Factors Influencing Heat Loss in Cantaloups During Hydrocooling

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FACTORS INFLUENCING HEAT LOSS IN CANTALOUPS DURING HYDROCOOLING

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SUMMARY AND CONCLUSIONS

Removal of heat from cantaloups during hydrocooling was studied; a pilot flood-type hydrocooler was used. Factors affecting the cooling were evaluated by using half-cooling times--the time required to reduce by one-half the initial temperature difference (gradient) between melons and water. Evaluation by this method does not require identical initial gradients.

It was shown that:

(1) The water flow rate should be at least 10 gallons per minute per square foot of cooler area. Cooling was not improved by increasing the flow rate above 12 gallons per minute.

(2) Cantaloups may be run through the hydrocooler in one to four layers without affecting the cooling in any layer.

(3) The addition of a wetting agent to the water did not improve the cooling of the melons.

(4) Melons of sizes 27 and 36 were found to have a half-cooling time of 20 minutes. Using this figure, it is possible to predict melon temperatures at the end of hydrocooling. For example, with an initial melon temperature of 82° F. and a water temperature of 32°, the initial gradient of 50° would be reduced to 25° in 20 minutes and would result in a melon temperature of 57°. Size 45 melons, having a half-cooling time of 11 minutes, would, under the same conditions, cool to 57° in 11 minutes. After 20 minutes of cooling they would be at 46°.

(5) To obtain the average temperature of a cantaloup, the thermometer bulb is inserted to a point half-way between the surface and the cavity for melons of all sizes.

(6) Temperature changes in the melon after hydrocooling were studied. While temperatures continued to decrease near the center for about 30 minutes to 1 hour, the melon as a whole warmed rapidly when exposed to summer air temperatures. Delays between hydrocooling and loading in a refrigerated car or truck should be avoided.

BACKGROUND

Cantaloups are usually precooled by rapidly melting top-ice from the load in a railway car, using the air blast from built-in or auxiliary fans. This method is generally used for melons packed in crates. Rapid and effective precooling is important as a means of attaining early in the transit period temperatures of 35° to 40° F. which melons at maturities now harvested require. Recently a few shippers in California have hydrocooled cantaloups to be packed and shipped in fiberboard containers. Since hydrocooling has only

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recently been used with cantaloups, little is known of the factors affecting their rate of cooling by this method. Rates of cooling determined for other commodities cannot be applied to cantaloups because of their large size. Moreover, the surface area from which the heat is removed from cantaloups is relatively small in proportion to the volume of the fruit, in contrast to sweet corn or asparagus.

Observations by Lipton and Stewart made with a commercial hydrocooler suggested that critical tests should be made to study the factors that might affect heat removal from cantaloups during hydrocooling.[2] Tests were conducted, therefore, at the U. S. Horticultural Field Station, Fresno, Calif., during the summer of 1959 to determine the effects of (1) initial temperature difference between melons and water, (2) rate of water flow through hydrocooler, (3) number of layers of melons in the cooler, (4) size of melons cooled, and (5) a wetting agent in the water. The pattern of warming of melons after hydrocooling was also studied.

MATERIALS AND EQUIPMENT

Cantaloups were cooled in a pilot-model, flood-type hydrocooler (fig. 1) which was fitted with removable screens to dispense the water evenly over the produce.[3] Three screens were available, each of which had different-sized perforations on 2-inch centers. By choosing the proper screen and adjusting the hydrostatic head of water above the screen, rates of flow from 5 to 39 gallons per minute per square foot of cooler area (g.p.m./ft.^{2}) were obtainable.

Temperatures during hydrocooling were obtained with a 12-lead thermocouple cable in conjunction with a 12-point temperature-recording potentiometer. In some tests 2 cables were used so that temperatures could be taken in as many as 24 positions. The sensing portions of the thermocouples were short (about 1/16 inch) to allow the measurement of temperature at specific depths in the flesh of the melons.

Melons of size 36 were used in most of the tests. When the effect of melon size on cooling was studied, sizes 45 and 27 were also used.[4] The maturity of the melons ranged from half- to full-slip.

All cooling tests were replicated three times except some of those with wetting agents.

