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AN IMPROVED ICY BALL REFRIGERATOR

by

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U. S. ARMY LAND WARFARE LABORATORY
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Two Icy Ball Refrigerator Units of improved designed compared with earlier units fabricated under this program were tested in the laboratory and in the field. Under both laboratory and hot-wet field conditions the units performed reliably. Adequate inside-the-box refrigeration temperatures were maintained in a 4 cu ft insulated storage box under hot-wet field conditions. The present units, however, did not maintain acceptable refrigeration temperatures under these conditions in an 8 cu ft box.

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PREFACE

The work described in this report was performed under USALWL Contract No. DAAD05-73-C-0549. With the completion of the reliability testing both units were sent to US Army Natick Labs, MA for military test and evaluation.

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INTRODUCTION

At the request of the US Army Land Warfare Laboratory, a test program to evaluate the continuous performance of the Icy Ball Refrigerator was performed under Contract No. DAAD05-73-C-0549, Amendment/Modification No. P00001.

This document presents a technical discussion concerning the ambient conditions in which the tests were performed, the cycle time, and system pressures. Test results are summarized and a final discussion of the results is presented along with some conclusions and recommendations that emerged from the test program.

PROCEDURES

Two Icy Ball Units (Unit 1 and Unit 2) were tested in 4 cu ft boxes insulated with 2-1/2 inches of 2-pound density polyurethane foam. Figure 1 shows the various components of the Icy Ball system, including the refrigeration unit, heating stove, cooling water tank and insulated box. The present Icy Ball Units each had an initial internal pressure of approximately 15 psig.

Laboratory Tests

For these tests, the insulated boxes were loaded with 4 containers, each holding 12.5 lb of water, placed uniformly at the bottom of the box. Temperature measurements were made in the center of each container of water. To perform the regeneration process, a Coleman stove and a cooling water tank with 22 gallons of water were used, identical to those supplied to the Government under an earlier contract.

Icy Ball system temperatures and pressures were recorded prior to, during and after regeneration. It was assumed that a five-minute period would be required to record the initial data, start the Coleman stove and place the Icy Ball Unit in the water tank. Pressure readings were taken every five minutes for the first twenty minutes and then at intervals of ten to fifteen minutes for the remaining portion of the 90-minute regeneration cycle. During the regeneration cycle, the pressure history was recorded. Continuous temperature recordings were made with a Honeywell/Brown circular chart recorder.

Field Tests

Two Icy Ball Refrigerator Units were tested in the Chiva-Chiva antenna farm area of the US Army Tropic Test Center, Panama Canal Zone. The tests were conducted with a 4 cu ft box and also with an 8 cu ft box. Meteorological data were taken during 16 days of continuous tests to provide a record of the prevailing ambient conditions.

Figure 1. Icy Ball Refrigerator System Showing Refrigeration Unit, Heating Stove, Cooling Water Tank And Insulated Box

RESULTS

Laboratory Tests

Averages of the daily temperatures maintained by each of the two Icy Ball Units tested in 4 cu ft boxes are shown in Table 1. The range of daily temperatures is also shown in this Table. It can be seen from Table 1 that the average daily temperatures, with the exception of Day 1 (2-2-74), varied from 31°F to 41°F in Box 1 and from 33°F to 45°F in Box 2. Daily average temperature fluctuation (range) was about 7°F in both boxes.

The test period during which the data of Table 1 were obtained included regular regeneration periods during which the internal box temperature was maintained by the stabilizer. Thus, it is evident that, under these conditions the Icy Ball Unit in a 4 cu ft insulated storage box is a stable refrigeration source.

Table 2 represents a sample data sheet showing mainly the internal pressure history of the Icy Ball system during regeneration (heating the hot ball). The Table shows that at zero time (the start of a 90-minute regeneration phase), the internal pressure was 15 psig. The pressure rose steadily with heating until at 90 minutes it was 140 psig. The Table also shows the rapid pressure drop that occurred within the first 10 minutes of the refrigeration phase, with a rise in cooling water temperature of only a few degrees.

