0.272 to 1.180 kg/hr) over the practical operating range of the subsystem. These process rates were reduced to zero as the wicks were dried down. Degradation in process rates occurred when the solid concentration in the wick evaporators exceeded

33 percent by weight. This phenomenon was prevalent in all the tests and appeared to be independent of process temperatures or method of urine collection and pretreatment.

Comparison of wick-life tests 1 and 4 over similar operating conditions shows the process rates for wick configuration 2 were lower than those for wick configuration 1. (See fig. 6.) This lower rate is thought to be attributed to the improved water distribution within the wick, which allowed the wick to process at a lower temperature; thus the waste-water vapor pressure was lowered; and consequently the process rate was reduced.

Water-recovery efficiency, defined as the weight ratio of the water recovered to the urine and flush water processed excluding the urine solids, was virtually 100 percent. The solids in the urine and flush water averaged 3.5 percent by weight (4.7 percent for urine only). A total of 729.6 pounds (331 kilograms) of urine and flush water was processed.

Water Quality

A complete chemical and physical analysis of the recovered water, as presented in reference 3, was not attempted during this evaluation. Only selected properties, as shown in table II, were obtained to give an estimate of water quality.

Figure 7 shows the conductivity of the recovered water as a function of solid concentration in the wick evaporator. The excursions in the curve for test 4 were due to operating temperature changes and adjustment of waste liquid in the wick.

The results indicate that regardless of the method of urine collection and pretreatment and of subsequent operating temperatures, the conductivity and the ammonia concentration in the recovered water increased rapidly when the solid concentration in the wicks exceeded 70 percent by weight. Comparison of figures 7 and 8 shows that the shape of the curves is the same for both conductivity and ammonia concentration; this similarity suggests that ammonia may be the major contaminant in the recovered water.

Examination of figure 9 shows that the concentration of urea in the recovered water was negligible for tests 3 and 4. Significant quantities of urea did, however, appear during tests 1 and 2. Usually, urea cannot appear in the recovered water unless physically transported to the condenser through flooding of the wick or entrainment (ref. 4) in the airstream. Figures 10 and 11 show that the wicks were not flooded since the initial capacity of the wicks was not exceeded during these tests. Entrainment does not appear to be the cause since no appreciable urea was detected in the recovered water during tests 3 and 4. Therefore, no explanation for this phenomenon was apparent.

Table II shows that for the chemical properties analyzed the recovered water meets those requirements established in reference 3.

The physical requirements were met only during test 3. The objectionable odor present in the recovered water during tests 1 and 2 was primarily caused by ammonia. The odor found during test 4 was thought to have been caused by other sources since the ammonia content was low and an odor (sulfur) was detected in the recovered water.

Power Requirements

The powers required to obtain the process rates shown in figure 6 are listed in table I. These requirements varied from 0.85 to 1.44 kW. These values include 0.10 kW to operate the fan in the air circuit but do not include any allowance for cooling condensation. The remaining power was required to heat the air prior to its flow through the wicks. While the electrical power requirements appear to be high, utilization of waste heat from a Brayton cycle power subsystem or incorporating individual radioisotopes in the air circuit could substantially reduce these requirements.

Wick Life

Tests 1 and 2 were terminated because of the objectionable odor, excessive turbidity, and high conductivity of the recovered water. Although a conductivity limit was not given in reference 1, an upper limit of 1700 μmhos/cm, established in reference 5, was used during these tests. The excessive physical constituents of the recovered water were attributed to the inability of the collection and pretreatment method to prevent the production of ammonia in the urine and flush water prior to processing.

Test 3 was terminated after 191 pounds (86.7 kilograms) of the waste water had been processed. This test was terminated for convenience. Water quality was acceptable throughout the test, even though evaporator inlet temperature was varied during operation. (See table I.) Solids retained in the wick amounted to 6.8 pounds (3.1 kilograms) at the completion of the test.

Test 4 was terminated after 281 pounds (127.4 kilograms) of waste water had been processed. Test termination was due to objectionable odor (as previously discussed) and insufficient process rate to reclaim the daily accumulation of urine and flush water provided by a four-man crew. Wick saturation was maintained throughout the test by adjusting the automatic feed control to continuously increase the waste-water content in the wick in proportion to the increase in solid content. Operating the wick in this manner utilized the full capacity of the wick to retain urine solids. Figure 15 shows the wick after test 4 with 10.6 pounds (4.8 kilograms) of solids retained in the wicking material. The dot points on top of the wick show the water-input locations of the modified water-feed wick holder. Figure 16 shows the interior of the modified wick holder with the wick removed. A quantity of black mud-like solids with a very offensive odor had accumulated in the exit end of the holder.

Results from the tests of wick configuration 1 show that when the urine and flush water is sufficiently pretreated to prevent the production of ammonia and the wick is operated at its saturation level, 184.2 pounds (83.6 kilograms) of water can be recovered that meet selected chemical and physical requirements from reference 3. The test for wick configuration 2 indicated that when the wick is operated at a sufficient saturation level, 270.4 pounds (122.6 kilograms) of water can be recovered before the process rate is insufficient to maintain the daily water balance for a four-man crew. This is equivalent to recovering the available water from the urine output of four men for 17 days plus the water used for urinal rinse. This quantity is also equivalent to 36 days/man/pound of wick material (79 days/man/kilogram of wick material).

Automatic Feed Control

Figures 10, 11, 12, and 13 show the range of automatic operation during the wick-life tests. The data from approximately every fifth batch is plotted in figures 10, 11, and 12, whereas the data from approximately every tenth batch is plotted in figure 13. Various modes of feed control were used to determine the feasibility of the technique to maintain the desired amount of waste water in the wick evaporator. Initially the wicks were manually filled with 5.95 pounds (2.7 kilograms) of urine and flush water. This quantity represents approximately 95 percent of the saturation of a clean wick as observed visually.

During tests 1 and 2 (figs. 10 and 11), the feed control was adjusted to maintain a constant total-weight operating range. When 1.3 pounds (0.59 kilogram) of water had been recovered, an equal amount of urine and flush water was automatically fed into the wicks. This technique did not compensate for solid buildup in the wicks, and they tended to dry down during extended periods of operation.

The excursion in the operating level shown in figure 10 was due to initial adjustments of the feed control to maintain the desired liquid in the wick. Subsequent to these adjustments the batching range stabilized as shown in figures 10 and 11.

The batching interval used during test 3 (fig. 12) was the same as that used during tests 1 and 2. Subsequent to the recovery of 110 pounds (49.9 kilograms) of water, additional waste water was added to the wick until saturation was visually observed. Then the wick was automatically fed as previously discussed. This procedure was repeated at intervals until the test was terminated, which indicated that the wicks could retain more solids than initially thought.

During test 4 (fig. 13), the automatic feed control was adjusted to compensate for solid buildup in the wick. The excursions in the operating range are due to operator errors. Once the feed control was properly adjusted, the range stabilized. The batching quantity was shortened to 0.875 pound (0.397 kilogram) for this test.

The automatic feed control functioned satisfactorily during these tests with an accumulation of 572 cycles.

CONCLUDING REMARKS

A performance evaluation of an evaporative water-recovery subsystem over a range of operating conditions was conducted. The importance of sufficiently pretreating the urine and flush water to preclude the production of ammonia and the resulting effects on the recovered water were demonstrated. The results showed a degradation in the process rate when the solid concentration in the wick evaporators exceeded 33 percent by weight. Recovery of virtually 100 percent of the available water in the mixture of urine and flush water was demonstrated. The chemical and physical properties of the recovered water degraded rapidly when the solids in the wick evaporator exceeded 70 percent by weight. The electrical power requirements were high, but utilization of waste heat from a Brayton cycle power subsystem or incorporating individual radioisotopes in the air circuit could substantially reduce these requirements. Wick life for the configurations tested can be extended to recover water from the urine output of four men for 17 days when the wick is operated at its saturation level. The feasibility of utilizing an automatic feed control was demonstrated through 572 cycles of operation in which the desired amount of waste water was maintained in the wick evaporator.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., May 19, 1970.

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TABLE I.- SUMMARY OF WICK-EVAPORATOR-LIFE TESTS

Test	Operating temperatures				Input of urine and flush water		Water recovered		Solids		Power	Process time	Automatic batch
	Wick evaporator air inlet		Condenser air outlet										
	^{o}F	^{o}C	^{o}F	^{o}C	lb	kg	lb	kg	lb	kg	kW	hours	cycles
1	201	93.9	82	27.8	124.0	56.3	119.6	54.3	4.4	2.0	1.44	65	89
2	161	71.7	60	15.6	133.6	60.6	129.0	58.5	4.6	2.1	1.26	89	98
3	126	52.2	51	10.6	143.0	64.9	138.2	62.7	4.8	2.2	0.86	110	99
	165	73.9	51	10.6	48.0	21.8	46.0	20.9	2.0	0.9	1.28	34	34
4	200	93.3	81	27.2	191.0	86.6	183.2	83.1	7.8	3.5	1.26	101	168
	155	68.3	79	26.1	28.0	12.7	27.0	12.2	1.0	0.5	0.85	35	26
	178	81.1	77	25.0	62.0	28.1	60.2	27.3	1.8	0.8	1.11	90	58

