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

Prof Louw Hoffman
Department of Animal Sciences
Stellenbosch University
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Principles

- 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

Principles

- 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

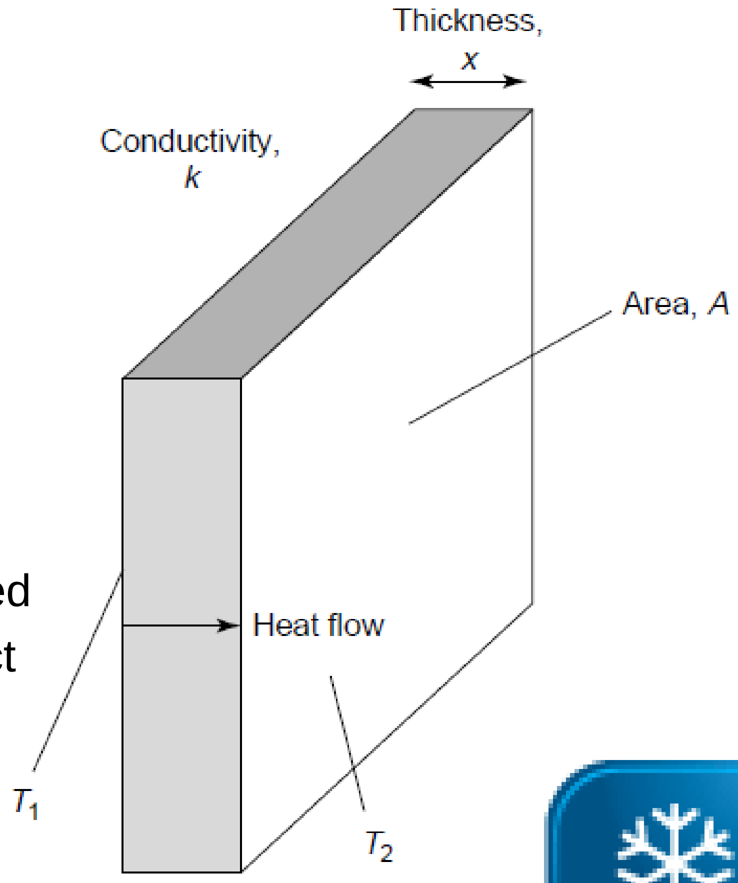
Conduction

- 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):

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



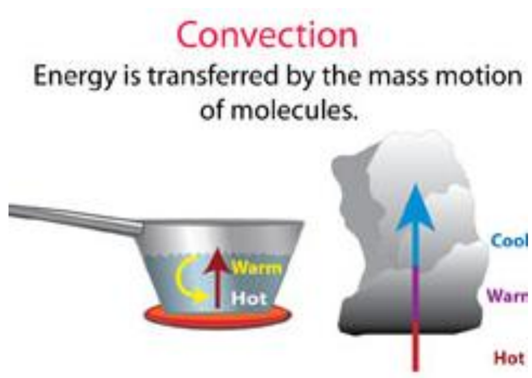
- k = thermal conductivity
- A is area over which heat is conducted
- X is distance through which heat is conducted
- T_1 & T_2 temperatures either side of the object

Conduction

- 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

Convection

- 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



Refrigeration systems

- Heat does not flow naturally from cold to hot object
- To cool object below surrounding ambient temperature need to use some form of refrigeration system

- Types range from simple to complex (consult refrigeration engineer)
  - Essential principles are similar

Cryogenic refrigeration

- 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
  - CO_2 & 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

