Forced - Air Precooling of Fruits and Vegetables

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Research in post-harvest technology of horticultural crops in the USA and Europe has clearly demonstrated that, prompt precooling of fruits and vegetables, immediately after harvesting, inhibits growth of decay-causing microorganisms, reduces enzymatic and respiratory activity, reduces moisture loss thus leading to a longer storage life.

With the absence of organized retail of fruits and vegetables and subsequently a cold chain in India's old economy, the need for precooling of these products has not been felt for generations and people in the country are accustomed to buying their daily needs of seasonal fruits and vegetables, fresh from the local bazaar or the nearest hawker with his *thela* (cart) or head basket. Fortunately the country is the second largest grower of fruits and vegetables in the world and, in spite of a huge loss of such products due to decay, rotting and lack of refrigerated storage, the common man has enough supply to meet his needs. The main sufferers are the farmers and the hawkers who have to end up absorbing such losses.

There is one lone exception to this need for precooling and that is, grapes. With globalization and the efforts on various fronts to increase our exports, some entrepreneurs with support from APEDA (Agricultural Produce Export Development Authority) started to export grapes, grown abundantly around Nashik in Maharashtra to the affluent market in the UK, around 1990-91. The sea voyage to England in reefer containers (refrigerated boxes) takes about three weeks and allowing for transport to the retail stores and some storage time in distribution/ logistic warehouses, the grapes had to appear fresh and attractive to the English buyer, for six weeks at least after harvesting in Nashik. Indian farmers and exporters soon realized that the only way to meet this requirement was precooling immediately after harvesting and thus started the first precooling centre using mechanical refrigeration. Experience gained over the years with precooling of grapes can now be used to precool other fruits as well as vegetables, which will certainly be required by the organized retail chains now being estab-

About the Authors

Mahesh Aswaney, is a mechanical engineer with specialisation in refrigeration. He pioneered the use of high humidity systems for preservation of fresh fruits and vegetables. His company has built over 200 packhouses which has fackitated the export of quality grapes from Maharashtra to European markets. He can be contacted at anwaneymahesh@yahoo.com

lished by large companies with huge investments.

Methods of Air Cooling

There are several methods for cooling produce with air as the cooling medium. The *ASHRAE Refrigeration Handbook* has a list of five different methods:

1. With air circulated in refrigerated rooms adapted for the purpose
2. In rail cars using special portable cooling equipment that cools the load before it is transported
3. With air forced through the voids of bulk products moving through a cooling tunnel on continuous conveyors
4. On continuous conveyers in wind tunnels
5. By the forced–air method of passing air through the containers using pressure differential

Each of the methods is used commercially and each is suitable for specific products when properly applied. *Figure 1* shows a schematic of a serpentine forced air cooler. Forced–air cooling is ideal for small, delicate products such as grapes and strawberries that cannot be handled in bulk and that are packed in cardboard cartons before precooling. In India, this is the method that has been most commonly used for precooling grapes for the export market.