TABLE II.- SELECTED CHEMICAL AND PHYSICAL PROPERTIES OF THE RECOVERED WATER

Test	Operating temperature				Water recovered		Solids in wick evaporator	Chemical, parts per million (ppm)						Physical					
	Wick evaporator air inlet		Condenser air outlet					Ammonia	Chloride	Sulfate	Alkalinity	Phosphate	Urea	Total solids (a)	Color (a)	Odor (a)	Turbidity (a)	pH	Conductivity (b)
	°F	°C	°F	°C	lb	kg	Percent by weight	Nitrogen	(a)	(a)			Nitrogen	ppm	$PtCl_6$ units	Threshold no.	Silica ppm		μmhos/cm
1	201	93.9	82	27.8	6	3	8	0	4	12	47	9	7	497	<5	0	12	5.8	100
					45	20	33	20	10	19	70	3	24	133	<5	0	11	7.8	180
					62	28	44	33	23	6	130	5	19	47	<5	0	12	8.1	330
					84	38	60	61	13	6	245	4	22	160	<5	0	12	8.5	405
					91	41	64	103	25	8	310	4	2	120	<5	3	21	8.3	720
					106	48	73	99	30	6	350	5	27	68	<5	3	10	8.7	750
					107	49	74	109	20	13	390	9	21	104	<5	3	28	8.5	885
					117	53	81	279	85	6	395	7	13	223	<5	3	10	9.0	1850
					119	54	82	294	95	9	1180	7	91	263	<5	3	10	9.0	2150
					120	54	100	203	43	8	625	5	31	180	<5	3	10	8.9	1380
2	161	71.7	60	15.6	16	7	14	4	3	4	30	2	1	28	<5	0	10	7.2	46
					39	18	29	13	3	7	50	2	0	52	<5	0	8	7.5	89
					53	24	38	11	3	3	60	2	0	28	<5	2	18	7.1	100
					62	28	44	19	3	4	75	3	0	512	<5	3	13	7.3	142
					73	33	52	32	3	4	105	4	0	56	<5	2	15	7.4	220
					86	39	60	32	5	7	140	3	44	124	<5	1	12	7.5	290
					100	45	69	71	5	9	285	3	92	72	<5	3	17	7.8	590
					106	48	74	97	5	8	315	3	109	88	<5	3	18	8.0	640
					116	53	80	256	13	11	1120	11	302	180	<5	3	13	9.0	1700
					124	56	85	572	8	7	1955	18	0	95	<5	3	13	9.0	2600
					126	57	87	356	23	8	1230	11	0	108	<5	3	13	9.2	2400
					129	59	100	407	13	6	1240	10	0	121	<5	3	11	9.1	2200
3	126	52.2	51	10.6	7	3	8	3	15	2	30	3	0	80	<5	3	4	6.3	67
					10	5	10	2	5	2	25	1	0	28	<5	0	7	5.9	33
					12	5	11	0	3	2	30	1	0	48	<5	0	2	6.2	25
					15	7	13	4	3	3	20	1	0	180	<5	0	2	7.1	21
					33	15	25	0	5	2	20	1	0	51	<5	0	4	6.9	12
					43	20	32	0	5	2	25	0	0	41	<5	0	4	6.5	11
					52	24	38	0	3	2	20	0	0	---	<5	0	4	6.0	13
					70	32	50	0	3	5	20	0	0	108	<5	0	4	6.8	12
					77	35	52	1	3	5	15	0	7	52	<5	0	2	6.3	12
					85	39	60	1	5	5	15	0	1	---	<5	0	2	5.7	13
					92	42	64	1	3	3	20	0	0	43	<5	0	4	6.8	13
					103	47	72	1	3	3	25	0	0	45	<5	0	4	6.5	14
					107	49	74	2	3	2	25	0	0	---	<5	0	2	6.5	17
					121	55	84	1	3	3	15	0	0	36	<5	0	4	6.7	12
					127	58	88	0	3	3	20	0	0	51	<5	0	4	6.6	9
					138	63	[c]74	2	3	2	15	0	0	66	<5	0	4	6.5	9
	165	73.9	51	10.6	148	67	[c]69	0	5	5	25	1	4	58	<5	0	4	6.3	30
					161	73	[c]66	0	5	3	30	0	4	34	<5	0	5	5.9	28
					174	79	[c]66	13	8	3	50	2	1	43	<5	0	4	6.1	105
					182	83	[c]80	30	18	2	80	2	0	42	<5	0	4	6.1	205
					184	84	100	66	40	5	170	5	0	35	<5	0	5	6.5	510

[a]Potability limits from reference 3:

Chloride, 450 ppm; sulfate, 250 ppm; total solids, 1000 ppm; color, <15 platinum chloride $(PtCl_6)$ units; turbidity, <10 ppm; odor, none objectionable.

[b]Conductivity limit from reference 5, <1700 μmhos/cm.

[c]Solid concentration in wick evaporator decreased because total-weight operating range was raised. (See fig. 12.)

TABLE II.- SELECTED CHEMICAL AND PHYSICAL PROPERTIES OF THE RECOVERED WATER – Concluded

Test	Operating temperature				Water recovered		Solids in wick evaporator	Chemical, parts per million (ppm)						Physical					
	Wick evaporator air inlet		Condenser air outlet					Ammonia	Chloride	Sulfate	Alkalinity	Phosphate	Urea	Total solids (a)	Color (a)	Odor (a)	Turbidity (a)	pH	Conductivity (b)
	°F	°C	°F	°F	lb	kg	Percent by weight	Nitrogen	(a)	(a)			Nitrogen	ppm	$PtCl_6$ units	Threshold no.	Silica ppm		μmhos/cm
4	200	93.3	81	27.2	2	1	5	9	15	3	45	0	4	---	<5	1	3	7.6	100
					13	6	11	3	5	2	25	1	0	71	<5	0	4	6.7	44
					41	19	24	2	3	2	20	0	0	52	<5	0	7	6.1	11
					49	22	28	2	3	2	20	0	0	---	<5	0	2	6.5	11
					55	25	30	2	3	2	20	0	0	16	<5	0	5	6.1	11
					68	31	37	0	3	2	20	0	3	36	<5	0	4	6.7	15
					82	37	44	4	5	0	25	0	2	52	<5	0	4	6.6	29
					92	42	48	4	3	2	35	0	4	18	<5	0	4	7.0	46
					107	49	54	9	3	2	50	0	5	57	<5	0	2	6.2	78
					118	54	56	21	5	3	75	0	0	24	<5	0	2	6.6	118
					124	56	57	30	8	3	90	1	0	43	<5	0	5	6.7	170
					131	59	58	46	43	5	150	1	1	79	<5	3	5	7.0	350
					132	60	59	65	50	5	145	0	1	42	<5	2	3	7.0	400
					138	63	60	65	60	3	145	0	0	---	<5	2	4	7.1	430
					146	66	60	34	20	5	105	0	0	62	<5	3	4	6.8	230
					152	69	61	30	18	2	145	0	1	52	<5	0	4	6.8	205
					168	76	62	43	30	2	130	0	1	108	<5	1	5	6.9	300
					172	78	63	48	28	5	130	0	0	268	<5	2	4	7.2	300
					177	80	63	41	30	5	140	0	5	84	<5	2	6	7.7	310
					183	83	64	18	10	3	70	0	3	48	<5	0	7	7.0	112
	155	68.3	79	26.1	193	88	68	14	8	2	60	0	0	116	<5	1	5	6.8	99
					195	89	69	15	5	2	60	0	1	84	<5	1	5	6.9	100
					199	90	72	18	5	5	65	0	1	---	<5	3	7	7.0	117
					201	91	73	21	10	5	80	0	1	55	<5	1	7	6.4	150
					210	95	75	35	25	7	125	0	0	108	<5	1	7	6.8	265
	178	81.1	77	25.0	213	97	75	42	33	3	130	0	0	---	<5	3	5	6.8	330
					215	98	76	48	35	3	135	0	0	46	<5	3	5	6.9	340
					221	100	77	47	28	3	135	0	6	60	<5	3	5	7.0	340
					229	104	77	55	33	2	135	0	0	24	<5	3	5	7.0	320
					241	109	77	53	33	5	165	0	0	32	<5	1	12	7.3	365
					252	114	78	66	43	3	185	0	7	108	<5	2	10	7.5	410
					258	117	78	62	45	5	185	0	10	72	<5	3	11	7.7	405
					262	119	78	78	53	5	220	0	0	80	<5	3	11	7.7	528
					263	119	78	94	75	3	220	0	0	---	<5	1	8	7.8	615
					268	122	80	77	55	5	230	0	5	---	<5	3	5	7.9	572
					270	123	100	114	80	5	270	0	0	94	<5	3	4	8.0	678

[a]Potability limits from reference 3:

Chloride, 450 ppm; sulfate, 250 ppm; total solids, 1000 ppm; color, <15 platinum chloride $(PtCl_6)$ units; turbidity, <10 ppm; odor, none objectionable.

[b]Conductivity limit from reference 5, <1700 μmhos/cm.

