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Automatic Equipment for Freezing-and-Thawing Tests

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Automatic Equipment for Freezing-and-Thawing Tests

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Automatic Freezing-and-Thawing Equipment For a Small Laboratory

WILLIAM A. CORDON, Associate Professor of Civil Engineering, Engineering Experiment Station, Utah State University, Logan

●CONCRETE DURABILITY is important in establishing performance of concrete in northern climates. Resistance to disintegration when subjected to alternate cycles of freezing and thawing is an accepted measure of durability.

Automatic freezing-and-thawing equipment in the laboratory provides a valuable tool in determining the performance and acceptance of proposed materials. Correlation between concrete strength and durability tests provides a means of establishing field control.

The cost and complicated nature of freezing-and-thawing equipment which automatically produces alternate cycles of freezing and thawing has discouraged extensive use of this test. Hand methods of placing specimens in freezing cabinets and thawing tanks are also costly and laborious. Hence, freezing-and-thawing tests are generally limited to research and performance tests in the larger laboratories.

Comparatively inexpensive automatic freezing-and-thawing equipment has been developed by the Engineering Experiment Station, Utah State University. This equipment produces up to 9 cycles of freezing and thawing in each 24-hr period. The cost of the equipment may be within the budget of most small laboratories.

This paper discusses the details of construction of the automatic freezing-and-thawing equipment and also presents typical test results obtained with the development model of this equipment.

AUTOMATIC FREEZING-AND-THAWING EQUIPMENT

Figure 1 shows a general view of the apparatus. The cabinet is 6 ft 10 in. by 2 ft 10 in. wide by 10 in. deep. All sides have 4 in. of insulation, including a 4-in. insulated lid. The freezing compartment is only 6 in. deep, 2 in. wide, and 6 ft 2 in. long.

Temperatures to 0 F are obtained during the freezing cycle by means of a 2- by 6-ft commercial cooling plate attached to a ½-horse-power commercial compressor (Fig. 2). Thawing is accomplished with electric resistance heaters rated at 500 watt, 220 v, placed along the sides of the containers and connected in parallel to a 110-v circuit.

Specimen containers are soldered copper trays. The soldered joints were cause for concern since it was feared that the alternate contraction and expansion of the ice during the freezing-and-thawing cycle would break the soldered joint. This was prevented, however, by making the copper container only ¼ in. wider than the concrete prism, leaving only ⅛ in. of water on each side. The total expansion of this water was not significant. After more than one year's service, there has been no difficulty experienced with leaking or breaking the soldered joints. Specimens are blocked up ⅛ in. to prevent direct contact between the metal container and the specimen.

The equipment does not limit the size or shape of specimens, since containers may be built to accommodate various specimen sizes. Two- by 2- by 10-in. prisms and 3- by 3- by 16-in. prisms have been tested successfully.

The length of cycle depends upon the time required to reduce the temperature at the center of the control prism (Fig. 3) from 40 to 0 F and back to 40 F. The length of a complete cycle averages about 2.7 hr. The freezing-and-thawing cycle is controlled by means of a thermostat placed in the center of a control prism and relays which start the compressor and turn off the heater at 40 F and reverse the procedure at 0 F. A gas-charged thermometer bulb and a recording thermometer keep a continuous record of the temperature at the center of the control specimen. It is possible to adjust the cycle at any time to take care of variable conditions.

The most unique features of the automatic freezing-and-thawing apparatus are undoubtedly its efficiency and simplicity. Rapid freezing of the specimens is accomplished through metal-to-metal contact between the cooling plate and the metal containers. Freezing progresses from three sides of the container to the center of the specimen. There is only a space of 6 in. of air above the specimens which is rapidly cooled and provides freezing conditions on the fourth side. The total amount of water used in the equipment is very small and, therefore, requires a minimum of heat exchange to freeze and thaw. For these reasons, $\frac{1}{3}$-hp commercial compressor is adequate to provide the required refrigeration to freeze the specimens in accordance with ASTM specifications.

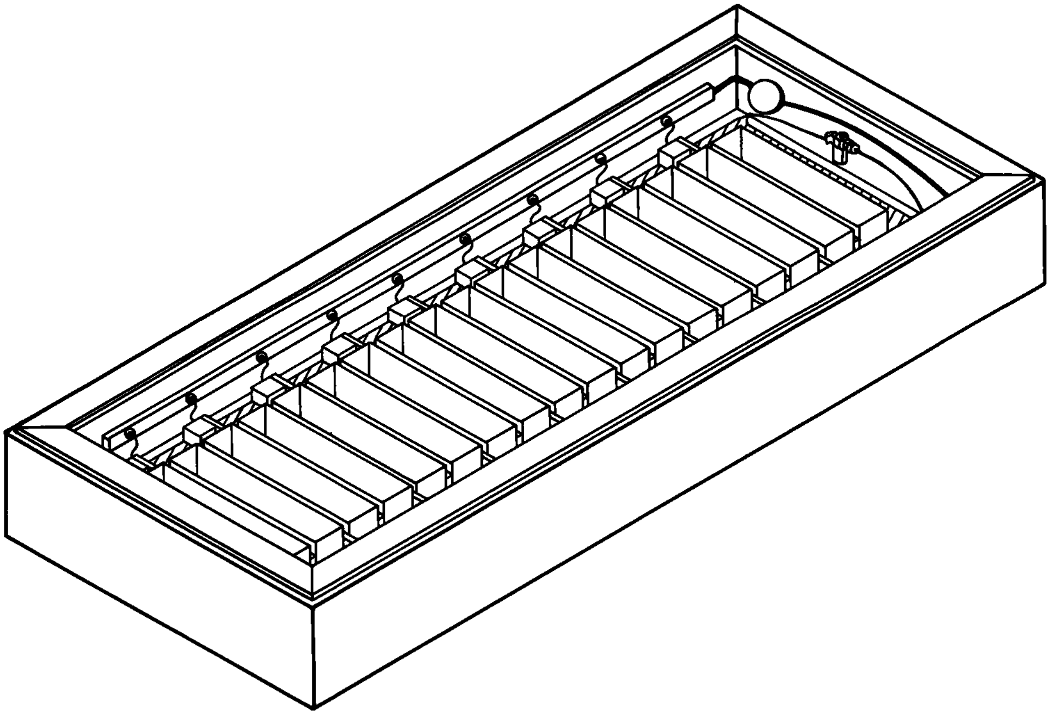

Figure 1. Automatic freezing-and-thawing equipment.

The thawing cycle is also efficient. Strip heaters are placed in direct contact with the sides of the metal containers. Here again, heat transfer is obtained with metal-to-metal contact. The ice surrounding the specimen is melted before the concrete is thawed. Thawing takes place directly from the sides and bottom of the metal container. The cooling plate itself becomes warm during thawing action. The amount of heat developed during the thawing cycle can be controlled by controlling the voltage to provide any desired rate of thawing. The simplicity of the apparatus provides flexibility of both thawing and freezing and undoubtedly will accommodate most requirements.

The specimens are rotated at the completion of each 50 cycles. At this time the water surrounding the specimens is changed. There is no assigned pattern for locating the specimens in the cabinet. Specimens are replaced at random after completion of each 50 cycles of freezing and thawing.

A typical graph of the recording thermometer during one 24-hr period is shown in Figure 4. This graph illustrates the variation in temperature with time for the freezing cycle and also the thawing cycle. Excellent uniformity among cycles of freezing and thawing at different times during the day is indicated. It is interesting to note that

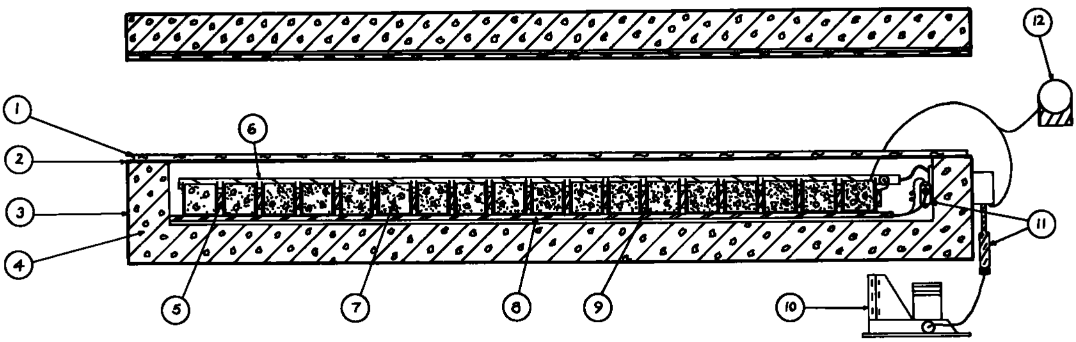

Figure 2. Sectional view of the automatic freezing-and-thawing equipment.

the recording thermometer faithfully records the pause in the cycle at 32 F during the time that ice is being melted and also the time the water must be frozen before the drop in temperature continues.

The uniformity of the temperature throughout the cabinet is shown in Figure 5. The time temperature curve is close throughout most of the cycle, and the only significant difference being at the end of the thawing and beginning of the freezing cycle.

Investigation showed that the strip beaters did not fit snug against the metal container in all cases. This has been corrected by holding the beaters against the containers with stainless steel clips. The probes were also placed in the containers in water, one near the surface and the other two near the bottom. The temperature time curve above freezing was, therefore, influenced by the rate and amount of ice melted and does not necessarily represent the temperature of the specimen.

RESULTS OF TESTS WITH FREEZING-AND-THAWING EQUIPMENT

In the final analysis, the value of testing equipment is determined by the results of tests performed with the equipment. Automatic freezing-and-thawing equipment should differentiate between the durability of various concretes. The results of various tests are shown in Figures 6 and 7.

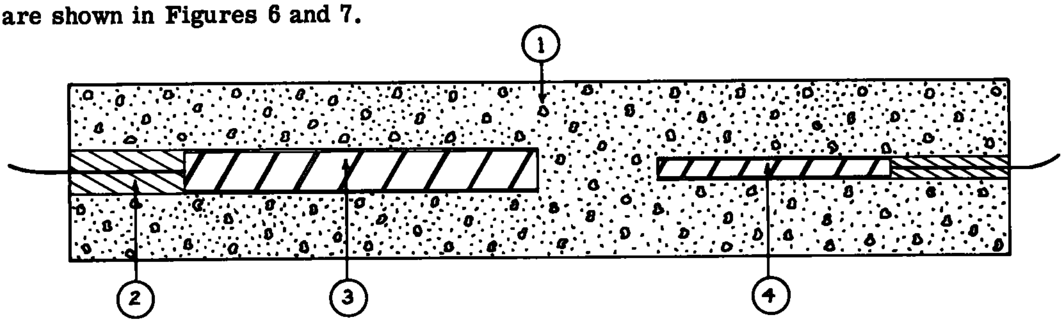

Figure 3. Automatic freezing-and-thawing control specimen.

The comparable durability of concrete with and without pozzolanic materials is illustrated in Figure 5. Because the purpose of these tests was to determine the relative durability of concrete containing each of the various pozzolans and to differentiate between the concretes containing pozzolans and a control mix with no pozzolan, there were no air-entraining agents used. Without entrained air one would expect the deterioration of concrete due to freezing and thawing to be rather rapid. Rapid deterioration was indicated from these tests which showed a 25 percent weight loss occurring at approximately 80 cycles in concrete containing pumice and about 150 cycles in concrete without pozzolan. The test adequately differentiated between the different types of concrete. In the lower part of the figure the same tests are presented showing the drop in dynamic modulus of elasticity. In this case, failure occurred at a minimum of approximately 40 cycles with flyash and a maximum of 90 cycles in concrete in which pozzolans were not used. These tests are considered typical of the durability of concrete before air-entraining agents were generally used.

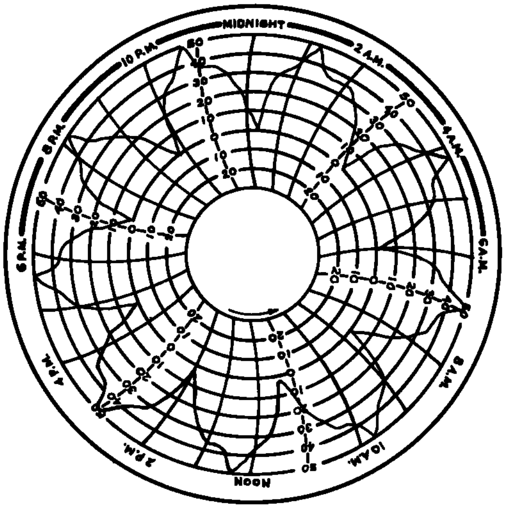

Figure 4. Typical graph of the recording thermometer.

