CHILLING CYCLES FOR BEEF AND SMALLSTOCK

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1. Factors to Consider in Selecting a Chilling Cycle

In chilling meat immediately after slaughter we aim to optimise the following parameters:

Meat Quality

- microbiology
- meat colour
- fat colour
- drip (purge)
- tenderness
- texture

Economics

- yield (shrink)
- energy costs

Industrial

Boneability and safety (fat hardness)

Fortunately there are cycles we can use, provided we have the right hardware in the chillers and sufficient engine room refrigeration capacity, that will cater for all of these with the exception of tenderness and energy costs.

Please note that I have left out capital cost from the list of parameters as the benefits to be gained far outweigh this cost which can be recouped in less than twelve months. The additional cost is not related to selecting 'Rolls Royce' equipment when 'Holden' will do the job adequately, but only to ensuring that the equipment can deliver the chilling conditions necessary to achieve the desired results.

Tenderness

While we cannot tenderise meat which is inherently tough due to genetics, or the environment in which it has been produced we must ensure that we do not toughen the meat by 'cold shortening'. We can do this by using a slow chilling cycle which ensures that the susceptible loin muscles (e.g. the LD) temperature does not fall below 10°C until the body is in full rigor, but this will adversely affect all the other attributes we wish to enhance. Since the development of electrical stimulation technology we have a means of avoiding cold shortening. The stimulation causes the muscles to contract thus using up glycogen which is the 'fuel' of the muscle engine. Once the glycogen stores are depleted the muscle is in rigor mortis and it cannot contract through cold shortening and the meat is not toughened. Very heavy beef with a thick fat cover cools much more slowly than light beef and smallstock and so can be chilled without cold shortening occurring, even when it has not been stimulated. However, cold shortening can still occur in some muscles of very heavy (320 kg) carcasses when chilling rates comply with those prescribed in Meat Order 250. By contrast, rapid chilling of unstimulated lamb carcasses will reduce the deep muscle temperature below 20°C before it is in rigor and cold shortening will result. The deep muscle temperature should not fall below this level within 2½ hours of sticking if cold shortening is to be avoided. Figure 1 shows the rate of fall of lamb loin temperatures under fast, medium and slow commercial conditions. Cold shortening in lamb muscles is not a problem provided it is not excessive. The shortening and toughening which occurs in lamb muscles under average conditions of chilling is resolved by 3 days ageing. This lamb will not be perceived as tough provided it is not eaten less than 3 days post slaughter. Excessive shortening results if lamb carcasses are frozen immediately after slaughter. This form of shortening will not be reversed by ageing.

Energy Costs

The program cycles we must use to optimise chilling will cost more in energy in two ways; for the actual power consumed and for the demand charge. The power is simply the cost of the energy used and for most tariffs is the same regardless of when it is used. The demand charge is levied on the maximum draw sustained for thirty minutes (fifteen in some states) that the plant makes on the power supply in any month or 80% of the maximum demand in the previous eleven months, whichever is the greater.