Mechanical vapour compression refrigeration

- 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

Mechanical vapour compression refrigeration

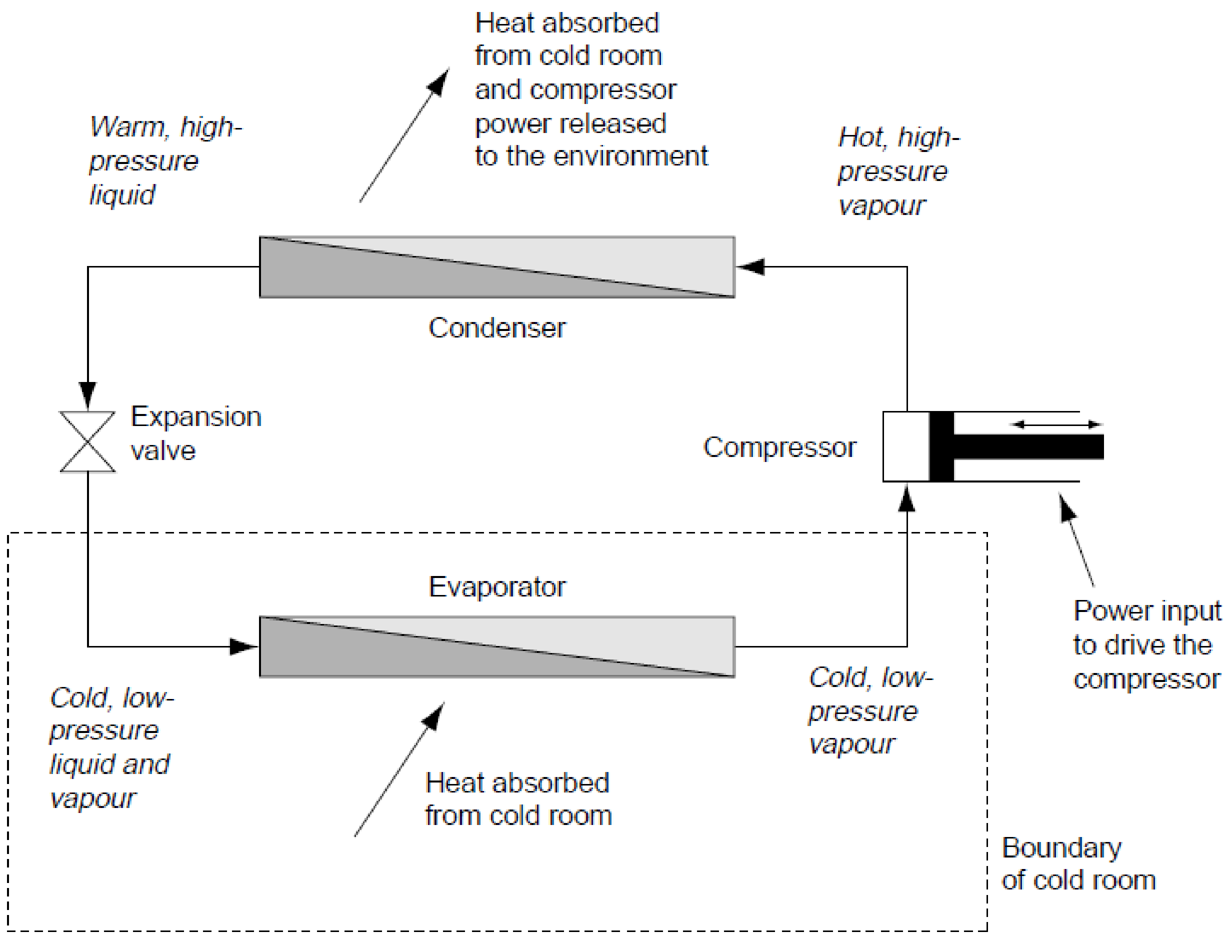


Diagram of a mechanical vapour compression refrigeration system. The arrows show the movement of refrigerant around the cycle, driven by the compressor, and the flows of heat and energy into and out of the system

