TEMPERATURE OF MECHANICALLY HARVESTED PROCESSING TOMATOES HELD IN DIFFERENT CONTAINERS AND ITS RELATION TO FRUIT QUALITY

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TEMPERATURE OF MECHANICALLY HARVESTED PROCESSING TOMATOES HELD IN DIFFERENT CONTAINERS AND ITS RELATION TO FRUIT QUALITY

By

EDUARDO GONZALEZ ORBEGOSO

AN ABSTRACT

Submitted to the College of Agriculture of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
IN
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ABSTRACT EDUARDO GONZALEZ ORBEGOSO

The mechanical tomato harvester, under development at MSU for the past five years was used in 1962 to harvest tomatoes into bulk boxes of different materials and construction characteristics. It was important to determine whether any one of the boxes used would keep the tomatoes cooler while exposed to the summer sun.

Tomatoes and containers were instrumented to permit recording of the tomato internal and surface temperature as well as the inside surface container temperature. A 16 point recording potentiometer and copper-constantan thermocouples were used.

Two preliminary runs were conducted to get the equipment properly set up and establish procedures. A series of tests were performed throughout the harvesting season. The first test was made to record only the surface temperature of empty containers to provide an idea of their comparative heating during the day. Later tests were made to record surface temperatures of containers filled with tomatoes together with tomato internal and surface temperatures.

No meaningful differences were recorded between internal and surface temperatures of tomatoes in a given box, so the internal tomato temperature was used to establish comparisons among boxes. A difference of up to 4°F for the mean

temperature of a 24 hour period was found between the internal tomato temperatures in the wire mesh container as compared to the internal tomato temperature in the steel, wooden and plastic containers. This difference was responsible for a calculated 21% increase in respiration. Very small differences were found between the internal tomato temperature in the steel, wooden and plastic containers. An interesting heat transfer phenomenon found under the conditions of this study was the four hour lag which existed between internal temperatures of tomatoes and the air temperature.

A review of literature was conducted to determine the effect of temperature on tomato quality. Few direct references were found, but most of the information indicated that overheating of ripe tomatoes is undesirable since respiration is accelerated and losses of organic constituents of the fruit become significant.

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INTRODUCTION

The value of the 1961 U.S. processing tomato crop exceeded 125 million dollars (24). The cost of harvesting these tomatoes is estimated to be 25% of the dollar value of the crop or over 30 million dollars (19). The difficulty in securing hand labor and the expense involved in harvesting by hand have accelerated the trend towards mechanization and bulk handling of the tomato crop in the last five years.

Mechanical tomato harvesting and handling studies have been conducted at Michigan State University since 1958 (20). The third MSU tomato harvester, built in 1960, was used again for the 1962 tests. This machine placed the fruit into bulk boxes holding approximately 500 to 750 lbs.

It is important from the standpoint of fruit quality preservation to determine whether some types of bulk boxes would be more advantageous than others in avoiding overheating of the tomatoes while they are in the field exposed to the summer sun. Containers of different materials and construction characteristics were considered. The different rate of radiant energy absorptivity and thermal conductivity of the materials of these bulk boxes would have an influence on the resulting temperature of the fruits. Variations in the construction characteristics such as solid sides and bottom as compared to spaced sides and bottom (wire mesh) would also be responsible for differences in heat transfer between the tomatoes, the box and the environment. The influence of these factors on the tomato temperature was investigated.

This study was undertaken to find whether significant temperature differences occurred between tomatoes held in various types of bulk boxes (wood, steel, plastic, wire mesh), and if so, to determine from the literature whether these temperature differences were large enough to affect the quality of the tomatoes. The effect of temperature on tomato respiration and quality was to be considered in evaluating any differences that occurred.

REVIEW OF LITERATURE

Effect of Temperature on the Tomato Fruit Respiration

In any consideration of fresh fruits and vegetables, it should be remembered that these commodities are alive and that they therefore carry within themselves many of the processes characteristic of all living things. The most important of these processes is respiration, by which the oxygen of the air is combined with the carbon of the plant tissues, occurring chiefly in sugars, to form various decomposition products and eventually carbon dioxide and water.

Wright et al (27) stated that during the processes of respiration, energy is released in the form of heat, the amount of which varies with the commodity and increases as the temperature increases up to about 100°F. Wright and Whiteman (28) have given the following approximate rates of evolution of heat per ton of ripe tomatoes:

Table 1. Heat generated by respiration of tomatoes

Ambient Temperature, $^{\circ}$F	Heat Generated, Btu/ton/hr.
40	52
60	235

When determining the temperatures of tomatoes, it should be kept in mind that increases in ambient temperature will produce an acceleration of the rate of respiration with a subsequent increase in tomato temperatures.

The rate of production of CO_2 is usually taken as a measure of the amount of heat generated by fruits and vegetables assuming all heat is a result of the combustion of hexose sugar. Since the heat calculated from CO_2 is difficult to measure, calorimeter measurements of the heat of respiration are made. Green (8) found that the heat measured by calorimeter was higher than the heat calculated from CO_2 by an amount varying from 0 to 230 Btu/ton/hour. He also found that the heat produced was always higher at 65°F than at 45°F. From these observations he concluded that the quantity of heat produced by fruits and vegetables varies greatly among samples, to the extent that it is almost impossible to compare independent measurements and expect close agreement.

Tomato respiration and ripening has been studied by many researchers (1), (2), (4) all of which have agreed that an increase in temperature brings about accelerated respiration and ripening. Alban (1) measured the respiration rate of tomatoes at three controlled night temperatures: 57°, 62° and 67°F. In general, the respiration was higher at 67°F. The respiration rate for the three different temperatures decreased heavily from 0 to 72 hours after harvest, maintained itself uniform from 72 to 120 hours after harvest and increased slightly from 120 to 144 hours after harvest. In determining the ripening of tomatoes at different temperatures by observation of color, firmness and acidity, Ayres and Pearce (2) found that the rates of ripening proceeded in the following order: ambient room $>77^{\circ}>68^{\circ}>59^{\circ}>50^{\circ}F$. He also reported that tomatoes stored at $50^{\circ}F$ kept for $2\frac{1}{2}$ months and for 2 months at $59^{\circ}F$. The fruits spoiled in less than $1\frac{1}{2}$ months at $68^{\circ}F$ and in a few days at $77^{\circ}F$ or at ambient temperature. Diehl (4) stated that tomatoes were not injured when held for one day at 30° to $31^{\circ}F$. Tomatoes held at $50^{\circ}F$ ripened gradually in about nine days, while at $70^{\circ}F$ they ripened in five to seven days.

Gore (7) in studying fruits held at four controlled temperatures of which $97.7^{\circ}F$ was the highest, observed that a rise in temperature was accompanied by a very rapid increase of the respiratory activity. The rate of respiration increased from 1.89 to 3.01 times or an average of 2.37 times for each $18^{\circ}F$ rise in temperature for 49 sets of determinations with 40 different species of fruits. These figures are an indication of changes occurring in respiratory rate, which are to be expected, with the increase in the tomato temperatures influenced by greater ambient and container temperatures.

Haller (10) pointed out that in general as temperature increased from 32° to $100^{\circ}F$, the respiration rate also increased. He also emphasized the importance of the respiration rate of fruits in relation to temperature, stating that the respiration rate is a measure of the rate of metabolism and is an index to the rate of deterioration of fruits. Similarly, he stated that the loss of material at high temperature (80°F) may become quite significant and consequently will be to some extent a measure of the rate of deterioration.

