



Temperature Management

Cooling Methods & Principles

Mark Ritenour
 Indian River Research and Education Center, Fort Pierce
 Jeff Brecht
 Horticultural Science Department, Gainesville



1




Benefits of Cooling


- Decreased Respiration

Lower Respiration => Longer Shelf Life

- For every 10°C (18°F) decrease in temperature
 - respiration decreases two to three fold
 - shelf life increases two to three fold




2




Benefits of Cooling

- Decreased Respiration
- Reduced Water Loss
 - Greatest water loss occurs from warm product
 - Faster cooling = less water loss
 - In some products, 1 hr. in warm, dry air can equal the water lost during 1 week of cold storage with high humidity




3




Benefits of Cooling

- Decreased Respiration
- Reduced Water Loss
- Reduced Decay
 - Harvest temperatures = Optimum growing temperatures for many decay organisms
 - Reducing fruit temperature greatly reduces pathogen development




4




Where does the Heat Come?

- Sensible heat (field heat)
- Vital heat (heat of respiration)
- Heat transmission (across walls, floors, etc.)
- Air change or leakage
- Miscellaneous heat sources
 - Lights, motors, personnel, etc.




5

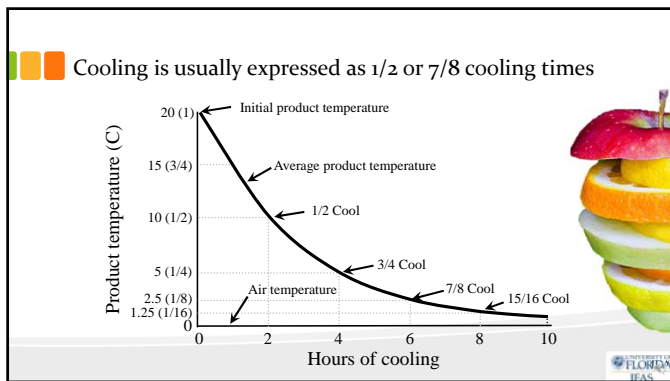


Where does the Heat Come?

- ~50% from the field (sensible heat)
- ~28% comes through the walls, roofs, and plus warm air infiltration
- ~12% heat of respiration
- ~10% service load
 - Fans, lights, personnel, forklifts, etc.



6



7

■ ■ ■ Heat is Removed Through...

- Conduction
- Convection
- Evaporation
- Radiation

8

■ ■ ■ Heat is Removed Through...

- **Conduction**
 - Heat moving along gradient from high temperature to low temperature
 - E.g. stick the end of a metal rod in a fire and the end your are holding begins to get hot
 - Rate of heat movement is determined by heat gradient and the material's **thermal conductivity**

9

■ ■ ■ Heat is Removed Through...

- **Convection**
 - When cooler molecules contact warmer molecules, the heat is shared between them
 - => both move towards a common temperature
 - **Convection currents** => temperature differences cause the cooling medium (air or water) to move around the product
 - By continually moving new cool medium (e.g. air or water) past the product, the product is cooled

10

■ ■ ■ Heat is Removed Through...

- **Evaporation**
 - As water evaporates it absorbs energy
 - This is why we are cooled by perspiration and plants are cooled by evapotranspiration
 - Evaporation is used indirectly by evaporative coolers to cool air and directly by evaporating water off commodities (e.g. vacuum cooling)

11



■ ■ ■ Heat is Removed Through...

- **Radiation (electromagnetic waves)**
 - All bodies radiate energy => the hotter the body, the greater the energy radiated (e.g. the sun or quartz space heaters)
 - However, at biological temperatures, energy lost through radiation is very low
 - Radiation is not very important for the cooling of horticultural crops

12

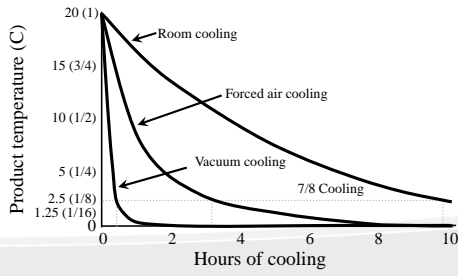


■ ■ ■ Cooling Methods

- Air cooling
 - Room cooling
 - Forced-air (or pressure) cooling
- Hydrocooling
- Ice cooling
- Vacuum cooling

13



■ ■ ■ Cooling is usually expressed as 1/2 or 7/8 cooling times

14

■ ■ ■ Cooling with Air

- Air is free cheap and easy to move
- Low thermal capacity
- Two types:
 - Room cooling
 - Forced-air cooling






15

■ ■ ■ Cooling with Air

Room Cooling

- Requires less refrigeration capacity than other cooling methods because heat removal is spread over longer periods (i.e. overnight)
- Product can be stored where it is cooled
- Slowest cooling method