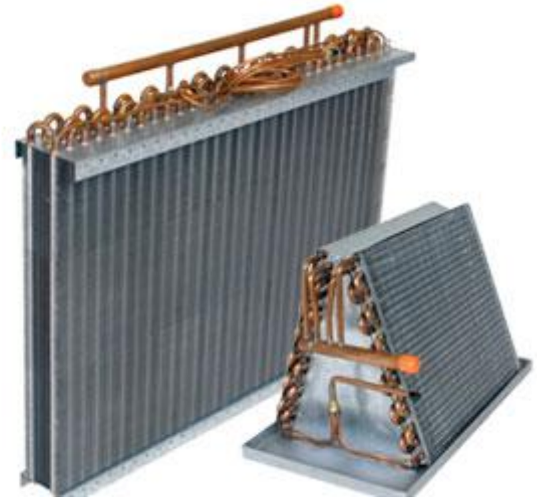
Evaporator

- 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

- 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

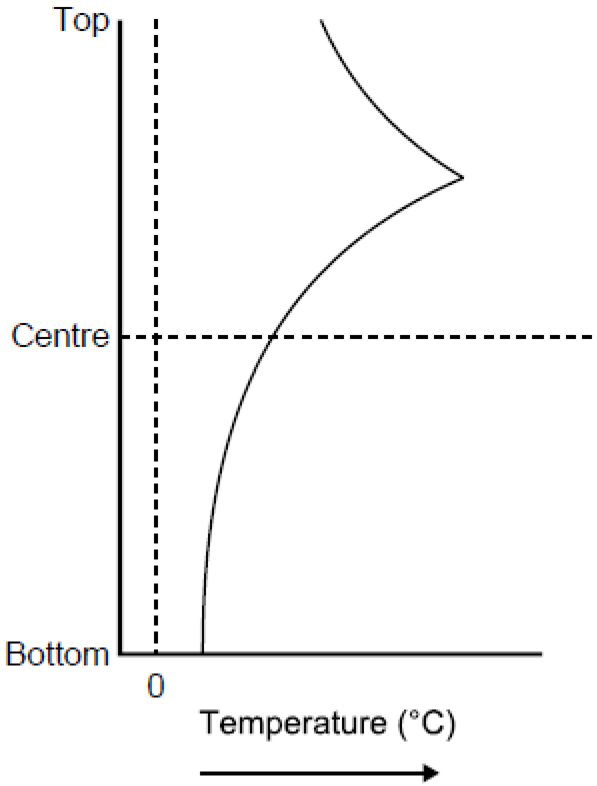
Temperature (°C)	Time (days)
0	10
1	7
3	4
5	3
10	2
16	1