Effect of Temperature on Tomato Quality

Since excessive temperature is known to be a limiting factor in the production of many vegetable crops, an attempt was made to find from the literature, the correlation between temperature and tomato fruit quality in terms of color, carotenoid content, ph, acidity, soluble solids and total solids.

It is not unusual to find both the grower and the canner storing tomatoes in the open where the sun shines on them throughout the day. Others place the filled boxes under sheds until they can market their produce. Tomatoes stored under these conditions are likely to be subjected to different temperatures which should influence their quality.

MacGillivray (14) found that tomato fruits show a gradual continuous loss in weight after they had been removed from the plant. The amount of this loss was greatly influenced by the surrounding temperature and also by the absence or presence of any cuts or cracks. This loss in weight was proportional to the temperature inasmuch as the greater the temperature the greater the loss in weight. During these experiments fruits were cut across the stylar end to imitate cut or crushed fruits and the tomatoes were held at three controlled temperatures: 57°, 76°, 109.5°F. Slit fruits seemed to suffer greater losses than uncut fruits at the same temperature. The losses of organic constituents such as sugars and acids were found to be directly proportional to temperature. The quality of the fruit was impaired because of the unequal losses of these two constituents as well as a gain in undecomposed material. Similarly, Haber (9) found that tomatoes stored at 70°F lost weight and acid rapidly.

Ripe samples of shaded and unshaded tomato fruits were used by MacCollum (12) to determine the effect of sunlight exposure on the sugar, total solids, carotenoid and ascorbic acid content of tomato fruits. Analysis were made early and late in the harvesting season. The data showed the unshaded fruits to be higher in ascorbic acid, total solids and sugar than the shaded ones. These constituents vary within a fruit, depending on side exposed. The exposed fruits although high in quality constituents were shown to be low in total carotenoids specially when high temperatures prevailed.

Tomatoes exposed to sunlight often show decoloration or even injury (sun scald) depending upon the conditions of exposure, according to MacCollum (11). In studying light as one of the factors affecting acid content he concluded that the fruits with greater exposure to sunlight had a higher ascorbic acid content. No consistent relationship was found between ascorbic acid, total solids and sugar content.

Tomatoes produced for the canner are harvested at red ripe stage as maximum color is required. Forshey (6) emphasizes that color is extremely important in tomatoes that are to be processed. The red tomato pigment, lycopene, develops most rapidly in temperature ranges of 70°-75°F according to several authors (5), (26), (25) and its formation decreases rapidly as the temperature drops below or rises above this rather narrow range.

A number of measurements taken by Skok (23) have indicated that tomato fruits exposed to the sun will often reach temperatures as high as 100°-120°F during bright days. Fruit temperatures of 90°F are quite common during the daytime. He stated that since fruit temperatures are predominantly in the nineties during the latter part of July and August and often in the sixties during the latter part of September, conditions for optimum coloration are unfavorable during a large portion of the tomato season. This means that fruits must remain on the plants longer for lycopene accumulation than they would if optimum temperature prevailed. Over-ripe and soft fruits often result and a high proportion is lost.

Losses sustained in the field vary with weather conditions. Sometimes only half the crop is harvestable (23). It is obvious that the longer fruits stay in the field the greater these losses will be; and conversely the earlier the fruits are harvested the greater will be the recovery. This problem may be more severe with the once-over mechanical harvest since fruit is required to stay longer in the field to obtain a greater proportion of ripe fruit.

MacGillivray (16) pointed out that in warm regions in mid-summer, field grown tomatoes would often be subjected to high temperatures during portions of the day which would inhibit lycopene development, but lower temperatures at night would permit lycopene formation during a part of the 24 hours of most days. The temperature of tomatoes was found to vary directly with air temperature. The side of the tomato nearest the sun was higher in temperature than the shaded side. The variation in temperature between the exposed and shaded side ranged from 15° to $47^{\circ}F$. The poorly foliaged fruits ripened more rapidly since they were exposed to higher temperatures during the day and slightly lower temperatures at night. The air temperature for these measurements ranged from 56° to $102^{\circ}F$ during the 24 hours of the day. It was not uncommon for fruits to have temperatures of $96^{\circ}F$ or more, but never $90^{\circ}F$ for 24 hours at one time.

Sayre et al (22) reported that tomatoes ripened within a

temperature range of 100°F in the daytime and 85°F at night would never develop sufficient lycopene to make the fruits sufficiently red. However, tomatoes ripened at a temperature range of 80°F during the daytime and 65°F at night produced a well-colored fruit that was high in lycopene and carotene, regardless of whether the fruits were ripened on the vine or detached at the turning stage of maturity. Under these conditions an average of nine days was required for tomatoes to become red. The carotene content was not greatly affected by the different temperature used in these experiments.

The amount of red color is an important factor in determining the market value of tomatoes for processing. Several authors (5), (21), (25) have shown that lycopene, the red coloring pigment of tomatoes, does not develop at temperatures below 50°F and is inhibited at temperatures above 86°F. Duggar (5) stated that when green fruits are ripened at a temperature of 86°F or above, a yellow-orange or orange-red color was produced instead of the red pigment, lycopene.

MacCollum (13) found that tomato fruits exposed to direct sunlight in the field often develop poor color due primarily to a low content of lycopene or a decrease in the development of this red pigment. He stated that at favorable temperatures (70°-75°F) the rate of development of this pigment is increased by illumination. Light is effective until chlorophyll disappears. It was also found that carotene is increased by illumination of tomato fruits during ripening. Thus, fruits which are exposed to direct sunlight are usually higher in carotene.

The effect of heat during processing upon tomato quality was investigated by MacGillivray (15) in color studies of tomato pulp, tomato juice and canned tomatoes. It was of interest to note that in all cases heating to 212°F was accompanied by an impairment of color. During the concentration of the raw juice to pulp the greatest color impairment occurred in the first period of the concentrating time. There was a loss of color during the heating period of sterilization in canned tomatoes. The same sample of pulp was found to have a better color at low temperatures than at high temperatures thus a sample of pulp at 41°F was better in color than one at 86°F.

Nutting (17) studied the tomato quality retention among several different concentrations of tomato products during a three year period. He found that samples with 5.6 to 8.8% total solids changed less in flavor and color than those of 21 to 38.4% when held at elevated temperatures for varying periods of time.

The effect of temperature on tomato respiration and quality can be approached from several points of view as has been shown. However, most of the authors seem to agree that increased temperatures would bring about an acceleration in the rate of respiration and consequently in the rate of deterioration.

Having presented the relationship between temperature and tomato quality, the next step was to arrange the set-up that would allow the recording of temperatures according to the objectives of this study.

PROCEDURE

The materials and methods described in the following paragraphs were used for determining the temperature of mechanically harvested processing tomatoes when handled in bulk boxes made of various materials.

The tomatoes for these studies were grown at the MSU horticulture farm and were mostly of the Fireball, Libby C-52 and Heinz 1370 varieties. Four types of boxes, as described in Table 2, were used throughout the tests.

Table 2. Description of the boxes used in tomato temperature studies.

Material	Construction	Measurements, Inches Length		Width		Depth
Wood	Slats	47	x	47	x	16
Steel (rusty)	Welded sheets	41	x	40	x	16
Plastic (Polyethylene)	One piece	47	x	38	x	15
Wire Mesh*	Welded	47	x	47	x	16

* The wire mesh container was aluminum coated and had a $1\frac{1}{4}$" x $1\frac{1}{4}$" bottom and 3" x $1\frac{1}{4}$" side design.