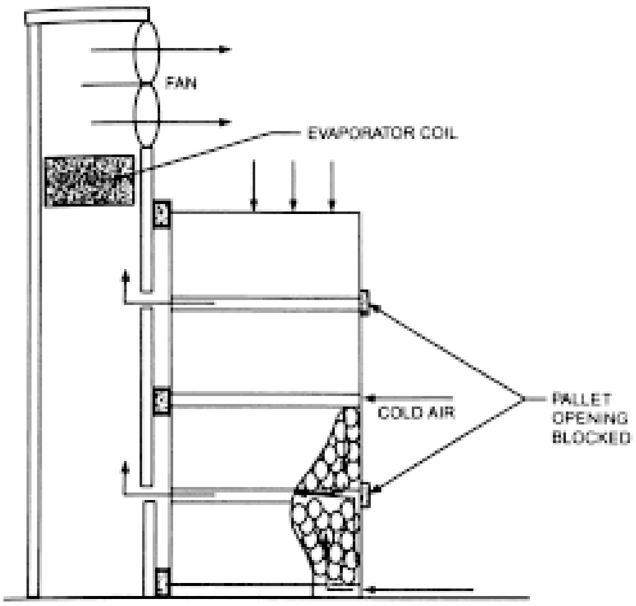

Figure 1: Serpentine Forced-Air Cooler

Products that Require Precooling

Metabolic activity in fresh fruits and vegetables continues for a short period after harvest. The energy required to sustain this activity comes from respiration, which involves oxidation of sugars to produce carbon dioxide, water and heat. A commodity's storage life is influenced by its respiratory activity. By storing it at low temperature, respiration is reduced and senescence is delayed, thus extending storage life.

Examples of products that are highly perishable and must begin cooling as soon as possible after harvest are: cauliflower, broccoli, vine-ripened tomatoes, leafy vegetables, cabbage, carrots and radishes. Commercially important fruits that need immediate precooling include apricots, avocadoes, peaches and plums, tropical fruits such as guavas, mangoes, papayas and pineapples. Grapes, pears and citrus fruit have a longer post-harvest life, but prompt cooling is essential to maintain high quality during holding.

How Forced-Air Cooling Works

Forced air or pressure cooling involves definite stacking patterns and baffling of stacks so that cooling air is forced through, rather than around individual containers. Success requires a container with vent holes in the direction air will move and a minimum of packing materials that would interfere with free air movement through the containers. Under these conditions, a relatively small pressure differential between the two sides of the container results in good air movement and excellent heat transfer. Differential pressures in use are about 0.25 to 3 inches of water with air flows ranging from 1 to 3 cfm/ lb of product.

Because cooling air comes in direct contact with the product being cooled, cooling is much faster than with conventional room cooling. This gives the advantage of rapid product movement through the cooling plant and the size of the plant is typically one-third to one-fourth that of an equivalent cold room type of plant.

Research studies in the USA have shown that forced-air cooling usually cools in one-fourth to one-tenth the time needed for conventional room cooling.

Effects of Containers and Stacking Patterns

Forced-air precoolers can be made more efficient by several minimum cost methods and by better management. These methods include sealing air leakage areas to forcing additional air through products, improving carton-stacking configurations or orientation, modifying pallet-tunnel length and width and proper temperature monitoring. Carton design must allow a minimum of 5% side-wall venting.

Palletisation is essential for shipment of many products and pallet stability is improved if cartons are packed closely together. Thus cartons and packages should be designed to allow ample air flow through the stacked products.

Air Management

Fans supplied with the refrigeration equipment are used to cool the air by forcing it past the evaporator coils. These fans are not large enough, nor are they properly located in most cases, to force air directly past the produce. It must be mixed with the warmer air inside the room to prevent chill injury. Therefore, additional fans are required to move the air past the produce. To achieve good air distribution, these fans should pull, never blow the cooled air through the produce as far as practical.

Several different fan positions and produce stacking arrangements have proved successful for forced air cooling. The shell arrangement shown in *Figure 2* uses a portable pallet-mounted fan and is preferred by many because of its versatility. Two parallel rows of produce, positioned approximately 2 to 3 feet apart and covered by a cloth or plastic strip, form the shell. Cold air is pulled through the space between the rows and out through the fan. In another arrangement known as the 'cooling wall', the fans are located permanently along one wall. This design may be more convenient for producers and shippers who handle large volumes of produce, especially if they handle the same commodity or compatible ones.