The durability of concrete containing adequate air entrainment is illustrated in Figure 6 and Table 1. The purpose of these tests was to differentiate between the dur-

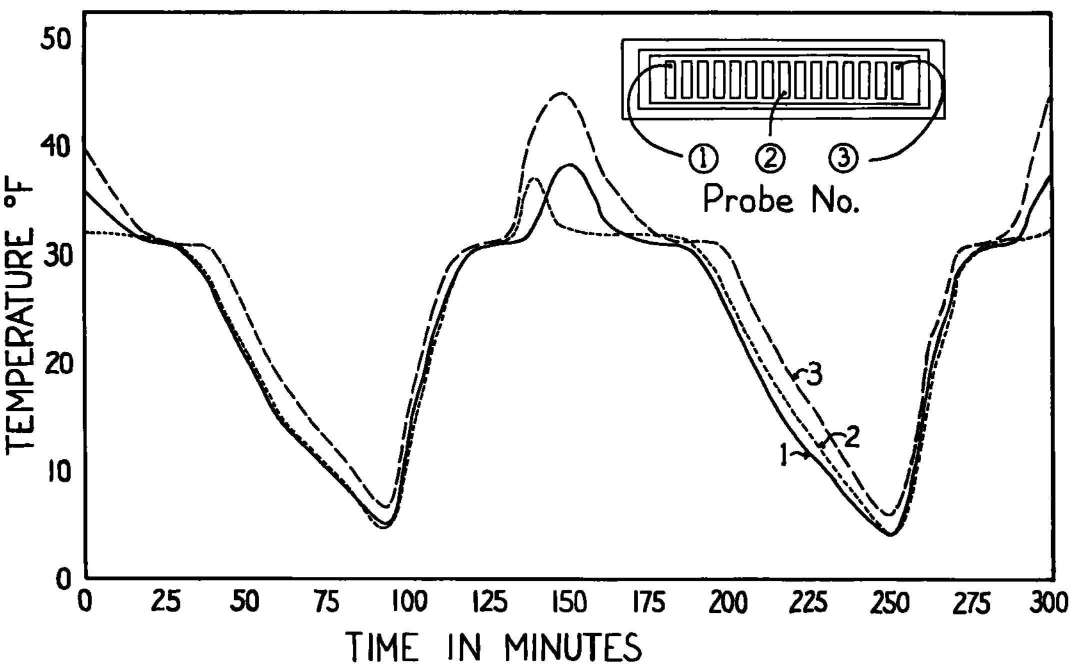

Figure 5. Time-temperature relation at three locations in the automatic freezing-and-thawing cabinet.

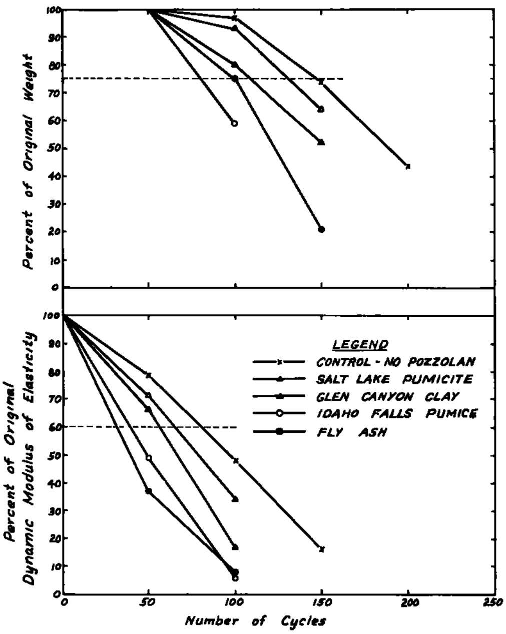

Figure 6. Freezing-and-thawing durability 2- by 2- by 10-in. concrete bars containing pozzolans.

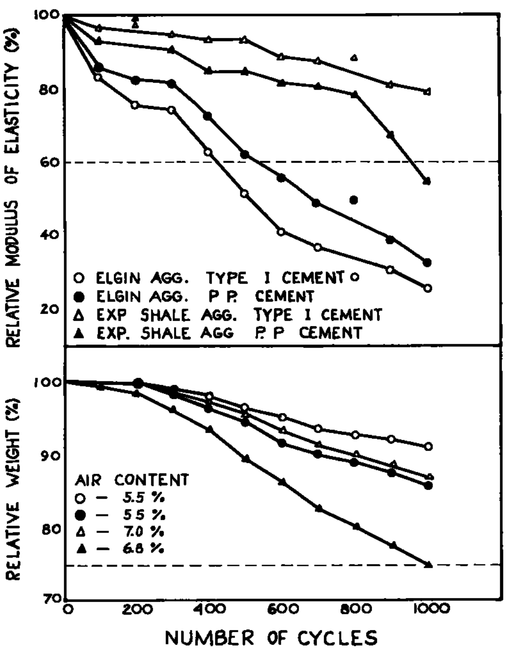

Figure 7. Durability of concrete with natural and lightweight aggregate—Type 1 portland pozzoland cement.

ability of concrete containing combinations of (a) natural aggregate from Elgin, Ill., (b) expanded shale lightweight aggregate, (c) Type I portland cement, (d) portland-pozzolan cement.

None of the concretes tested sustained a 25 percent weight loss before 1,000 cycles of freezing and thawing. These results are comparable to what might normally be expected with high quality air-entrained concrete.

REPRODUCIBILITY OF TEST RESULTS

Another measure of the adequacy of laboratory tests is the ability to produce similar results with similar samples. One method of measuring reproducibility is to analyze the range of results obtained with specimens fabricated from the same sample

TABLE 1

REPRODUCIBILITY OF FREEZING AND THAWING DURABILITY TESTS

Cement	Aggregate	Age in Days	Relative Weight, %-1000 Cycles					Relative Dynamic E, %-300 Cycles				
			Bar 1	Bar 2	Bar 3	Mean	Range	Bar 1	Bar 2	Bar 3	Mean	Range
Type I	Elgin	28	90.6	92.4	90.3	91.1	2.1	75.0	71.4	76.6	74.3	5.2
Type I	Exp. shale	28	86.4	86.1	88.1	86.9	2.0	93.7	94.4	96.7	94.9	3.0
P. P.	Elgin	28	85.2	87.1	86.2	86.2	1.9	88.0	75.5	81.9	81.8	12.5
P. P.	Exp. shale	28	76.1	74.1	74.6	74.9	2.0	85.7	88.8	97.2	90.6	11.5
Type I	Elgin	90	95.2	93.9	90.6	93.2	4.6	63.8	74.8	60.8	66.5	14.0
Type I	Exp. shale	90	86.9	90.9	89.8	89.2	4.0	91.8	91.0	88.1	90.3	3.0
P. P.	Elgin	90	90.4	84.6	87.4	87.5	5.8	66.9	70.7	-	68.6	3.8
P. P.	Exp. shale	90	86.0	84.9	87.3	86.1	2.4	83.0	85.8	81.5	83.4	4.3

	Relative Weight		Relative Dynamic E	
[1]Within test standard deviation and coefficient of variation.	Range	$\bar{R}$ = 3.1	Range	$\bar{R}$ = 7.1
	Mean	$\bar{X}$ = 86.9	Mean	$\bar{X}$ = 81.3
	Standard deviation	σ = 1.83[1]	Standard deviation	σ = 5.91[1]
	Coefficient of variation - V =	2.1[1]	Coefficient of variation - V =	7.3[1]

of concrete. Table 1 is a compilation of test results where three duplicate prisms were fabricated and tested from the same batch of concrete. The degree of uniformity of durability tests is indicated by the range, standard deviation, and coefficient of variation. These results are only academic since duplicate tests made with other equipment are not available. The relative weight loss among comparable specimens shows excellent uniformity, however, and the coefficient of variation is lower than obtained with strength tests. The dynamic modulus of elasticity tests do not show comparable uniformity. There is also poor correlation between the relative durability as indicated by weight loss and by the loss of dynamic modulus. Concrete made with expanded shale aggregate shows superior durability when measured by the relative modulus of elasticity, whereas the expanded shale aggregate is inferior to natural aggregates when measured by weight loss. This apparent discrepancy cannot be attributed to poor reproducibility of the freezing-and-thawing equipment since both tests were made with the same specimen. The poor correlation between testing methods in this case is caused by differences in aggregates. Further investigations of weight loss versus loss of dynamic modulus with natural and lightweight aggregates is warranted.

CONCLUSIONS

Experience in the construction, development and use of the automatic freezing-and-thawing equipment indicates the following:

1. Automatic freezing-and-thawing equipment discussed in this paper is satisfactory for durability tests and can be manufactured at a cost which makes its use practical in small laboratories.
2. Simplicity and efficiency of the proposed freezing-and-thawing equipment makes its use sufficiently flexible and practical for acceptance tests and research.
3. Results indicate that freezing-and-thawing tests have good reproducibility.
4. Further investigations should be made to determine the influence of the position of the specimen and to check the uniformities of temperature throughout the cabinet.

Automatic Equipment for Rapid Freezing And Thawing of Concrete in Water

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This paper describes the construction and operation of an automatic, 25-specimen capacity, freezing-and-thawing device for the testing of standard concrete specimens. The cycle employed is rapid freezing and thawing in water in accordance with AASHO Designation T 161 – ASTM Designation C 290, which is the method specified for the evaluation of both air-entraining admixtures for concrete and air-entraining additions for the manufacture of air-entraining portland cement.

Details of construction, instructions for operation and maintenance, and a list of component parts with their individual costs and over-all construction cost, are provided in the Appendices.

Experiences with operation of the equipment over a period of four years and typical test results obtained on concrete specimens are discussed.

● THE DEVELOPMENT of satisfactory methods for determining the durability of concrete, in terms of resistance to freezing and thawing, has been the goal of a great number of investigators over an extended period of time.

Early work on the subject was primarily of a basic research nature to determine the effect of aggregates and various concrete proportions on the frost-resistance of the concrete. The early procedures generally consisted of slow cycles of freezing in air and thawing in water. The equipment required was relatively inexpensive and was normally available or could be obtained at low cost by most concrete laboratories. A great variety of household refrigerators, deep-freeze boxes, and existing coldrooms, were adapted to the purpose in conjunction with an assortment of water tanks, drums, and water sprays. Freezing temperatures, rate of freezing, thawing temperatures, and rate of thawing varied from laboratory to laboratory, as did the treatment of the specimens prior to and during the freezing-and-thawing cycles, to say nothing of specimen size and shape.

In 1928, Scholer (1) published the first paper recognizing the desirability of accelerated procedures and reporting the results obtained from the rapid freezing and thawing of concrete. The advent of air-entrainment gave added impetus to the development of accelerated freezing-and-thawing methods and equipment since it created a pressing need for evaluating not only the effectiveness of various materials in entraining air in concrete but a rapid means of determining the effectiveness of this air in improving concrete durability. It also made mandatory as high a degree of standardization as possible, including rigid control of all phases of the concrete making, curing, and testing operations. This was stated as one of the primary requirements in the paper by Wuerpel and Cook (2), which described what is believed to be the first automatic apparatus for the rapid freezing and thawing of concrete in water, and on which the present ASTM Designation C 290 is based.

Subsequently, numerous investigators developed a variety of automatic devices to produce a variety of freezing-and-thawing cycles. Both the Highway Research Board Committee on Durability of Concrete—Physical Aspects, and Committee C-9 on Concrete and Concrete Aggregates of the ASTM realized the need for a standard test procedure. Before sufficient data could be developed on one procedure a number of organizations, at considerable expense, had built or otherwise obtained automatic equipment of their own, and others continued to use existing manual equipment predominantly based on the slower cycles. Because of this situation the ASTM, with the thought that it would be better to have four standardized methods than an unpredictable number, adopted procedures for the four methods now in greatest use. They are:

1. C 290 - Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water.
2. C 291 - Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water.
3. C 292 - Resistance of Concrete Specimens to Slow Freezing and Thawing in Water or Brine.
4. C 310 - Resistance of Concrete Specimens to Slow Freezing in Air and thawing in Water.

The Highway Research Board Committee on Durability of Concrete—Physical Aspects undertook, in 1953, a cooperative program to determine the reproducibility of results that could be obtained with the four ASTM methods. The results of this work have very recently become available in Highway Research Board Special Report 47 (3).

It is not the purpose of this paper to discuss the relative merits of the four methods of test. This has been covered quite adequately in the above reference (3). It is believed, however, that the rapid methods have advantages over the slower methods from a laboratory operational standpoint, greatly reduced time requirements, and in their ability to discriminate on a relative basis between good and poor concretes or concreting materials. It is also a fact that ASTM Designation C 290 is the only one of the four methods presently specified by the ASTM and the AASHO as the procedure to be followed in evaluating air-entraining admixtures for concrete and air-entraining additions for portland cement, in terms of resistance of concrete specimens to freezing and thawing.

The experience of the author has been that there are surprisingly few laboratories in the United States properly equipped to run rapid freezing-and-thawing tests in water. The principal reasons for this situation are believed to be the relatively high cost of the equipment, a lack of published information on details of design, construction, and operation, and the scarcity of manufacturers of complete units. The author knows of only one company (4) that manufactures an assembled unit designed to meet ASTM requirements.

This paper has therefore been prepared primarily for the purpose of making available in the literature detailed information on the design, construction, and operation of automatic equipment for performing rapid freezing-and-thawing tests of concrete in water. The equipment is modest in size, holding 25 specimens, and is relatively modest in cost ($5,029.24 in 1955, including installation). It is similar in operation, although of smaller specimen capacity, to that described in reference (2) and differs somewhat with respect to tank arrangement, heat transfer fluid, and mechanical details. The information provided, including dimensioned photographs, electric wiring details, and description of the various components, is in sufficient detail to enable a contractor or even laboratory personnel to assemble the equipment.