The tomatoes and containers were instrumented to permit recording of the internal and surface tomato temperatures together with the inside surface temperature of the container.

A view of the arrangement of the four full containers is given in Figure 1. A 16 point recording potentiometer with a temperature range of -40° to 140°F and its printing mechanism speed set to allow recordings every 30 seconds was used. The internal tomato temperature was measured by thermocouples inserted half way into the tomato at the calyx end of the fruit (Figure 3). The surface tomato temperature was measured by thermocouples attached with tape to the surface of the tomato. All instrumented fruits were placed in the bulk boxes at mid-level from north to south. All thermocouples measuring inside surface temperatures of the containers were placed symmetrically on the south side of the containers.

Thermocouples were made from copper-constantan duplex wire with thermoplastic insulation. The lead wires were single copper and constantan wires insulated by enamel and cotton cloth. All extension wires were put through rubber tubing to facilitate their handling and to protect them (Figure 1). The considerable number of thermocouple wires made it necessary to use independent eleven point connectors for each box to permit consecutive recordings of all points in the four boxes (Figure 2). The copper and constantan wires from each box were attached to double sets of female connectors which were attached to four wooden saw horses, one placed next to each box. The lead wires were attached to two male connectors which were manually switched between

Figure 1. Tomato temperature study showing the four different types of bulk boxes, the potentiometer and lead wires

Figure 2. Manual switching between containers at intervals

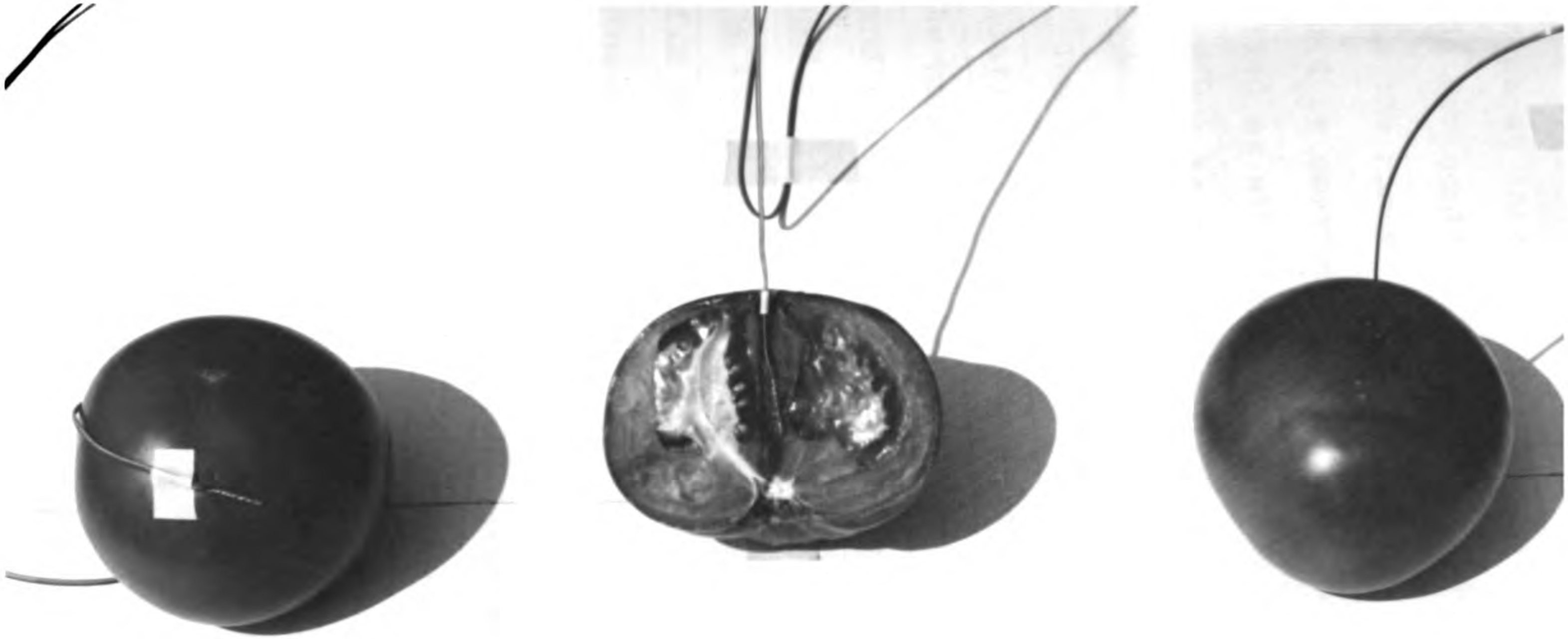

Figure 3. The position of thermocouples: surface (left), internal (center and right)

containers at intervals (Figure 2). A different arrangement was made for continuous recordings during the night by reducing the number of thermocouples in each box so that they all could be covered in one cycle. Daytime recordings were controlled at all times watching for precise switching time, failures due to bad contact or rupture in lines, presence of occasional clouds which would influence recordings unevenly, etc. The general set-up proved to be practical since the installation could be removed completely to allow the fork-lift to handle the boxes every time it became necessary to dump and bring in freshly harvested tomatoes. A nitro-compound fruit fly dust (Pyrethrin) was very helpful in keeping flies away, especially after the tomatoes had been kept for more than one day.

The air temperature was recorded during all tests at the same interval as the other recordings. Parallel measurements of air temperature made by MSU were available for comparison. The air temperature appearing in the results corresponds to that recorded by MSU on hygro-thermograph charts.

A preliminary trial run was conducted with the empty sheet steel and wooden boxes. This test revealed the importance of the symmetric location of thermocouples in one box with respect to another to provide equivalent readings and to avoid the shading of thermocouples by the container's wall. Differences of about 5°F were obtained when thermo-couples were not placed flat on the container surface.

A second trial run was conducted using only the sheet steel container partially loaded with tomatoes to determine whether any differences between internal and surface temperatures of the tomato could be recorded with the thermocouples used. The results revealed that differences were measurable and the data gave a partial idea of the results to be expected from later experiments.

A series of tests were performed throughout the harvesting season. The characteristics of these tests are summarized in Table 3. The first tests were made to record only the surface temperature of the empty containers to provide an idea of their comparative heating at different times during the day. The later tests were made to record surface temperatures of full containers together with internal and external tomato temperatures. After a few tests the effort was concentrated on tomato temperature resulting from different containers during the day, as the higher daily temperatures would be more harmful to the tomatoes than differences observed at night.

In all tests a total of 107 hours of records were made corresponding to 6,572 individual readings. The results and conclusions drawn from this study are based on approximately 65% of this data. The data obtained under inadequate environmental conditions was not used in the analysis.

