Effective temperature, relative humidity and air velocity combinations to provide most effective chilling

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- Equipment
- Product quality
- The future: re-visiting an old friend
Most meat not consumed immediately
To extend shelf life and minimise bacterial growth
  - Drying, curing, smoking, heat processing, fermentation, irradiation, canning & refrigeration
Product indistinguishable from fresh product
Transferring heat from one product to another
Heat flows naturally from hot to cold

Masses of material also moved around by refrigeration system

Include:

- Air/liquid in which heat is carried from food product to air/liquid cooler
- Water vapour/other gases carried in the air
- Primary & secondary refrigerants in refrigeration system self
Fundamentals of heat transfer

- Three fundamental mechanisms
  - Conduction
  - Convection
  - Radiation

- Most refrigeration processes contain combination of conduction & convection

- Radiation occasionally significant
Conduction

Molecules of solid/liquid/gas in contact with each other

Two molecules in contact – one with higher energy transfers energy to one with lower level

Relative energy levels indicated by temperature

Thus temperature (energy) flows from molecule with high temperature to molecule with low temperature
Conduction

- Figure indicating heat conduction through slab of material

- The rate of heat flow ($Q$):

$$Q = \frac{kA}{x}(T_1 - T_2)$$

- $k =$ thermal conductivity
- $A =$ area over which heat is conducted
- $X =$ distance through which heat is conducted
- $T_1 \& T_2 =$ temperatures either side of the object
To increase rate of heat flow:

- Increase conductivity \( k \)
- Increase the area, \( A \)
- Decrease the thickness, \( x \)
- Increase temperature difference between two sides of the object \( (T_1 - T_2) \)

Thermal conductivities for

- Air = 0.03 Wm\(^{-1}\)k\(^{-1}\)
- Lean meat = 0.5 Wm\(^{-1}\)k\(^{-1}\)
- Frozen meat = 1.5 Wm\(^{-1}\)k\(^{-1}\)
- Steel = 43 Wm\(^{-1}\)k\(^{-1}\)
- Copper = 380 Wm\(^{-1}\)k\(^{-1}\)

Thus air surrounding a carcass when not allowed to circulate

= a good insulator
Movement of air/fluid over surface allows heat transfer

Most practical method in which heat transferred from solid to liquid or gas (or vice versa)

Two forms:

- Forced: fan
- Natural: differences in air density causes flow
  - Rate of air movement determined by temperature differences
Heat does not flow naturally from cold to hot object.

To cool an object below its surrounding ambient temperature, one needs to use some form of refrigeration system.

Types range from simple to complex, and one should consult a refrigeration engineer.

Essential principles are similar.
When material changes phase:

- Solid → liquid → gas
- Requires heat additional to the heat required to raise the temperature of the material
- Latent heat of fusion / melting
- Latent heat of evaporation / sublimation

- If you have a material that melts/boils/sublimes at a low temperature, this material will draw heat from surrounding environment in order to change its phase
- Placing this material in contact with meat product, most of the heat required can be drawn from meat, thus cooling meat
Cryogenic refrigeration

- Materials that melt, boil, sublime at temperatures well below room temperature - known as cryogens

- Choice of cryogen in meat industry restricted by food safety, quality, environmental considerations:
  - direct contact with food
    - $\text{CO}_2$ & $\text{N}_2$

- 2 issues make cryogenic refrigeration expensive:
  - Only used once and lost to atmosphere
  - Manufactured using very low temperature processes that require lots of energy
Refine cryogenic process in two ways:

- Refrigerant not in direct contact with meat but retained inside tubes of an evaporator – part of refrigeration system

- 3 pieces of equipment (compressor, condenser, expansion valve) convert gaseous refrigerant back into a cold liquid that can be recycled around and evaporated again in a continuous cycle
Diagram of a mechanical vapour compression refrigeration system. The arrows show the movement of refrigerant around the cycle, driven by the compressor, and the flows of heat and energy into and out of the system.
Point where heat transferred from object being cooled to evaporating refrigerant

- Simplest way: bring object into direct contact with evaporator

Meats do not have flat, parallel sides for plate refrigeration
Evaporator designed as set of tubes containing refrigerant, with fins mounted outside to increase heat transfer area

Air blown by fans across evaporator tubes & fins (where air is cooled), across meat product (cold air warms, meat cooled) and back to evaporator

Water/brine better because of their higher heat capacity to volume & greater heat transfer coefficient (liquid & surface vs air & surface)
Applications

- Main application: cool the meat
  - Decreases rate of microbiological spoilage
  - Decreases rate of chemical deterioration

- Also used as air conditioning: deboning plants
  - Comfortable for staff
  - Decrease bacterial spoilage
Rate of development of bacterial slime on meat surfaces at different temperatures

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
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<td>10</td>
<td>2</td>
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<td>16</td>
<td>1</td>
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The chilling process

- Moisture rich material (e.g. meat): process of decreasing temperature (normally around 38 °C) to around freezing temperatures of meat (around -1 °C for fresh meat).

