DESIGN AND DEVELOPMENT OF A PRECOOLING UNIT FOR TROPICAL FRUITS AND VEGETABLES


ABSTRACT

A precooling unit was designed and developed to evaluate different methods of cooling namely: hydrocooling, air cooling/forced-air cooling, and hydaircooling. The unit was mainly used to precool tropical fruits and vegetables having varied and distinct product cooling requirements. Selected fruits and vegetables such as cucumbers, mango and papaya were evaluated using the different precooling methods. The most adaptable and efficient methods for precooling each product was determined. Results indicated that cucumber, mango and papaya could be best precooled through hydaircooling, hydrocooling and forced-air cooling, respectively.

INTRODUCTION

Losses in quantity and quality occur in fruits and vegetables after harvesting and are estimated to be about 10 to 30% in developing countries (Anon, 1985). Tropical fruits and vegetables are harvested under ambient temperatures from 25 to 35°C. Under this temperature, the respiration rate is high and the storage life is short. In many tropical countries, harvesting is done early in the morning to take advantage of lower temperatures. This practice however, may not be feasible for large growers that require the whole day to harvest their crop.

Precooling is a process of removing field heat from freshly harvested produce in a sufficient time to prevent spoilage and maintenance of pre-harvest freshness and flavor (ASHRAE, 1982). Usually most produce is precooled just before loading for transport to market or before short or long term storage. Prompt cooling after harvest is important for most fruit crops since a product may deteriorate as much in one hour at 32°C as 24 hrs at 10°C (Guillo, 1960). Precooling also reduces bruising damage from vibration during transit, and reduces the amount of refrigeration required during transport. Today, precooling systems applies the concept of cooling produce using cooling mediums such as water or air, or a combination of both so that heat is transferred from the product to the medium.

The benefits of precooling is based on the rate at which ‘field heat’ is removed. The factors that determine precooling rates of produce with air or water are: the initial and final temperature of the fruit; the temperature of the cooling medium and its capacity to absorb heat, the size and shape of the fruit, especially the surface to volume-mass ratio; the thermal properties of the fruits, such as specific heat, and thermal conductivity to the cooling medium, and the volume and velocity of the cooling medium passing around the fruits (Pentzer and Ryall, 1974).

Produce can be cooled either by means of cold air such as in room cooling and forced-air cooling. Cooling could also be done by cold water, such as in hydrocooling, by direct contact with ice, as well as by the evaporation of water from the produce (evaporative cooling, vacuum cooling) (Guillo, 1960; Pentzer and Ryall, 1974). Henry and Bennet (1973) studied the feasibility of cooling vegetable products in unit loads using a combination of air and water which is called hydaircooling.

The measurement of cooling is generally by half cooling times. Many researchers used the half-cooling time to determine the feasibility of a precooling system and to evaluate cooling performance. (Guillo, 1960; O’Brien and Gentry, 1967; Bennet, 1969) and Parsons et al., 1970).

The aim of this study was to design and develop a precooling system for tropical fruits and vegetables. The performance of the precooling system in terms of the cooling rates and half-cooling times of selected fruits and vegetables were evaluated for hydrocooling, air/forced-air cooling and hydaircooling methods.

MATERIALS AND METHODS

Construction. The designed precooling system for tropical fruits and vegetables is shown in Figure 1. The system consists of a 1 cu. meter produce chamber where the produce is stacked and cooled. A water reservoir with a capacity of 150 liters is located at the bottom of the produce chamber which allows water passing the produce to be recooled.
Recycling is accomplished by a refrigeration system, before the water is recirculated by the pump through the pipings and nozzles installed at the ceiling of the produce chamber. An evaporative air cooler is also attached to this chamber by means of ducts located on the top and bottom of the evaporative cooler. The evaporative air cooler is 0.25 m² in cross-sectional area and 1.3 m in height. The packings are plastic mesh of one mm² openings with a volume of 0.125 m³. The cool water is sprayed as a fine mist through nozzles at the top of the packings.

Operation and Instrumentation. The operation depended on the methods of cooling selected to meet the specific product cooling requirements of hydrocooling, forced-air cooling or hydraircooling. Fifty kg. each of the selected fruits and vegetables (cucumber, mango and papaya) were selected for the test. Product temperatures at different sections within the products and within the total product load were measured using copper constantan thermocouples. For mangoes, the thermocouples were placed 1-1/2 cm deep from the surface, while for papayas 4 thermocouples were used to monitor the fruit temperature at the center, the inside surface of the flesh, the middle of the flesh and at 2 mm from the surface. For cucumber, the thermocouple was placed at the center. The average value resulting from the 4 thermocouples was used to plot the temperature ratio-time curves. Water and air temperatures at different locations within the system were also measured using thermocouples. Airflow was measured in each test run by means of a hot wire anemometer. The water flow was established by means of a control valve setting. In each test run for the different produce the airflow was measured. This is because the different produce, have varying packing arrangements in different containers which causes a pressure resistance against air flow. Pressure drop across the fan was measured using an U-tube manometer. Energy use was also recorded by means of a watt-hour meter. Temperature signals from the produce, the air, as well as water within the system was recorded at different locations by means of a data acquisition system. Components of the system included a 20 channel high speed Kyowa scanner to accept analog inputs from the thermocouples. This scanner was connected to a Kyowa Ucam 5BT data logger which was interfaced with an NEC microcomputer. The temperature readings were saved in a diskfile.