Because of the length and detailed nature of the information it is presented as an Appendix although it is considered to be the primary reason for the preparation of the paper.

DESIGN, OPERATING, AND MAINTENANCE PROBLEMS

It will be noted that the heat transfer fluid is calcium chloride brine. The author's previous experience has been with an alcohol-water mixture or ethylene glycol. The decision to use brine rather than alcohol was based on the uncontestable reason that the laboratory was located in the same building as the manufacturing facilities of the company and the insurance underwriters would not permit the use of the large volumes of relatively inflammable alcohol that would be required. A decision was made against the use of ethylene glycol because of its high initial cost plus inevitable spillage and because of its increase in viscosity at the lower temperatures, with consequent pumping difficulties (5). The use of calcium chloride brine, however, was approved with some misgiving because of its corrosive properties. Very close attention therefore was paid initially and on a routine operational basis to its proper inhibition with sodium chromate, and by maintenance of optimum pH of the solution. These details have proved to be very effective and worthwhile and are covered in the Appendix. The equipment has been in operation for over four years and the tank and piping surfaces exposed to the brine have shown no signs of corrosion. On a very few occasions one of the solenoid valves has stuck. This sticking apparently has been caused by a build up of salts around the valve bodies and seats. Generally it has occurred after the equipment has been shut down for a number of days. Operating the equipment for a cycle or so every three days has tended to prevent this difficulty.

ADJUSTMENT OF BRINE TEMPERATURES

The author's previous experience had been primarily with alcohol-water solutions for the cold and thaw fluids. To obtain 0±3 F and 40±3 F at the centers of the concrete specimens it was necessary to maintain the alcohol-water solutions at about -20 F and +50 F, respectively. When the equipment described herein was first started the calcium chloride brine in the cold and thaw fluid tanks was placed at the above respective temperatures. It was noted on the first cycle that the central specimen temperatures were reduced to almost -20 F on the cold cycle and +50 on the thaw cycle. A few trial cycles indicated that the brine temperatures must be maintained at 0 F and 40 F to produce the specified specimen temperatures of 0±3 F and 40±3 F. This unexpected phenomenon may be attributed to several reasons:

1. Differences in the thermal properties of alcohol-water and calcium chloride brine.
2. More rapid solution circulation in the present equipment.
3. Better circulation of solution around the specimens.
4. Smaller specimens and therefore also less water to be frozen and thawed. The previous equipment used specimens 3½ by 4½ by 16 in., whereas the present equipment uses 3- by 4- by 16-in. specimens.

While it was a simple matter to adjust the brine temperatures, as described above, the rapidity with which the temperatures of the specimens were lowered and raised was of considerable concern since the cycle produced results on specimens that were much more severe than produced by alcohol-water solutions using the same time cycle, in the other equipment.

RESULTS OBTAINED ON CONCRETE SPECIMENS

The early use of this equipment indicated, on the basis of tests made on concrete specimens, that while it was adjusted to meet the existing requirements for ASTM C 290, it produced a more severe cycle than was contemplated by ASTM Designation C 260, "Tentative Specifications for Air-Entraining Admixtures for Concrete." This specification requires that concrete containing an acceptable air-entraining admixture must have a relative durability factor not less than 80. This factor is calculated by dividing the durability factor for the test admixture by the durability factor of the reference admixture (generally Vinsol resin) and multiplying the result by 100. It contemplates that specimens containing both admixtures be subjected to 200 cycles of freezing and thawing, although the 200 cycles is not mandatory if the relative dynamic modulus of elasticity in percent drops below 70 percent.

Concrete specimens, including non-air-entrained concrete, air-entrained concrete containing neutralized Vinsol resin, and concrete containing a "test" air-entraining admixture, were tested in the equipment. Both the reference admixture and the test admixture reached a relative dynamic modulus of elasticity of 70 in slightly more than 71 cycles of freezing and thawing. The concrete design data and freezing-and-thawing test results obtained in this series of tests are given in Table 1.

Subsequently, the severity of the rate at which the brine was circulated around the specimen containers was reduced. That the severity of the cycle was reduced is indicated by the fact that a somewhat comparable concrete mixture, containing the same reference admixture, went for over 150 freezing-and-thawing cycles before reaching a relative dynamic modulus of elasticity of 70. The results of this series of tests, which included four "test" admixtures, are given in Table 2.

It appears from these tests that the cycles of freezing and thawing are still somewhat more severe than may be desirable but that, within limits, further adjustment in rate of fluid circulation will make the cycles less severe. This has not been done because within the next few months the equipment is to be dismantled and moved to a new location. Also, the ASTM, largely on the basis of results obtained in the recent Highway Research Board Cooperative Tests (3), is currently considering more closely defining the time-temperature curve during the freezing-and-thawing cycles. The equipment will be adjusted to fit this curve, if and when it is adopted by the ASTM.

Table 1

Test Results Before Adjustment of Apparatus

A. MATERIALS

Cement: Type I

Fine Aggregate Natural, sp gr 2.62, f m 2.83

Coarse Aggregate. Crushed Limestone, max size 3/4-in., sp gr 2.79

Reference Admixture Neutralized Vinsol Resin

B. CHARACTERISTICS OF THE CONCRETE

Mix No.	1	2	3
Admixture	None	Reference	Test
Slump, in.	4-1/2	4	4
Cement, sks/cu yd	5.50	5.47	4.40
Water/Cement, gal/sk	6.47	6.04	6.72
Water, gal/cu yd	35.6	33.0	29.6
Sand/Aggregate, percent	44	43	41
Air Content, percent	2.4	5.5	6.0

C. DURABILITY DATA

Relative Dynamic Modulus of Elasticity = p(1)

Number of Cycles of Rapid Freezing and Thawing in Water

Mix No.	12	48	71	129	DF(2)	RDF(3)
1	41	--	--	--	--	--
2	93	81	73	52	28	100
3	91	82	77	58	32	114

(1)p = relative dynamic modulus of elasticity in percentage of the dynamic modulus of elasticity at 0 cycles.

(2)DF = durability factor of the concrete under test = PN/200
where P = (as indicated in (1) above)
N = number of cycles at which P reaches 70%

(3)RDF = DF/DF$_1$ x 100 where DF = the durability factor of the concrete under test and DF$_1$ = the durability factor of the reference concrete (Mix No. 2).

Table 2

Test Results After Adjustment of Apparatus

A. MATERIALS

Cement Type 2

Fine Aggregate Natural Sand, sp gr 2.62, f m 2.50

Coarse Aggregate Crushed Limestone, Max size 3/4-in., sp gr 2.82

Reference Admixture Neutralized Vinsol Resin

B. CHARACTERISTICS OF THE CONCRETE

Mix No.	1	2	3	4	5
Admixture	Reference	A	B	C	D
Slump, in.	3-1/2	4	4	4	4
Cement, sks/ cu yd	4.95	4.97	4.97	4.96	4.98
Water/Cement, gal/sk	6.14	5.73	5.52	5.50	5.50
Water, gal/cu yd	30.4	28.5	27.4	27.3	27.4
Sand/Aggregate, percent	41	41	41	41	41
Air Content, percent	6.0	5.2	5.7	6.0	5.7
Comp Strength, 28-da, psi	3950	5680	5230	4990	4500

C. DURABILITY DATA

Relative Dynamic Modulus of Elasticity = p(1)

Number of Cycles of Rapid Freezing and Thawing in Water

Mix No.	11	35	47	59	83	108	132	156	181	196	217	232	DF(2)	RDF(3)
1	89	80	77	77	76	74	74	67	59	--	--	--	51	100
2	88	86	84	84	82	79	78	73	70	68	63	59	63	124
3	89	85	82	82	79	78	78	74	70	68	64	60	63	124
4	89	85	85	85	80	78	76	73	66	66	58	--	59	116
5	88	83	81	80	76	75	72	70	66	60	--	--	55	108

(1)p = relative dynamic modulus of elasticity in percentage of the dynamic modulus of elasticity at 0 cycles.

(2)DF = durability factor of the concrete under test = PN/200
where P = (as indicated in (1) above)
N = number of cycles at which P reaches 70%

(3)RDF = DF/DF$_1$ x 100 where DF = the durability factor of the concrete under test and DF$_1$ = the durability factor of the reference concrete (Mix No. 1).

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Appendix A

DESCRIPTION OF, AND INSTRUCTIONS FOR, OPERATION OF AUTOMATIC FREEZING-AND-THAWING APPARATUS

Principle of Operation

This equipment consists essentially of three insulated tanks, one for the cold fluid, one for the thaw fluid, and one for the specimens, with means for refrigerating the cold fluid, heating the thaw fluid, and the necessary pumps, valves, and controls to circulate the solutions through the specimen tank at the required temperatures, time intervals, and rates of flow. The apparatus is designed to reduce the temperature of twenty-five 3- by 4- by 16-in. concrete specimens to 0±3 F in one hour and raise their temperature to 40±3 F in the next hour. It will automatically repeat the above two-hour cycle for any desired number of cycles. It is designed to meet the requirements of ASTM Designation C290 "Method of Test for Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water."

Description of Component Parts

The principal parts are described in detail in the following. Illustrations of the respective parts are also given. A complete list of all parts, and their cost (in 1955) is given in Appendix B.

Tanks

Three tanks are required for the apparatus. All three tanks are constructed of No. 10 gage galvanized iron and all three are 30 in. wide by 36 in. long inside. The cold tank is 54 in. deep and has 8 in. of insulation on all six sides. The thaw tank is 36 in. deep and has 4 in. of insulation on all sides except the bottom which has 8 in. The specimen tank is 30 in. deep and has 6 in. of insulation on all six sides. The bottom insulation for all three tanks is fiberglass board obtained in 1- and 2-in. thicknesses, built up to the required total thickness in at least three courses with staggered joints. The insulation board is of sufficient rigidity to support the loaded tanks without other supporting material other than 2- by 4-in. wood columns which support the metal flanges of each tank at each corner. Since the thaw and cold tanks are on the same base they both have 8 in. of insulation on the bottom. Each tank has a galvanized iron cover with edges turned up to contain the fiberglass board insulation. The sides of each tank are insulated with mineral wool packed between the outside of the metal tank liner and the ⅝-in. plywood which forms the outside surface of the completed tanks. Similar plywood forms the top surface of each of the tank covers, fitting into and screwed to the metal sides of the tops. A vapor barrier of aluminum foil is placed between the plywood and the insulation on all sides including the top and bottom. The covers for the thaw and cold tanks rest on a sponge rubber gasket ½ in. thick and ½ in. wide cemented completely around the top edges of the tanks. The top for the cold tank is split to accommodate the refrigeration pipes to the plates inside the tank. The cover for the specimen tank is hinged at the back and counterbalanced for ease of opening. The bottom of the specimen tank is sloped 1 in. from the sides to the center in which is located the central drain pipe. A perforated removable galvanized iron plate ¼ in. thick rests in the bottom of the tank supported on ¼-in. square bars about 6 in. long at the center of each side and welded to the bottom of the tank. The removable plate also has pieces of iron welded to it to locate the 25 specimen containers equidistant from each other. Appropriate holes and pipe fittings are located in the respective tanks for fluid circulation, heating and cooling equipment, and for overflow protection. Details of tank construction, insulation, and the locations of pipe fittings are shown in Figs. 1 through 10. The thaw and cold fluid tanks are located above the tank.

Specimen Containers

Twenty-five metal containers are required to hold the concrete specimens. The inside dimensions of the containers are 3¼ by 4¼ by 22 in. The 22 in. dimension is the depth. In use the concrete specimens are placed in the containers and the containers filled with water to cover the tops of the specimens ½ in. deep. Loose fitting metal covers which extend 1 in. down the sides of the containers are placed on them before starting a test. Two containers, one with, and one without, a cover in place, are shown in position in the specimen tank in Figure 2. The containers are made of 18-gage galvanized iron.