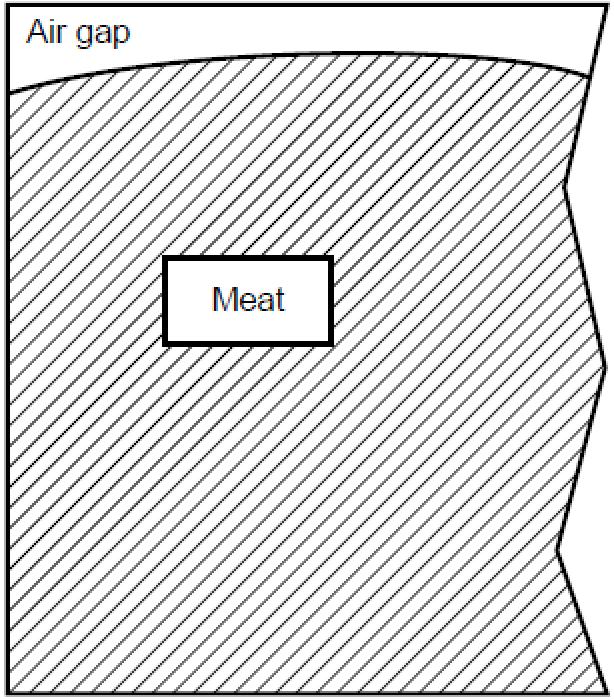
The chilling process

- 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



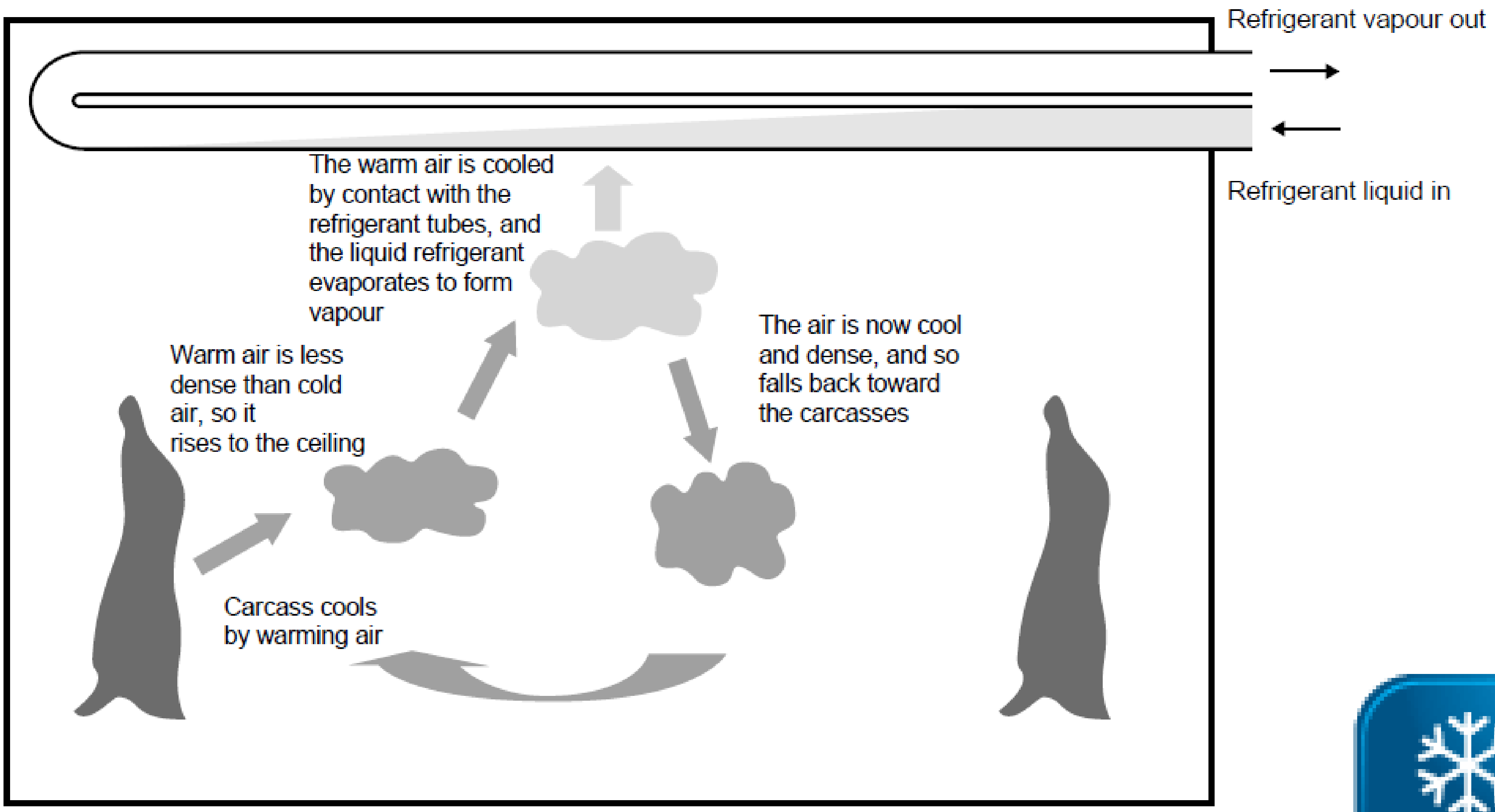


Carcass

- 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

The chilling methods

Natural convention – hot air rises

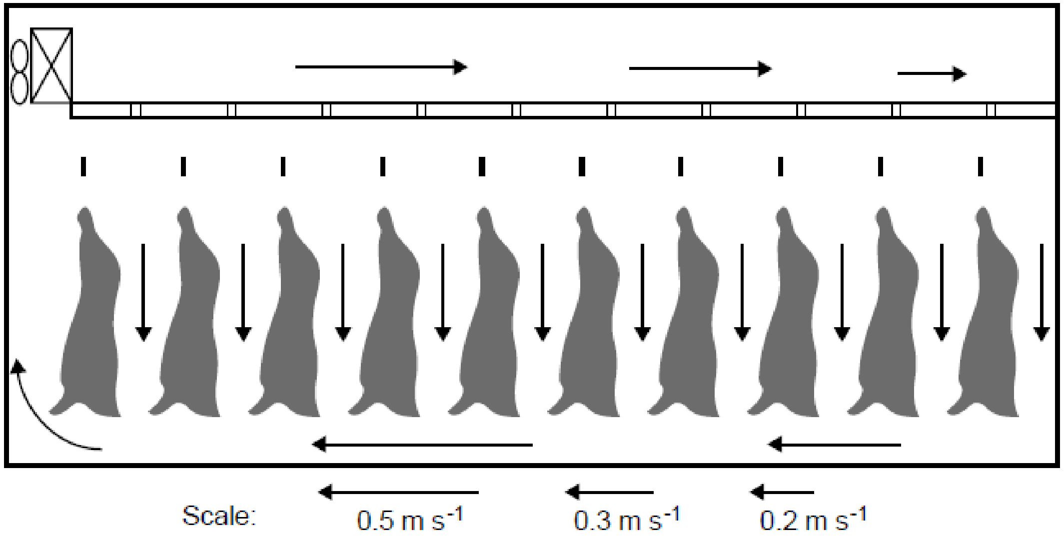


Natural convection

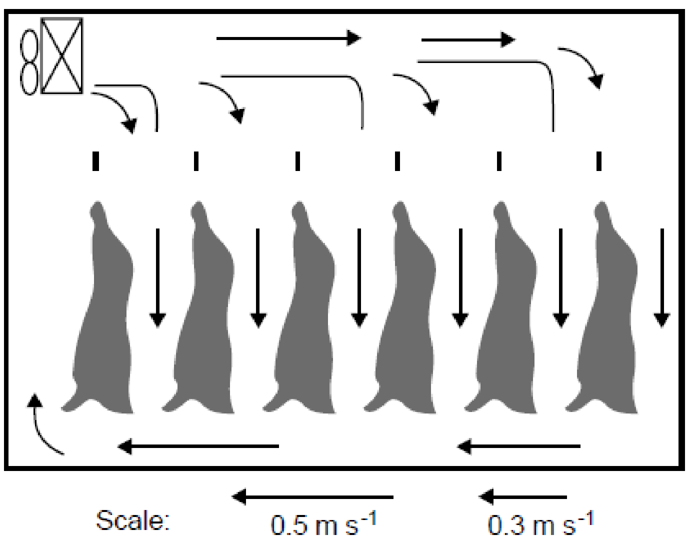
- Slow
- Uncontrollable - rate determined by thickness of meat and temperature of the air
- Rate of chilling can be accelerated by reducing air temp.
- Limited: if air temperature below freezing temperature of meat – meat surface starts freezing – product quality

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)



(b)

a: slotted ceiling

b: turning vanes

Forced convection chilling

- 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 and condensation