Table 3. Summary of the tests

Test No	Test Description	Date	Test Parts & Time	Test Interval for same Point	Number of Points	Test Duration Partial	Test Duration Total
1	Empty container temperature recordings	8-27-62	10 am - 2 pm	32 min.	44	-	9 hrs
2	"	8-28-62	I 9 am - 7 pm	1 hour	44	10 hrs.	24 hrs
		8-29-62	II 7 pm - 9 am	8 min.	13	14 hrs.	
3	Tomato internal and surface temperature and container temperature recordings	8-29-62	I 2 pm - 7 pm	1 hour	44	5 hrs.	24 hrs
		-	II 7 pm - 9 am	8 min.	13	14 hrs.	
		8-30-62	III 9 am - 2 pm	1 hour	44	5 hrs.	
4	"	9-5-62	7 am - 3 pm	1 hour	44	-	8 hrs
5	"	9-6-62	8 am - 8 pm	1 hour	44	-	12 hrs
6	"	9-7-62	8 am - 8 pm	1 hour	44	-	12 hrs
7	"	9-12-62	8 am - 8 pm	1 hour	44	-	12 hrs
8	"	9-13-62	8 am - 2 pm	1 hour	44	-	6 hrs

RESULTS AND DISCUSSION

Comparative Temperatures of Empty and Full Containers

The results of the initial tests (No. 1 and 2, Table 3) measuring surface temperatures of empty containers (Figure 4) show that there was a $70^{\circ}F$ variation between the hot and cold extremes for a 24 hour period. During these tests the air temperature fluctuated from a maximum of $88^{\circ}F$ at 4 p.m., to a minimum of $60^{\circ}F$ at 5 a.m. The mean air temperature for the 24 hour period was $73.8^{\circ}F$. The sheet steel bulk box maintained the highest temperature throughout the day followed by the wooden, plastic and wire mesh containers. All containers were hotter than the air temperature throughout the day until 6 p.m., ($85^{\circ}F$) after which the air was warmer than the containers since they had radiated their heat to the sky. At 7 a.m., ($67^{\circ}F$) the containers again became warmer than the air. During the night the wire mesh container remained warmer than the others by about $3^{\circ}F$. The sheet steel container reached a maximum temperature of $125^{\circ}F$ at 12 noon.

The surface temperatures of containers when filled with tomatoes are shown in Figure 5 and the data correspond to test No. 3 in Table 3. During these tests the air temperature fluctuated from a maximum of $87^{\circ}F$ at 3 p.m., to a minimum of $58^{\circ}F$ at 6 a.m., with a mean temperature of