16





17

■ ■ ■ Cooling with Air

Forced-Air Cooling

- Much faster than room cooling
 - Fruit takes only 1/4 to 1/10 as long to cool
- Product can be shipped faster, taking up less floor space
- Requires larger refrigeration capacity to handle peak heat removal

18



19



20



21

Factors that Influence Speed and Efficiency of Cooling

22

Factors Affecting Speed of Air Cooling

- Refrigeration Capacity
 - Inadequate refrigeration will allow air temperatures to rise when new product is added.
- Air temperature in the cooler
 - Allowing the air temperature to rise, especially near the end of cooling, will delay cooling.
- Initial temperature of the fruit
 - Product going into the cooler at higher temperatures will take longer to cool

23

Speed of air flowing over the product



- Air is the cooling medium => carries heat away from the product

No Air to the Product
 ↓
Very Slow Cooling

24

■ ■ ■ Fan Speed and Pressure Differential



- Coolers often are designed to provide airflow of ~ 1 cfm/lb product
- Doubling airflow to 2 cfm/lb ...
 - ~ 40% faster cooling
 - Requires ~ 4 times more pressure differential
 - Requires ~ 6 times more fan power
- Fans should be selected that can operate against at least 2 inches w.c. pressure

25

■ ■ ■ Uneven Cooling Rates



- Fruit closest to the intake fan cools faster than fruit furthest from the fan
 - Increase air return width to decrease difference

26

■ ■ ■ Uneven Cooling Rates



- Fruit on top of the pallet cools faster than fruit on the bottom.
 - Increase air supply width to decrease difference

27

■ ■ ■ Uneven Cooling Rates



- Fruit that comes in contact with the airflow first cools faster than fruit further in
 - Increase airflow rate to decrease difference

28

■ ■ ■ Carton Design



- Vent holes in cartons are required for adequate cooling rates
 - ~ 5% vent area
 - A few larger vents are better than many small ones
 - Oblong vents are better than round ones
 - Vents should be at least 2 inches from the corners
 - Vents should align so that when cross-stacked, air can pass through the entire pallet
- Packing material inside cartons can greatly reduce airflow through the carton

29

■ ■ ■ Monitoring Cooling

- Base cooling progress on fruit mass average (1/3 to core) temperature
- Before taking measurement, insert thermometer into fruit several times to equalize temperature
- Measure temperature of fruit that cool the slowest
 - Warmest fruit are usually located farthest from the fan, at the bottom, tunnel-side of the pallet

30

Hydrocooling



31

Advantages of Using Liquid Water for Cooling

- Water has a high heat capacity (1 kcal/kg/°C)
 - It absorbs a lot of heat energy before raising 1C
- High heat conductivity (5.2 cal/g/h/°C)
 - Disperses heat quickly
- Using water for cooling prevents water loss during the cooling process



32

Many Fruits and Vegetables can be Hydrocooled

- Hydrocooling is one of the most rapid means of cooling
- A large variety of fruits and vegetables are compatible with hydrocooling
- Commodities usually not hydrocooled:
 - Those that cannot tolerate free water. E.g., Grapes, cut flowers and most berries
 - Those that can be cooled more efficiently using other techniques
 - E.g., Leafy vegetables => vacuum cooled



33

Types of Hydrocoolers Shower vs. Product immersion

- Shower => use a drip pan or spray nozzles that deliver water overhead and allows the water to flow through the container
 - Bulk bins vs. Packed cartons



34

Types of Hydrocoolers Shower vs. Product immersion

- Product immersion => product is dumped into a flume of water
 - Product moves with the flow of water or are moved using conveyers with cleats
 - Some commodities are not compatible because of water/pathogen intrusion (e.g. apples & tomatoes)



35

Types of Hydrocoolers Conveyor vs. Batch

- Conveyor – Product is loaded onto a conveyor at one end of the hydrocooler and carried at a given rate through it
 - Allows product to be cooled as new product is being loaded (minimizes down time)




36

Types of Hydrocoolers

Conveyer vs. Batch


- **Batch** – The product is stationary, being loaded into the hydrocooler, cooled, and then unloaded
 - Typically less expensive to construct
 - Often can be better insulated and sealed when running (less warm air intrusion during running)



37

Factors Affecting Cooling Rate


- **Product size (diameter)**
 - Larger sized commodities take longer to cool
- **Barriers to direct contact with the commodity**
 - Sweet corn husks act like jackets, trapping air (insulator) between the husks and kernels
 - Leaf litter can prevent water movement within a bin



38

Factors Affecting Cooling Rate


- **Flow of water around the product**
 - **Shower type coolers** - maintain an adequate flow of water down through the product
 - Recommended flow rates from Thompson et al., 1998
 - Flow rate of 7 to 10 gpm/ft² for a single layer of product
 - Flow rate of 20 to 25 gpm/ft² for double stacked bins
 - **Immersion type coolers**
 - Maintain circulation of tank using mixing pumps and propellers



