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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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ABSTRACT

At the request of the United States Army Natick Laboratories, the Center for Building Technology tested four commercial ice making machines for their ice-making process efficiency and for the latent heat of fusion, clarity, and purity of the ice which they produced. This was done to provide quality estimation guidelines for field testing of these units and to indicate the ranges of ice quality and machine efficiency that could be expected.

Key Words: Calorimetry; heat of fusion; ice; ice machine tests; ice makers; latent heat; refrigeration equipment

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1. Introduction

The Thermal Engineering Systems Section of the Center for Building Technology of the National Bureau of Standards (NBS) was requested by U. S. Army Natick Laboratories through Project Order No. AMXRED 73-314 dated May 18, 1973 to develop testing and rating methods for measuring the ice production of ice makers under field conditions.

Electrical power consumption and pounds per hour of machine output are relatively simple to measure. They are determined by using a watt-hour meter and small platform scale. The output of these machines, however, has some water content so that a simple weight measurement of the machine output is not a measurement of the ice output. The accurate determination of the water content of the ice requires a laboratory calorimeter.

In this project, calorimeter measurements were made of ice produced in several different sizes and by different processes to determine the probable magnitude of the moisture content likely to be encountered in the field and also to provide rule-of-thumb values for estimating this variable.

Measurements were also made of the electrical power required to operate these machines so that thermal efficiencies for the various ice making processes tested could be calculated.

2. Test Specimens

Four commercial ice makers were tested. Three of these were new machines provided especially for these tests by U. S. Army Natick Laboratories and the fourth was NBS property which had been used as a laboratory ice maker for approximately 3 years. These machines were chosen to provide samples of three different sizes of ice particles, cubes, flakes, and crushed ice produced by two basic methods, batch and continuous operation.

Machine B-1 produced cube ice by a batch process in which ice was formed by spraying water into inverted, refrigerated molds and then harvested by warming the molds with water which had been heated by condenser heat during the refrigeration cycle. The ice cubes were cylinders approximately 1 1/4 inches in diameter and 1 1/2 inches long.

Machine B-2 produced flake ice in a batch process by freezing water into refrigerated flat plates, harvesting the flat ice sheets with hot gas, and then breaking the sheet ice into flakes in a mechanical, motor-driven cracker. The ice flakes were approximately 3/16 inch thick and varied in size from roughly 1/4 inch in diameter to 1 inch in diameter with the average diameter about 5/8 inch.

Machine C-1 produced ice in a continuous process by scraping the interior of a refrigerated drum on which the ice was frozen with a motor driven worm which also compressed the ice and forced it through a 3/8 inch by 5/8 inch rectangular die. This rectangular, extruded rod of ice was then broken into sections of diced ice varying from 1/2 inch to 2 inches in length.

Machine C-2 produced ice in a continuous process by scraping ice from a refrigerated surface. The crushed ice particles produced were irregularly shaped and approximately 1/4 inch in diameter.

The batch process machines recirculated the water which was frozen during the refrigeration cycle; dumped the remaining water and took a supply of fresh water at the end of each batch. Dumping this water resulted in some lost efficiency but produced clearer ice by eliminating impurities in the water.

The continuous process machines have no waste water. The nature of their cycles prevents their producing clear ice even if the water impurities were not frozen.

3. Test Apparatus and Procedure

3.1 Test Apparatus

The primary objective of this test series was to determine the latent heat of fusion of the ice produced by these machines, i.e., the moisture content (wetness) of the ice, and secondarily to determine their ice production rate. For this reason the primary effort was to construct and operate a calorimeter for measuring the ice sample latent heat of fusion.

Figure 1 illustrates the calorimeter that was constructed for latent heat of fusion measurements. The calorimeter was heavily insulated (approximately 4 inches of urethane foam) so that the energy used to melt the test ice sample would be provided by metered electric heat instead of sensible heat gain through the calorimeter walls. The circulating pump was provided to insure uniform conditions within the calorimeter.

In addition to the calorimeter apparatus, calibrated, commercial watt-hour meters were used to measure the ice making machine power requirements and a beam balance with a smallest division of 1/100 pound was used to weigh ice samples.

3.2 Test Procedure

3.2.1 Latent Heat of Fusion Measurements

At the start of a test the calorimeter was filled to the drain and its interior heated to 40 °F. The drain was then plugged, the ice sample to be tested weighed and added, and the temperature again heated to 40 °F. Since the sensible heat gain to the calorimeter was negligible both because of its heavy insulation and because the surrounding temperature was held to 32 °F by the test laboratory refrigeration system, the latent heat of fusion for the total sample was the electrical power input to the calorimeter required to return it to its original state.

The calorimeter filled to its drain held approximately 40 pounds of water. Ice test samples ranged in weight from 7 to 12 pounds.