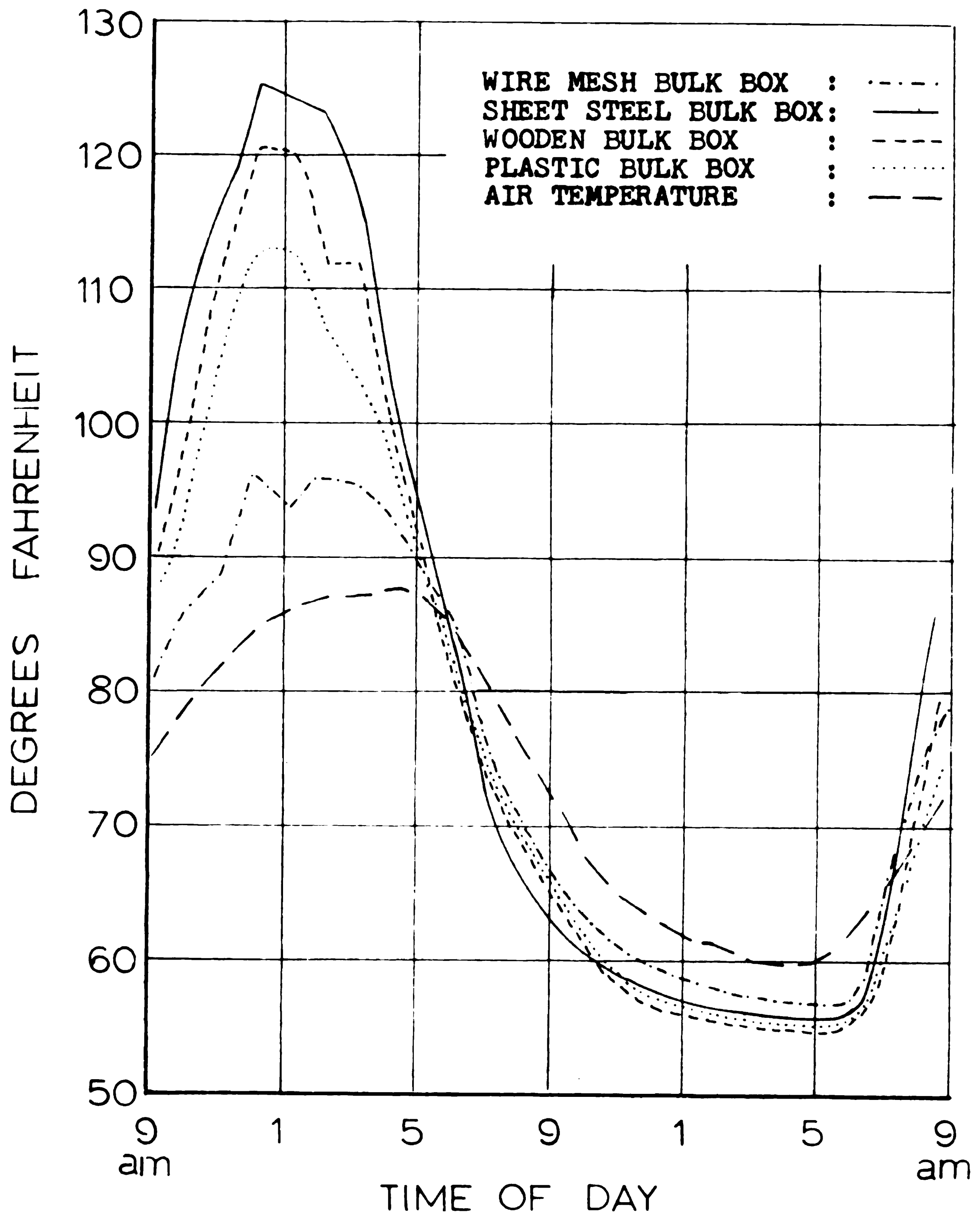

Figure 4. Surface temperatures of empty containers

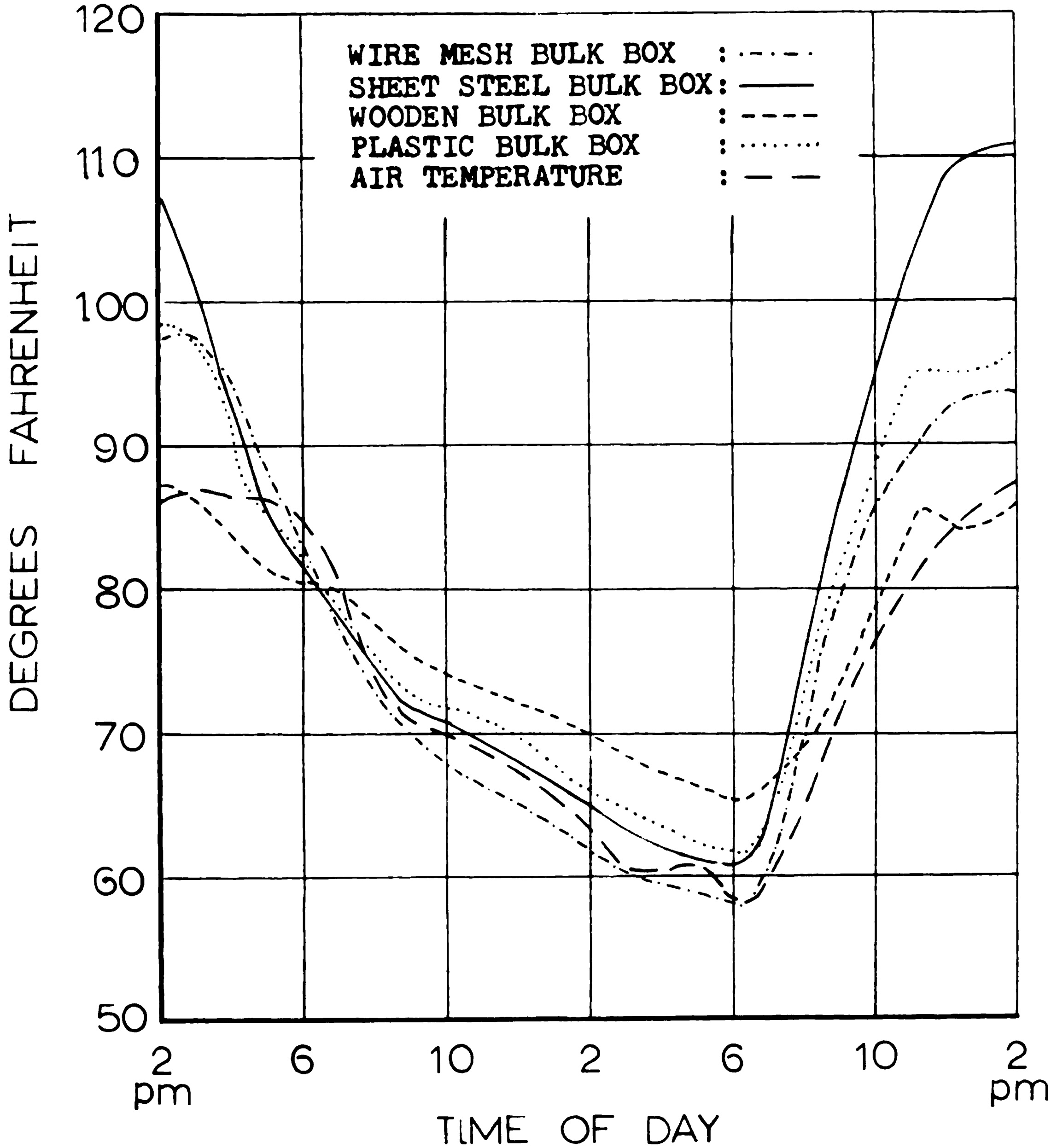

Figure 5. Surface temperatures of containers filled with tomatoes

73.7°F for the 24 hour period. Comparing Figures 4 and 5, it can be seen that although there was not much difference in air temperature during the recordings for these two groups of tests, there are considerable differences in the surface temperatures between empty and full containers. As would be expected, the surface temperatures of full containers were lower during the day than those for empty containers since part of the heat was being passed on to the tomatoes by conduction. The free circulation of warm air inside of the empty containers during the day contributed towards their higher temperatures. The wire mesh container, because of better ventilation, was the coolest at night among the full containers. Both for the empty and full container tests the surface temperature of the wire mesh bulk box was the closest to the air temperature during the night. The wooden container being a better insulator, had the lowest inside surface temperature during the day and the highest temperature at night.

Tomato Temperature as Related to Type of Container Used

The internal and surface tomato temperatures as compared to surface container temperatures are shown in Figure 6 for the wire mesh and sheet steel bulk boxes, and in Figure 7 for the wooden and plastic bulk boxes. On the whole, no meaningful differences were recorded between internal and surface temperatures of tomatoes in a given box. There was

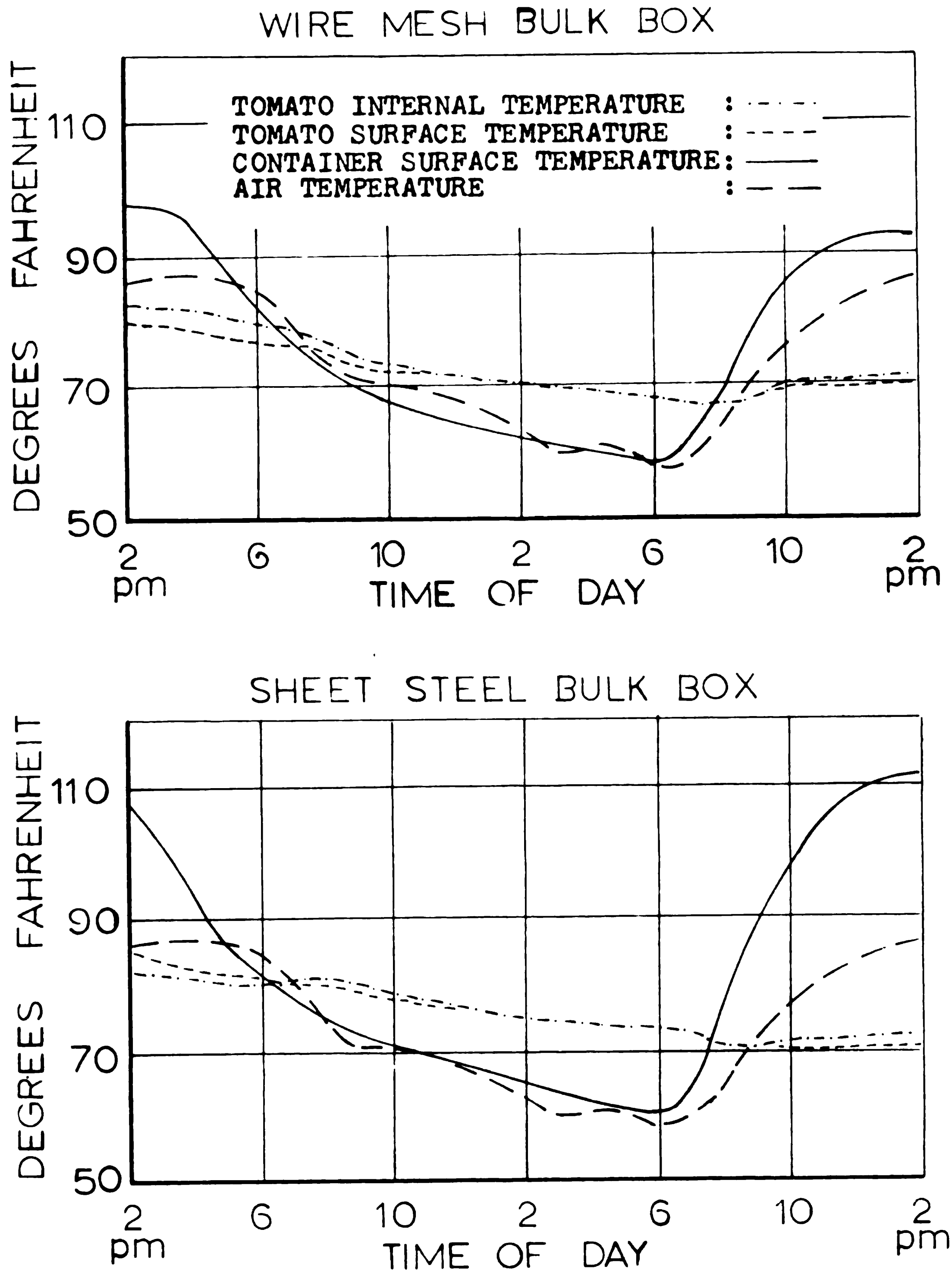

Figure 6. Tomato internal and surface temperatures compared to container temperatures