Pumps, Valves, and Piping

Fluid circulation is accomplished by two iron-body centrifugal pumps rated at 20 gpm at a total 30-ft head. The pumps are cradle mounted and directly connected to ½ hp, 220 v, 3 ph, squirrelcage induction motors. The normal speed of the pumps is 3,500 rpm. Since only one solution is circulated at a time both pumps are connected to a common 1¼-in. suction line coming from the bottom of the specimen tank. The 1¼-in. suction line is connected to 1-in. lines which are connected to the suction side of each pump. The discharge side of each pump is ¾ in. which is increased to 1 in. by a bushing permitting the use of 1-in. pipes in pumping the solutions directly into the bottom of the cold and thaw fluid tanks. Leakage of solution from the cold and thaw fluid tanks through the pumps to the specimen tank is prevented by check valves in the discharge line from each pump. Hand operated gate valves are also installed in the pump lines between the cold and thaw fluid tanks and the check valves to facilitate repairs. Cold or thaw fluid flows from the respective tanks to the specimen tank by gravity through 1½-in. pipes coming from the bottom of each tank. These pipes extend up

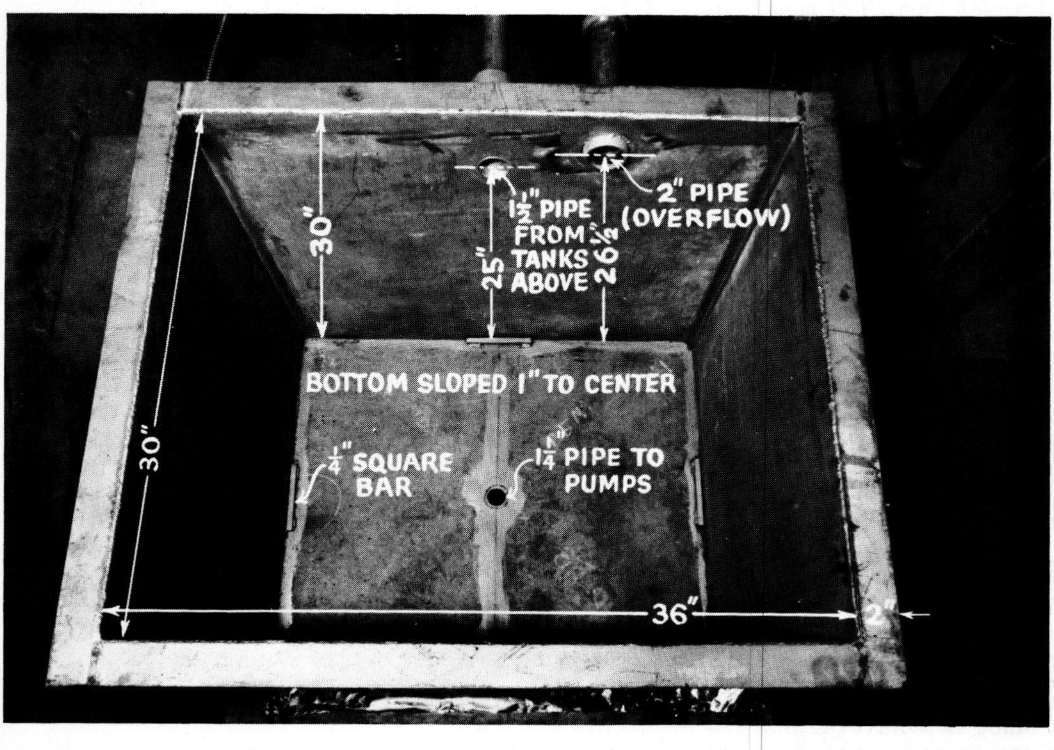

Figure 1. Specimen tank liner without removable plate.

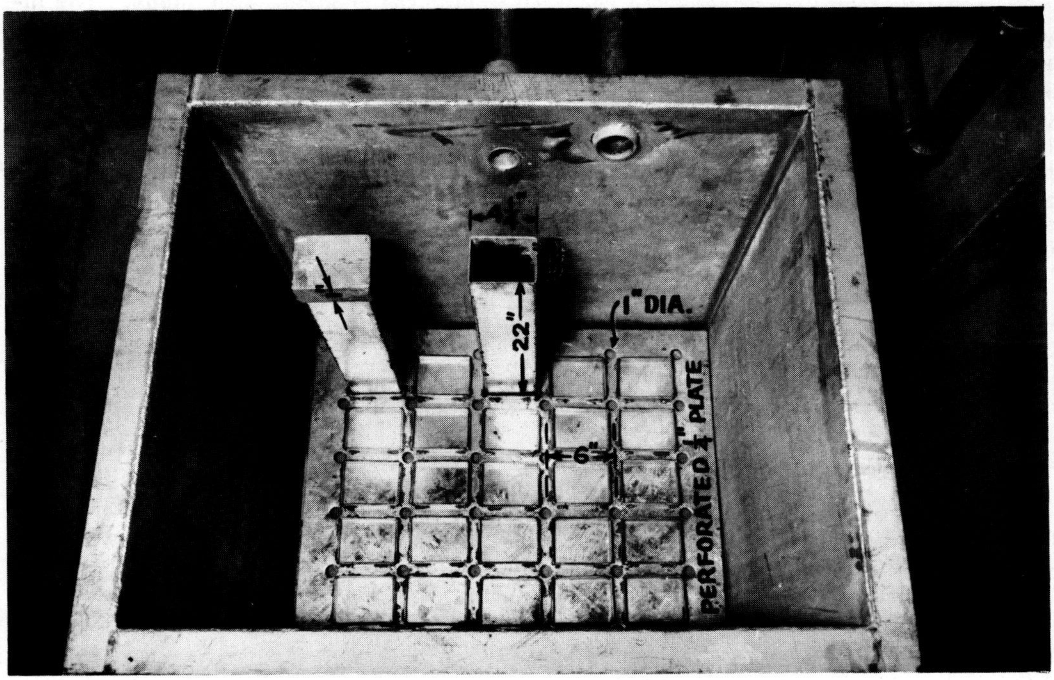

Figure 2. Specimen tank liner with removable plate and two specimen containers.

into the cold and thaw fluid tanks to a height that will only permit enough fluid to drain from each of the tanks to fill the specimen tank to a depth equivalent to the length of the concrete specimens, plus 1 in., when the specimens are in their containers and a full load of containers is in the specimen tank. This pipe is 23 in. long in the thaw tank and 34 in. long in the cold tank. The thaw tank is initially filled to a depth of 32 in. and the cold tank to a depth of 43 in. In other words, the depth of solution in the specimen tank is controlled by the depth of solution in the thaw tank for the thaw cycle and in the cold tank for the cold cycle and there should be no more solution in the thaw or cold tank than will properly fill the specimen tank when the solution has been drawn down to the top of the overflow pipes inside the cold or thaw fluid tanks. This depth is adjusted initially so that the solution in the specimen tank will not reach the covers on the specimen containers, and should be checked frequently to see that this does not occur. Flow of solution from the cold and thaw fluid tanks to the specimen tank is controlled by solenoid-operated valves in the 1½-in. drain line from each tank. Hand operated gate valves are also located in these 1½-in. lines between the solenoid valves and the overhead tanks. The solenoid valves are of the normally closed type; being shut when no electrical energy is provided to them. The solenoid valves require no attention under normal operating conditions, and the hand valves should be full open. A 2-in. overflow opening and pipe is connected to the top of each tank to drain excess fluid to waste, should any of the tanks become too full because of abnormal or faulty operation. In addition, an overflow float is located in the specimen tank to shut off all fluid circulation and prevent brine from getting into the specimen containers.

Timer and Control Wiring

Since all control valves and pumps are electrically operated, circulation of the solutions is made entirely automatic by means of a 2-hr, 5-circuit timer. The timer consists of a series of properly shaped cams, two cams per circuit, mounted on a common shaft and driven by a 2-hr electric clock motor. As the shaft revolves, the cams open and close the various circuits in their proper sequence. The fifth circuit may be used to operate a cycle counter. The operation of the four active circuits and the sequence in which they operate is tabulated below. Circuit No. 1 is the circuit at the front, or dial end of the timer and the circuit numbering progresses toward the back.

Circuit Number	Elapsed Time Hr	Min	Sec	Degree Setting	Contact Position	Operation
1	0	0	0	0	On	Open cold solenoid valve
2	0	3	0	9	On	Start cold pump
1	0	57	0	170	Off	Close cold solenoid valve
2	0	59	30	178	Off	Stop cold pump
3	1	0	30	182	On	Open warm solenoid valve
4	1	3	0	189	On	Start warm pump
3	1	57	0	350	Off	Close warm solenoid valve
4	1	59	30	359	Off	Stop warm pump

Each of the circuits also turns a pilot light on or off as a visual indication of the phase of operation of the equipment at any given time. While timers can be obtained with a dial calibrated in degrees this one was not. A dial was made of bristol-board and degrees ruled on it at 5 deg intervals, up to 360 deg. This dial was fastened to the timer under the pointer knob. The controls are wired and the timer adjusted so that the timer will perform the operations indicated in the tabulation above. The timer is set properly initially and should require no further adjustment. In the event that adjustment becomes necessary it should be made only by someone entirely familiar with its operation and construction. All control circuits are 110 volt. The complete wiring diagram is shown in Figure 11. It will be noted that the float switch is wired into the control circuit so that when the fluid level in the specimen tank is too high the float switch will open all timer control circuits. To restore the liquid levels to normal it is necessary that the pumps and valves be operable. A canceling or by-pass switch has therefore been provided so that the overflow switch can be by-passed, the timer set in the proper position to pump the excess fluid to the proper tank and the operation of the equipment resumed. To prevent the by-pass switch from being accidentally closed, thereby canceling the overflow protection, it is of the type requiring a key for its operation. In the event the float switch operates and it is necessary to use the by-pass switch it must be returned to its original position after normal liquid levels have been restored. The float switch is an inclosed mercury switch mounted on the end of a rod outside of the specimen tank above the liquid level inside the tank. The rod enters the tank, is bent 90 deg and is connected to a float inside the tank. As the liquid level rises the float rises with it rotating the mercury switch outside the tank. The mercury switch is mounted so that it will operate and open all circuits if the liquid level becomes too high. There is also a separate switch to stop the clock motor independent of the other control circuits. The circuits for the heating equipment for the thaw tank and cooling equipment for the cold tank are independent of the timer and control circuits for fluid circulation and are discussed individually below. The electric supply comes from a single 220 v, 60 c, 3 ph, power-supply line. Power to operate the 110 v circuits and all 110 v devices is obtained from this 220 v line through a transformer. This arrangement provides a 110 v power source that will not fail because of overloading due to use of other equipment, which sometimes happens when a lighting or other 110 v source is used.

Heating Equipment

The thaw fluid is heated by means of six 1000 w, 220 v immersion heaters, three of which are screwed into $1\frac{1}{4}$-in. pipe flanges in each of the long sides of the tank wall at the one-quarter points and on a centerline 6 in. from the bottom of the tank. Two heaters are connected to each phase of the 220 v, 3 ph line to provide a balanced load. The heaters are controlled by a Fenwall thermo-switch screwed into a ¾-in. fitting centered in one end of the tank and 20 in. from the bottom of the tank. The thermo-switch is set to maintain the temperature of the thaw fluid between 40 and 42 F. The thermo-switch operates the 110 v holding coil on a 220 v starter which operates the heaters. The heaters and thermo-switch may be seen in the tank in Figure 7.

Cooling Equipment

The cold fluid is cooled by means of six 22- by 30-in. refrigeration plates immersed

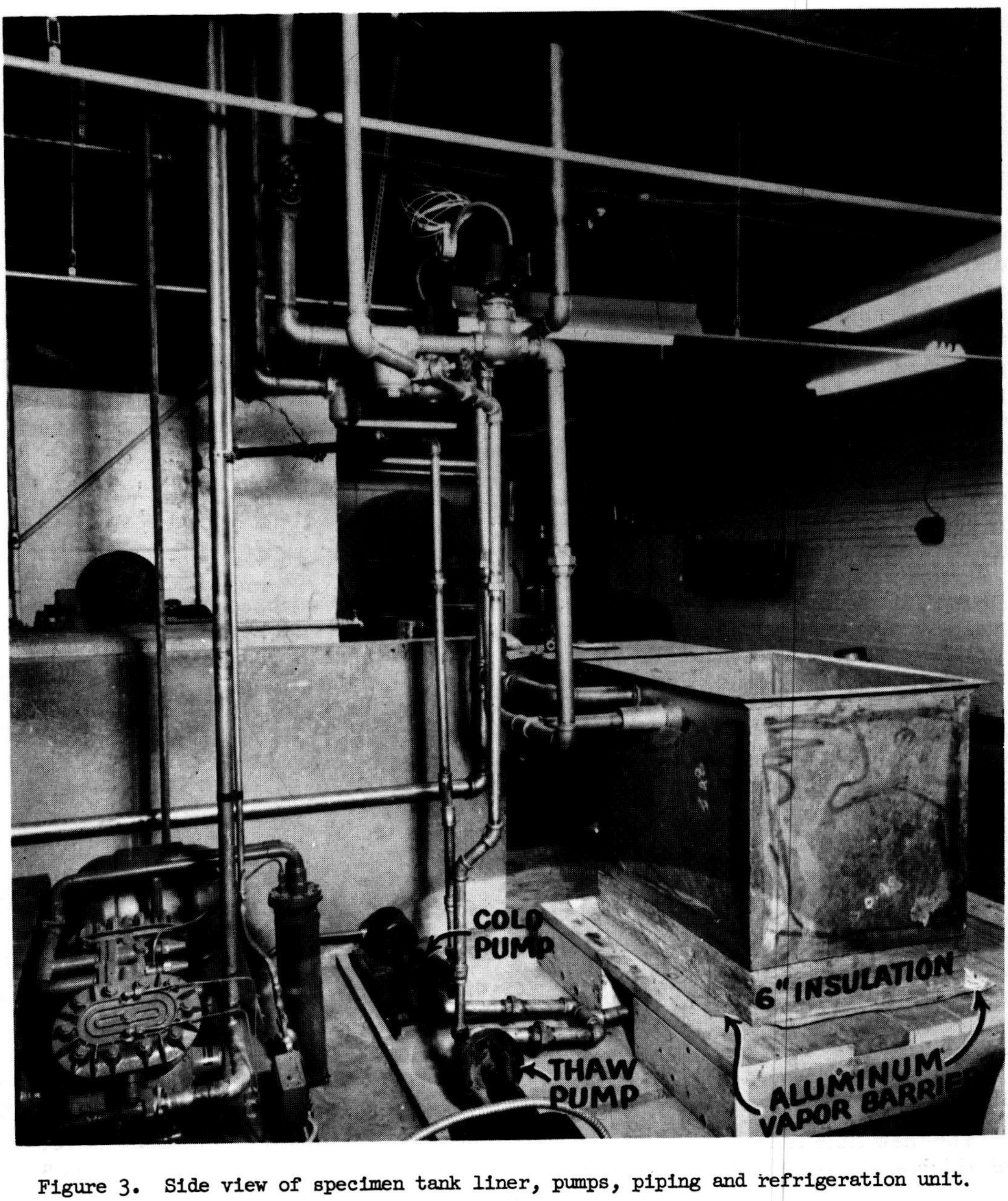

Figure 3. Side view of specimen tank liner, pumps, piping and refrigeration unit.

in the cold tank. The plates are cooled by a 7½ hp water-cooled refrigeration compressor, using Freon 22 as the refrigerant. The compressor is controlled by an adjustable thermostat with a bulb immersed in the cold fluid. The thermostat operates a solenoid valve located in the refrigerant line. This solenoid valve can also be closed by operation of a manual switch. Closing of the solenoid valve either by the thermostat or manual switch causes the compressor to pump the refrigerant from the plates into the receiving tanks under the compressor and shuts off the compressor by operation of the high pressure switch connected to it. The thermostat is set to maintain the temperature of the cold fluid between 0 and -5 F.

