Temperature Management

Cooling Methods & Principles

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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

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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

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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

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Where does the <u>Heat</u> 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.

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Where does the <u>Heat</u> 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.

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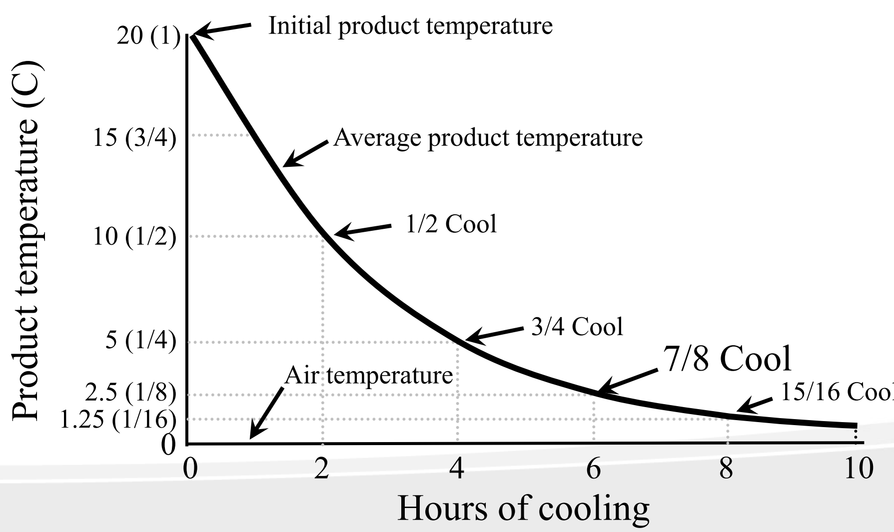
Cooling is usually expressed as 1/2 or 7/8 cooling times



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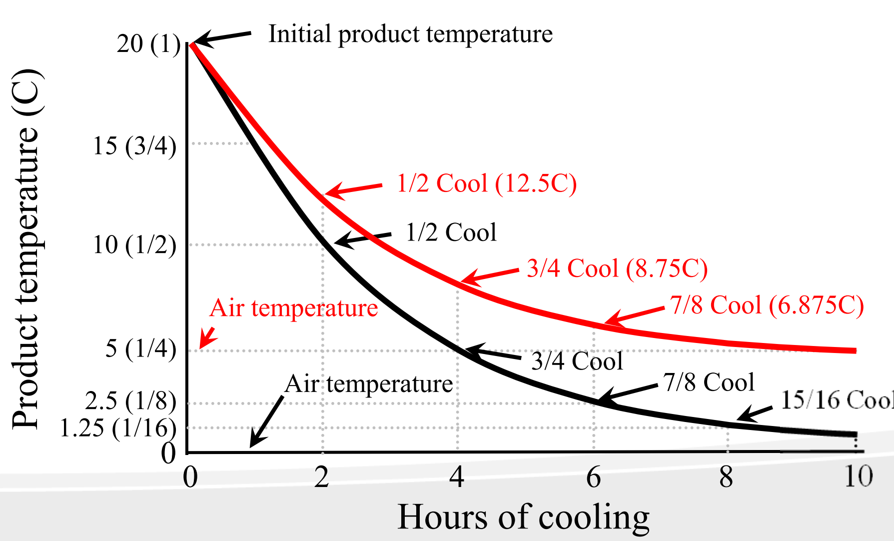
Effect of Cooling Medium Temperature



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Heat is Removed Through…

- Conduction
- Convection
- Evaporation
- Radiation

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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

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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

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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)

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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

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Packaging Design Related to Cooling

- Add information from a bunch of papers and illustrations I downloaded in 2020.

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Cooling Methods

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

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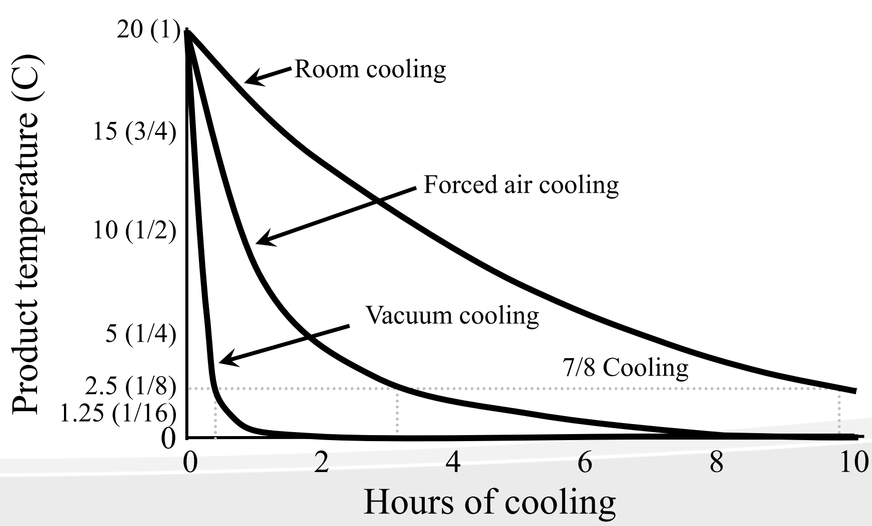
Cooling is usually expressed as 1/2 or 7/8 cooling times



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Cooling with Air

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

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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

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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