HALF-COOLING TIME

Definition.--Half-cooling time is the time required to reduce the initial temperature difference (gradient) between the commodity and the coolant by one-half.[5] For example, with an initial melon temperature of 82° F. and a water temperature of 32°, the initial gradient is 50°. The time required to reduce this difference by one-half (25°) is the half-cooling time. A guide for determining melon temperatures after several cooling periods is given in table 1. The use of half-cooling times precludes the necessity of having identical initial gradients for tests which are to be compared, since half-cooling time, unlike rate of cooling (temperature reduction per unit of time), is theoretically independent of gradient. As pointed out by Guillou, it is related only, by a constant, to the heat capacity of the object and the heat conductance to its surroundings--in this case, cantaloups and water (see footnote 5).

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[2] Lipton, W. J., and Stewart, J. K., Commercial Hydrocooling of Cantaloupes Tested. Western Grower & Shipper 30(6): 14-16. 1959.

[3] Cantaloups were donated by Murietta Farms, Mendota, Calif., and the California Cantaloupe Advisory Board, Fresno, Calif.

[4] Size designations indicate the number of melons that can be packed in a jumbo crate.

[5] Guillou, R. Some Engineering Aspects of Cooling Fruits and Vegetables. Paper presented at Conf. of Amer. Soc. of Agr. Engrs., Chicago. Mimeo., 8 pp. 1956.

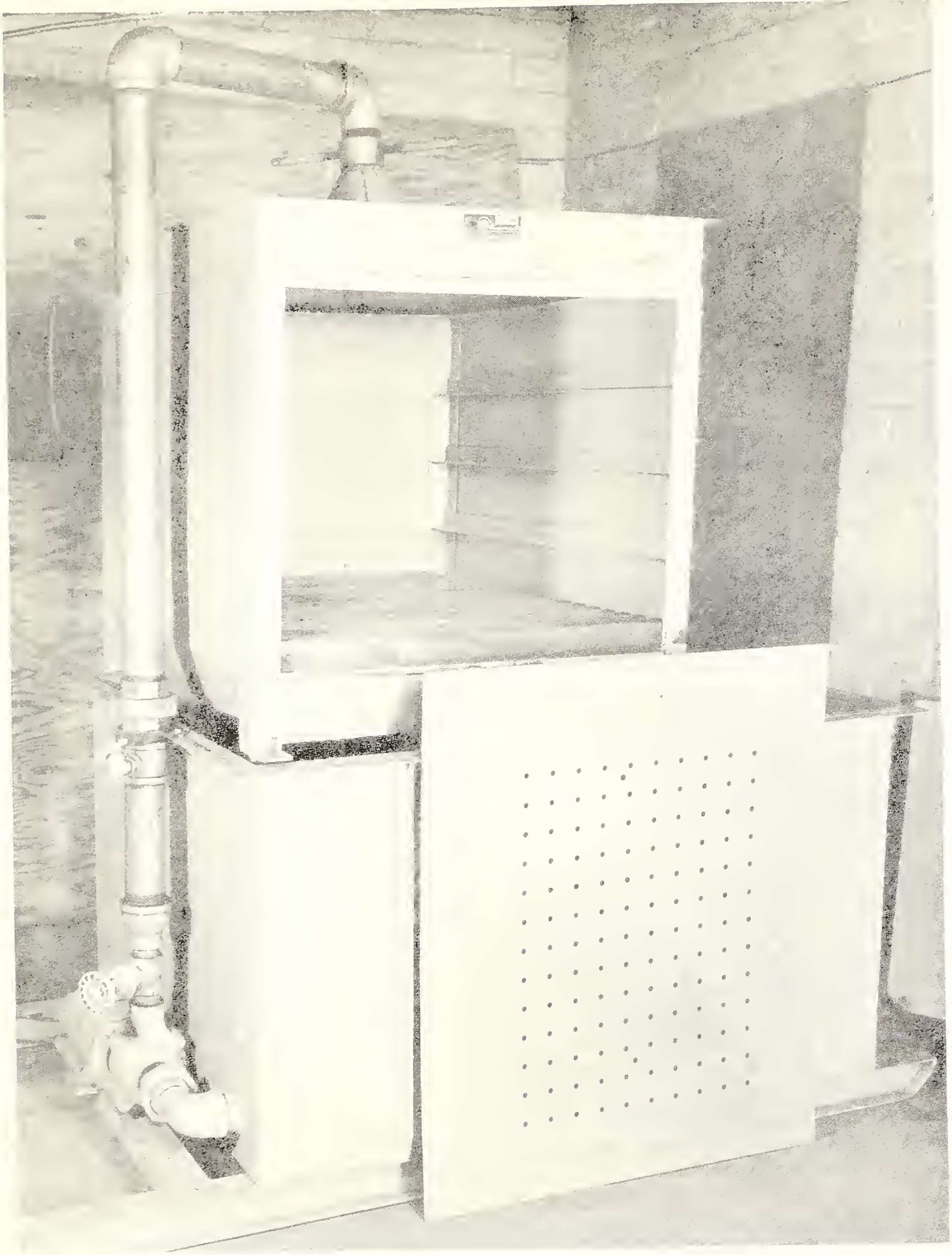

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Figure 1. --Pilot hydrocooler and one of the screens used in hydrocooling studies.