Heating and Cooling Fluids

The cold and thaw fluids are both 26 percent solutions of calcium chloride having

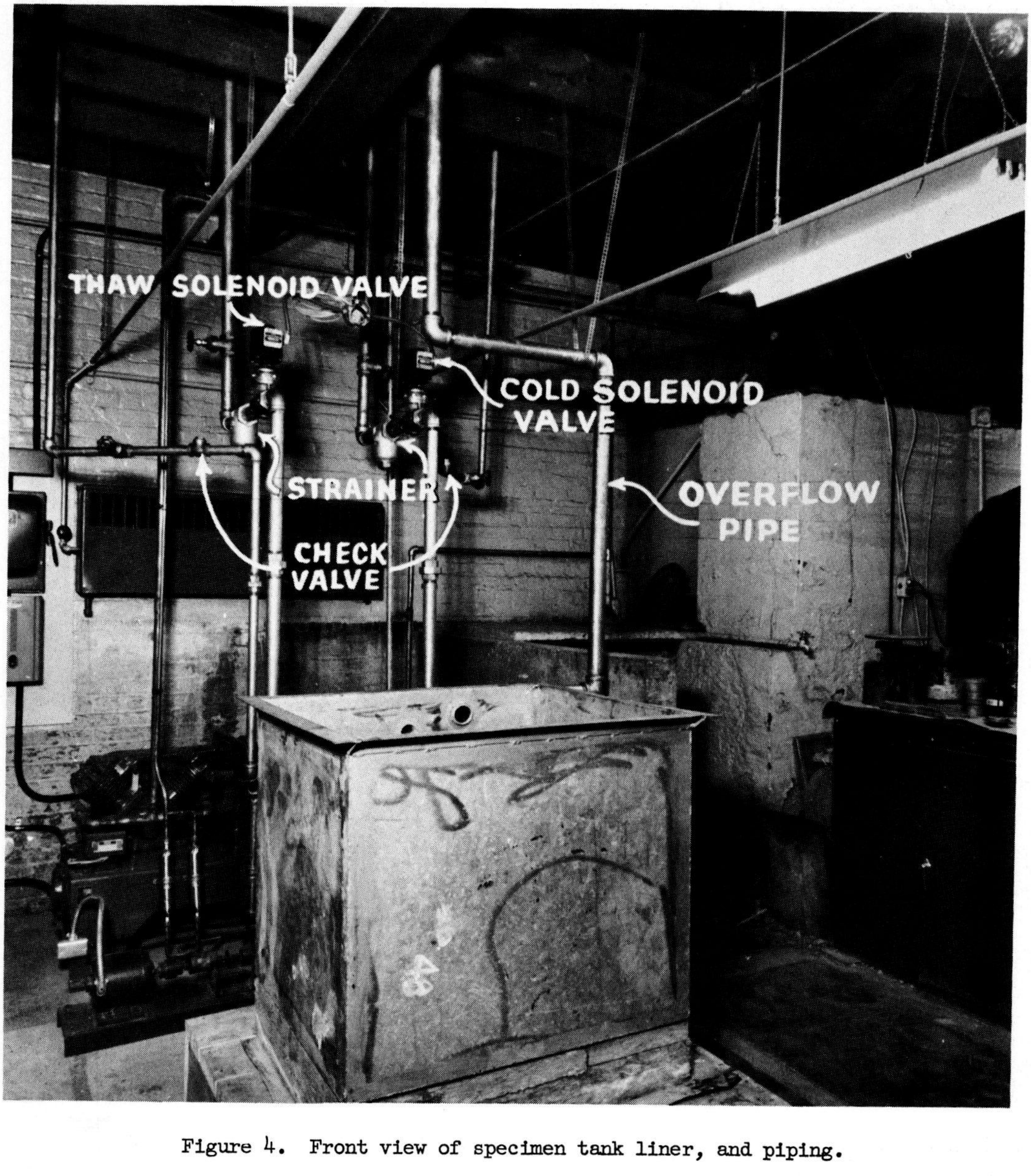

Figure 4. Front view of specimen tank liner, and piping.

a specific gravity of 1.250 at 60 F. This brine has a freezing point of -25.8 F and is made by using 3.48 lb of 78 percent flake calcium chloride per gallon of solution. Since calcium chloride brine is corrosive under certain conditions it is inhibited by the addition of sodium chromate. It is cheaper to do this by adding sodium dichromate and sodium hydroxide to the brine. This is done by making separate solutions of the dichromate and caustic soda, each in concentration of two pounds per gallon of water. These solutions should be added in a ratio approximately the same as the dry weights which are to be used. The dry weights are 0.66 lb of sodium dichromate and 0.18 lb of caustic soda for each 100-lb of flake calcium chloride. In adding the inhibitor combinations, the increments of dichromate solution should always precede those of the caustic soda. After the inhibited brine solution has been made, the pH of the solution should be adjusted to and maintained at about 7.5. This is done by adding small increments of caustic soda or hydrochloric acid depending upon whether the solution is acid or basic, respectively. Manual RM-1, "Calcium Chloride for Refrigeration Brine," published by the Calcium Chloride Institute, contains excellent tables and other detailed information on all aspects of this subject. The quantities of materials used in making the initial brine solutions for the apparatus described herein were approximately as follows:

	Water, gal	FLAKE $CaCl_2$, lb	$Na_2Cr_2O_7$, lb	NaOH, lb
Thaw Tank	105	490	3.23	0.88
Cold Tank	130	632	4.18	1.13
TOTAL	235	1122	7.41	2.01

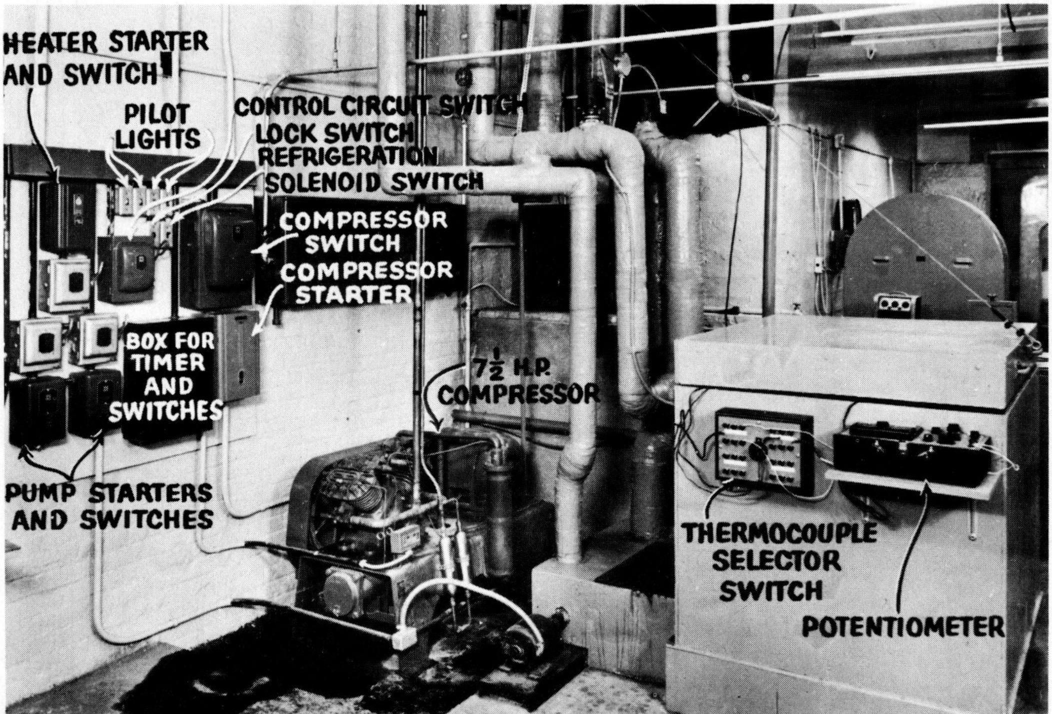

Figure 5. Side view of completed specimen tank and piping, with insulation.

INSTRUCTIONS FOR OPERATION

Starting the Apparatus

The equipment normally will be started at the beginning of a thawing cycle and also will be stopped at the end of a thawing cycle. Since the operation of starting the equipment under the above condition is somewhat different than starting it at other times separate instructions covering the two conditions are given below:

1. When starting the equipment at the beginning of a thawing cycle the specimen tank should contain no solution. Since the specimens are removed from the specimen tank for test at the end of a thaw cycle the setting on the timer will be approaching the position for starting the freezing cycle on the new run. The timer setting should be

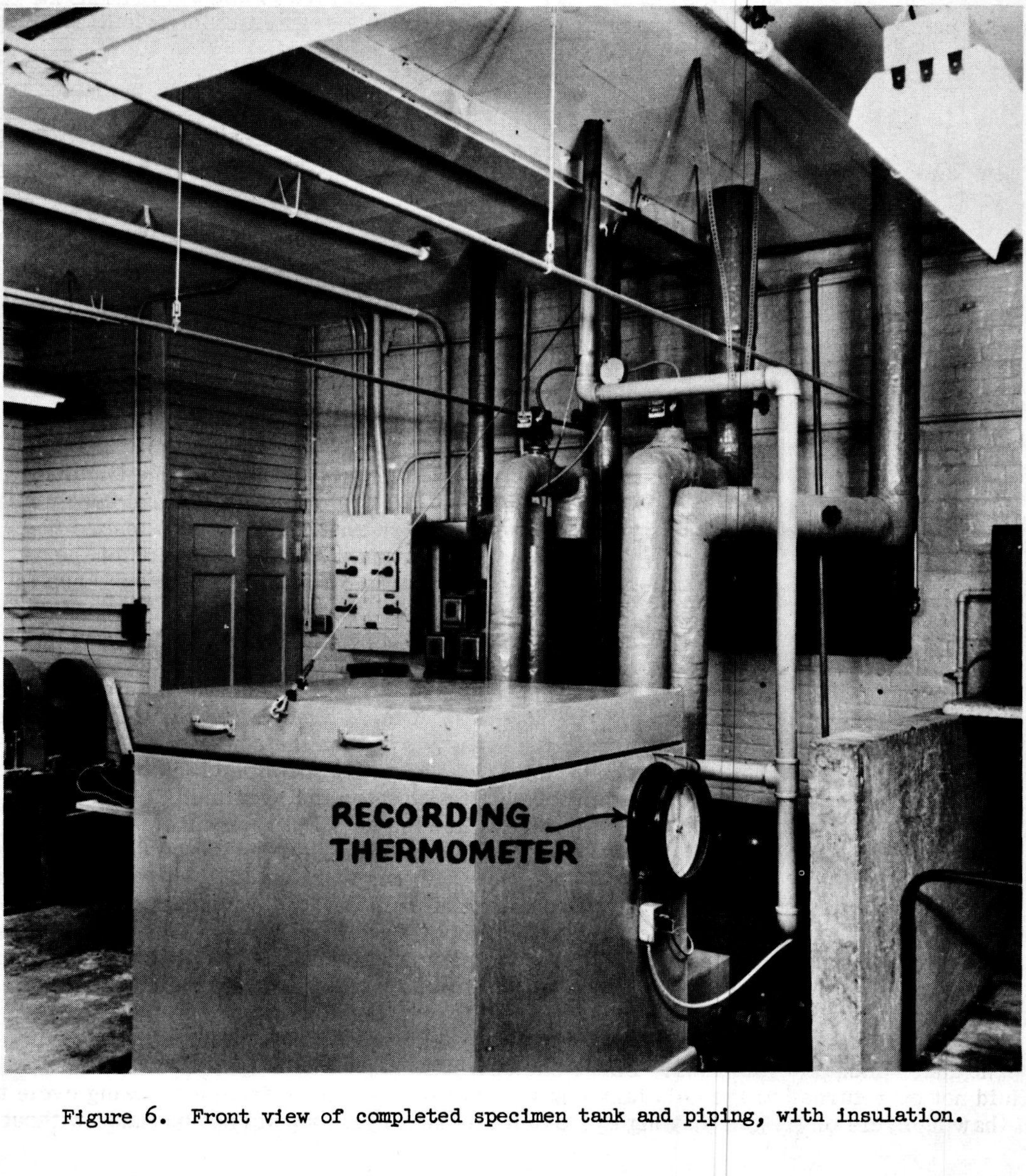

Figure 6. Front view of completed specimen tank and piping, with insulation.