Samples of standard ice which had been stored at a subfreezing temperature were used to check the accuracy of the test setup on each test day. Since these samples were subcooled, a mathematical correction for sensible cooling was applied to the calculations for these calibration tests. The ordinary test samples from the machines were assumed to be near saturation and their temperatures were not measured.

3.2.2 Efficiency and Ice Production Rate Measurements

The ice production rate test was not performed at standard test conditions. Normal laboratory supply water was used. Water and ambient temperatures stayed substantially constant during the two months in which these tests were performed.

Each test reflects approximately one 8 hour day's continuous operation for the machine with the ice production weighed and the power consumption read hourly.

4. Test Results

4.1 Calorimeter Calibration

Calibration of the calorimeter using standardized ice was performed on 10 different days.

The average value was sufficiently close to the expected value of 144 Btu/lb that no correction factor was applied to the test results. The range of values measured indicates that the accuracy of a single calorimeter test could be expected to be better than 3%.

The individual test results are summarized in the first column of Table I.

4.2 Latent Heat of Fusion Measurements

Measured latent heats of fusion for samples of ice from the four machines tested are summarized in Table I. The calculated ice quality included in the table is defined as the latent heat of fusion for the test sample divided by that of the standard ice and is equivalent to the percent of the ice sample that is actually ice instead of water.

In addition to the tests listed in Table I, tests were made of ice samples from machines B-1 and B-2 that had been stored overnight in their mcchines's storage bins. Values of 142.4 and 137.0 Btu/lb were measured for the aged ice from these two machines, respectively, indicating that there is no appreciable difference between fresh and aged ice.

4.3 Observations

The ice produced by the batch process machines, B-1 and B-2, was clear in appearance whereas that produced by the continuous scraping and compacting processes was translucent.

No off taste or noticeable odor or discoloration was imparted to the ice by any of these machines.

4.4 Efficiency and Ice Production Rate Measurements

Table II lists the results of the ice production rate and efficiency tests. The coefficient of performance listed in the table was obtained by dividing the heat equivalent of the ice production rate by that of power consumption after both had been converted to similar units.

The lbs/hr of ice produced is the actual measured weight and is not corrected to 144 Btu/lb ice equivalent. All tests were performed with an ambient air temperature surrounding the machine of approximately 68 °F and a water supply temperature of approximately 72 °F.

In addition to the tabulated results, measurements were also made of the power requirement of the harvesting motor on machine C-1 (88 watts) and of the heat lost in the blow-down water on machine B-1 (624 Btu/hr).

5. Discussions and Conclusions

The ice from the batch type machines was clearly higher in quality than from the continuous machines. The continuous process of scraping and compacting ice from a plate on which running water is continuously being frozen results in unclear ice with included water.

The highest and lowest values of ice quality (percent ice in sample) were 98 percent and 82 percent, respectively, a range of 16 percent. The data in Table I indicate that good rule-of-thumb values for ice quality would be 96 percent for batch type machines and 83 percent for continuous process machines. Since ice from batch machines does not have included water as does ice from continuous machines, its moisture content would be expected to vary with cube surface area. No appreciable difference was observed between fresh and aged ice.

Machine C-1 with the highest coefficient of performance (twice that of the second most efficient machine) produced the lowest quality ice. Conversely machine B-1 produced the highest quality ice but had the lowest efficiency. This would suggest that it is possible to trade off ice quality for increased efficiency.

Rejecting a large amount of cold blow-down water at the end of a batch, as machine B-1 did, results in a major loss of efficiency. This loss could be reduced without loss of ice clarity by fitting an efficient heat exchanger onto the machine.

High quality, clear ice is also promoted by a low temperature on the freezing surface on which the ice is formed. This is directly related to efficiency--the thermal efficiency of a compression refrigeration system falling off with lowering evaporator temperatures.

The difference in efficiencies between machines C-1 and C-2 which produced similar quality ice by similar processes indicates that lowered ice quality does not mean an automatic efficiency increase. Careful design is necessary to achieve this end.

No off taste or noticeable odor or discoloration was imparted to the ice by any of these machines.

6. Acknowledgment

Appreciation is expressed to David K. Ward and Boyd L. Shomaker for constructing the special equipment required for these tests and attending to the daily operation of this test series.