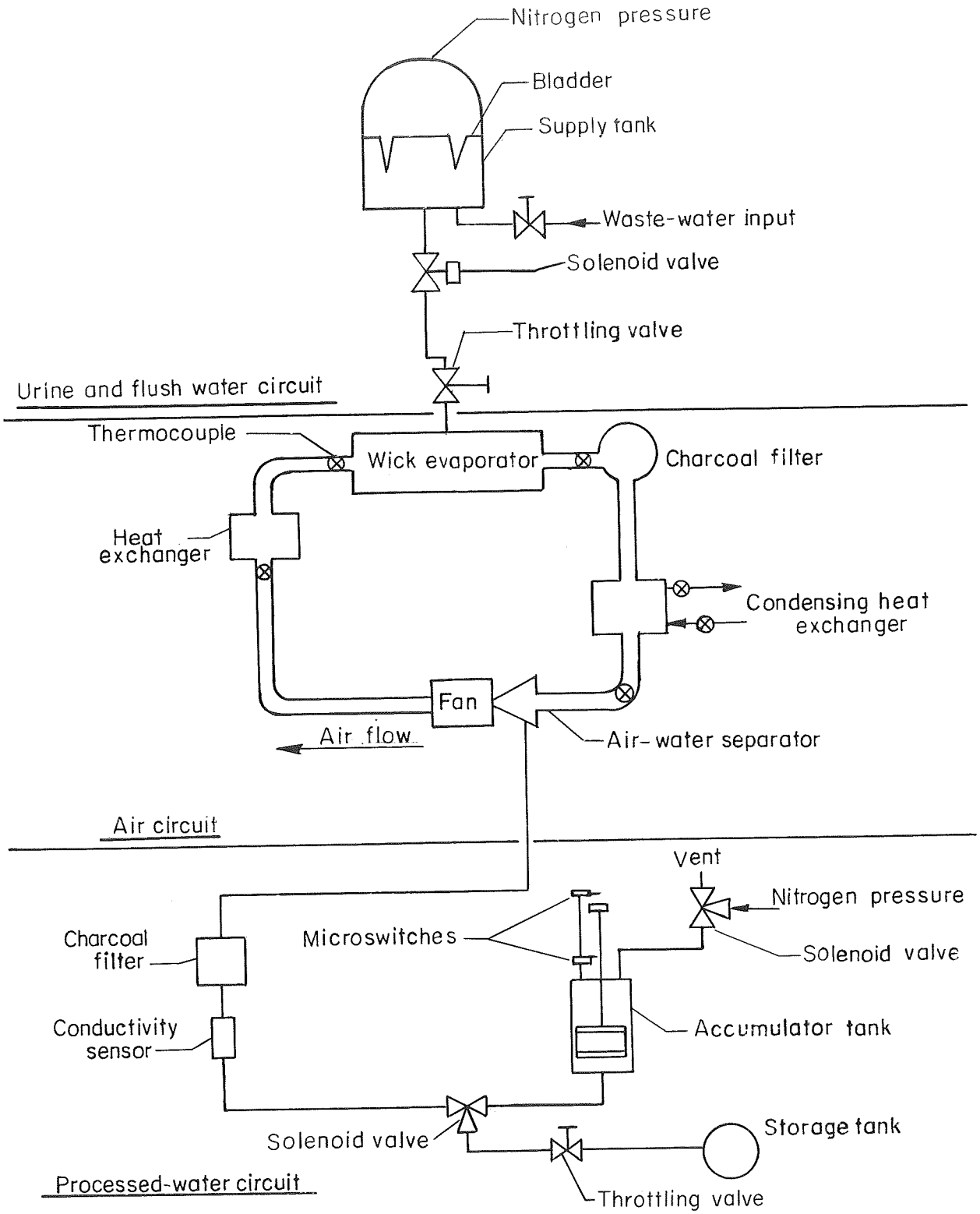

Figure 1.- Schematic drawing of evaporative water-recovery subsystem.

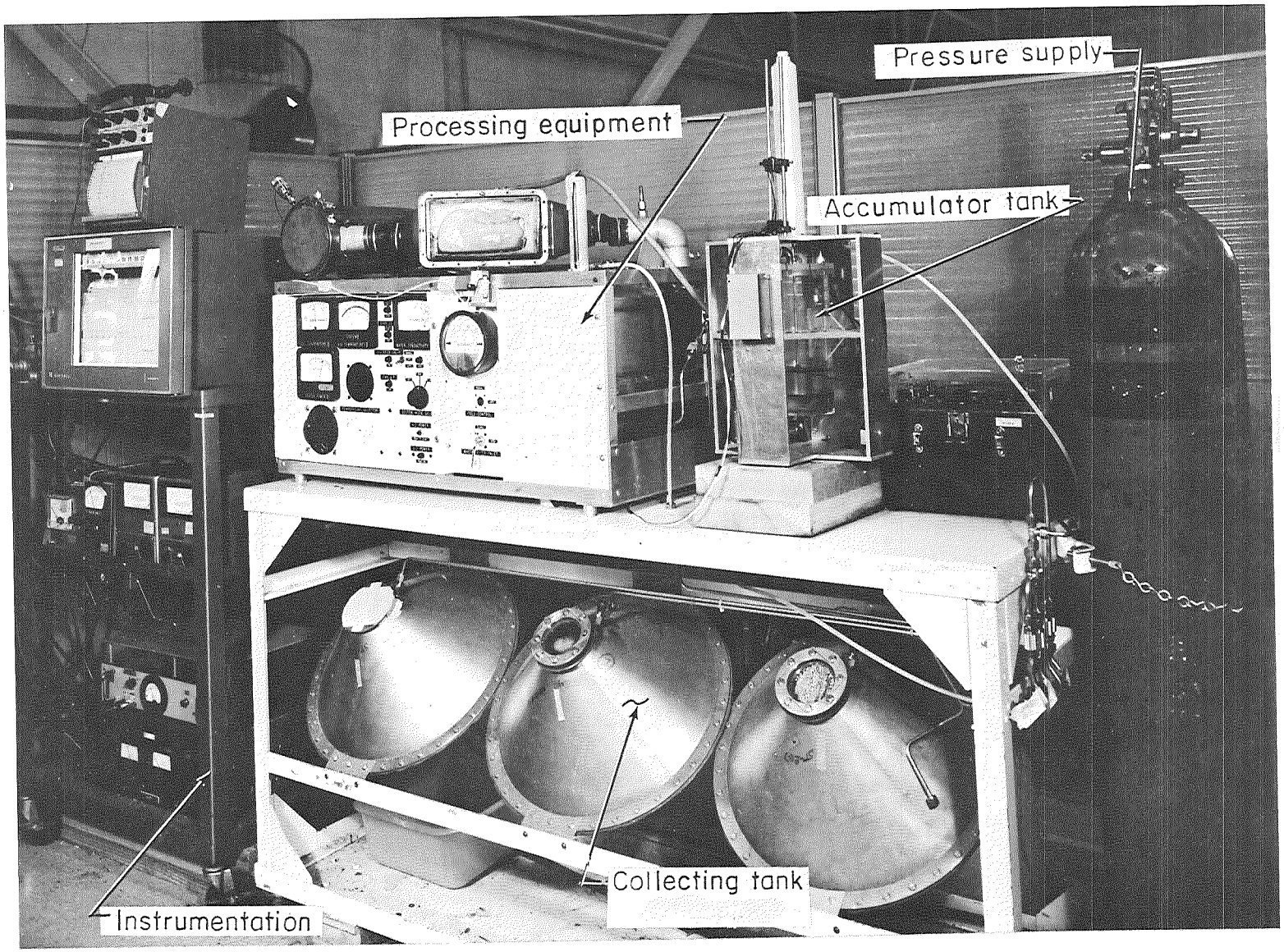

Figure 2.- Test setup.

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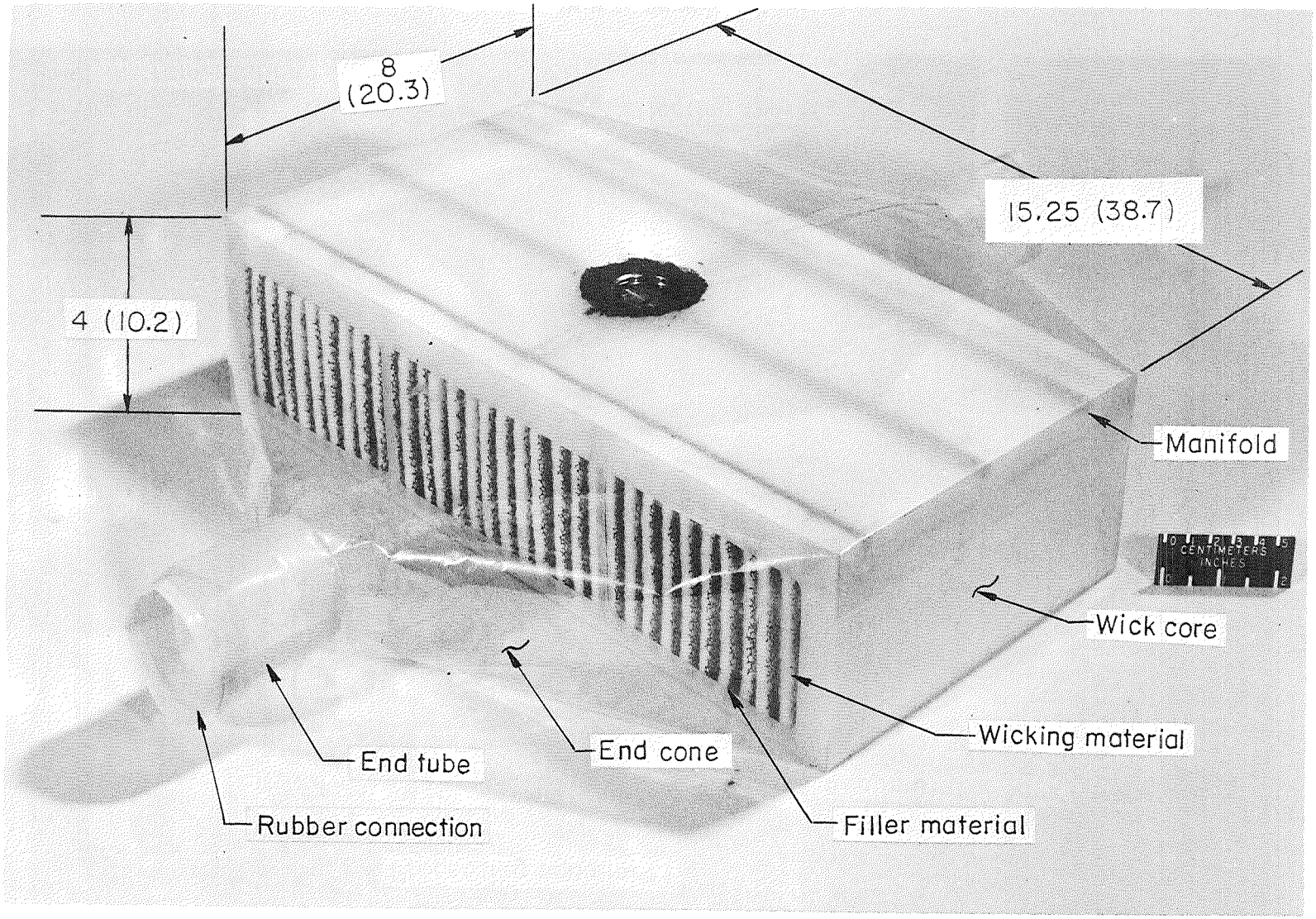

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Figure 3.- Wick configuration 1. (All linear dimensions are given in inches and parenthetically in centimeters.)