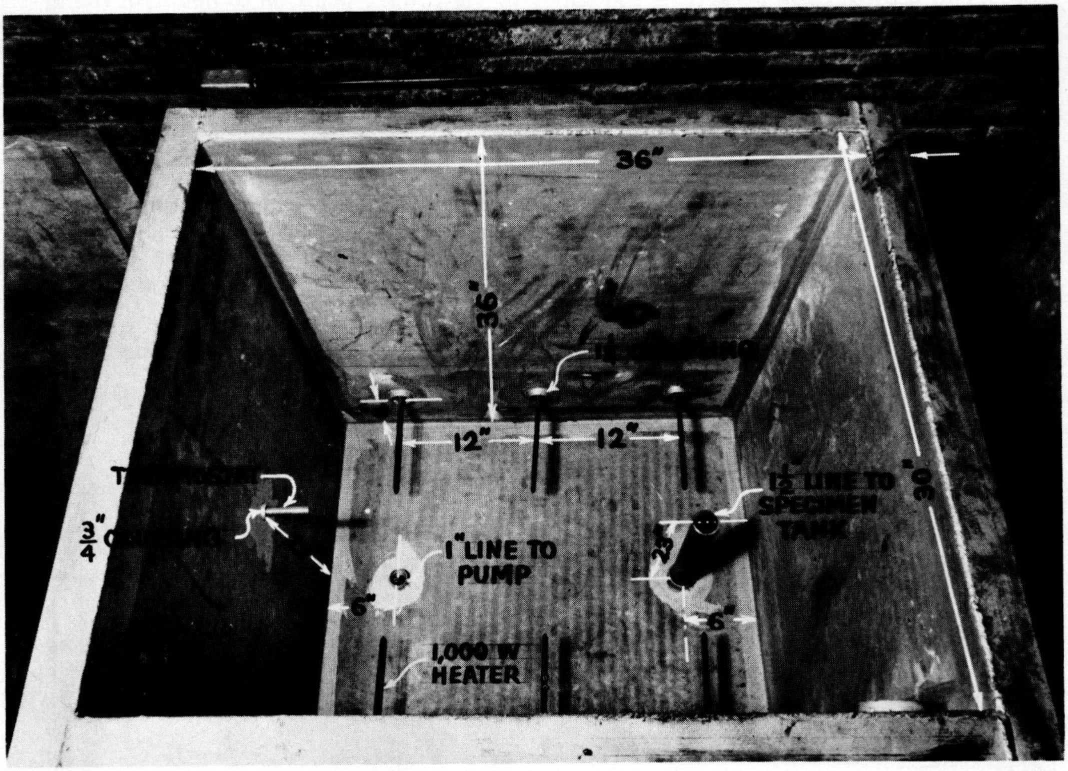

Figure 7. Thaw fluid tank liner and heaters (inside).

reset to 180 degrees by turning the pointer in a clockwise direction with the timer circuit switch and the timer clock switch off. All other switches on the control board will normally be on. Before starting the equipment a check should be made to insure that this is so and that the specimen tank contains no solution. After completion of the above operations it is only necessary to turn on the timer circuit and clock switches to start the apparatus.

2. If the apparatus has been stopped at any other phase of its operation it can be restarted at that particular phase by simply turning the two timer switches on. In the above situation and in the following situation the assumption is made that both timer switches were turned off originally. If, however, it is desired to restart the apparatus at the beginning of a freezing cycle it is necessary to return the solution in the specimen tank to the proper storage tank. If cold fluid is in the specimen tank turn the timer to 170 deg at which point no additional cold fluid will enter the specimen tank and fluid already in it will be pumped to the cold tank. As soon as all of the cold fluid has been pumped from the specimen tank, as evidenced by the pilot light for the cold pump going out, turn off both timer switches, set the timer to 0 deg and turn the two switches back on. If the equipment is on a thaw cycle at the time it is desired to restart it on a freezing cycle set the timer to 350 deg at which point the thaw solenoid valve will close and the thaw fluid in the specimen tank will be pumped to the thaw tank, and the freezing cycle will start. The operations described in this paragraph will not be necessary in connection with regular tests and under normal operating conditions. In the event of power failures and other unpredictable events it may be necessary to restart the equipment under unusual conditions. Under such circumstances it is essential that thaw fluid not be returned to the cold tank and vice versa. A change from a freezing cycle to a thawing cycle or from a thawing cycle to a freezing cycle should not be made without

first pumping the fluid already in the specimen tank to the proper overhead storage tank. This can be done by setting the timer to the proper position to perform the desired function as indicated by the table under "Pumps, Valves, and Piping." It is always desirable in changing the timer setting to have the timer switches in the off position.

Stopping the Apparatus

The apparatus can be stopped at any phase of its operation by turning off the two timer switches. However, under normal operating conditions these switches should only be turned off when removing or installing specimens at the end of the thawing cycle. If the switches are turned off at any other time the apparatus will stop with either cold

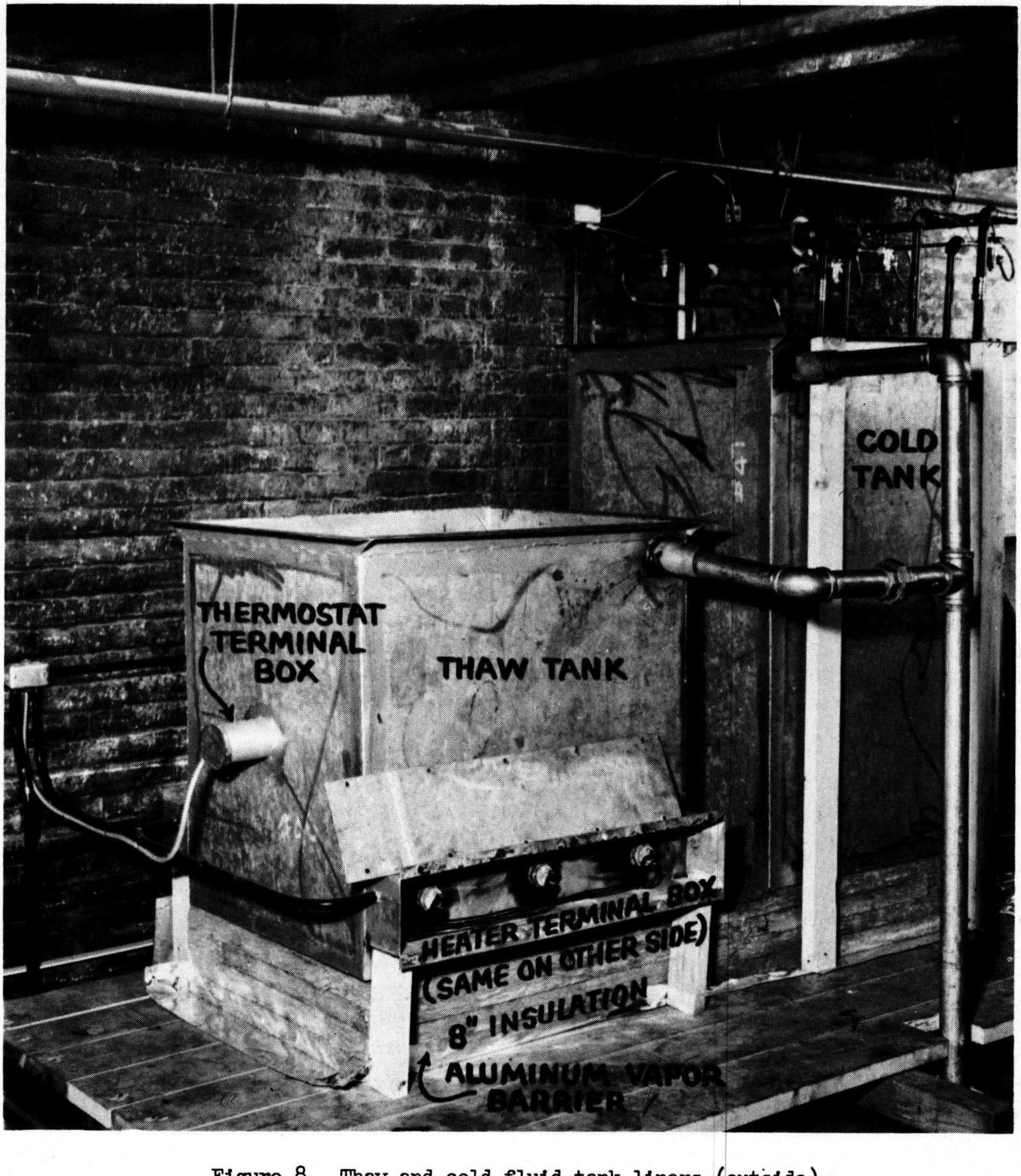

Figure 8. Thaw and cold fluid tank liners (outside).

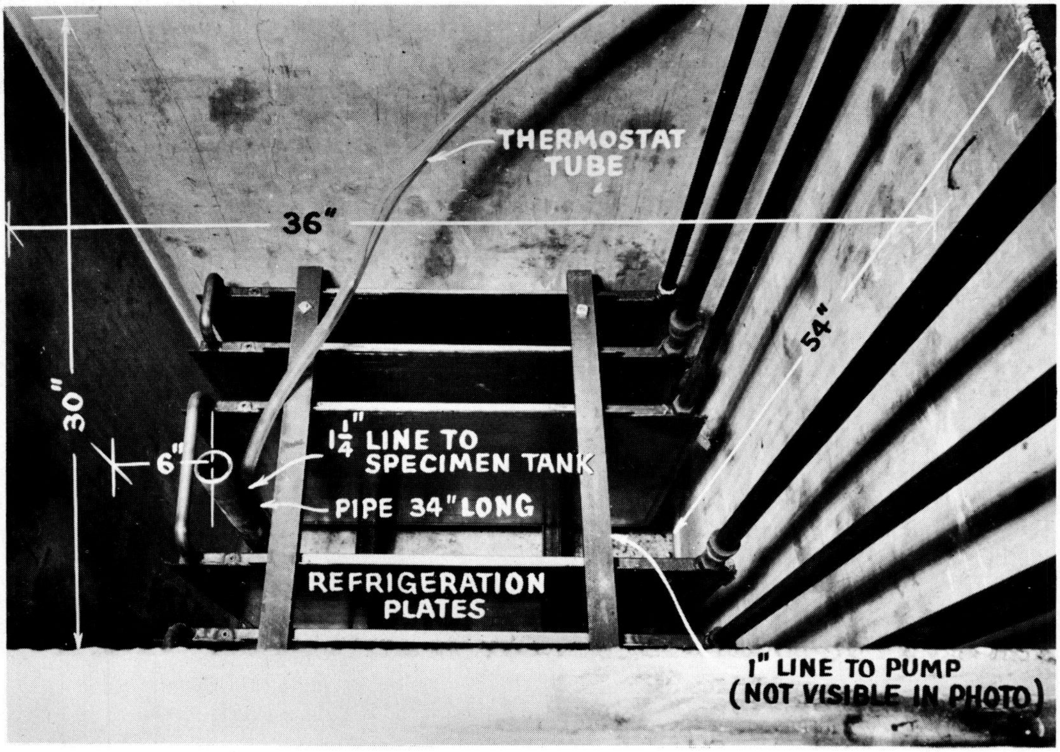

Figure 9. Cold fluid tank liner and refrigeration plates (inside).

or thaw fluid in the specimen tank. The clock switch is in series with the timer switch. Therefore, whenever the timer switch is turned off, the clock is also off. However, when only the clock switch is turned off, the apparatus will continue to perform the operation it was performing at that particular time, until the clock is again turned on. If stopped at any phase of the operation other than at the end of a thaw cycle, the precautions discussed in item 2 under "Starting the Apparatus" should be observed in restarting.