TABLE 1.--Cantaloups, sizes 27 and 36, placed in hydrocooler at various initial gradients: Estimated reduction in temperature of melons after specified times in hydrocooler

Initial temperatures			10 minutes hydrocooling		15 minutes hydrocooling		20 minutes hydrocooling[1]		40 minutes hydrocooling	
Melons	Water	Gradient	Temperature reduction[2]	Temperature of melons	Temperature reduction[2]	Temperature of melons	Temperature reduction[2]	Temperature of melons	Temperature reduction[2]	Temperature of melons
°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
97	37	60	17	80	24	73	30	67	45	52
92	32	60	17	75	24	68	30	62	45	47
87	37	50	14	73	20	67	25	62	37	50
82	32	50	14	68	20	62	25	57	37	45
77	37	40	12	65	16	61	20	57	30	47
72	32	40	12	60	16	56	20	52	30	42
67	37	30	9	58	12	55	15	52	22	45
62	32	30	9	53	12	50	15	47	22	40

[1] Half-cooling time for sizes 27 and 36 cantaloups.
[2] Determined from a logarithmic plot of initial gradients vs. time in hydrocooler.

Calculations.--Half-cooling times were determined by plotting the gradients between melon and water temperatures on a logarithmic scale against time. The initial gradient and the gradient after 20 minutes of cooling were chosen as points for determining the curves since 20 minutes is a reasonable commercial hydrocooling period. The half-cooling times were then obtained graphically from the gradient curves.

FACTORS STUDIED AND THEIR EFFECT ON COOLING

Gradient

Half-cooling times, as expected, were not influenced by variations in initial gradients (table 2). The half-cooling times for melons in four tests were similar, 20 to 22 minutes, although the initial gradient between water and melons varied from 20° to 57° F.

Although the gradient had no effect on the half-cooling time, it had a great effect on the rate of cooling. An initial gradient of 20° F. resulted in a reduction of 10 degrees during 20 minutes of cooling while a 57° gradient resulted in a 29-degree reduction during the same period. Under commercial conditions of hydrocooling, therefore, the water temperature should be maintained as close to 32° as possible to achieve the maximum initial gradient and the fastest possible rate of cooling.

Rate of Water Flow

Rate of water flow was studied using 5, 7, 12, 15, 21, and 39 g.p.m./ft.^{2} to determine its effect on half-cooling time. With these rates of flow, the half-cooling times at the 3/4-inch depth varied from 20 to 25 minutes (table 3). Flow rates of 5 and 7 g.p.m./ft.^{2} were equally effective in cooling the melons, but these low flow rates were inferior to flow rates in the range of 12 to 39 gallons. The half-cooling times within this higher range were not significantly different from each other.

Reduced efficacy of cooling at the lower flow rates may have been due to discontinuous contact between the water and the melons or to an insufficient amount of water passing over the melons to remove the heat from the surface as rapidly as it was conducted through the fruit.

TABLE 2.--Half-cooling time and temperature reduction observed in size 36 cantaloups placed in hydrocooler at various initial gradients[1]

Initial gradient between melon and water temperature	Half-cooling time[2]	Temperature reduction in 20 minutes
°F.	Minutes	°F.
20	22	10
40	21	21
48	21	24
57	20	29

[1] Rates of water flow were 15 and 21 g.p.m./ft.^{2}. Temperatures were measured at 3/4-inch depth in melon flesh.
[2] Differences not significant by the F test. Temperature gradient varied slightly during hydrocooling which accounts for apparent discrepancy between half-cooling time and temperature reduction.

TABLE 3.--Rates of water flow during hydrocooling: Effect on half-cooling time of size 36 cantaloups[1]

Rate of flow	Half-cooling time	Probability level[2]
g.p.m./ft.^{2}	Minutes	
5	25	b
7	25	b
12	20	a
15	22	a
21	20	a
39	21	a

[1] Temperatures were measured at 3/4-inch depth in melon flesh.
[2] Means followed by the same letter are not significantly different from each other; means not followed by the same letter are significantly different at probability levels of 5 percent and 1 percent.