Table I Latent Heat of Fusion Measurements

Date	Standard Ice	Machine B-1	Machine B-2	Machine C-2	Machine C-1
1/16/74	145.4		137.8	123.0	121.6
1/15/74	144.9			122.1	
1/14/74	148.1	143.2	134.8		
1/8/74	144.0	140.3			119.2
1/7/74	146.8			122.8	116.4
1/4/74	145.3			127.2	
12/28/73	144.2			123.0	114.7
12/27/73	145.2	144.3			125.8
12/26/73	141.7		135.1		
11/15/73	144.3		135.2		
Average, Btu/lb	145.0	142.6	135.7	123.6	119.5
Quality, percent	100	98	94	85	82

Table II Efficiency and Ice Production Rate Measurements

Machine	Ice Production Rate lb/hr	Energy Consumption W	Efficiency (c.o.p.)
C-1	30.4	1,010	1.06
B-2	17.5	1,300	0.54
C-2	3.0	280	0.39
B-1	5.3	660	0.34

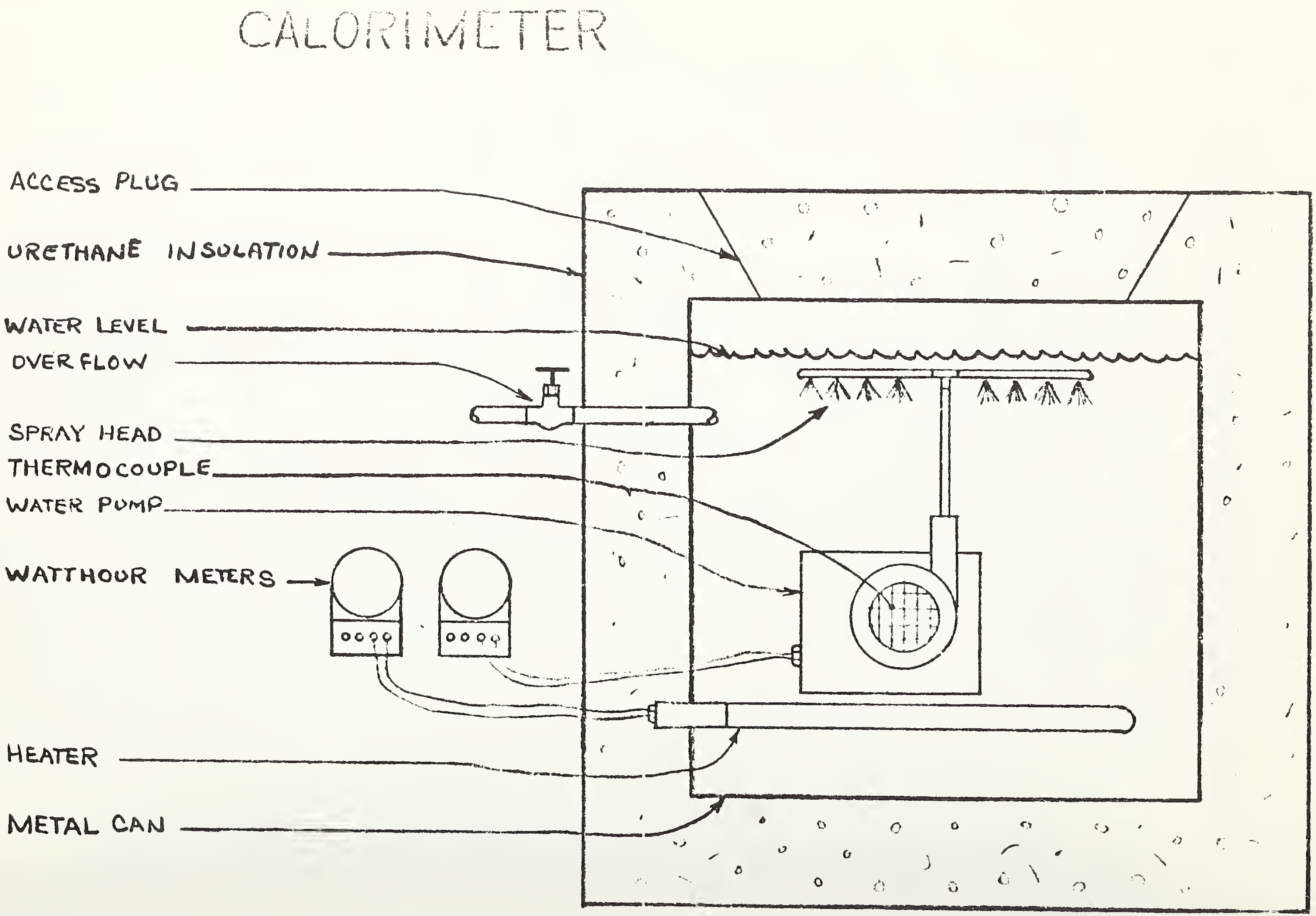

Figure 1 Ice Calorimetry Apparatus

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At the request of the United States Army Natick Laboratories, the Center for Building Technology tested four commercial ice making machines for their ice-making process efficiency and for the latent heat of fusion, clarity, and purity of the ice which they produced. This was done to provide quality estimation guidelines for field testing of these units and to indicate the ranges of ice quality and machine efficiency that could be expected.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name, separated by semicolons)*

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