Operation of Cold Tank and Refrigeration Equipment

The portion of the freezing-and-thawing apparatus causing the freezing of specimens consists of the cold tank, cold fluid, refrigeration equipment, cold pump line, cold feed line to specimen tank, and their controls. The operation of the various units are described below:

1. Cold Tank and Cold Fluid — The construction of the cold tank is described under "Tanks." The composition and concentration of the cold fluid (brine) is described under "Heating and Cooling Fluids." The concentration and pH of this solution should be checked at least weekly and adjusted as necessary. The brine capacity of the cold tank with plates installed and when filled to a depth of 42 in. is approximately 160 gal. The liquid level of the cold fluid when not in circulation should not exceed 43 in. from the bottom of the tank but should be maintained as closely as possible to this level. If the level exceeds 50 in. the brine will overflow to the 2-in. drain line and be wasted. If the level is lower than 40 in. there will not be sufficient brine available to properly

fill the specimen tank to freeze the specimens when the brine is in circulation. The liquid level can be checked by inserting a measuring stick in the cold tank when the brine is not in circulation or by observing the maximum depth in the specimen tank when the cold brine is in circulation. In the latter procedure a depth less than 17 in. in the specimen tank indicates that there is insufficient brine in the cold tank and a depth more than 19 in. indicates too much brine. These depths will be increased about 1 in. if the fluid is not in circulation. Instructions for transferring or adding brine to maintain the proper level are given under "Transfer of Solution."

2. Refrigeration Equipment — The refrigeration equipment is described under "Cooling Equipment." Its operation is entirely automatic and normally requires no attention. However, in the event that the cold fluid temperature or the temperature of the thermocouple specimen in the specimen tank is not normal (see "Temperatures") something is probably wrong with the refrigeration equipment. The trouble will undoubtedly be evidenced by a rise in the temperature of the cold fluid. The operation of the refrigerating system depends on the following items which should be checked as indicated.

3. Electric Power — If the compressor is not operating the trouble may be due to failure of electric power either to the compressor or to the solenoid valve controlling the operation of the refrigeration unit. The toggle switch controlling the solenoid valve should be on. If this switch is on, the temperature of the cold fluid is above 0 F and the compressor still does not run the fuses in the compressor master switch, and the reset on the compressor starter should be checked. If the freezing-and-thawing apparatus is otherwise operating normally the fuses for the solenoid valve are all right. Otherwise, the fuses in the master switch for the 110 v control circuit should also be checked.

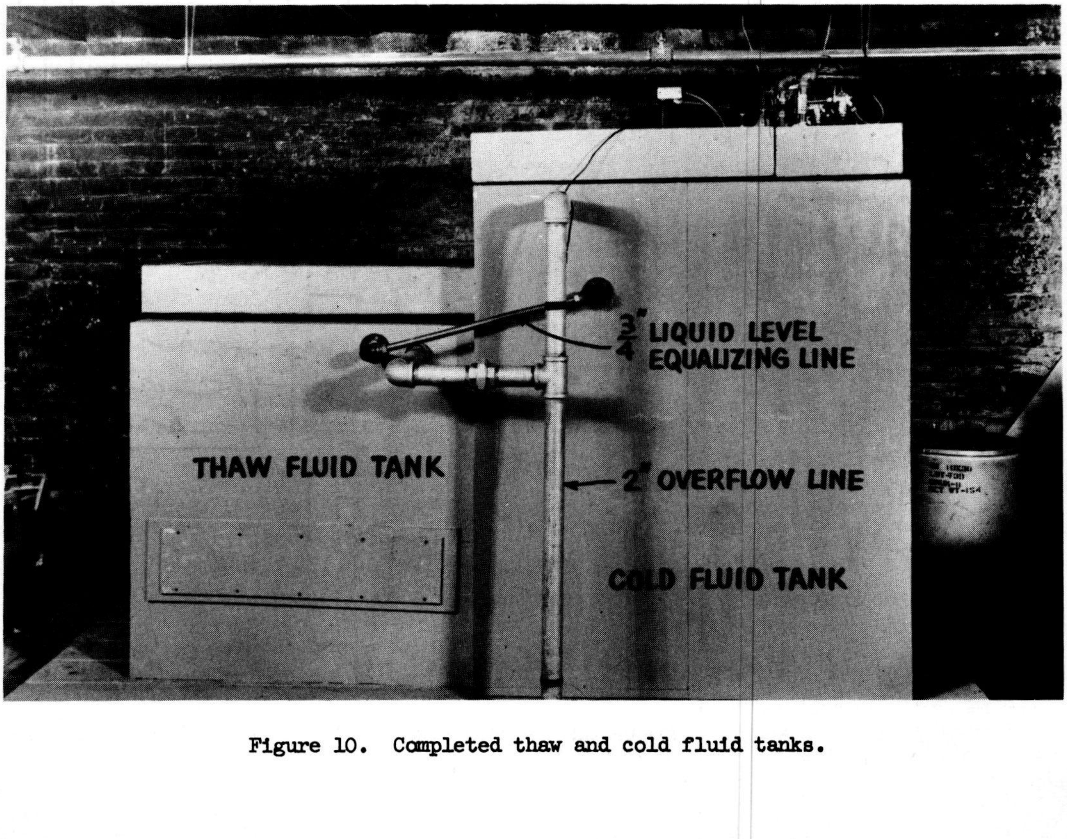

Figure 10. Completed thaw and cold fluid tanks.

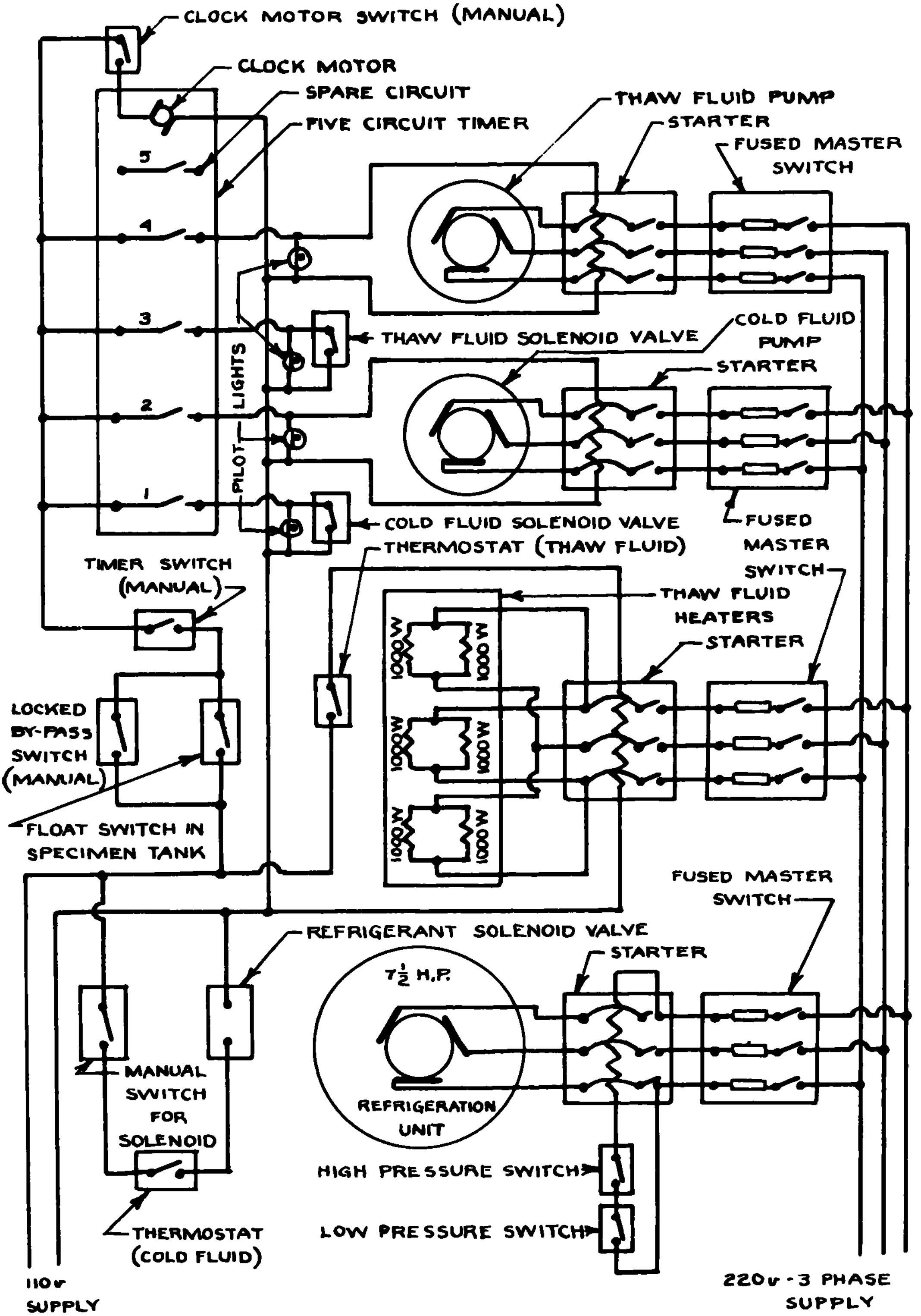

Figure 11. Wiring diagram.

4. Cooling Water — Since the condensing unit is water cooled a supply of cooling water should be available at all times. The cooling water is supplied to the cylindrical tanks under the compressor by a 3/4-in. line connected to the tanks. The shutoff valve is located in this line and should be open at all times. The closing of the valve or failure of the water supply will stop the compressor.

5. Refrigerant — A leak in the refrigeration lines or equipment will of course result in a loss of the refrigerant (Freon 22). A small leakage of refrigerant will be evidenced by a steady rise in the temperature of the cold fluid and the continuous operation of the compressor but will otherwise probably be nondetectable. A large leak may be found by visual observation. In either case, the compressor should be stopped by first turning off the solenoid switch, allowing the compressor to run until it shuts off, and then pulling the master compressor switch. The compressor may run for several minutes after the solenoid switch is turned off. The reason for stopping the compressor in this manner is to pump all of the Freon into the tanks under the compressor, which will serve to save as much Freon as possible and also will prevent it from condensing as a liquid in the refrigeration plates with consequent difficulty in restarting. If a leak is discovered in the cold plates, or the lines to them, below the brine level, the compressor should be stopped immediately with the master switch because pumping the unit down will suck brine into the compressor.

6. Thermostat — The thermostat controlling the temperature of the cold fluid should not normally require resetting but if this is necessary the temperature adjusting screw should be turned clockwise for higher temperatures and counterclockwise for lower temperatures. The thermostat is protected by the fuses in the 110-v control circuit master switch.

In the event that the refrigeration equipment is not operating properly and the trouble cannot be corrected by following the instructions contained in 3 through 6 above, it probably will be necessary to call in a refrigeration repairman, and he should be called in any event if the difficulty is caused by refrigerant leakage.

7. Cold Pump Line — The cold pump line consists of the necessary pipe connections, a hand operated gate valve, a check valve, and a pump. The check valve requires no attention unless it becomes stuck. It would be most unusual for it to stick shut but this would be evidenced by lowered or complete stoppage of discharge into the cold tank when the pump is running. If stuck open, the pump will run backwards when turned off and all of the brine in the cold tank will drain into the specimen tank. This is the only situation where the float valve in the specimen tank will not stop the flow. The hand-operated gate valve in the pump line should be closed immediately. In either event it will be necessary to remove the insulation from the top of the check valve, unscrew the top of the valve and correct the reason for the sticking of the valve. The pump is controlled by circuit No. 2 on the timer which energizes the pump motor starter and the pilot light on the control board. In the event the pump does not run with the timer on and in the proper position the reset button on the starter and the fuses in the pump master switch should be checked.

8. Cold Feed Line to Specimen Tank — This line consists of the necessary 1¼-in. pipe connections, a hand operated gate valve, a strainer, and a solenoid operated valve. The hand operated gate valve should remain open at all times during normal operation. The solenoid valve and its pilot light is controlled by circuit No. 1 of the timer. If it does not open when the timer is in the proper position the circuit should be checked and any difficulty corrected. If it does not close when the timer is in the proper position and the pilot light is off it is probably due to debris under the valve or sticking. In either event it will probably be necessary to remove the insulation around the valve and take the valve apart to correct the difficulty. The hand gate valve should be closed before undertaking this operation. If both valves are open and fluid does not flow, the strainer may need cleaning. This can be done by unscrewing the bottom of the strainer and cleaning the straining element. The hand gate valve should also be closed before undertaking this operation.