39

Factors Affecting Cooling Rate


- **Flow of water around the product (Continued)**
 - **Adequate venting of packages and bins** to allow water to flow through
 - **Vents must align** to allow water to pass from one container to another



40

Factors Affecting Cooling Rate


- **Water temperature**
 - Colder water => larger temperature gradient => heat moves faster from the product to the water
 - Can even use water near 32F on chilling sensitive crops to cool to desired, non-chilling temperature



41

Manually Verify Effective Cooling



- **Do not assume** the cooler is cooling product correctly
 - Check initial and final fruit pulp temperatures
 - Many thermometers to choose from (do not use glass)
 - Use calibrated thermometers



42

Other Important Considerations



- Maintain water relatively free of decay causing organisms (covered in depth earlier in class)
 - Use high-quality water & change daily
 - Use an approved sanitizer
 - Wash particularly dirty commodities prior to hydrocooling
 - Use self-cleaning screens at pump intakes to remove larger debris

43

Other Important Considerations



- Design hydrocooler for easy cleaning (e.g. access to distribution pan, reservoir, etc.)
- Use stainless steel (\$\$\$) where possible (corrosion resistant). May also use non-metal or painted metal
- Keep height of water dropping onto the commodity below 8 inches
- Packing material must be able to withstand free water (\$\$\$\$)

44

Reducing Operation Costs



- Shift peak electrical demand by using an ice accumulator
- Reduce heat infiltration by insulating the hydrocooler and its plumbing. Locate hydrocooler in the shade or in a cold room
 - Typically, only ~ 50% of the refrigeration is used to cool the crop
- Do not use excessively large pumps or head pressures
- Use shower pans instead of spray nozzles

45

Reducing Operation Costs

- Minimize water reservoir volume
- Hydrocool product after eliminating unmarketable fruit
- Utilize equipment at maximum capacity

46





Package Icing or Top Icing



47

Advantages of using ice for cooling



- Water has a high heat capacity (1 kcal/kg /°C)
 - It absorbs a lot of heat energy before raising 1C
- High heat conductivity (5.2 cal/g/h/°C)
 - Disperses heat quickly
- Using water for cooling prevents water loss during the cooling process (maintains humidity)

48

Advantages of using ice for cooling (continued)



- **High heat of fusion** (80 kcal/kg)
 - When water goes from a liquid to a solid, it releases heat energy. Principal behind freeze protection
 - From solid to liquid, water absorbs energy. Added benefit for top-icing
- 1 pound of ice will cool 3 pounds of product by ~ 50F (28C)
- Ice can **continue to cool the product** throughout the marketing chain as it melts

49

Methods of Cooling with Ice


- **Top icing** – flaked or crushed ice is placed on top of product in a container
 - Ice does not directly contact all the product and therefore does not cool near as quickly as hydrocooling


50

Methods of Cooling with Ice

- **Liquid ice injection** (a slurry of water and ice. Typical ratios = 1:1 to 1:4)
 - Distributes ice throughout the carton = much better surface contact





Talbot, Sargent & Brecht (UF-EDIS)



51

Liquid Ice Injection

- A slurry of ice and water is injected into the top, vents or hand holes of cartons
 - A little salt is added to depress the freezing point of the slurry
- As the slurry flows past the product, **ice is deposited in the air spaces** and heat is carried away with the water
- Water drains out the bottom
- A pallet can take as little as 3 minutes to cool

52



53



54

Ice Supply

- Purchasing bulk ice blocks is usually only economical for small coolers with short cooling season
- Ice is often generated on site using any of a number of commercially available equipment
 - Ice making equipment usually runs continually
 - Small refrigeration capacity needed (peak demand is spread out over 24 hrs.)
 - Night electricity rates are often cheaper



55

Disadvantages of Using Ice for Cooling

- Difficult to obtain good contact with product
- Water resistant (e.g. waxed) fiberboard cartons are expensive
- Adds weight (additional 35 to 40%) => less commodity can be loaded into a container



56

Disadvantages of Using Ice for Cooling

- Melting water is “messy” and can damage other commodities within a load
 - Hazardous around warehouses
- Cannot be used on air shipments



57

Disadvantages of Using Ice for Cooling

- For liquid injection systems, much cooling capacity is wasted
 - ~18% used to cool the product
 - ~26% melts during transportation
 - ~31% is lost to cooling injection equipment (e.g. pumps, siding, warm air infiltration)
 - ~25% is required to remain as ice to satisfy customer demands



58

Use of Sealed Ice Packs

- Can be used on previously cooled products
 - Much less ice (& weight) is required to simply maintain temperatures
- Sealed ice packs do not release their water and thus reduce water hazards and possible damage to other commodities
 - e.g. used often with cut flowers to help maintain the cold chain