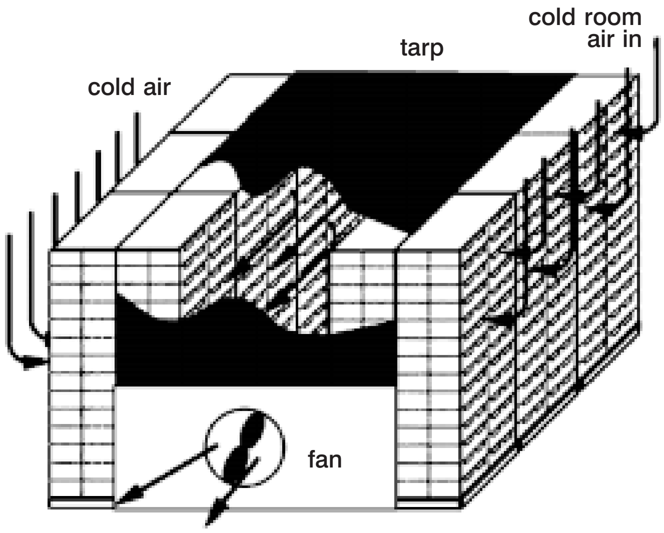

Figure 2: Schematic of a tunnel-type precooler

Cooling Time Calculations

The rate of cooling is directly related to the temperature differences between the cooling medium and the product. Initially when the product is warm, temperature drops quite rapidly; later the rate slows as product temperature drops. Average product temperature during cooling follows a pattern similar to *Figure 3*. The product is considered 'half cool' when its temperature drops to half the difference between its initial temperature and the cooling medium temperature. After another half-cooling period the product is 'three-quarters'

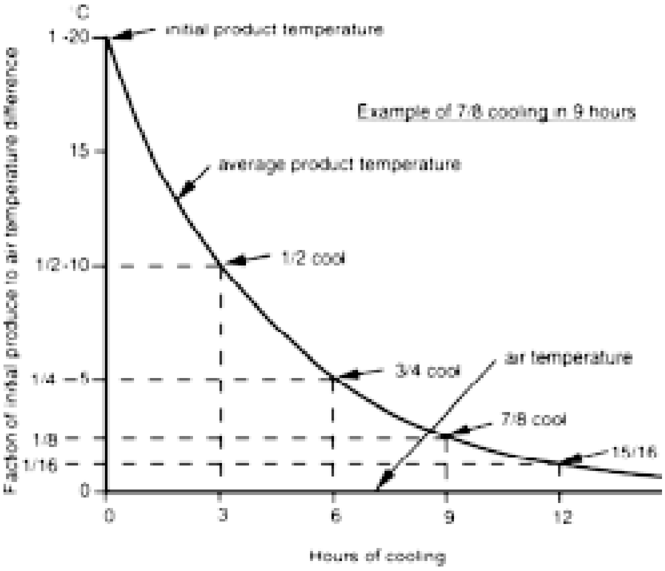

Figure 3: Typical time-temperature pattern in produce cooling. Numbers along the temperature curve indicate the fraction obtained by dividing the difference between product temperature and air temperature in the cooler by the difference between the initial produce temperature and the air temperature.

cool. Product is usually finished cooling at 'seven-eighths' or 'fifteen-sixteenths' cool.

Moisture Loss in Forced-Air Cooling

Moisture loss in forced-air cooling ranges from very little to amounts significant enough to damage produce. Factors that affect moisture loss include product initial temperature and transpiration co-efficient, humidity, exposure to airflow after cooling and whether waxes or moisture-resistant packaging is used.

High initial temperature results in high moisture loss; this can be minimized by harvesting at cooler times of the day (i.e. early morning or at night) and cooling or at least shading products immediately after harvest.

The primary advantage of high humidity during cooling is that product packaging can absorb moisture, which reduces its capacity to absorb moisture from the product itself.

High transpiration coefficients also increase moisture loss. For example, carrots with a high transpiration rate, can lose 0.6 to 1.8% of their original weight during cooling. Polyethylene packaging can reduce moisture loss in carrots to 0.8% although cooling times are about five times longer.

To prevent exposing product to unnecessary air flow, forced air coolers should reduce or stop air flow as soon as the target product temperature is reached. Otherwise, moisture loss will continue unless the surrounding air is close to saturation. One method is to link cooler fan control to return air plenum temperature, slowing fan speed as the temperature of the return air approaches that of the supply air.

Controlling Relative Humidity

Proper selection of the cooling coil or direct expansion evaporator plays a major role in maintaining a high relative humidity of 90% to 95% in the pre-cooling process and thus minimizing moisture loss in the product.