Field Tests

Meteorological data taken during 16 days of continuous field tests in the Panama Canal Zone show the ambient temperature range was 66°F to 90°F and the relative humidity varied from 47% to 96% (Table 3). The field test results are summarized in Table 4 and they show that the Icy Ball Unit in a 4 cu ft box under these ambient conditions maintained an average inside-the-box temperature of 43°F (std. dev. 2.9°). This meets the major performance requirement for the present stage of development. In an 8 cu ft box, however, the present Icy Ball Unit did not maintain an average inside-the-box temperature low enough to preserve food and medical supplies. As shown in Table 4, the average temperature in an 8 cu ft box was 62.5°F (std. dev. 5.5°F).

TABLE 1

AVERAGE DAILY TEMPERATURES IN 4 CU FT BOXES WITH ICY BALL TEST UNITS UNDER LABORATORY CONDITIONS

BOX #	DATE	TEMPERATURE, °F	
		Average	Range/Day
Box 1	2-2-74	Start 67.5	
Box 2	2-2-74	Start 68.0	
1	2-3-74	35	30-40
2	2-3-74	41	33-49
1	2-4-74	31	28-34
2	2-4-74	33	28-38
1	2-5-74	35	31-39
2	2-5-74	37	35-39
1	2-6-74	38	35-41
2	2-6-74	44	41-47
1	2-7-74	33	30-36
2	2-7-74	41	38-44
1	2-8-74	32	30-34
2	2-8-74	35	33-37
1	2-9-74	31	28-34
2	2-9-74	41	39-43
1	2-10-74	38	36-40
2	2-10-74	41	37-45
1	2-11-74	41	39-44
2	2-11-74	45	39-50
1	2-12-74	35	32-38
2	2-12-74	41	38-44
1	2-13-74	33	30-36
2	2-13-74	45	41-49
1	2-14-74	Not recorded	
2	2-14-74	Not recorded	

TABLE 1 (Cont'd)

BOX #	DATE	TEMPERATURE, °F	
		Average	Range/Day
1	2-15-74	Not recorded	
2	2-15-74	Not recorded	
1	2-16-74	35	32-38
2	2-16-74	43	38-48
1	2-17-74	35	30-40
2	2-17-74	37	33-41
1	2-18-74	36	32-40
2	2-18-74	38	36-40
1	2-19-74	Not recorded	
2	2-19-74	Not recorded	
1	2-20-74	35	33-37
2	2-20-74	37	35-39
1	2-21-74	34	30-38
2	2-21-74	39	33-45
1	2-22-74	35	31-39
2	2-22-74	41	38-44
1	2-23-74	33	30-36
2	2-23-74	40	38-42
1	2-24-74	31	27-35
2	2-24-74	35	32-38
1	2-25-74	35	32-37
2	2-25-74	38	34-42
1	2-26-74	35	31-39
2	2-26-74	39	35-43
1	2-27-74	35	33-37
2	2-27-74	37	33-41
1	2-28-74	35	30-40
2	2-28-74	40	38-42

TABLE 2

ICY BALL REGENERATION DATA UNDER LABORATORY CONDITIONS

TIME (Min)	CONDITION	PRESSURE (psig)	COOLING WATER TEMPERATURE (^{o}F)
0	On Burner	15	--
+5	"	20	--
10	"	30	--
15	"	40	--
30	"	45	--
45	"	70	--
60	"	120	--
75	"	130	--
90	"	140	--
0	Off Burner/ in Water*	100	68
+5	In Water	60	74
10	"**	40	74

*Start of refrigeration phase.
**Removed from cooling water after ten minutes.