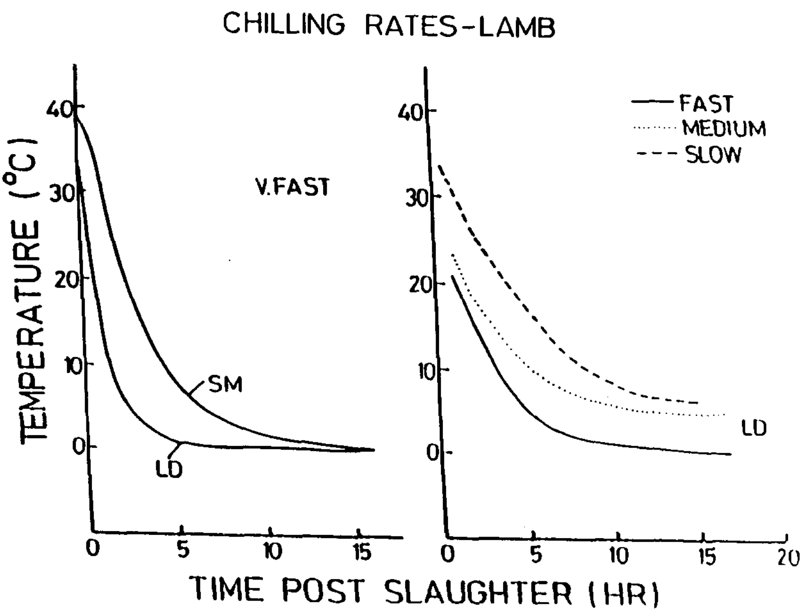

Figure 1: *Typical lamb cooling curves*

Because the fundamental condition we are seeking to achieve is to bring the surface temperature of the meat down very rapidly and to dry the surface, we cannot delay refrigeration in order to keep electrical maximum demand to a target level. This means we must use low refrigerant temperatures which cost us more than a slow chill, and we must have sufficient evaporator heat exchange capacity to rapidly extract heat from the meat. Most works operate their refrigeration plants at two temperatures at least; a high side operating at somewhere around -5°C to -10°C and a low side operating somewhere around -30°C to -40°C. The temperature at which the chiller evaporators are operating does not influence the power cost unless it is the lowest in the entire system. It is the condition at which the engine room machinery operates which determines the power cost. Thus the lowest refrigerant temperature requirement of any part of the system is what counts in terms of this aspect of power costs.

General

Key factors in achieving a good quality out-turn from a chill cycle are as follows :

- ensure that sufficient refrigeration is applied to the chiller during loading to prevent condensation (we found 10°C return air temperature and 75% fan capacity adequate);
- commence active refrigeration as soon as possible after dressing is completed (ideally use chillers with no more than 1 hour's kill capacity so active refrigeration commences within that time frame);
- have sufficient evaporator capacity in the chiller, and adequate engine room capacity to service it, to achieve a return air temperature of 0°C to 2°C within 1 hour of commencement of active chilling;
- for meat which is to be boned the next day, continue this phase of chilling until the heat transfer rate of the meat becomes the factor which controls the speed of deep butt temperature reduction, rather than the amount of refrigeration effort being applied. **Reduce the fan speed to about 50% of capacity and gradually raise the return air temperature to not more than 8°C for the remainder of the chilling cycle. The air temperature should rise at no more than 2°C hour^{-1} to prevent secondary condensation on the chiller steelwork. Electronic backpressure controllers are available which automatically adjust the evaporator capacity to match the refrigeration load and minimise the temperature differential (TD or tΔ) across the coil.**

  For safety and industrial reasons, a re-heat phase can be carried out immediately prior to boning. If automatically controlled electrical elements mounted on the air-off side of the evaporators are used, the return air temperature during re-heat should be maintained at no more than 15°C for a period sufficient to soften the surface fat. The deep butt temperature will not rise during the re-heat phase and usually continues to fall as equilibration of temperatures throughout the meat occurs;
- for meat which is to be shipped in quarters or carcass form, active refrigeration should be continued at the higher rate as temperature reduction in a chiller is cheaper in energy cost than in a freezer and hard fat is not a problem;

- if the evaporators in a particular chiller are properly sized for a full chiller load and there is adequate engine room capacity to service them, but the evaporators do not have automatic backpressure control, i.e. the evaporators operate at system suction temperature of perhaps as low as perhaps -10°C at all times, do not partly load the chiller unless there is no other option. A Russian researcher discovered many years ago that evaporators tend to remove a **weight** of water from the product stored in a chiller or freezer, rather than a **percentage**.

  While the relationship is not linear, it does mean that if 1% of weight is lost from a load of, say, 50 x 150 kg bodies then somewhat under the same weight will be lost from 25 bodies, i.e. a percentage loss of some 2%.

  If you have to part load a chiller do so by loading only as many rails as are necessary at standard carcass spacing if the air direction is parallel to the rails. If the air direction is at right angles to the rails, load on the face at standard carcass spacing. Evaporators outside the loaded area of the chiller can then be switched off, better matching the capacity to the load. If, however, automatic backpressure controls are fitted which automatically match the refrigeration to the heat load in the room, the above precautions are not necessary. The same type of problem arises if smallstock are loaded into a beef side chiller, i.e. the capacity will far exceed the load and greater proportional weight loss will occur.

2. Chilling Cycles for Beef

Beef for Boning

The cycles for different types of beef destined to be boned follow the same pattern, but the timing of the phases depends on the weight of the sides. The quick chill phase should be maintained for sufficient length of time to ensure that the surface temperature does not rise above 7°C during subsequent equilibration or holding phases. The reduction of the surface temperature as rapidly as possible is the initial aim. This minimises both shrink and bacterial growth.

As the carcass surface temperature is reduced so too is the vapour pressure of the water at the surface. Evaporation, or shrink, is reduced as the vapour pressure of water at the surface approaches the partial pressure of water vapour in the air. Therefore low shrink is best achieved by reducing the surface temperature as rapidly as possible. Bacterial growth is controlled by both the temperature and the water activity at the meat surface. Most bacteria of public health significance grow either not at all, or slowly once the temperature falls below 8°C. The free water on the surface of the meat from the final carcass wash evaporates during initial chilling and thus the water activity falls and bacterial growth is inhibited.