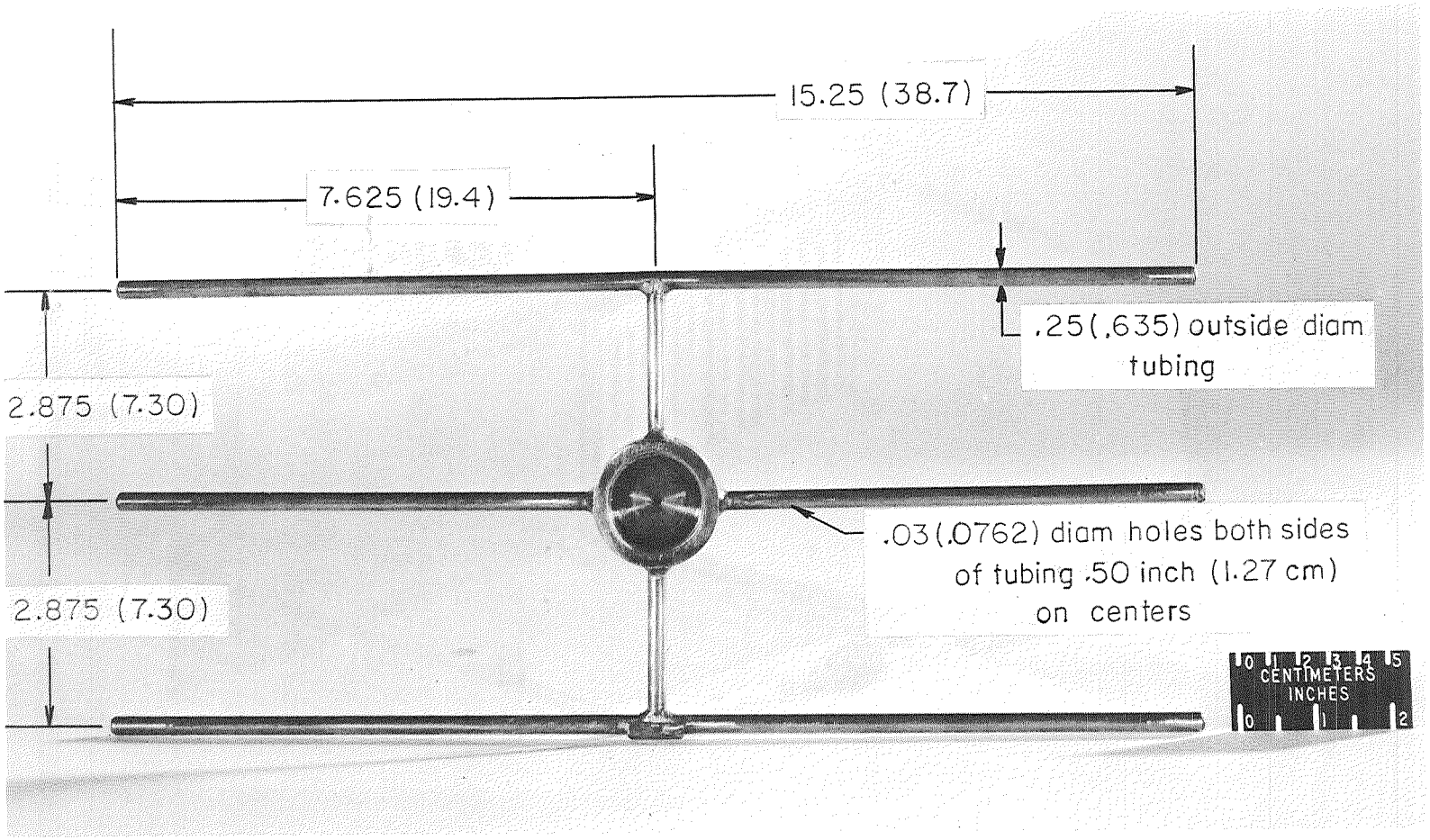

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Figure 4.- Waste-water-distribution manifold for wick configuration 1. (All linear dimensions are given in inches and parenthetically in centimeters.)

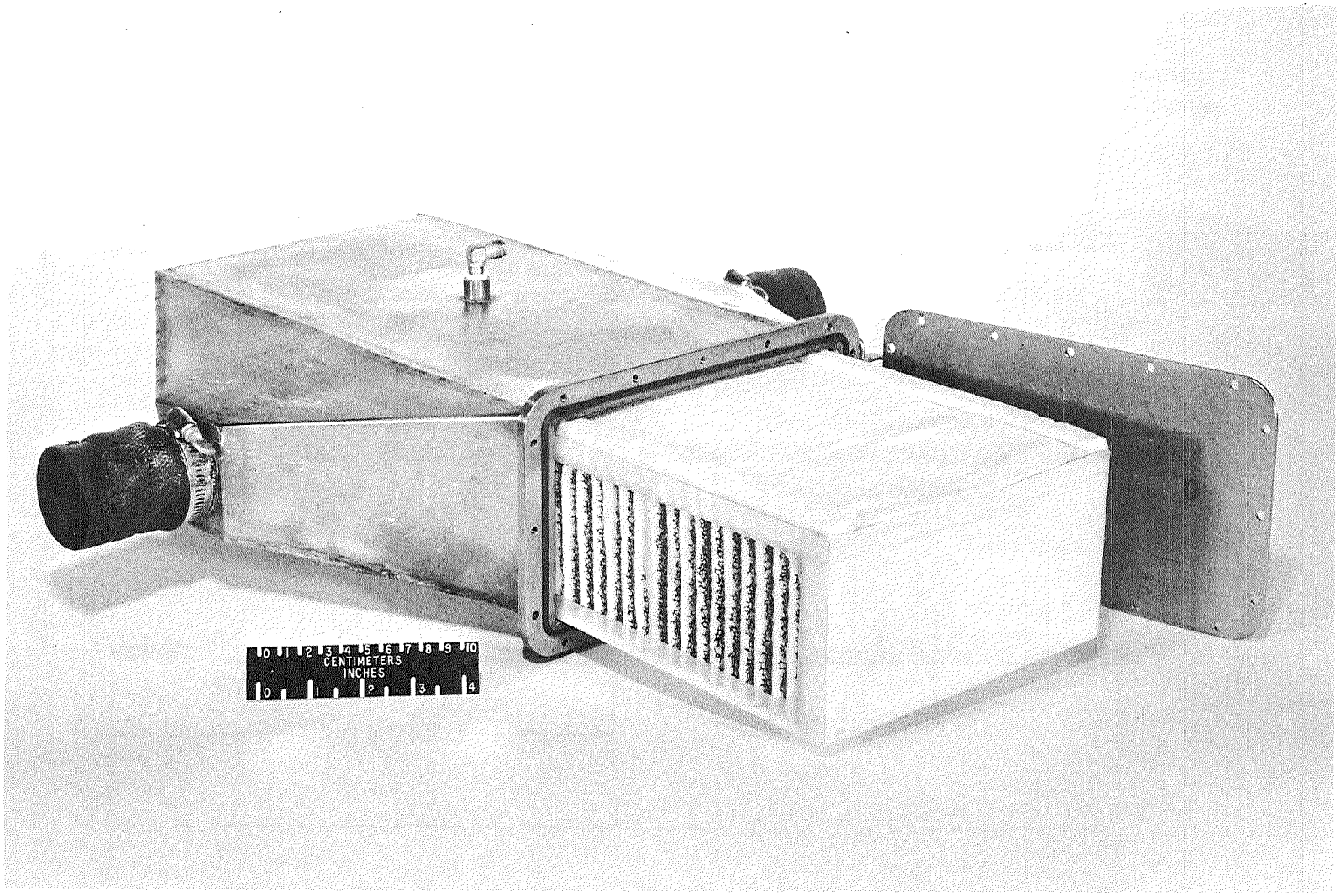

Figure 5.- Modified wick holder and wick configuration 2.

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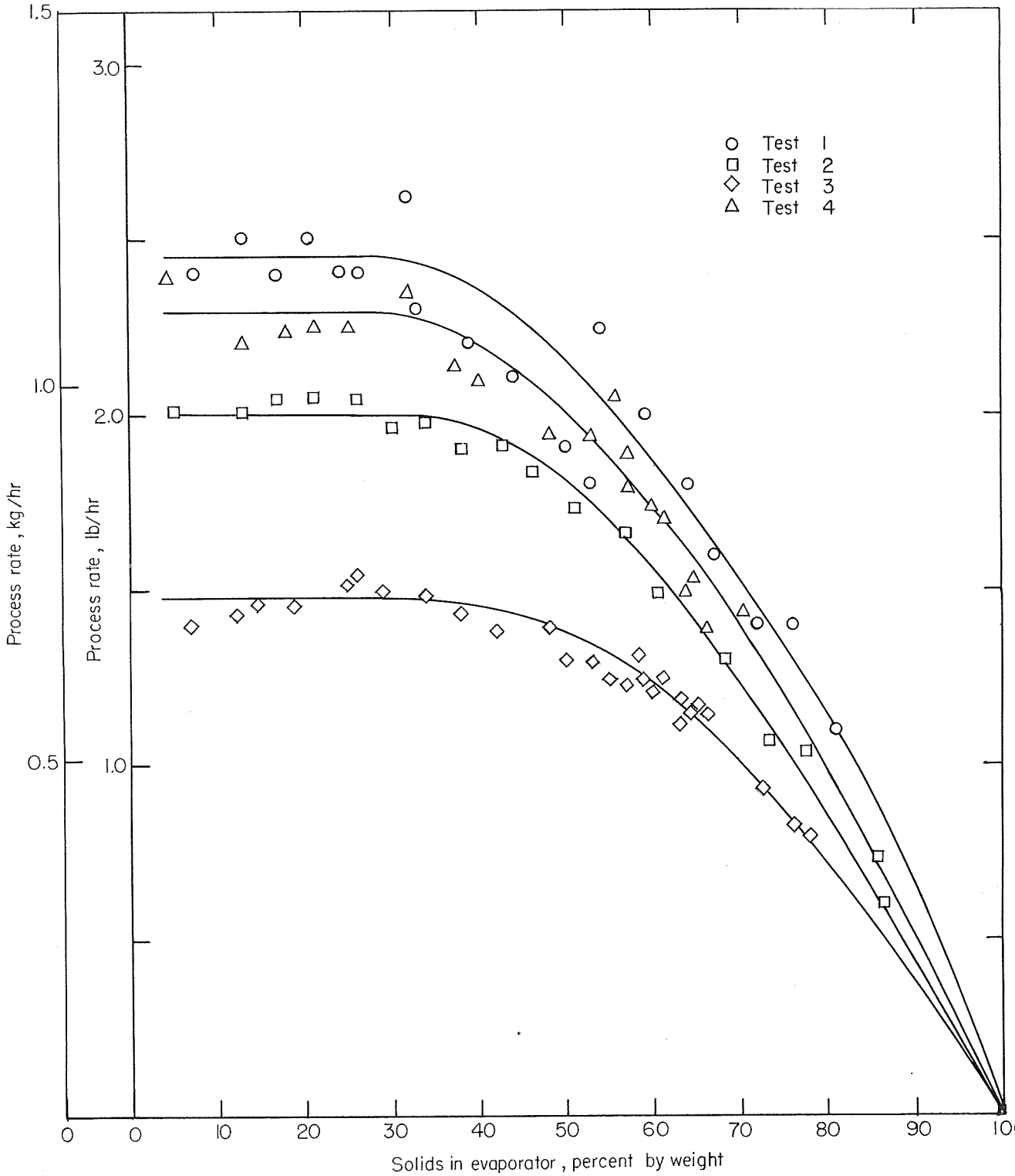

Figure 6.- Process rates as a function of solids in evaporators.