For commercial application, any flow rate that assured uniform and complete coverage would probably be satisfactory. The actual rate needed would vary with each installation, but approximately 10 g.p.m./ft.^{2} would probably be the minimum flow rate advisable for adequate cooling.

Number of Layers of Melons

Canteloups are usually passed through the hydrocooler in several (usually two to four) layers. Tests made with melons placed four layers high in the hydrocooler showed that, half-cooling times of each of the four layers were not significantly different from each other (table 4) or from melons cooled in single layers.

TABLE 4.--Four layers of size 36 cantaloups in hydrocooler: half-cooling time of melons in each layer at low and high rates of water flow

Melon layer	Half-cooling time[1]	
	Low flow rate[2]	High flow rate[3]
	Minutes	Minutes
1 (top)	24	22
2	26	21
3	26	23
4 (bottom)	24	22

[1] Differences between layers not significant by F test. Temperatures were measured at 3/4-inch depth in melon flesh.
[2] Averages of 5 and 7 g.p.m./ft.^{2}.
[3] Averages of 15 and 21 g.p.m./ft.^{2}.

Size of Melon

The three sizes of melons (45, 36, and 27) most commonly shipped from California were hydrocooled to compare their half-cooling times. Average diameters of these melons were 4-1/2, 5-1/8, and 5-1/4 inches, respectively. The difference in volume between size 36 and size 27 melons was due largely to a difference in length between the two sizes--5-1/2 inches and 6-1/8 inches.

Half-cooling times were determined for all three melon sizes at several depths in the flesh--1/4, 3/4, and 1-1/4 inches (1-1/8 inches for the size 45 melons)--and also in the center of the cavity. The times were found to increase greatly with increasing depth (table 5 and fig. 2).

TABLE 5.--Half-cooling times of 3 sizes of cantaloups in hydrocooler, by depth in melon flesh at which temperatures were taken[1]

Depth	Half-cooling time		
	Size 45 melons	Size 36 melons	Size 27 melons
	Minutes	Minutes	Minutes
1/4 inch...........	6	8	9
3/4 inch...........	16	20	19
1-1/8 inches.........	35	-	-
1-1/4 inches.........	-	61	63
Weighted half-cooling time[2]...............	11	20	20

[1] Rate of water flow was 21 g.p.m./ft.^{2} for all tests.
[2] See text for explanation.

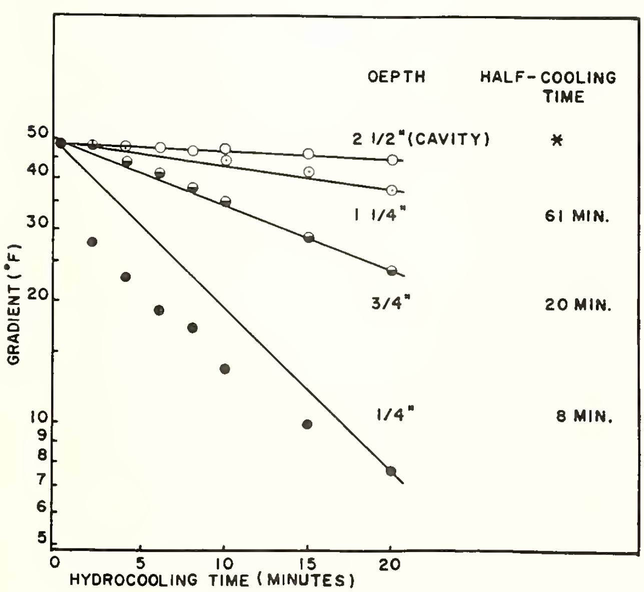

Figure 2. --Gradients (temperature difference between melons and water and half-cooling times for indicated depths during hydrocooling of size-36 cantaloups. No half-cooling time was calculated for cavity (see text for explanation).