- 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

Achievable cooling rates

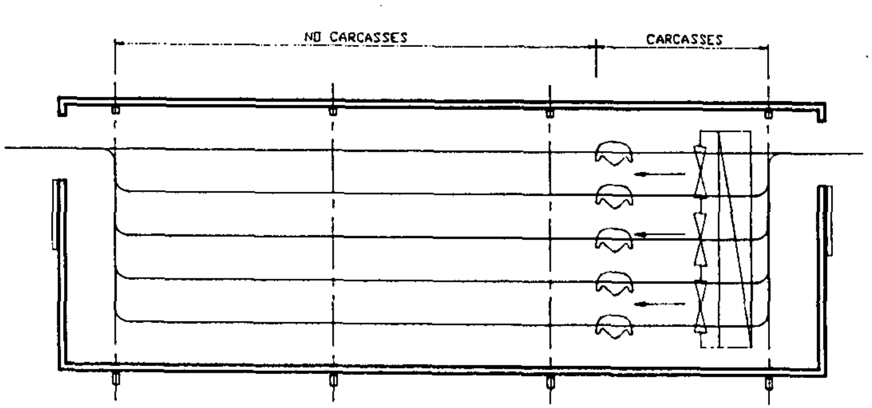
- Function of air temp, air velocity & carcass weights
- Loading time = 1 hrs kill
  - Longer loading time, difficult to achieve specified cooling rate for first vs last carcass
  - Full capacity of equipment is used for max 4 hrs during initial stage of cooling
  - Conveyorised blast chillers?

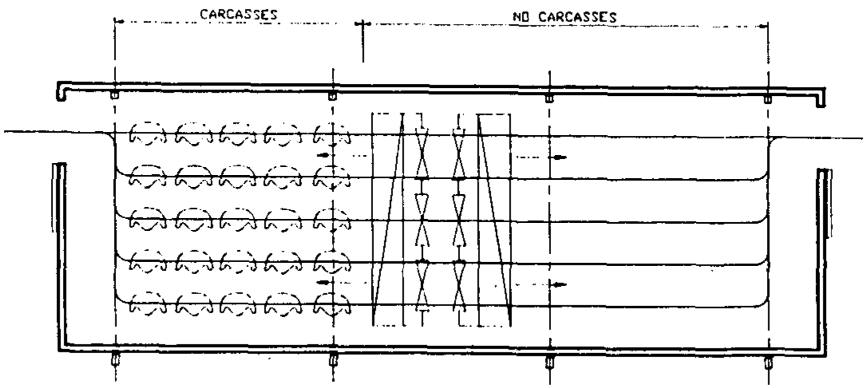
Estimated cool time for 400kg carcass, heavy fat cover

Air velocity m/s	Air temp °C	Cool time (hrs) to:		
		30°C	20°C	10°C
0.5	0	13.0	20.0	23.5
0.5	6	14.0	23.0	27.5
2.0	0	12.0	19.0	22.0
2.0	6	13.0	21.0	26.0

Air flow distribution

- Air flow always follows least resistance
  - Anemometers to measure flow
  - Do not overload
  - Part loading – uneven air flow