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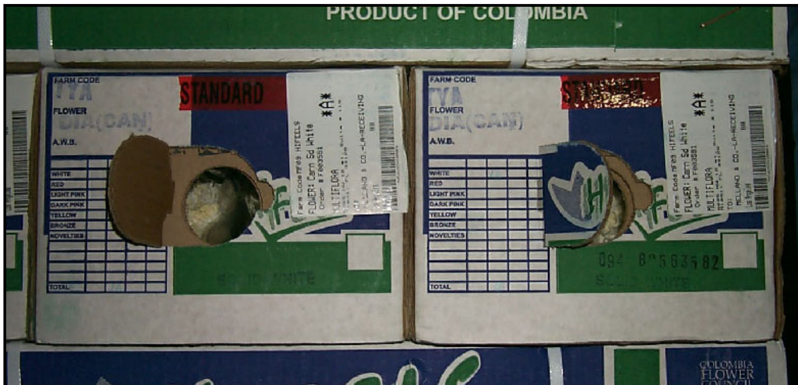

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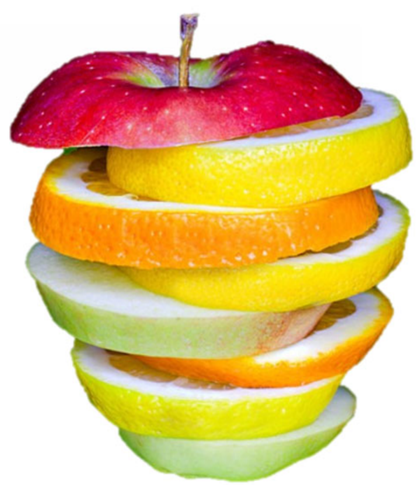
Factors that Influence Speed and Efficiency of Cooling



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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

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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

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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

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Uneven Cooling Rates

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

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Uneven Cooling Rates

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

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Uneven Cooling Rates

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

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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

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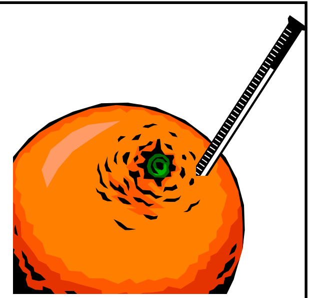
Monitoring Cooling



- 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

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Hydrocooling

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Advantages of Using Liquid Water for Cooling

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

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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

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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

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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)

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Types of Hydrocoolers

Conveyer vs. Batch

- Conveyer – Product is loaded onto a conveyer 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)

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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)

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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

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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/ft^2 for a single layer of product
    - Flow rate of 20 to 25 gpm/ft^2 for double stacked bins
  - Immersion type coolers
    - Maintain circulation of tank using mixing pumps and propellers

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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

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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

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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

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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

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Other Important Considerations

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

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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

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Reducing Operation Costs

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

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Package Icing or Top Icing

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Advantages of using ice for cooling

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

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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

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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

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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)

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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

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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

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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

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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

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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

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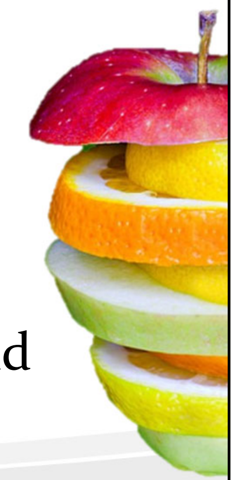
Use of Sealed Ice Packs



- 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

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Vacuum Cooling

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Using Water Vaporization for Cooling

- Previous advantages for using water for cooling do not apply hear. 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

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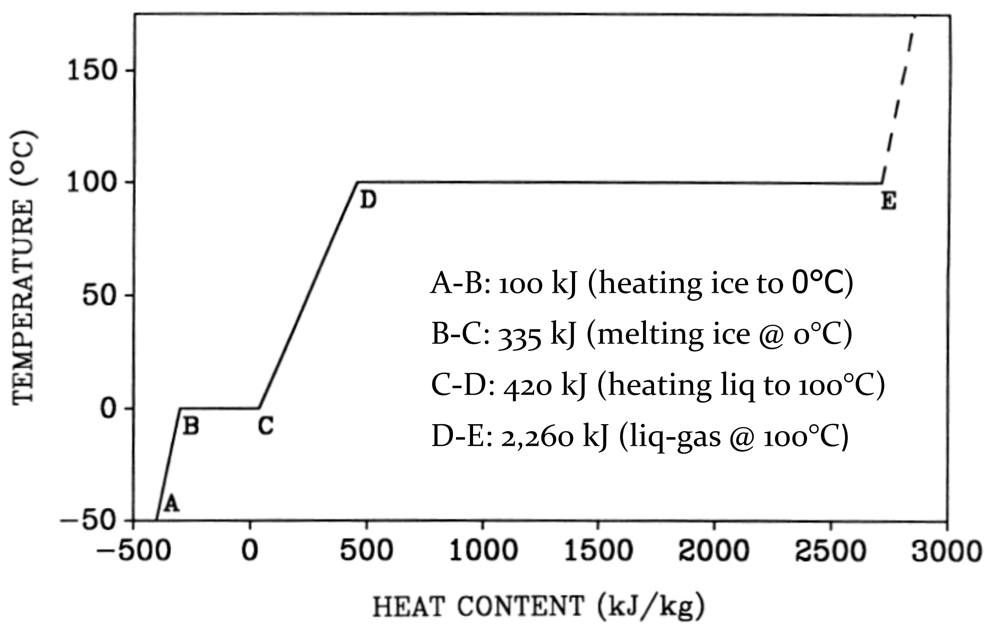

Kays, 1997

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Principles of Vacuum Cooling

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

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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 3C when pressure is 32 mm Hg)

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Principles of Vacuum Cooling

- When pressure drops to 4.6 mm Hg, water boils at 32F
  - 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

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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

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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

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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

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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

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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.

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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

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Reducing Energy Use

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

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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)

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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

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