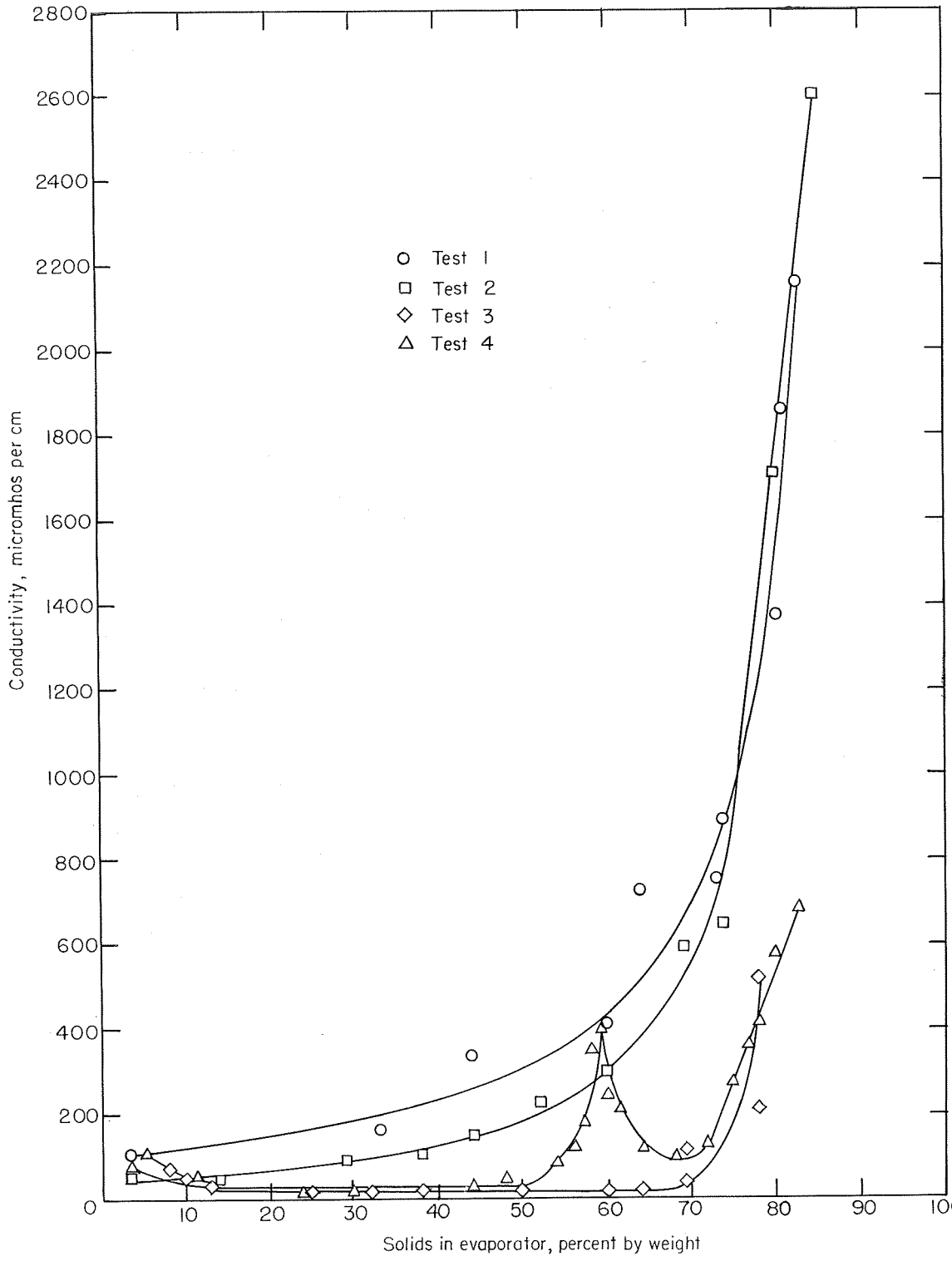

Figure 7.- Conductivity of recovered water as a function of solids in evaporators.

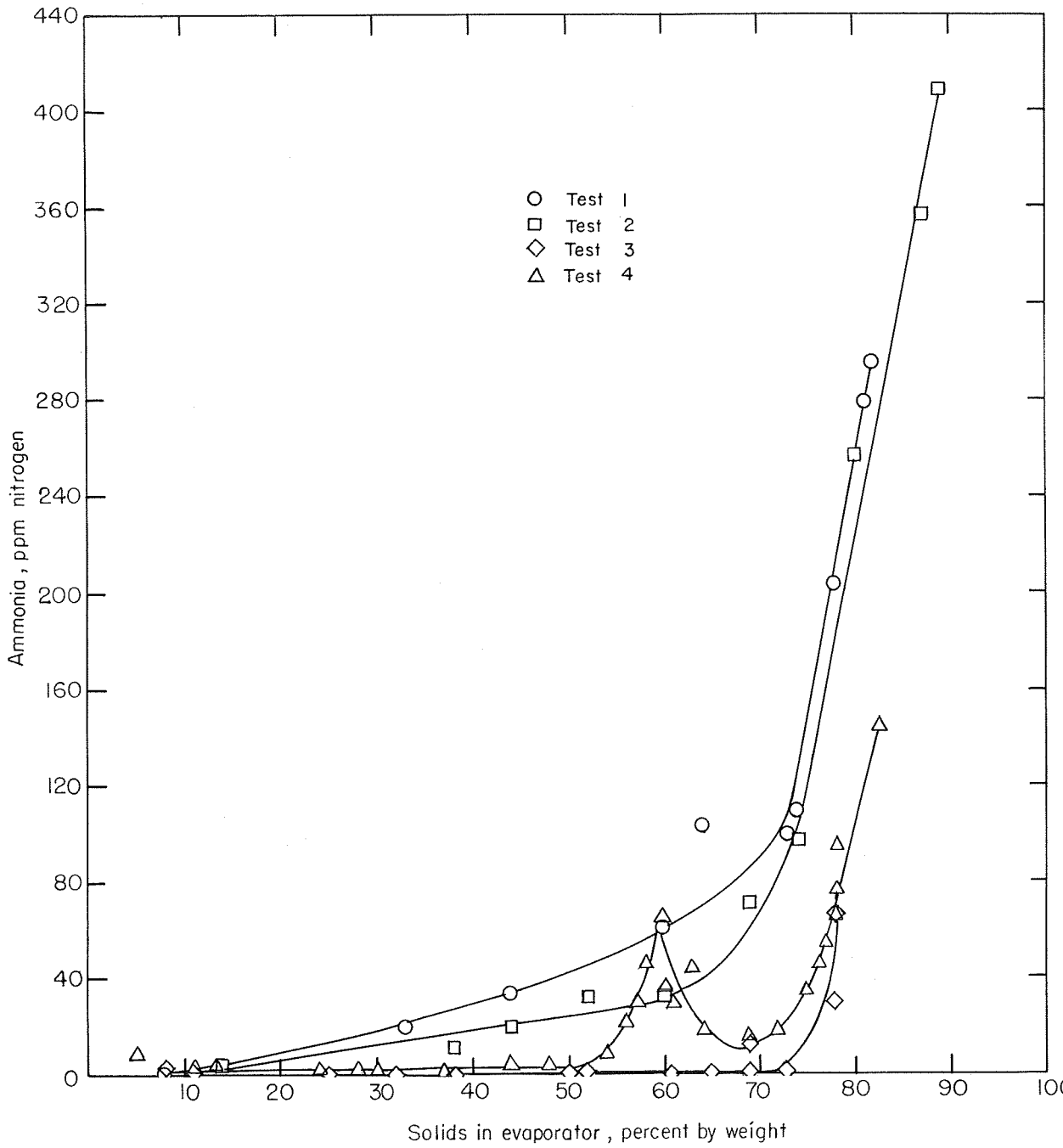

Figure 8.- Concentration of ammonia in recovered water as a function of solids in evaporators.