Moisture evaporation

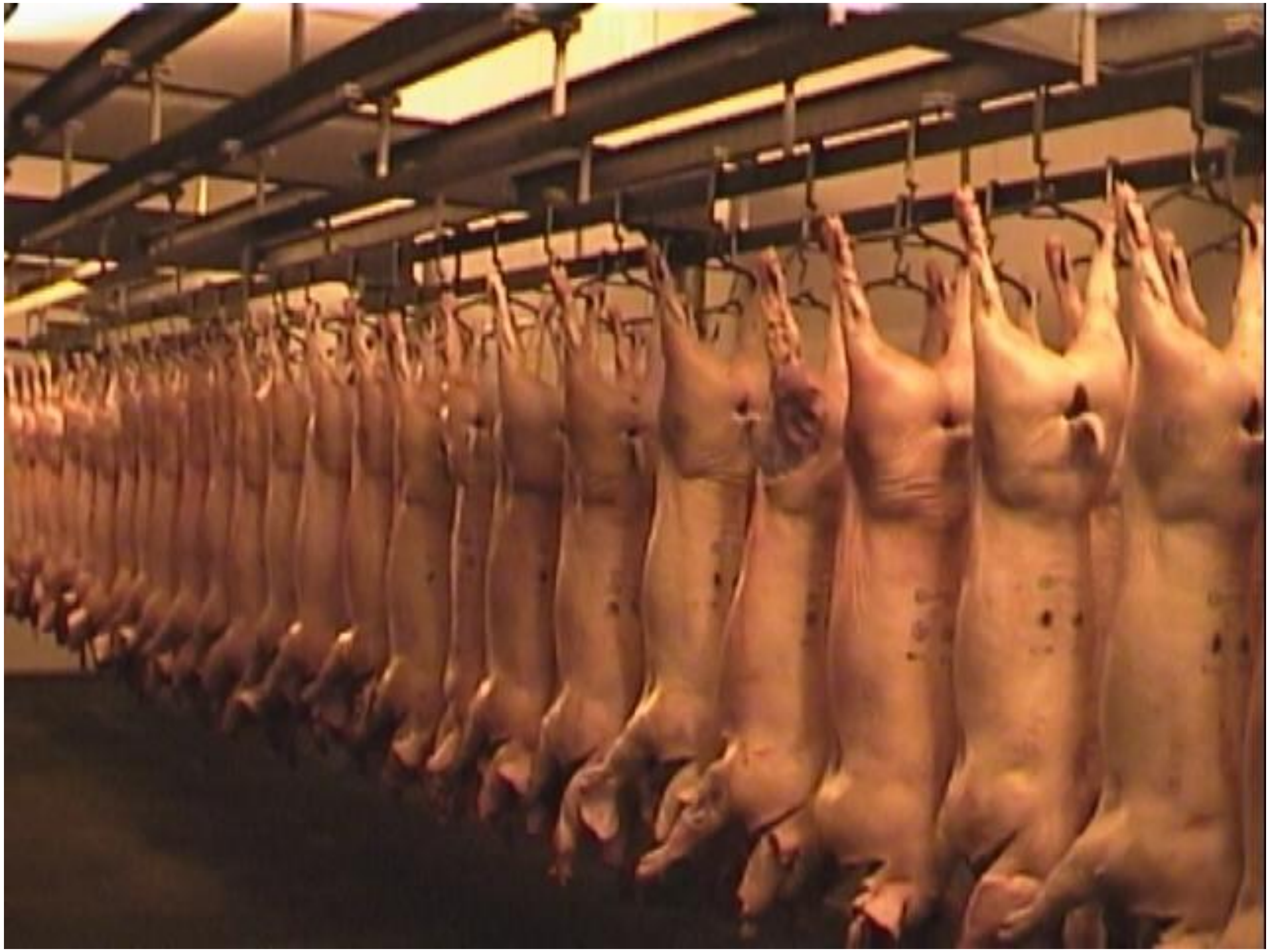
- Surface of meat dry – undesirable appearance
- Mass of meat product reduced
- Moisture evaporation increases the effective surface heat transfer coefficient compared with pure convention – increasing rate of chilling

Weight loss from beef sides in chiller

Conditions	% Weight Loss	
	Good-quality sides	Poor-quality sides
1 d at 0°C + 2 d at 20°C	1.7	3.8
3 d at 0°C	0.7	0.9
14 d at 0°C	1.6	3.2

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



Product quality

- 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

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