Since the temperature taken at each of the three depths in the flesh represented the temperature of a different proportion of the total volume of the melon, an average of the three half-cooling times would not be a true average of the entire flesh of the melon. Therefore, the half-cooling times were weighted to account for the proportion of the flesh represented by each depth according to the following equation:

$$T = \left(\frac{v_1}{V} \times t_1\right) + \left(\frac{v_2}{V} \times t_2\right) + \left(\frac{v_3}{V} \times t_3\right) \text{ or } T = \frac{1}{V}(v_1 t_1 + v_2 t_2 + v_3 t_3)$$

where T is the weighted half-cooling time for the entire flesh of the melon, V is the total volume of the flesh, v_1, v_2, and v_3 are the volumes represented by the three depths, and t_1, t_2, and t_3 are the half-cooling times obtained for the three depths.

The volumes v_1, v_2, and v_3 were bounded by points radially equidistant (1/4 inch) in both directions from the three given depths, thereby dividing the flesh of the melon into three nonoverlapping shells. For purposes of calculation, the melons were assumed to be spherical.

Cavity temperatures were not used to determine the weighted half-cooling time, since the cavities cooled only 1 or 2 degrees during 20 minutes and their volume represents a small percentage (6 percent for the size 36 melon) of the total volume.

The weighted half-cooling times for size 36 and size 27 melons were the same, 20 minutes, as would be expected from their similar diameters. The weighted half-cooling time for the size 45 melons was 11 minutes. The weighted half-cooling times for the larger fruits (sizes 36 and 27) were about the same as the half-cooling times obtained at the 3/4-inch depth, which was about halfway between the cavity and the surface. In the smaller fruits (size 45), the half-cooling time at the 3/4-inch depth was 16 minutes while the weighted half-cooling time was 11 minutes. To approximate the weighted half-cooling time, therefore, a point slightly closer to the surface than 3/4-inch should be used for the size 45 melon. This point would probably be about 5/8-inch from the surface, which is equidistant between the cavity and the surface.

The weighted half-cooling times for melons of all sizes were nearly the same as the half-cooling time obtained at points halfway between the surface and the cavity of the melons. Consequently, a temperature obtained at this point represents a true average of melon temperature.

Size was reported by Ford and Harmon to have little effect on rate of cooling of cantaloups.[6] A conversion of their data to half-cooling times substantiates this conclusion. The discrepancy between their findings and the present results cannot be explained on the basis of their data since they did not report the depth at which the melon temperatures were obtained. The fact that they found only small differences between the smallest and largest melons may be the result of having obtained the temperatures at the same depth in all three sizes.

Wetting Agent

A wetting agent (Triton W-30) was used in the hydrocooling water to determine if the rate of cooling of melons might thereby be improved. Theoretically, a wetting agent improves the contact between the cooling medium and the commodity by reducing the surface tension of the water. The cooling of peaches has been improved by adding a wetting agent to the water.[7] In these tests with cantaloups, however, cooling was not improved by adding a wetting agent to the water; the half-cooling times with or without a detergent were about the same with flow rates of 5 or 21 g.p.m./ft.^{2}. Results of the tests were as follows:

Rate of water flow and concentration of wetting agent [1]	Half-cooling time (minutes)
21 g.p.m./ft.^{2}:	
200 p.p.m.	21 [2]
600 p.p.m.	23 [2]
None	22
5 g.p.m./ft.^{2}:	
450 p.p.m.	25
None	25

[1] Wetting agent was Triton W-30, an alkyl aryl sulphate, donated by Rohm & Haas Co., Philadelphia.
[2] Nonreplicated test.

[6] Ford, K. E., and Harmon, S. A. Hydrocooling Cantaloupes to Remove Field Heat in Preparation for Market. Ga. Agr. Exp. Sta., Mimeo. Ser. N.S. 8. 10 pp. 1955.
[7] Harris, M., and Spigner, R. L. Personal communication. 1959.

Apparently the contact between water and cantaloups is adequate without a wetting agent, whereas that of water and peaches is not, perhaps because of the down on the peach skins.

TEMPERATURE CHANGES IN MELONS AFTER HYDROCOOLING

After hydrocooling, packed cantaloups are often stacked in the packing shed until suitable lots are assembled before loading into refrigerated rail cars or trucks. Delay during this period of exposure to summer temperatures results in loss of refrigeration. To evaluate this loss, temperature changes that would occur under these conditions and when the cooled melons were loaded directly into a pre-iced car were compared. Both conditions were approximated by holding melons in the shade at 81° to 92° F. (fig. 3) or in a room at 61° (fig. 4) after hydrocooling. Since individual melons in both lots were completely exposed to the air they probably reacted more rapidly to the air temperatures than they would under commercial conditions when the melons would be in containers. However, individual melons may also be exposed for a considerable time before they are packed under commercial handling.