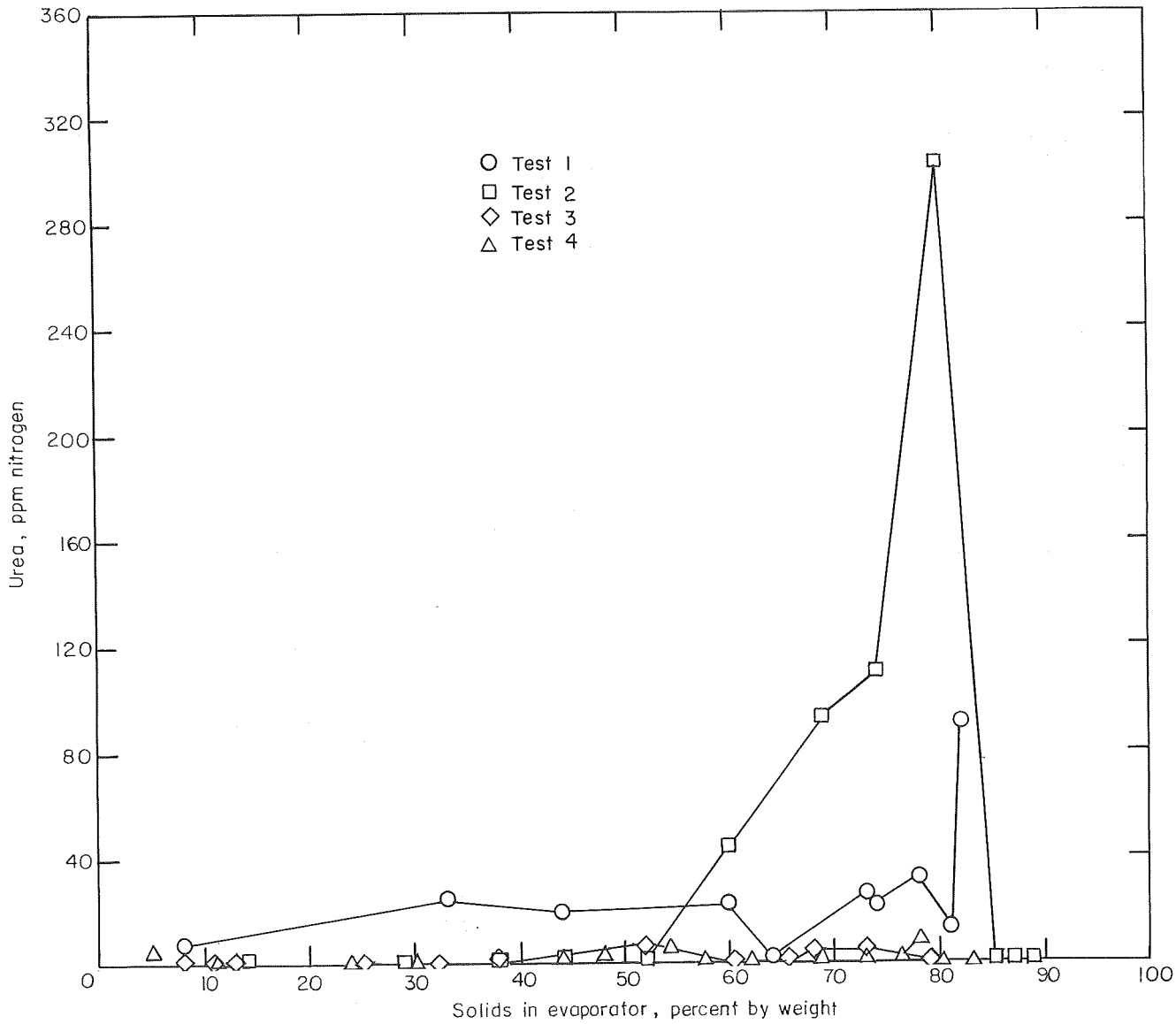

Figure 9.- Concentration of urea in recovered water as a function of solids in evaporators.

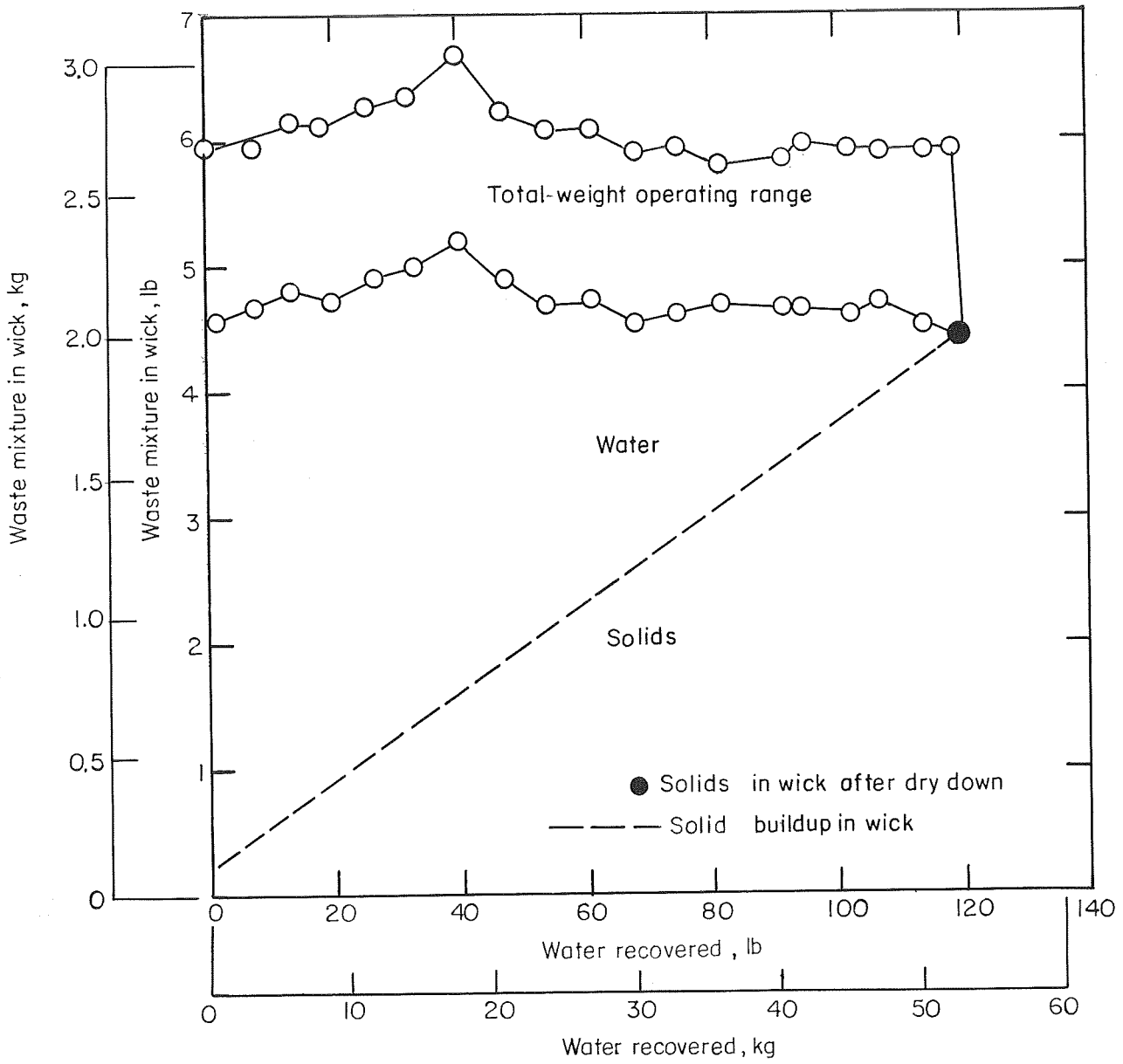

Figure 10.- Waste mixture in wick as a function of water recovered for test 1.

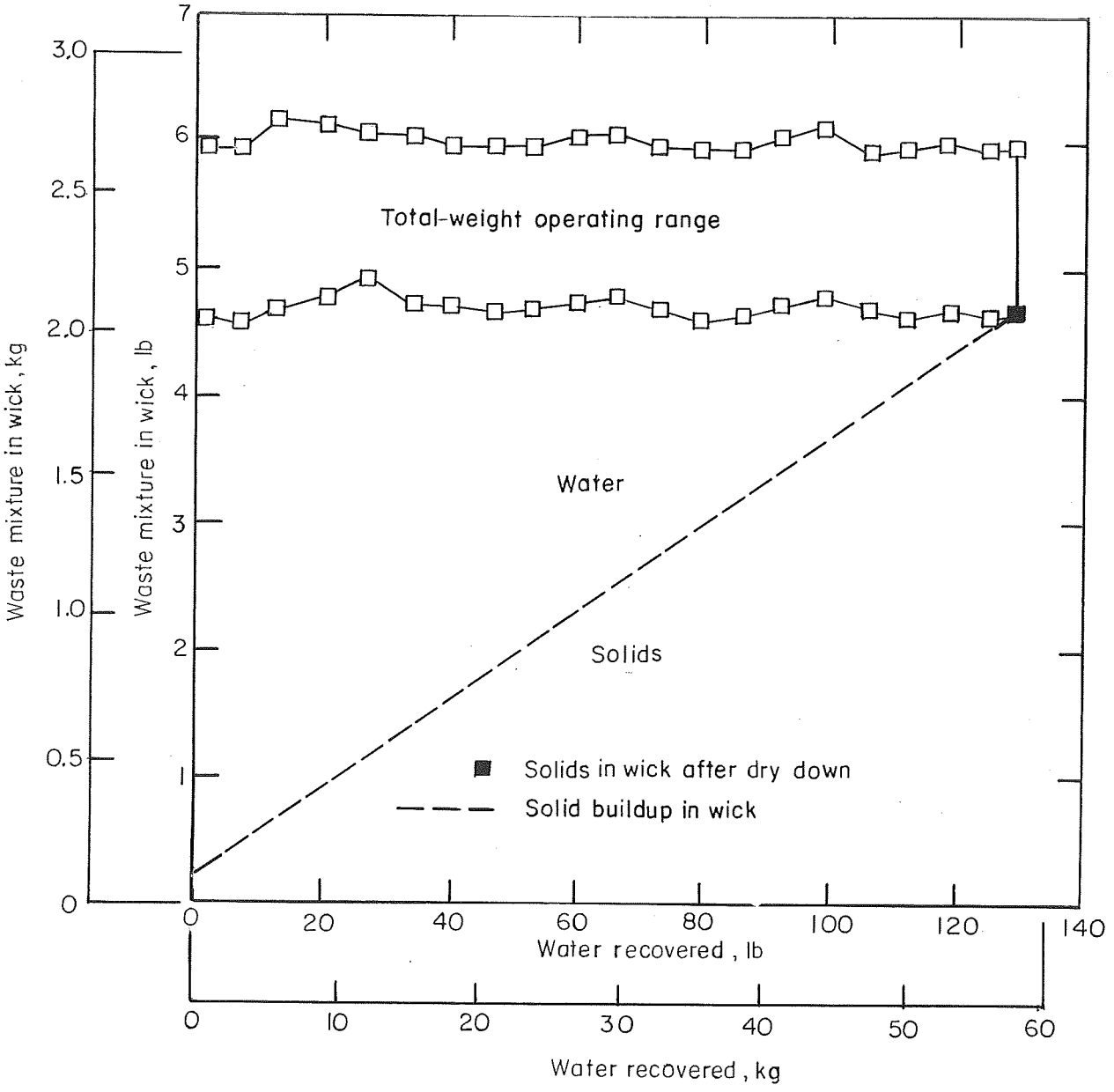

Figure 11.- Waste mixture in wick as a function of water recovered for test 2.