TABLE 3

MET DATA FROM CHIVA-CHIVA ANTENNA FARM (Open)
December 1973

DATE	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
TEMP. HIGH (^{o}F)	88	87	88	88	86	84	86	88	87	87	88	86	87	90	85	86	86
TEMP. LOW (^{o}F)	70	73	70	70	69	70	71	72	73	72	66	70	69	73	73	70	74
R. H. HIGH (%)	96	93	92	88	87	95	92	86	84	94	86	89	96	92	92	92	95
R. H. LOW (%)	53	53	48	48	54	67	61	54	48	49	53	53	55	47	56	54	71
RAIN-FALL (In.)	0	0	.07	0	0	0.70	1.25	0.45	.58	0	0	0.02	0	0	0	0	0

NOTE: Temperature and humidity are recorded by a hygrothermograph located under a standard meteorological shelter. Accuracy is $\pm$ 5%.

TABLE 4

TEMPERATURE INSIDE BOXES IN FIELD TESTS
(Recorded at approximately 24 hr intervals)

Date	8 Cu Ft Box	4 Cu Ft Box
4 Dec*	85°F	85°F
5 Dec	70°F	62°F
6 Dec**	65°F	38°F
7 Dec	57°F	40°F
8 Dec	58°F	40°F
9 Dec	58°F	40°F
10 Dec	60°F	42°F
11 Dec	60°F	42°F
12 Dec	76°F One gal anti-freeze put in stabilizer	42°F
13 Dec	70°F	44°F
14 Dec	65°F	44°F
15 Dec	62°F	49°F
16 Dec	55°F	44°F
17 Dec	59°F	45°F
18 Dec	65°F	45°F
19 Dec	66°F	46°F
20 Dec	63°F Testing stopped	46°F Testing stopped
Average***	62.5°F	43°F
Standard deviation	5.5°F	2.9°F

*Start-up
**Temperatures considered stabilized at 48 hrs
***From 6 Dec to 20 Dec

DISCUSSION

Performance of the Icy Ball Refrigerator in a 4 cu ft storage box under both laboratory conditions and hot-wet field conditions proved to be reliable. In laboratory tests a total of 52 regenerations was performed with no failures. This degree of reliability is a function of the pressure reached during regeneration. The maximum average pressure attained during regeneration in these tests was 150 psig, which is well below the pressure at which water begins to transfer to the cold ball. With the concentration of ammonia in water used in these units, steam begins to start generating and to transfer to the cold ball at approximately 175 psig.

Another favorable characteristic of these units was the rapid formation of ice on the cold ball during the 10-minute cooling of the hot ball. Ice started forming on the cold ball during the last 2 minutes of cooling, which is indicative of rapid heat transfer between the cooling water and the hot ball. The temperature of the cooling water was about 65°F. If warmer water had been used, formation of ice on the cold ball, however, may not have occurred until the pressure in the unit fell below 40 psig.

In each unit the cold ball was nearly empty after 24 hours of refrigeration, which is another indication of efficient ammonia transfer. In both the laboratory and field tests the present Icy Ball Units maintained a lower temperature in the 4 cu ft boxes than had been obtained with the earlier units fabricated under this program. The reason for this is probably that a small ratio of ammonia-to-water was used in the present units. If a larger volume of ammonia-water mixture in the same ratio were to be used, it is quite possible that a suitably low temperature (45°F) could be maintained in a 4 cu ft box under hot-wet ambient conditions for as long as 36 hours with a 90-minute regeneration time.

CONCLUSION

The Icy Ball Refrigerator developed under the present contract is a reliable system and can maintain temperatures averaging $43^{o}F$ ($\delta=2.9^{o}F$) in a 4 cu ft insulated box for a period of 24 hours under hot-wet ambient conditions.

RECOMMENDATIONS

1. Tests should be performed with the Icy Ball Units to determine their performance characteristics as a function of at least 4 specified levels of ambient temperature/relative humidity.

2. The maximum regenerating pressure in the Icy Ball system that should be permitted under operating conditions should be kept significantly below 175 psig, the pressure at which water vapor will transfer to the cold ball.

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