- To chill – outside temperature must be lower than surface temperature of object being chilled:
  - Heat flows away by conduction/convection.
  - When surface temp. lower than temp. of deeper parts, these parts will also cool via conduction of heat to the surface.
Temperature profile and thermal centre

Useful to define point in meat where temperature will remain warmest at any time during the cooling process.
Geometry of a carcass /side and the interplay of the surface heat transfer coefficient with the geometry are complex – thermal centre determined by experience

Many temperature measurements during cooling

- Beef side: deep butt – near head of thigh bone
- Lamb carcass: traditionally deep leg – against thigh bone but a quarter way down from pelvis.
- In practise, slow cooling inside the whole carcass – point between thickest part of the shoulder and inside of the cavity (deep shoulder) and between deepest part of the loin and inside surface can take just as long as deep leg to cool down
- Deep leg measured: associated with highest value cuts
Natural convention – hot air rises

The warm air is cooled by contact with the refrigerant tubes, and the liquid refrigerant evaporates to form vapour. Warm air is less dense than cold air, so it rises to the ceiling. The air is now cool and dense, and so falls back toward the carcasses. Carcass cools by warming air.
Natural convection

- Slow
- Uncontrollable - rate determined by thickness of meat and temperature of the air
- Rate of chilling can be accelerated by reducing air temp.
- Limited: if air temperature below freezing temperature of meat – meat surface starts freezing – product quality
Forced convection air chilling

- Common method

- Fans blow air over finned tubes containing evaporating refrigerant
  - Cool air passes over warm meat
  - Heated air passes over refrigerant evaporator to be cooled again
  - Changing rate of air flow—controls rate of chilling
  - Ensure rate of air flow over carcasses as evenly as possible to avoid large variations in chilling rate
    - Use vanes/slotted ceiling

- Normally a blast chill cycle followed by a holding cycle
a: slotted ceiling
b: turning vanes
Moisture at surface and within carcass can evaporate into the air.

Air cooled by contact with refrigeration system evaporator coils: humidity typically saturation humidity of air leaving the evaporator.

Thus absolute humidity of air lower than at surface of carcass.

Driver for moisture evaporation: diffs between absolute humidity at surface of meat (product of water activity and saturation absolute humidity at surface of meat) and absolute humidity of air passing over meat surface.

Thus moisture evaporation (weight loss)
RH = amount of moisture in air relative to the capacity of air at specific temperature
- 30°C or can hold 27.2 g kg\(^{-1}\)
- 0°C or can hold 3.8 g kg\(^{-1}\)

Early stages, dry air extracts moisture from carcass – latent heat of evaporation thus cooling carcass

Minimise weight loss – high RH

Condensation: temp of structures below due point of air in chiller
- Evaporator drain trays
- Ducting carrying cold air discharge away from evaporators
- Areas having intermittent contact with outside air – loading door
- Raising room temp too rapidly prior to deboning to soften fat
- During rapid loading if evaporators insufficient capacity
Function of air temp, air velocity & carcass weights

Loading time = 1 hrs kill

- Longer loading time, difficult to achieve specified cooling rate for first vs last carcass
- Full capacity of equipment is used for max 4 hrs during initial stage of cooling
- Conveyorised blast chillers?

**Estimated cool time for 400kg carcass, heavy fat cover**

<table>
<thead>
<tr>
<th>Air velocity m/s</th>
<th>Air temp °C</th>
<th>Cool time (hrs) to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30°C</td>
<td>20°C</td>
</tr>
<tr>
<td>0.5</td>
<td>0</td>
<td>13.0</td>
</tr>
<tr>
<td>0.5</td>
<td>6</td>
<td>14.0</td>
</tr>
<tr>
<td>2.0</td>
<td>0</td>
<td>12.0</td>
</tr>
<tr>
<td>2.0</td>
<td>6</td>
<td>13.0</td>
</tr>
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Air flow always follows least resistance

- Anemometers to measure flow
- Do not overload
- Part loading – uneven air flow
- Surface of meat dry – undesirable appearance
- Mass of meat product reduced
- Moisture evaporation increases the effective surface heat transfer coefficient compared with pure convention – increasing rate of chilling
Weight loss from beef sides in chiller

<table>
<thead>
<tr>
<th>Conditions</th>
<th>% Weight Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good-quality sides</td>
</tr>
<tr>
<td>1 d at 0°C + 2 d at 20°C</td>
<td>1.7</td>
</tr>
<tr>
<td>3 d at 0°C</td>
<td>0.7</td>
</tr>
<tr>
<td>14 d at 0°C</td>
<td>1.6</td>
</tr>
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How can moisture loss be avoided?

- Spray chilling: spraying surface of carcasses with water intermittently during chilling

- Note regulations for adding weight prior to selling

- Mixed finding on effect of spray chilling on product surface appearance
  - Either indistinguishable
  - Streaky appearance – developed microbial growth
Essential requirement is meat tenderness

Chill too rapid – cold shortening
  - Beef/lamb reach 10°C under 10 hrs

Apply correct ES
  - Also minimises two toning (heat ring)

Minimise weep
  - Fast chilling – deep butt temp < 30°C under 10 hrs
  - Deep butt < 25°C, rate of chilling can be reduced (slow fan speed, increasing refrigerant temp in evaporators)

Hot deboning
Carcass submersion

- Chickens
- Red meat in waterproof wrapping
- Submersion in cold liquid (brine)
  - Cooled rapidly – high heat transfer coefficient found between liquid & solid
Visiting an old friend...

- Hot deboning
- Then stretching and wrapping

Advantages
- Energy saving – chiller
- Higher deboning room temperature
- Worker comfort
- Higher yield
- Mince/processed products straight into process cycle
DANKIE / THANK YOU / ENKOSI KAHKULU