Operation of Thaw Tank and Heating Equipment

The portion of the freezing and thawing apparatus causing the thawing of specimens consists of the thaw tank, thaw fluid, immersion heaters, thaw pump line, thaw feed line to specimen tank, and controls. The operation of the various units are described below:

1. Thaw Tank and Thaw Fluid — The construction of the thaw tank is described under "Tanks." The composition and concentration of the thaw fluid (brine) is described under "Heating and Cooling Fluids." The concentration and pH of the solution should be checked at least weekly and adjusted as necessary. The brine capacity of the tank with the heaters installed is approximately 125 gal. The liquid level of the thaw fluid when not in circulation should not exceed 32 in. from the bottom of the tank but should be maintained as closely as possible to this level. If the level exceeds 32½ in. the brine will overflow to the 2-in. drain line and be wasted. If the level is lower than 30 in. there will not be sufficient brine available to properly fill the specimen tank to thaw the specimens when the brine is in circulation. The liquid level can be checked by the same means as for the cold fluid as described under "Stopping the Apparatus."
2. Immersion Heaters — The immersion heaters are described under "Timer and Control Wiring." The terminals for the heaters are on the outside of the tank on the long sides and are accessible by removing the long metal terminal box covers at the bottom of these two sides of the tank. The heaters are protected by fuses in the heater master switch and by the heater starter. A gradual decrease in the temperature of the thaw fluid indicates that probably one or more of the heaters has burned out or is not receiving electric power because of blown fuses. The cause should be determined and corrected. If it is necessary to replace a heater the thaw tank must be emptied before the heater is removed. In the event that none of the heaters are working the thermostat should be checked.
3. Thermostat — The thermostat controlling the immersion heaters is located in the round compartment on one end of the thaw tank. It is accessible by removing the round cover. Turning the set screw on the end of the thermostat clockwise will raise the temperature of the thaw fluid and turning it counterclockwise will lower the temperature. The thermostat activates the heaters by energizing the 110-v holding coil of the magnetic contractor for the heater starter. It is protected by the fuses in the 110-v control circuit master switch.
4. Thaw Pump Line — The thaw pump line is identical to the cold pump line (see "Cold Pump Line" under "Operation of Cold Tank and Refrigeration Equipment") except that the pump is controlled by timer circuit No. 4.
5. Thaw Feed Line to Specimen Tank — The thaw feed line is identical to the cold feed line (see "Cold Feed Line to Specimen Tank" under "Operation of Cold Tank and Refrigeration Equipment") except that the solenoid valve is controlled by timer circuit No. 3.

Overflow Protection

Protection against overflow is provided in three ways as described below:

1. Overflow Pipes — Two-inch overflow pipes are located at the top of the cold and thaw fluid tanks and at the top of the specimen tank. These pipes are connected to a common 2-in. line which discharges to a drain. In the event any of the tanks become too full the brine will run out of these overflow pipes and it will be necessary that it be replaced in the concentration described under "Heating and Cooling Fluids."
2. Liquid Level Float — In addition to the overflow protection described above, a float switch is located in the specimen tank which will shut off the timer circuit and clock, and stop all operation of the equipment if the liquid level in this tank approaches the tops of the specimen containers. The single exception is if a check valve in one of the pump lines should stick open, as described in "Cold Pump Line" under "Operation of Cold Tank and Refrigeration Equipment." In the event that this float operates, the locked by-pass switch should be operated to re-establish proper liquid levels before restarting the equipment. The locked by-pass switch should be turned off and the key removed after the liquid levels have been restored. The reason for the high liquid level should also be determined and corrected.
3. Transfer Overflow Pipe — Since there is a slight tendency for transfer of solu-

tion from the thaw tank to the cold tank, or vice versa, the timing and pumping operations have been deliberately adjusted so that the transfer is always from the thaw to the cold tank. A ¾-in. pipe is located in the side of the cold tank adjacent to the thaw tank at the height at which it is desired to maintain maximum liquid level and runs from this point through the top of the thaw tank. By this means any excess solution transferred to the cold tank is automatically returned to the thaw tank.

Transfer of Solution

Under unusual circumstances it may become necessary to transfer thaw fluid to the cold fluid tank, or vice versa. To describe the transfer operation it is assumed that thaw fluid is to be transferred to the cold tank. The problem is to restore the level of the thaw solution in the specimen tank to its proper minimum depth of 18 in. when it contains a full load of specimens and the fluid is not in circulation. This may be done by following the steps listed below:

1. Start the transfer operation when the specimen tank is full of specimens and thaw fluid is circulating. Note the timer setting.
2. Pull off the master switches for both the cold and thaw pump, leaving the timer circuit on and turning the clock motor off.
3. Allow thaw fluid to drain from thaw tank into specimen tank until it stops.
4. Close hand valve in cold fluid drain line.
5. Set the timer to any point between 10 and 160 deg and turn on timer circuit switch.
6. Turn on cold pump master switch and pump thaw fluid from specimen tank to cold tank until depth of solution in specimen tank is reduced to 18 in., then immediately turn pump off by opening its master switch.
7. Turn off the timer switch, open hand valve in cold fluid drain line, turn on both pump master switches.
8. Turn timer to original setting noted in (1) above and turn on both timer switches to resume operations at the point before transfer of solution was started.

If solution is to be transferred from the cold tank to the thaw tank follow the above instructions but substitute the word "thaw" for "cold" wherever they appear. In step 5 substitute 190 and 350 deg for 10 and 160 deg.

Temperatures

The temperatures of the circulating solutions are recorded on a single-pen recording thermometer with the bulb in the specimen tank. The temperatures of the concrete specimens are determined by means of a General Electric Type PJ-3, nonrecording potentiometer, connected to the lead wires of thermocouples embedded in the center of control specimens installed in the specimen tank. The recording thermometer is used essentially as a cycle counter and as a convenient means of checking equipment operation. It should plot a regular time-temperature curve not exceeding 42 F on the high side and not less than -2 F on the low side. It should be checked at least daily. Any variation from the normal pattern indicates some trouble which should be investigated and corrected immediately. The temperature at the center of the thermocouple control specimens as indicated by the potentiometer should be 0±3 at the end of a freezing cycle, and 40±3 at the end of a thawing cycle.

Maintenance of Brine

The specific gravity and pH of the brine should be checked at least weekly. The specific gravity, corrected to 60/60 F, should be maintained at not less than 1.230 and not more than 1.270. Specific gravities higher than 1.270 should be corrected by the addition of water and below 1.230 by the addition of calcium chloride in the proper amounts. Whenever new calcium chloride is added, dichromate and caustic soda inhibitors should also be added in the proportions indicated in "Heating and Cooling Fluids." The pH should be maintained between 7.0 and 8.0 and when outside of these limits should be adjusted to 7.5 in accordance with the instruction in "Cooling Equipment."

Shutting Apparatus Down for Extended Periods

If the equipment is not to be used for several days or weeks the cold tank thermostat should be set to 35 F. This will prevent the formation of ice from condensed water inside the tank. The equipment should also be operated through a complete cycle at least once every three days. It has been found that the solenoid and check valves have a tendency to stick if not operated within the above interval.

Appendix B

SOURCES, DESCRIPTIONS, AND COSTS OF EQUIPMENT FOR FREEZING-AND-THAWING APPARATUS

Item No.	Amount Required	Description and Source	Cost per unit	Total Cost
1.	1	Cold tank liner and cover, without insulation. Any sheet metal company.	$ 180.00	$ 180.00
2.	1	Thaw tank liner and cover, without insulation. Any sheet metal company.	100.00	100.00
3.	1	Specimen tank liner, cover, and removable bottom plate, without insulation. Any sheet metal company.	250.00	250.00
4.	25	Specimen containers with lids. Any sheet metal company.	5.80	145.00
5.	16 bags	Rockwool insulation, in bulk.	1.54	24.64
6.	2 rolls	Aluminum foil vapor barrier, 83-ft long by 36-in. wide.	5.95	11.90
7.		Fiberglass, dual temperature pipe insulation in sizes and thicknesses indicated below		
		Insulation Thickness — Pipe Size		
	12 ft	1-1/2 in. — 1 in.	.57	6.84
	12 ft	1-1/2 in. — 1-1/2 in.	.66	7.92
	12 ft	2-1/2 in. — 1 in.	1.21	14.52
	12 ft	2-1/2 in. — 1-1/2 in.	1.32	15.84
		(See item 10 for source)		
8.	150 sq ft	Fiberglass Aerowrap pipe insulation, 3-ft wide, 3/4-in. thick (See item 10 for source).	.21	31.50
9.	88 sq ft	Fiberglass PF Insulation, Grade PF 615. 24- by 48-in. panels 1-in. thick. (See item 10 for source).	.114	10.03
10.	152 sq ft	Fiberglass PF insulation, Grade PF 615 in 24- by 48-in. panels, 2-in. thick. All Fiberglass insulation (items 7 thru 10) manufactured by Owens-Corning Fiberglass Corp., obtained thru local dealer.	.228	34.66
11.	2	1 by 3/4 SSRHB Centrifugal pumps with bases, couplings & crane Type NF8C-1 mechanical seals. Allis Chalmers Mfg. Co.	151.20	302.40
12	2	1/2 H.P. 3500 rpm, 3 phase, 60 cycles, 220-v, squirrel cage induction motors for above pumps. Allis Chalmers Mfg. Co.	43.00	86.00
13.	2	AC magnetic starters, size 0, in NEMA 1 inclosures, for operation of above motors with 115-v control circuit. Allis Chalmers Mfg. Co.	22.23	44.46
14.	2	Solenoid operated 1-1/2-in. valves, Cat.No. WP-HT-821012, for 7-8# brine, 130# maximum pressure, with coil for operation on 115 v, 60 cycles, consisting of screwed bronze body and trim and resilient composition disc. Valve to be supplied with waterproof type solenoid with high temperature, glass-insulated coil. Automatic Switch Co.	130.50	261.00
15.	2	Strainers, Type S, iron body for 1-1/2-in. pipe with No. 5-1/2 perforated brass screen. A.W. Cash Valve & Mfg.Co.	8.04	16.08
16.	Lot	Miscellaneous galvanized pipe and fittings including 2 brass 1-in. gate valves @ $2.85ea. 2 brass 1-1/2-in. gate valves @ 5.13ea. 2 brass horizontal 1-in. swing check valves @ 2.97ea.		110.66
17.	1	Multi-contact timer, Cramer Type CF6-5-2H 15 amp., 5 pole double throw, 115 v, 60 cycles. R.W. Cramer Co., Inc., Centerbrook, Connecticut.	26.48	26.48
18.	6	Immersion heaters, Chromalox, Cat.No. MT-110, 220 v, 1000 watts. Edwin L. Wiegand Co.	13.00	78.00
19.	1	Magnetic contactor, Chromalox, Cat.No. K3250, 3 pole, 22.5 amperes per pole, 220 v, 60 cycles, A.C., with 110-v holding coil. Same source as Item 18.	$ 21.75	$ 21.75
20.	1	Hex head thermo-switch, Fenwall, Cat.No. 17100 opens on temperature rise, range -100 to +400 F. Same source as Item 18.	10.40	10.40
21.	Lot	Refrigeration equipment and installation thereof, as indicated below One Brunner Freon 22 condensing unit, 4-cylinder, 3-1/4-in. bore by 2-1/4-in.stroke. One 7-1/2 hp, 220-v, 3 phase,60 cycle motor. One motor starter for above motor. One oil separator mounted on condensing unit. One heat exchanger. Six Dole freezer plates 22- by 30-in. One immersion type thermostat to control brine temperature. One Freon 22 solenoid valve, 115 v, single phase, 60 cycle. All necessary copper tubing, fittings, valves, drier, freon level indicator, charge of freon, and oil, required to complete the system. Local refrigeration company.		2,110.00
22.	Lot	Lumber as listed below		
		9 pcs. 1/2-in. - 4 by 8-ft.- plywood	74.20	
		1 pc. 3/4-in. - 4 by 8-ft.- plywood	12.53	
		5 pcs. 2 x 8-in. - 5 ft.	4.87	
		2 pcs. 2 x 8-in. - 6 ft.	2.35	
		8 pcs. 2 x 8-in. - 4 ft.	6.13	
		8 pcs. 2 x 8-in. -10 ft.	15.46	
		5 pcs. 4 x 4-in. - 7 ft.	8.99	
		20 pcs. 2 x 2-in. - 8 ft.	8.13	
		3 pcs. 1 x 2-in. -10 ft.	1.21	
		Local lumber company.		133.87
23.	1000 lbs	Flake calcium chloride	.14	14.00
24.	Lot	Fittings for specimen tank lid		
		2 pr. No. 6 heavy strap hinges	1.81	
		20 ft. 1/4-in. steel wire sash cord	1.20	
		6- wire rope clamps - 1/4-in.	.59	
		6- wire rope thimbles - 1/4-in.	.39	
		Local hardware store.		3.99
25.	Job	Labor for plumbing, insulation, and cabinet work.		310.00
		(Accessories)		
1A	24	Beam molds, 3- by 4- by 16-in.,Humboldt Mfg. Co., 2014 N. Whipple St., Chicago 47, Illinois.	17.09	410.16
2A	1	Type PJ-3 Thermocouple Potentiometer Single range - 1.5 to +4.5 mv. span with multiplier switch x 1, x 5, x 10. General Electric Co., Cleveland, Ohio.		191.10
3A	100 ft	No. JX14W6, Iron-constantan Thermocouple, extension wire. General Electric Co., Cleveland, Ohio.		10.23
4A	2	12 position, 3 pole, selector switches. List No. 31-3-0-3, with indices, and top reading knob and dial. Leeds & Northrup Co., 4907 Stenton Ave., Philadelphia, Pa.	17.09	35.80
		TOTAL		$ 647.29
		GRAND TOTAL		$5,739.53
26.	Job	Electric wiring, including materials except as otherwise listed. Local electrician.		727.50
27.	1	Mercoid tilting type switch, single pole, single throw, 10 amp. capacity - 115 v, Fig. 9-51R with mounting clip No. 7-59. The Mercoid Corp., 4201 Belmont Avenue, Chicago 41, Illinois.		2.80
		TOTAL		$5,092.24

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