Relative humidity is more difficult to control than temperature and often does not receive adequate consideration when designing precooling stations or regular cold storages for that matter. If the air is too dry, there may be enough water loss to affect the texture and cause visible shriveling or wilting. It can even make the product un-saleable.

Fruits such as apples and pears are most resistant to moisture loss, but during several months of storage they may lose 2-3% or more in weight because of water loss. A moisture loss of 4-5% results in spongy texture and visible shriveling of the fruit.

Excessive humidity on the other hand, is conducive to the growth of mold and decay organisms, particularly when water droplets form on the surface of the fruits. There is increasing evidence that very high humidity, particularly in the early part of cold storage, can contribute to physiological disorders in certain cultivars (cultivated variety produced by selective breeding) of apples. With most commodities however, the problem is one of maintaining sufficient moisture in the storage, although a few vegetables such as onions, garlic, squash (a gourd-like vegetable), and pumpkin require low relative humidity.

Vegetables are, in general, very susceptible to moisture loss in storage, with leafy vegetables losing moisture more easily; in an unfavorable environment they can suffer damaging water loss in a few hours. A moisture loss of 4% or more may necessitate trimming of the outside wilted leaves. Softening or wilting of root crops or cabbage heads is apparent when the total moisture loss exceeds 5%, whereas moisture loss in excess of 8% renders the product un-saleable. Most vegetables requiring storage at high relative humidity are resistant to increased decay or physiological disorders. For most vegetables that are susceptible to rapid water loss, the incidence of decay is usually not accelerated by the presence of condensation on the surface of the product if storage temperatures are maintained near those recommended for the product.

In a refrigerated storage, the best way to maintain high humidity is to use an evaporator coil that is large enough to provide rapid cooling of the air without requiring operation at a low temperature. An undersized cooling coil must be operated with a low surface temperature to cope with demands, especially during loading of the storage, that cause moisture to condense and freeze on the coil and effectively remove water from the storage environment. This lowers the humidity and results in abnormal moisture loss from produce. Also the accumulation of frost reduces the air flow over the coil and lowers its cooling efficiency still further.

Figure 4 shows how to select a commercial forced-air evaporator or unit cooler for varying relative humidity required in the room based on the temperature difference. (TD) between the refrigerant in the unit cooler and the room temperature.

It is extremely important not to spray water directly on the produce because any water on the surface of the produce encourages microbial growth. Alternatively, produce stored in bulk bins (about 385 kg) or field boxes (about 20 kg) may be enclosed with 38 micron thick perforated polyethylene (or equivalent) to maintain an atmospheric humidity of 94-98%.

Caution : A polyethylene barrier around produce that has not been pre-cooled slows field heat removal and increases deterioration of the product.

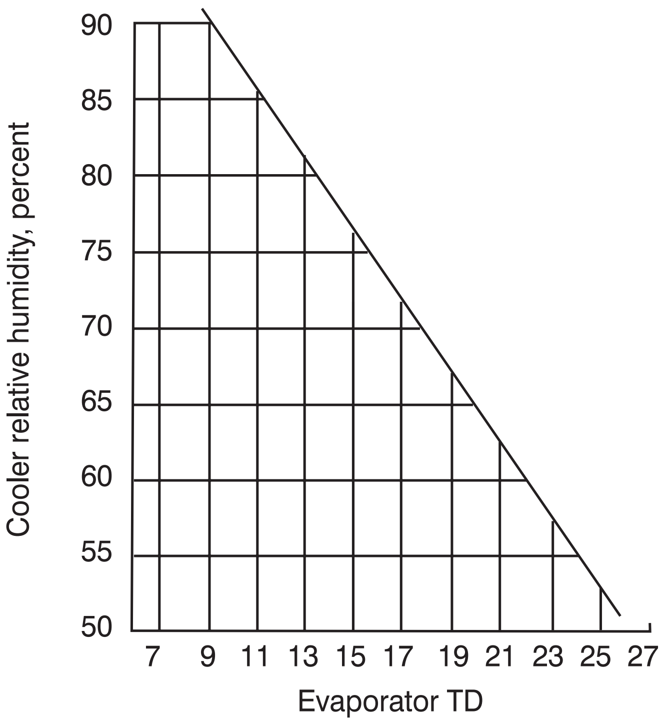

Figure 4: Approximate forced convection evaporator TD for 35F rooms.