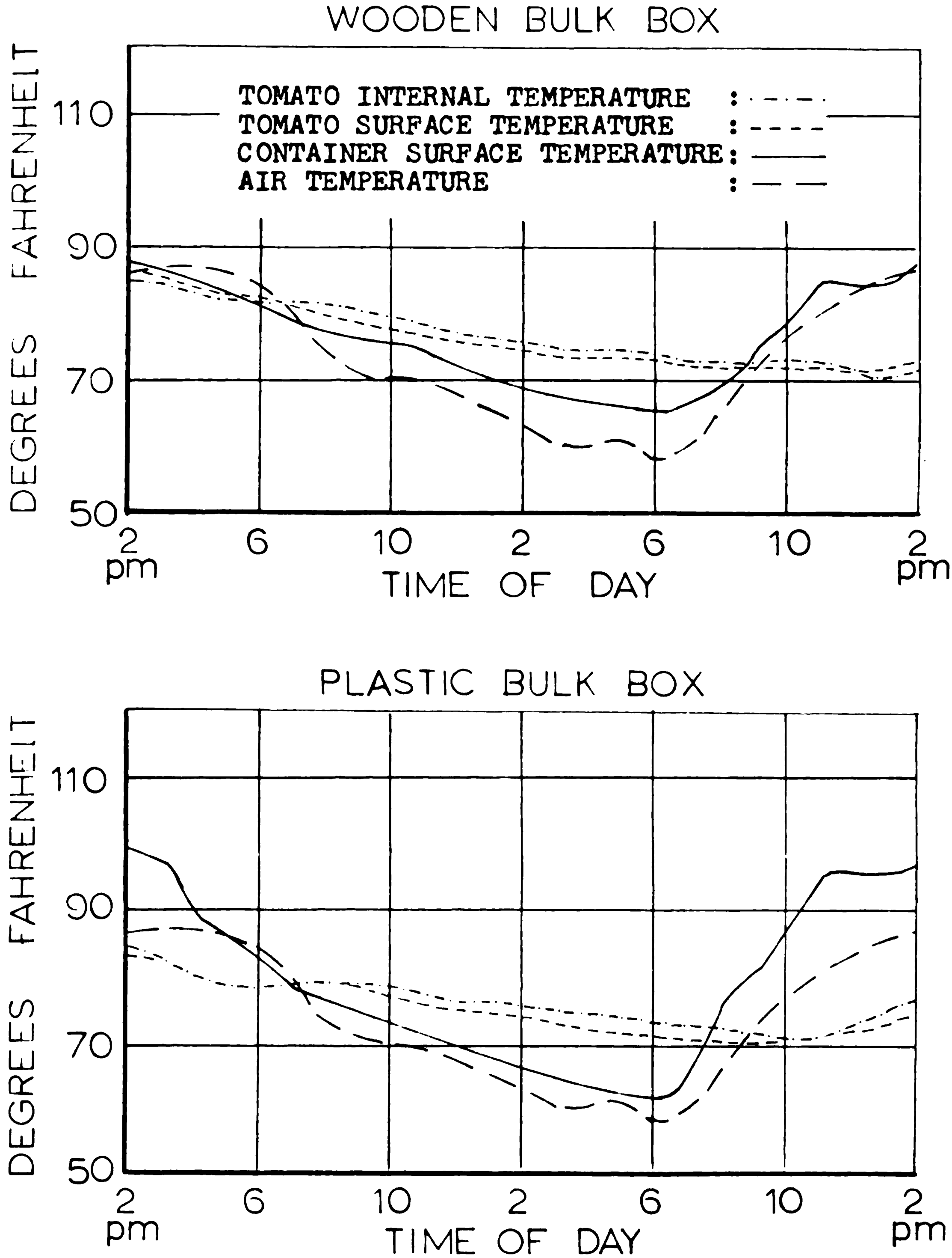

Figure 7. Tomato internal and surface temperatures compared to container temperatures

only 1 or 2 degrees difference during the day and usually a smaller difference at night. The data used for plotting these curves were recorded simultaneously for each box and at an interval of 8 minutes between boxes on the same day.

A difference of up to 4 degrees for the mean temperatures of a 24 hour period was found between the internal tomato temperatures in the wire mesh container as compared to the internal tomato temperatures in the other three containers, Table 4. However, no meaningful difference was found between the mean internal temperatures of the tomatoes in the steel, wood and plastic containers. The mean temperatures of the containers and tomatoes were above the mean air temperature for the steel, wooden and plastic boxes, while for the wire mesh container and its tomatoes these means were below the mean air temperature.

Table 4. Container surface and tomato internal mean temperatures (^{o}F) for a 24 hour period.

Mean air temperature = 73.7^{o}F

	Wire Mesh	Sheet Steel	Wood	Plastic
Full Container Inside surface (south)	72.7	77.0	74.5	75.2
Internal tomato temperature	72.6	75.5	76.7	75.7

Figure 8 shows comparative internal temperatures of tomatoes in different containers for a 24 hour test (test No. 3). A marked difference between internal temperatures of tomatoes in steel, wooden and plastic containers and the temperature of tomatoes in the wire mesh box existed from 7 p.m., to 9 a.m. Again it can be seen that the tomatoes in the wire mesh container approached the air temperature at night.

The internal tomato temperature during the day is best explained by Figure 9 which corresponds to the data on test No. 7. A steady increase can be appreciated from 8 a.m. to a peak in the mid seventies at 8 p.m. Figure 8 does not show the peak at 8 p.m. clearly because the thermocouples and tomatoes to be instrumented were exposed to the sun before they were placed in the box and covered by other tomatoes at 2 p.m. This did not happen for the test corresponding to the curves in Figure 9 since all the instrumentation was done the previous day. Nevertheless, a noticeable rise in all curves at 8 p.m. for Figure 8 is an indication that the peak temperatures should have occurred at that time. Both Figure 8 and 9 show the minimum internal temperatures occurring around 9 a.m. for all tomatoes except those kept in the wire mesh container which reach minimum temperature at 7 a.m. since they start getting heated earlier as air temperature starts going up at 6 a.m.