59



Vacuum Cooling



60

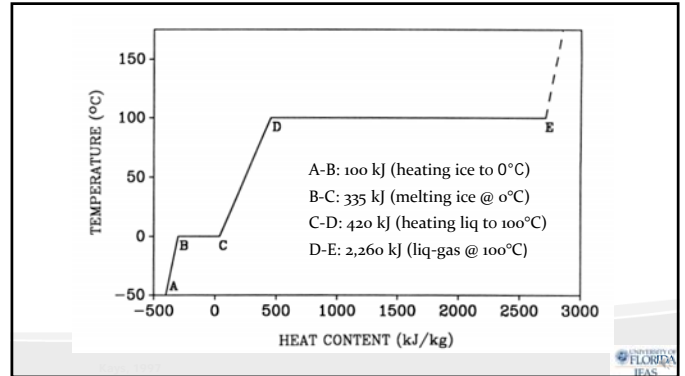
Using Water Vaporization for Cooling

- Previous advantages for using water for cooling do not apply here. Namely:
 - Water's heat capacity and conductivity are not used as previously and instead of preventing water loss, we are relying on water loss
- High heat of vaporization (540 kcal/kg)
 - Water that evaporates absorbs a great deal of heat as it transitions from liquid to gas => cools the plant tissue



UNIVERSITY OF FLORIDA IFAS

61



62

Principles of Vacuum Cooling

- Commodities are sealed in an air tight container
- Air is pumped from the container creating a vacuum



63

Principles of Vacuum Cooling

- As atmospheric pressure drops, the boiling point of water decreases
 - E.g. difficult to boil an egg at high altitudes because the water is boiling at cooler temperatures
 - Water starts to boil (evaporate) off commodities at field temperatures when pressure drop from 760 mm Hg (mercury) to below 40 mm Hg (e.g., water boils at 3°C when pressure is 32 mm Hg)



UNIVERSITY OF FLORIDA IFAS

64

Principles of Vacuum Cooling

- When pressure drops to 4.6 mm Hg, water boils at 32°F
 - This pressure only needs to be maintained for ~ 3 to 6 minutes for lettuce
- As water evaporates, it removes a great deal of heat uniformly throughout the load
- Water removed from the commodity condenses on refrigeration coils
 - These coils do not directly cool the product, but remove water vapor from the atmosphere



UNIVERSITY OF FLORIDA IFAS

65

Principles of Vacuum Cooling



- Cooling is completed when the commodity, not air temperature, has reached the desired level
 - Bulky tissue (e.g. base of lettuce stem) is usually warmer than leafy tissue
 - Tissue around temperature probes usually read a little colder because of damaged tissue (water release)
 - Check pulp temperature of product leaving the cooler to verify proper cooling



66

Commodities Suited to Vacuum Cooling



- Leafy vegetables with a large surface area (high surface to volume ratio)
 - Lettuce can be cooled in ~ 30 minutes
- Bulky commodities can be vacuum cooled but take considerably longer (2 to 4 hrs.)
- Evaporative surface area is what is important in determining cooling speed
 - Commodities like cabbage, though leafy, are so tightly wrapped that little evaporation occurs from inner leaves

67

The Problem of Water Loss


- Vacuum cooling works by removing water from the product (dehydrates commodities)
- For each 10F (6C) reduction in temperature, ~1% of water is lost from the product
 - Often, ~ 3% water loss is required to cool the commodity 30F (17C)
 - This can reduce quality and salable weight
- Use of sealed plastic liners to reduce water loss can greatly slow or stop cooling

68

The Problem of Water Loss - Remedy



- Add water to the commodity before vacuum cooling
 - Requires cartons & containers that can withstand free water
 - Evaporated water comes primarily from the added water and not from the commodity itself



69

Energy Use


- Vacuum coolers are more energy efficient compared to other cooling methods because they only cool the commodity
 - They do not have a cooling medium (e.g. circulated air or water) to cool
 - They do not have to remove heat from lights, fans, pumps, outside air, etc.

70

Energy Use


- Most (60 to 70%) of the energy is used to condense water vapor
- The rest (30 to 40%) is used by the air compressors to create the vacuum
- Use coolers at maximum capacity year round to spread equipment costs out
 - Many can be moved as production areas change



71

Reducing Energy Use

- Reduce vacuum capacity after cooling begins
- Fill chambers as completely as possible (less free space = less air to pump out)



72

Reduce Energy Use By:

- Use vacuum coolers in pairs and use the vacuum in one (at the end of its cycle) to establish a partial vacuum in the other (as it starts up)



73

Reduce Energy Use By:

- Leave refrigeration off at the beginning of the cycle when it is not needed
- Do not cool product requiring excessively long cooling times



74