Sweating

Cold produce exposed to a warm atmosphere usually becomes moist or even wet, which is referred to as sweating and is caused when the warm air loses moisture as it is cooled on contact with the produce. *Figure 5* shows how the occurrence of condensation at a given temperature is related to the humidity and temperature of the atmosphere.

One way to avoid sweating when produce is removed from storage is to warm it gradually to a temperature at or above the dew point of the atmosphere to which it will be transferred. When condensation cannot be avoided, produce subject to decay should be marketed promptly after removal from cold storage. Sweating may also occur in storages where relative humidity is maintained near saturation (98-100% RH). This phenomenon will result from fluctuations in storage air temperature, which occur after a defrost cycle. Evaporator coil temperature should be reduced at least to product temperature before the circulation fans are engaged, which prevents surface water from forming on the produce and retards fungal infections.

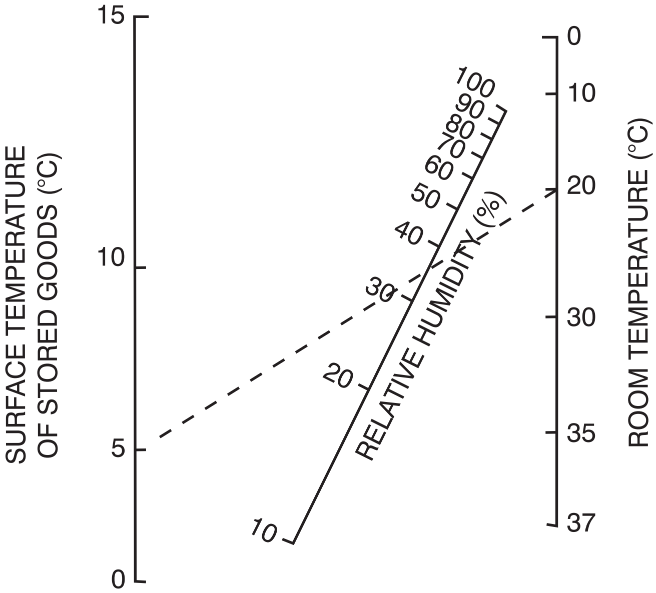

Figure 5: Relationship of room temperature, relative humidity, and surface temperature of the object to occurrence of condensation or sweating. In the illustration, room temperature is 20°C and relative humidity is 37%. An extension of a line through these points intersects the surface temperature scale at 5°C. Produce at this temperature or lower would be subject to sweating.

Precooling Technology Helps Indian Farmers Export Grapes to Europe

Grapes are one of the largest traded fruits globally and this has been largely due to the availability of appropriate cooling technology in the entire supply chain from the farm up to the plate. The first precooling station was developed in California, USA, one of the top growers of grapes in the world, around 1960.

The challenge for cooling of grapes (and most other fruits and vegetables), lies in generating the ultra high humidity required (typically in the range of 90 to 95%) and the proper placement of the fruit in suitable containers, so as to promote maximum heat transfer and thus achieve the shortest precooling times. Done correctly, this helps attain the objectives of cooling as fast as possible with a minimum loss of moisture (less than 1%) from the product. It is not unusual to achieve a cooling time of 5 to 6 hours and a shelf life of 60 days with the original farm-freshness maintained right up to the table. Thus, one of the biggest challenges i.e. distribution of grapes across the world has been achieved and retail chains around the world are proud to supply grapes throughout the year, by synchronizing supplies from different countries with varying harvesting seasons.

Photo 1: Packhouse maintained at 22°C & 75% RH for sorting, grading and packing.