Analytical Procedure. Results of the trials were evaluated in terms of cooling coefficients or cooling rates (CR) and half-cooling time (Z) of the produce.

Temperature ratio (TR) was derived by dividing the differences between initial product temperature (t₀) and the water or air temperature (tₚ) by the difference between the product temperature (t) and the medium temperature (tₚ) at any time during.

\[
TR = \frac{t - t₀}{tₚ - tₚ} \quad (1)
\]

Cooling Rate (CR) was determined by statistical regression analysis. The slope of the cooling curve was plotted on a semi-log graph from which the cooling rate was taken as,

\[
TR = j e^{-CR} \quad (2)
\]

where \( j \) = lag factor
\( e \) = time

The Half-cooling time (Z) was determined from the temperature ratio-time response of the product during cooling. The time corresponding to a temperature ratio of 0.5 was taken as the half-cooling time.

\[
Z = \frac{\ln (j * 2)}{CR} \quad (3)
\]

Data Analysis. The mean half-cooling time of each produce tested under the different cooling conditions was analyzed using the least significant different (LSD) test. This test was used to evaluate the uniformity of produce cooling and the effect of each cooling condition and method.

RESULTS AND DISCUSSION

Performance of the refrigeration system. The mechanical refrigeration unit selected was able to reduce the water temperature to 0°C in one hour. The water could be maintained at 5°C during circulation for cooling. The increase in
water temperature is attributed to the heat absorbed by water which is in contact with the produce. The cooling water temperature leaving the spray nozzle was between 8 to 15°C. This would be a good cooling temperature for a wide range of tropical produce.

Cooling Experiment. The results of the cooling times observed from the selected fruits and vegetables using the different cooling methods were evaluated in terms of cooling coefficients or cooling rates and half-cooling times in the different locations of the produce.

Cucumber. Table 1 shows the mean half cooling times for cucumber under different methods of cooling. Comparison of means showed non-significant differences for hydro-cooling using water flow rate of 26 and 44 liters/minute. Results indicated that water flow rate of 26 liters/minute must be used for cooling cucumbers, at mean half cooling times of 16 minutes per 50 kg of produce, due to lower operation cost of supplying cooling water. The differences in air-cooling with 5 and 11 m³/minute was also not significant based on comparison of means. The average mean half cooling time was about 61 minutes per 50 kg of cucumbers. Cucumber was found to be uniformly cooled using hydraircooling with no significant differences on mean half cooling times for various combinations of air and water flow rates. Satisfactory water and air flow rates combination of 26 liters/minute and 5 m³/minute, respectively was able to cool cucumber from 30°C to 12°C in about 12.5 minutes half cooling times. Comparison of various methods of cooling showed that hydraircooling method has the fastest cooling capacity (Fig. 2).

Mango. Table 2 shows the mean half cooling times for mango for different pre-cooling methods. Comparison of means showed no significant differences for hydrocooling at 26 and 44 liters/minute water flow rate. The 26 liters/minute flow rate was determined as suitable hydrocooling conditions for mango as it have less operational cost in supplying the cooling water. The average half cooling times was about 21 minutes for 50 kg of produce. Air cooling of mango showed significant differences at 5 and 7 m³/minute flow rates. Forced air cooling of mangoes in vented boxes using an air flow rate of 7 m³/minute was considered appropriate for air cooling mango due to its lower average half cooling conditions of 44 liters/minute and 11.5 m³/minute to cool mangoes from 26 to 13°C have average mean half cooling times of 23 minutes. Comparison of different methods of cooling for mangoes, showed that produce could be cooled faster using hydrocooling (Fig. 3). Forced-air cooling is best suited when mangoes were packed in vented cardboard boxes where cooling water cannot be possibly used, however with longer cooling times.

Papaya. Table 3 shows the mean half cooling times for papaya at different air flow rates. Papaya were cooled only with air due to its tendency to absorb water, resulting to quality deterioration. Comparison of means showed significant differences for 8 to 12 m³/minute air flow rates. Air flow rate of 10 m³/minute was selected as appropriate for cooling papaya based from lower cooling air flow rate required and mean half cooling times (Fig. 4).