An interesting heat transfer phenomenon illustrated by

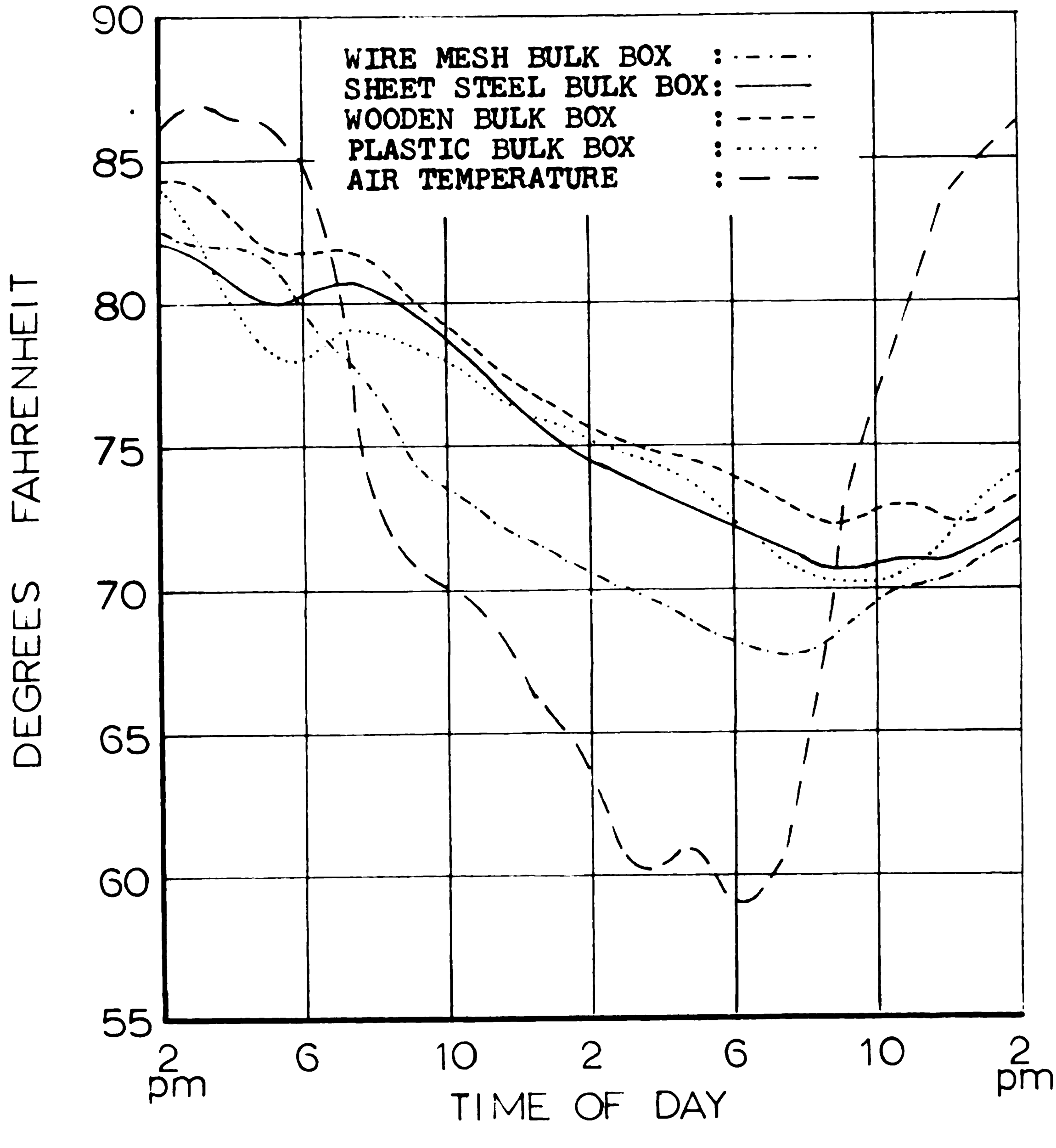

Figure 8. Internal temperatures of tomatoes in different containers

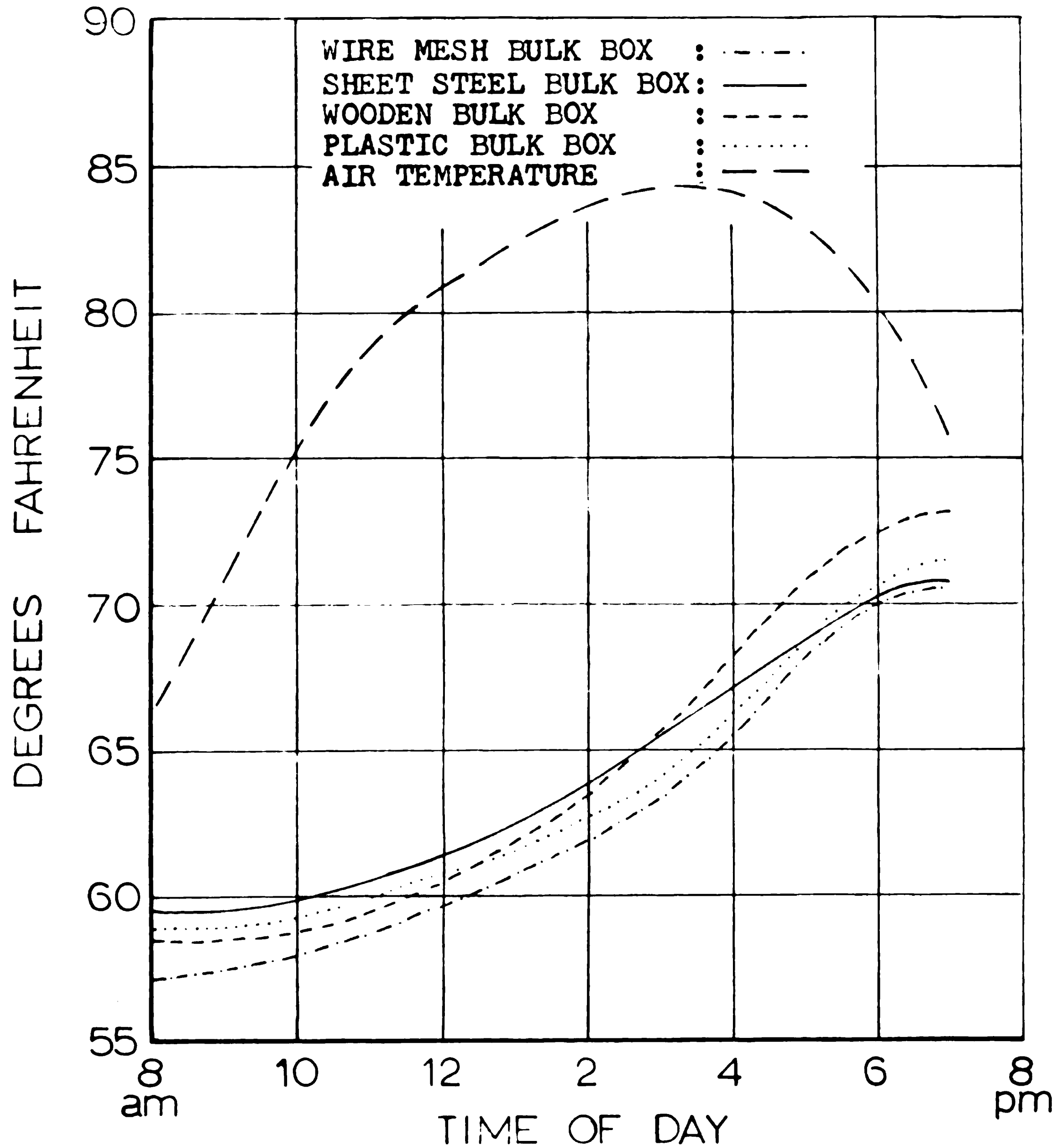

Figure 9: Internal temperatures of tomatoes in different containers

these curves is that under these conditions there exists approximately a four hour lag between the internal temperatures of tomatoes and the air temperature. This is known as temperature lag. It could help in arriving at a solution for keeping the tomatoes cool. One possibility is that of blowing air through the mass of tomatoes in each box to study the effect on the tomato temperature.

Effect of the Observed Temperatures on Tomato Respiration and Quality

A systematic study of tomatoes exposed to controlled temperatures, accompanied by an analysis of carotenoid content, acidity, soluble solids, total solids and other standard measures descriptive of quality, as well as a calorimetric measure of the heat of respiration at different temperatures would be necessary to define precisely the effect of varying temperatures upon tomato respiration and quality. It was not planned to enter into this area which falls outside the field of engineering. Nevertheless, an attempt was made to correlate the information available in the literature on these points with the results obtained on the various tests performed.