India was a late entrant in the global trade for grapes and the main hurdle was again, an appropriate cooling technology. It was in 1990-1991 that the first attempt was made, to export grapes from Maharashtra, which is the largest grape-growing state in the country (approximately 1 million tons per annum). In 2006, Indian exporters had shipped out to UK and Europe and all other parts of the world approximately 50,000 metric tons of the *Thompson Seedless* table grapes valued at approximately Rs. 500 crores. Some portion of these was exported from Karnataka and Andhra Pradesh.

Grapes, unlike apples and pears, do not continue to ripen after harvest, so they should be harvested or picked at optimum maturity. Harvesting should not be delayed after full maturity is reached. For maximum storage life, grapes should be precooled immediately after harvest by forced–air cooling or by tunnel cooling. A minimum air volume of 3 cfm per kg of grapes is recommended for room precooling.

An air temperature of –1°C to –0.5°C is recommended for precooling. High RH is necessary to minimize moisture loss and maintain stems in good condition. When grapes lose 1–2 % or more water by weight, their appearance is adversely affected. An RH of 90 to 95% is recommended. High humidity in a mechanically refrigerated storage is best maintained by keeping a low temperature split between air supply and air return temperature, in the vicinity of 1°C, or by the use of sophisticated atomisers.

In Indian farms, grapes are harvested early in the morning between 6 am and 9 am taking advantage of the coolest daylight hours in order to reduce field heat and hence the refrigeration load. They are then carried to a modern "packhouse" which is maintained at 22°C and 75% RH where they are sorted, graded and packed in 5 kg/10 kg corrugated, specially developed cardboard boxes which are provided with ventilation holes of approximately 5% of surface area to allow sufficient ventilation air through the holes. This air impinges on the grapes at a high velocity to increase the heat transfer coefficient and speed up the cooling cycle.

The boxes are then stacked on Euro pallets, duly packed but with plastic wrapper blankets opened on top for efficient circulation of air. The pallets are then arranged in two rows on either side of a tunnel formation approximately 2.5 feet wide. Please see the *Figure 2* depicting the tunnel configuration with an efficient air circulation system. A heavy tarpaulin sheet is then rolled over the pallets and air return channel and a high static pressure axial fan of capacity 25 mm of water is employed to achieve the whole air circulation process.

Grapes are precooled to a temperature of 0°C–2°C, preferably within four hours, which ensures a storage life of up to 60 days. As the time taken to complete the precooling process increases from 4 to 8 hours, the storage life reduces. The time required to transport the grapes from India to UK or Europe by ship is between 22 to 26 days and time for storage in distribution warehouses and display/ sale in supermarkets is at least another 15 days. Thus, the grapes must maintain their freshness for at least 45 days from the time they are harvested in India keeping some time for consumption as well. It is therefore extremely important to keep a close tab on the time taken for precooling.

Photo 2: Tunnel arrangement showing cooling coil, packed grapes ready for precooling and tarp rolled up.

Photo 3: After precooling grapes are stored in a cold storage maintained at 0°C & 90% RH ready for loading in refrigerated container for the journey by road to Mumbai port.

After precooling, the grapes are stored in a cold storage maintained at 0°C and 90% RH until approximately 15 tonnes of grapes has been collected to fill a 40-foot refrigerated container which is then transported by truck to the port in nearby Mumbai for the ocean journey to Europe or any destination of choice. The reefers are fitted with data temperature loggers during the entire cycle from the packhouse through the ocean journey to the importing port. This temperature data is a genuine control point for verifying compliance with commitments made by the shipping companies adn also a good reference point by the insurance companies.

The cold chain is extended at the import end by taking the reefer to the Distribution Centre where the grapes are unloaded and distributed on Europallet to the retail outlets. Most outlets have back-end cold storages and display cases at the retail store itself.

The long journey from the vineyards at Pimpalgaon near Nasik to the dining tables of choosy homemakers in England or Europe is a classical example of the benefits of the cold chain in a win-win situation for all stake holders in a globalised world. That Refrigeration technology plays a key role in the cold chain becomes obvious from this example!. ❖

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