Energy Consumption. The energy consumption of the cooling system in each test run was measured by a Kw-hr meter. The methods which had the lowest cooling times had the least energy consumption. The specific cooling energy requirements for each commodity using the different cooling methods was, however, generally low. For hydrocooling, an average of 1 Kw-hr of energy was consumed for each hour of the cooling operation. Energy consumed during forced-aircooling and hydraircooling was slightly higher because the pumps, the compressor and the blower are all in operation, as compared to hydrocooling where the only requirement was for running the pump and the compressor. Operating the cooling system for forced aircooling, air cooling and hydraircooling will consume 1.2 Kw-hr for each hour of cooling. The energy requirement and the system parameters must operate at its optimum operating conditions in order to obtain optimum cooling conditions for each commodity.

CONCLUSIONS

The pre-cooling system was designed, constructed, and developed for pre-cooling tropical fruits such as cucumber, mango and papaya using three cooling methods namely hydro-cooling, air-cooling and hydraircooling was found to perform very satisfactorily. Cucumber can be rapidly cooled by hydraircooling with average half cooling time of 12.53 minutes using 26 liters/minute and 5 m³/minute air flow rate. Mangoes would be cooled by hydro cooling at a half cooling time of 21.67 minutes at water flow rate of 26 liter/minute. Hydraircooling for papaya resulted in average half cooling times of 69.73 minutes at air volume 10 m³/minute. The energy consumption during hydrocooling is 1 Kw-hr/hr of cooling, while 1.2 Kw-hr/hr was needed for forced-air cooling and hydraircooling.

LITERATURE CITED


### TABLE 1. MEAN HALF COOLING TIMES FOR CUCUMBER UNDER DIFFERENT METHODS OF COOLING.

<table>
<thead>
<tr>
<th>Flow rates</th>
<th>Method of cooling (min)</th>
<th>hydaircooling average</th>
</tr>
</thead>
<tbody>
<tr>
<td>water 1/min.</td>
<td>air m³/min.</td>
<td>hydro-cooling average</td>
</tr>
<tr>
<td>26</td>
<td>15.86A</td>
<td>61.83A</td>
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<tr>
<td>44</td>
<td>14.16A</td>
<td>63.23A</td>
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<tr>
<td>5</td>
<td></td>
<td>12.53A</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>10.90A</td>
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<tr>
<td>26</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* highlighted values are selected as satisfactory conditions for pre-cooling cucumber.

** mean with similar letters in rows are not significantly different at \( p < 0.05 \) level.

### TABLE 2. MEAN HALF COOLING TIMES FOR MANGO UNDER DIFFERENT METHODS OF COOLING.

<table>
<thead>
<tr>
<th>Flow rates</th>
<th>Method of cooling (min)</th>
<th>hydaircooling average</th>
</tr>
</thead>
<tbody>
<tr>
<td>water 1/min.</td>
<td>air m³/min.</td>
<td>hydro-cooling average</td>
</tr>
<tr>
<td>26</td>
<td>21.67A</td>
<td>79.53A</td>
</tr>
<tr>
<td>44</td>
<td>16.63A</td>
<td>50.40B</td>
</tr>
<tr>
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<td>23.23</td>
</tr>
<tr>
<td>7</td>
<td></td>
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</tr>
</tbody>
</table>

* highlighted values are selected as satisfactory conditions for pre-cooling cucumber.

** mean with similar letters in rows are not significantly different at \( p < 0.05 \) level.
TABLE 3.  MEAN HALF COOLING TIMES FOR PAPAYA UNDER FORCED AIR-COOLING.

<table>
<thead>
<tr>
<th>Air flow (m3/min.-1)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>83.67A</td>
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<tr>
<td>10</td>
<td>69.73AB</td>
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<tr>
<td>12</td>
<td>59.80B</td>
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</table>

* highlighted values are selected as satisfactory conditions for pre-cooling cucumber.

** mean with similar letters in rows are not significantly different at p < 0.05 level.
FIGURE 2. TEMPERATURE RATIO-TIME RESPONSE FOR CUCUMBER AT DIFFERENT PRE-COOLING METHODS

LEGEND:

(1) 26 liters/minute and 5 cu. meters/minute
(2) 26 liters/minute
(3) 5 cu. meter/minute

FIGURE 3. TEMPERATURE RATIO-TIME RESPONSE FOR MANGOES AT DIFFERENT PRE-COOLING METHODS

LEGEND:

(1) 26 liters/minute
(2) 44 liters/minute and 11 cu. meter/minute
(3) 7 cu. meter/minute
FIGURE 4. TEMPERATURE RATIO-TIME RESPONSE FOR PAPAYA WITH AIR-COOLING