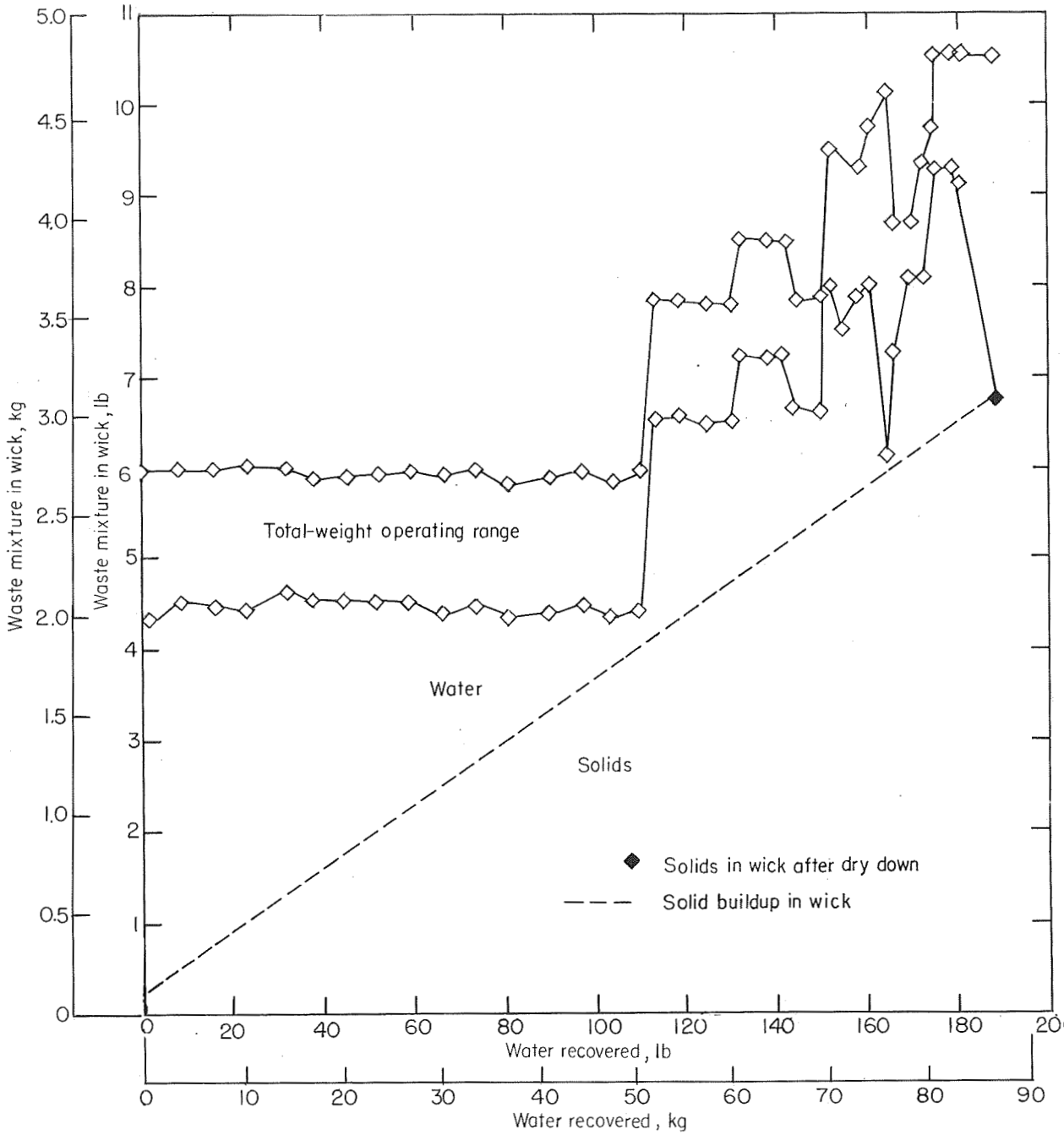

Figure 12.- Waste mixture in wick as a function of water recovered for test 3.

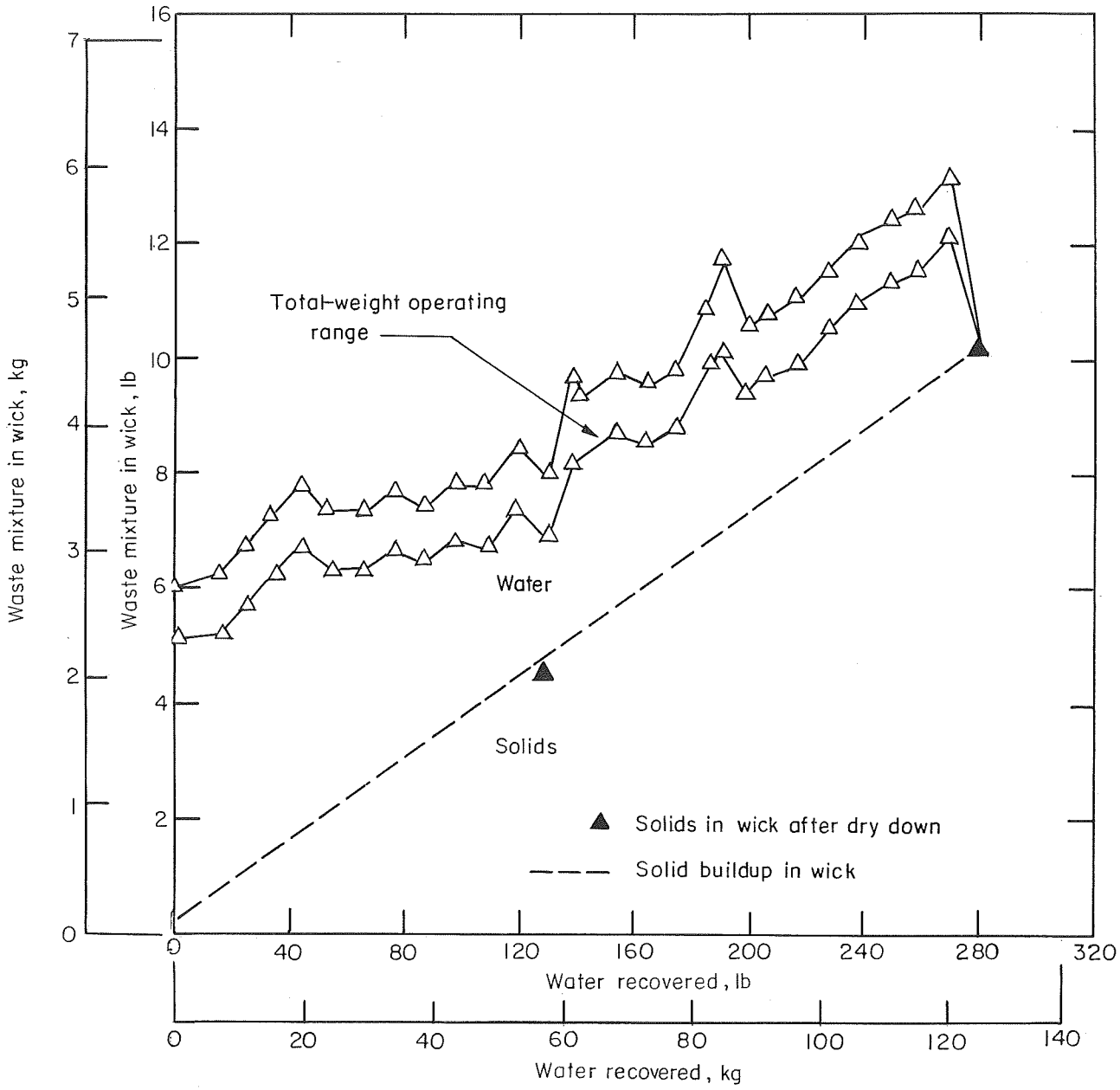

Figure 13.- Waste mixture in wick as a function of water recovered for test 4.