Temperature changes at the 1/4-, 3/4-, 1-1/4-, and 2-1/2-inch depths were taken in 2 lots of size 36 melons immediately after hydrocooling and at intervals until equilibrium with the surrounding air was approached (figs. 3 and 4). The melons were initially at a uniform temperature of about 71° F. However, after 20 minutes of hydrocooling, the temperatures at the 1/4- and 2-1/2-inch depths differed by about 28 degrees. The temperatures at the several depths approached uniformity in about half to three-quarters of an hour after the end of hydrocooling. During this period of equalization, the temperature at the 1-1/4-inch depth and in the melon cavity continued to decrease while the temperature at the 1/4- and 3/4-inch depths increased. Since about 70 percent of the volume of a size 36 melon is located between the surface and 3/4-inch depth, cantaloups, as a unit, begin to warm up immediately after hydrocooling when held at temperatures above the temperature of equalization, although temperatures near the cavity may continue to decrease for approximately 30 minutes to 1 hour.

The flesh at the 3/4-inch depth of the melons held in outside air had warmed to the initial temperature of the melons (71° F.) 2-1/4 hours after the end of hydrocooling while the temperature at all depths in the melons held at 61° was 59° when measured 5-1/4 hours after hydrocooling was ended.

To avoid loss of the refrigeration gained through hydrocooling, melons should be placed in a container and in a pre-iced car or other refrigerated space as soon as possible after hydrocooling.

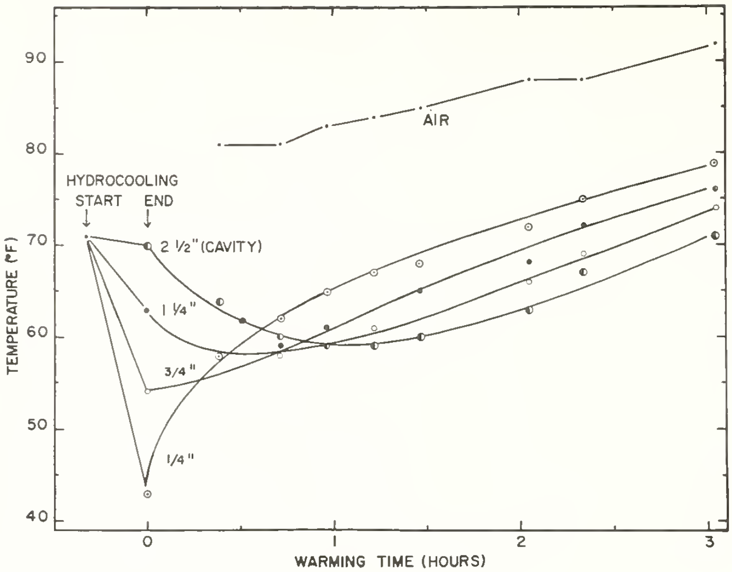

Figure 3. --Temperature changes in size-36 cantaloups at indicated depths during warming in outside air following 20 minutes of hydrocooling in 34° F. water.

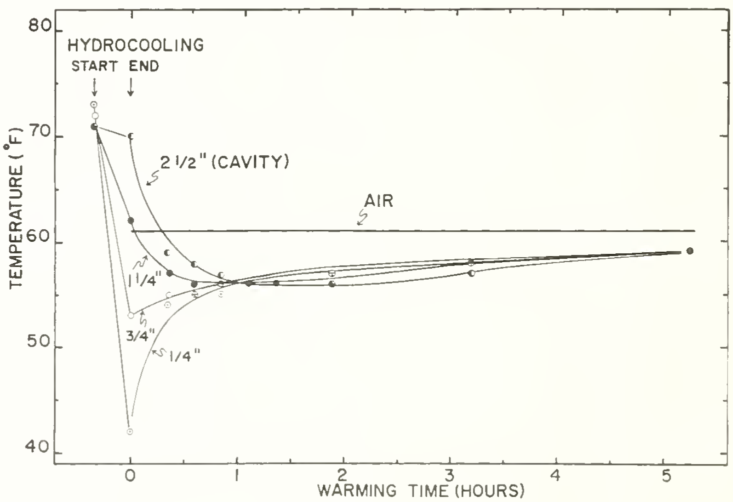

Figure 4. --Temperature changes in cantaloups at indicated depths during equalization in circulated air in a room at 61° F. following 20 minutes of hydrocooling in 34° water.

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