The observed internal temperatures of tomatoes ranged from about 80°-85°F at 3 p.m. to 65°-75°F at 6 a.m. The variation between the average maximum and average minimum internal tomato temperatures was approximately 15°F for most of the tests performed with all four types of containers.

As was pointed out before, differences of up to 4°F were found between tomatoes in wire mesh and those in the steel, wooden and plastic containers. The significance of these differences in terms of tomato respiration can be explained objectively by the theory of the temperature coefficient (3). The temperature coefficient is designated by the symbol Q_{10} and defined as the number of times that the rate of a process increases with a 18°F rise in temperature. Since the rate of respiration is increased 2 to 3 times for each 18°F rise in temperature, within the range 32° to 95°F, the temperature coefficient Q_{10} for respiration is 2 to 3.

The equations defining the respiration process are as follows:

$$\Delta R = \left(\frac{A}{B} - 1\right) 100 \quad \ldots\ldots\ldots \quad (1)$$

$$\frac{A}{B} = (Q_{10})^{\frac{T_2 - T_1}{18}} \quad \ldots\ldots\ldots \quad (2)$$

where ΔR = % increase in respiration

$\frac{A}{B}$ = ratio of respiration

A = rate of process at T_2

B = rate of process at T_1

Q_{10} = temperature coefficient

T_2 = higher temperature in degrees Fahrenheit

T_1 = lower temperature in degrees Fahrenheit

Taking $Q_{10} = 2.37$ as given by Gore (7) for fruits, and the $4^{\circ}F$ difference observed between T_2 and T_1 and substituting in equation (2):

$$\frac{A}{B} = 2.37^{\frac{4}{18}}$$

$$\frac{A}{B} = 2.37^{0.22}$$

$$\frac{A}{B} = 1.21$$

Therefore the ratio of respiration between the observed temperatures is 1.21. Substituting this value in equation (1) gives the following result:

% increase in respiration = (1.21 - 1) 100 = 21%

This computation shows a 21% increase in respiration for tomatoes held in steel, wood and plastic as compared to those held in wire mesh because of the $4^{\circ}F$ difference in temperature. Haller (10) has emphasized that respiration is a measure of the rate of metabolism and an index of the rate of deterioration. Since increases in temperature bring about increases in respiration, keeping the tomatoes cooler will minimize respiration and consequently maintain a better

fruit quality.

The tomato internal temperatures corresponding to the curves in Figure 8 are summarized in Table 5.

Table 5. Duration of internal temperatures for tomatoes in different containers during a 24 hour period

Temperatures, °F		Time above stated temperature, Hrs.			
		Wire Mesh	Sheet Steel	Wood	Plastic
Over	67.5	24.0	24.0	24.0	24.0
"	70.0	16.0	24.0	24.0	24.0
"	72.5	9.0	15.5	18.0	16.0
"	75.0	7.0	11.5	13.0	12.5
"	77.5	5.5	9.0	9.5	8.5
"	80.0	3.5	6.5	7.0	2.0
"	82.5	0.0	0.0	2.5	1.0
"	85.0	0.0	0.0	0.0	0.0

From this Table it can be seen that the tomatoes in the wire mesh box were exposed to temperatures over 67.5°F for shorter periods of time than the tomatoes in the other three containers. MacGillivray (14) indicated that tomatoes showed a continuous loss in weight after they had been removed from the plant. These losses were influenced by temperature and cracks. Losses of organic constituents were directly proportional to temperature. Haber (9) stated that tomatoes lost weight fast at 70°F and Haller (10) indicated that losses at 80°F were significant for this fruit.

The tomato temperatures observed during the warm days fell within the range considered critical by these authors, in terms of tomato quality preservation.

Keeping Tomatoes Cool in Bulk Boxes

Conduction, convection and radiation play a part in the heat transfer between the bulk boxes, the tomatoes and the environment. The cooling or heating rate of the tomatoes is influenced primarily by the distance from the center of the box to the face or faces of the mass of tomatoes where heat can be transfered to or from the air. Patchen and Sainsbury (18) have indicated that when conduction is the sole means of heat removal, cooling occurs almost as the square of the distance from the center of an apple container to its nearest face. If there are more than two parallel faces the heat is conducted primarily through the nearest face and the influence of the farthest pair is slight. This is an important consideration when stacks of bulk boxes are placed tightly together in rows.

The depth of the bulk boxes is usually about 2 feet which is almost one half their length or width. Consequently most of the cooling should occur from the top and bottom areas when the air temperature is lower than the tomatoes or containers. If the box depth were increased the circulation of air through the tomatoes should diminish and temperatures would increase inside the box. A provision to let air into the bulk boxes to accomplish as much cooling as possible by convection is of prime importance as was proved by the results obtained for the wire mesh container. Variations in construction of the bulk boxes to provide comparisons among them should be considered, such as slots, spaced sides, spaced bottom or combinations of these.

The thermocouples placed inside the boxes at mid-level measured temperatures of tomatoes at symmetrical locations. However, no measurements were made for those tomatoes in the top layer being additionally heated by radiation nor for the tomatoes on the sides adjacent to the container's wall which undoubtedly were exposed to more intensive heating. Skok (23) indicated that tomatoes exposed to the sun reached temperatures averaging $90^{o}F$ and MacGillivray (16) claims there is a difference of 15^{o} to $40^{o}F$ between the exposed and shaded side of the tomato. Nevertheless, the same tomatoes which had been exposed to the sun and in contact with the container's wall would be those which would be cooled faster when the air temperature started dropping. Patchen and Sainsbury (18) showed that when thermocouples were placed in apples at the outer edge, at bottom, top and middle positions and in the air at the center of a pallet box, the sides, bottom and top were found to cool the fastest in cold-storage rooms.

CONCLUSIONS

1. A difference of up to $4^{\circ}F$ for the mean temperatures of a 24 hour period was found between the internal tomato temperatures in the wire mesh container as compared to the internal tomato temperatures in the steel, wooden and plastic containers.

2. No meaningful differences were found between the mean internal temperatures over a 24 hour period for tomatoes held in steel, wooden and plastic containers.

3. The variation between the average maximum and the average minimum internal tomato temperatures was approximately $15^{\circ}F$ for most of the tests performed with all four containers.

4. There was approximately a four hour lag between the internal temperatures of tomatoes and the air temperature.

5. A provision to let air into the boxes to accomplish as much cooling as possible by convection is of prime importance as indicated by the results obtained for the wire mesh container.

6. A difference of $4^{\circ}F$ in tomato temperatures accounted for a calculated 21% increase in tomato respiration.

SUGGESTIONS FOR FURTHER STUDY

1. Variations in the construction of bulk boxes such as slots, spaced sides, spaced bottom or combinations of these, should be considered in order to minimize heating of produce.

2. Future tests should include a larger number of recordings per box to enable to measure tomato temperatures at mid-level as well as on the top and bottom layers and also adjacent to the containers wall. A complete heat transfer analysis could then be made.

3. Tests should be accompanied by an analysis of carotenoid content, acidity, soluble solids, total solids and other standard measures descriptive of quality.

4. A study of the actual respiration of tomatoes under bulk handling conditions should be considered.

5. Since the tomatoes in the wire mesh box remained cooler because of better ventilation, an attempt could be made on studying the effect of blowing air through the suggested slots of the tomato boxes.

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