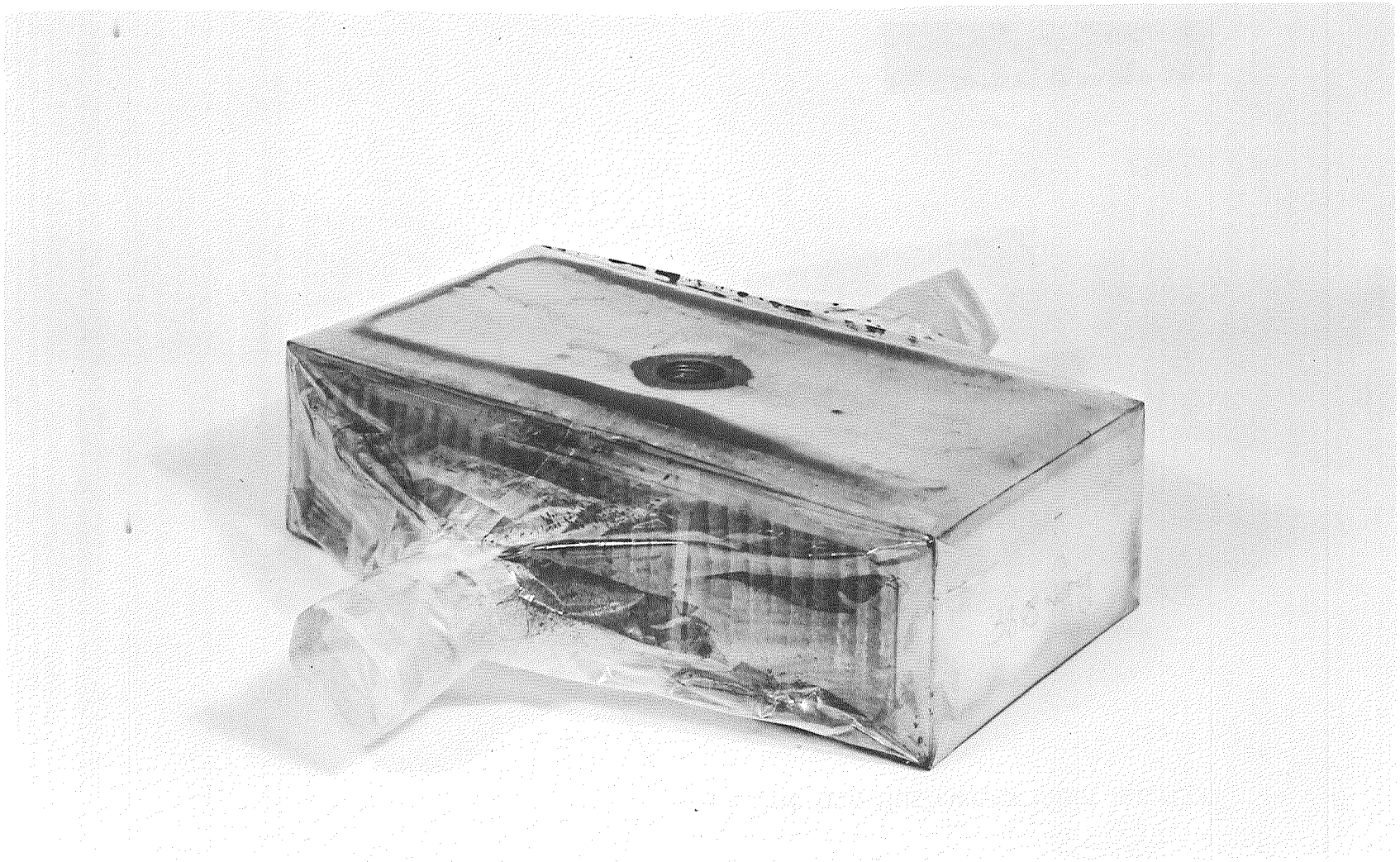

Figure 14.- Wick configuration 1 after test 3.

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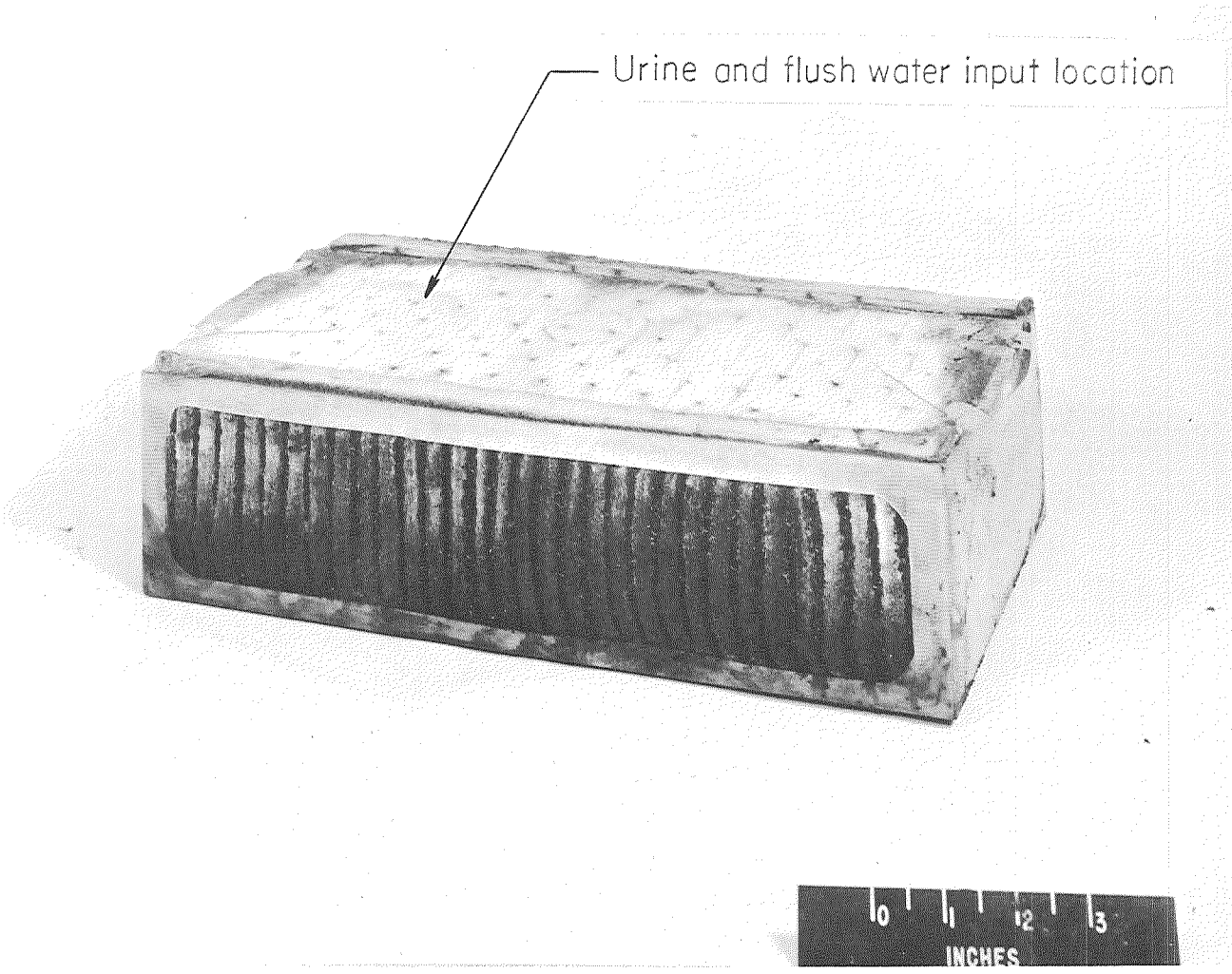

Figure 15.- Wick configuration 2 after test 4.

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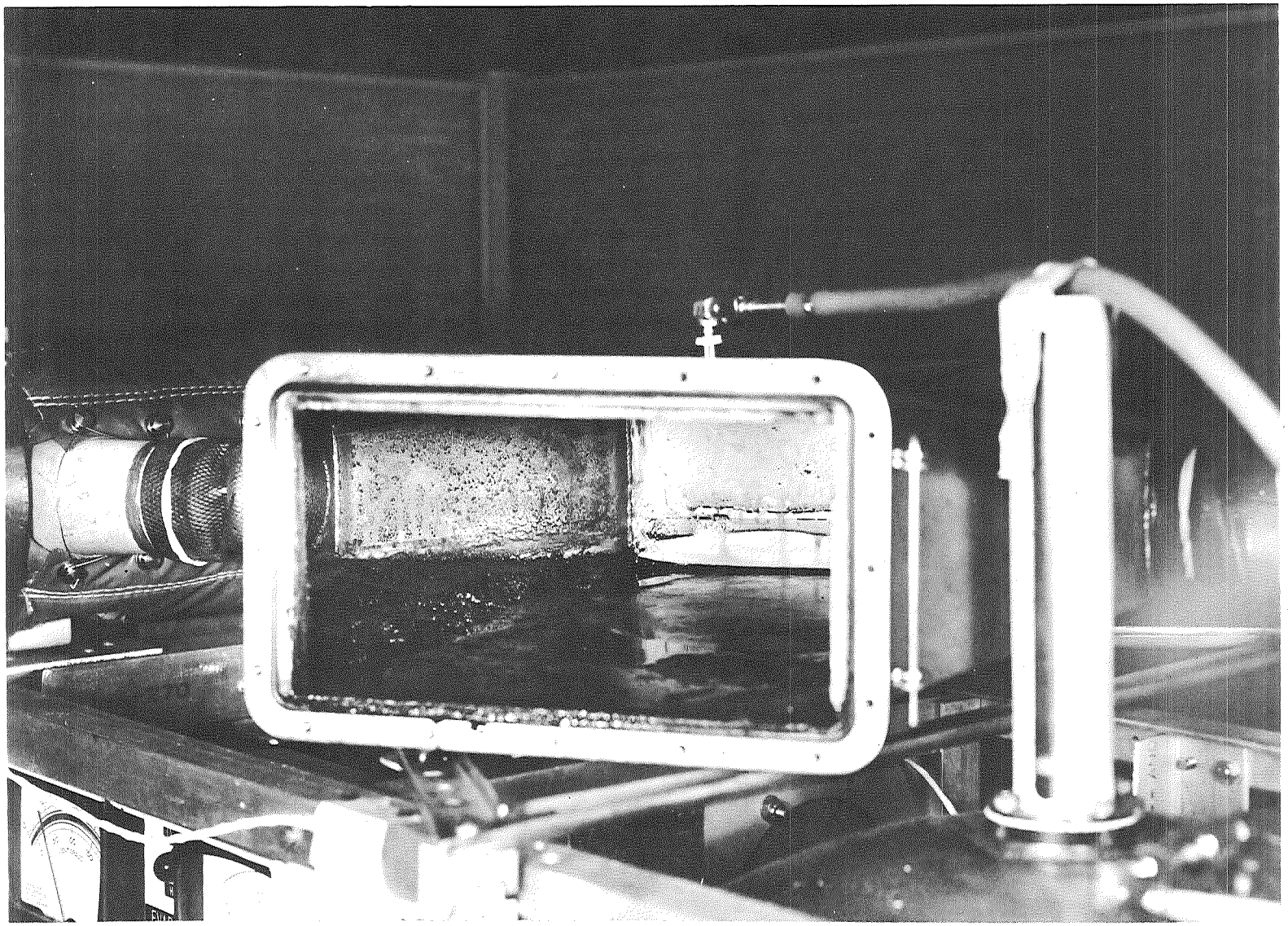

Figure 16.- Interior view of modified wick holder after test 4.

L-69-2087

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