Figure 2 shows the temperature plots of the deep butt temperatures of both a slow (unsatisfactory from a quality point of view) chilling cycle and a fast one. Control of shrink and bacterial growth and maintenance of meat and fat colour are the outcomes achieved from the faster program.

Figure 3 shows the temperatures achieved during the chilling of an ox of 210 kg side weight and 30 mm fat depth (grain fed for 300 days). Note that the high rate of chilling is maintained for the full cycle. This is necessary to achieve satisfactory deep muscle temperatures to ensure good meat colour and to avoid bone taint. The hardness of the subcutaneous fat depends on the type of feed the animal has been on and the length of time it has been on a particular regime. Grain feeding produces a fat which is hard at a higher temperature than grass feeding and different "recipes" of grain feeding produce fats of different hardness. Usually white fat is hard, and yellow, soft.

By contrast Figure 4 shows the temperatures achieved during the chilling of a lighter animal of 105 kg carcass weight and 105 mm fat depth. The fast chilling rate was continued for 10 hours only before the air temperature was raised gradually to just under 8°C.

Re-heating of chilled sides immediately prior to boning will produce no adverse effects **provided it follows a rapid chilling program similar to those recorded on the plots you have seen.** Hot gas re-heating is less satisfactory than electrical for a number of reasons:

- it is usually manually controlled and the air temperature quite often is unnecessarily high;
- when carried out in the early morning, before there is much load on the refrigeration system, the gas temperature may be low and getting the room air temperature up to reheat level may take a long time. Remember, bacterial growth depends on both temperature and time.

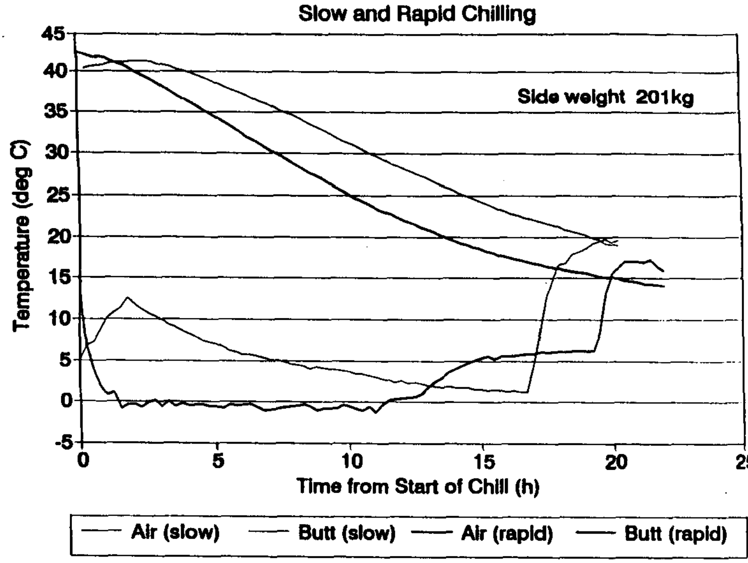

Figure 2: Temperature profiles for rapid and slow chilling regimes

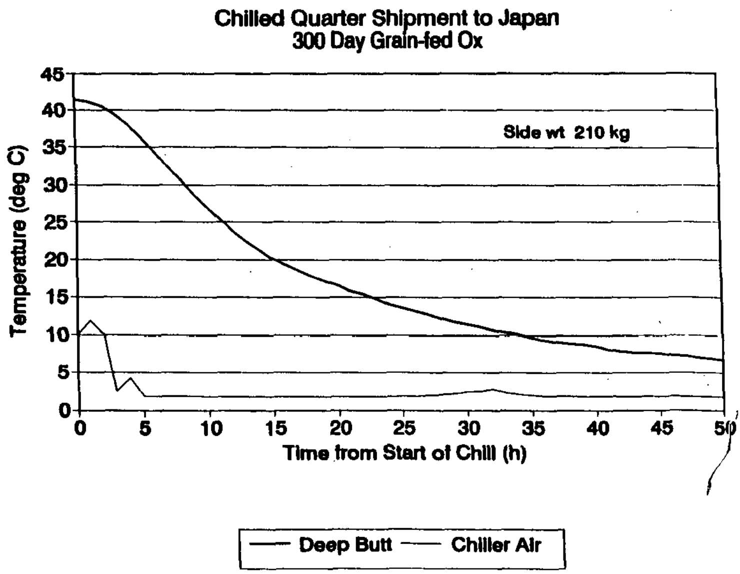

Figure 3: Temperature profiles for grain fed quarter beef

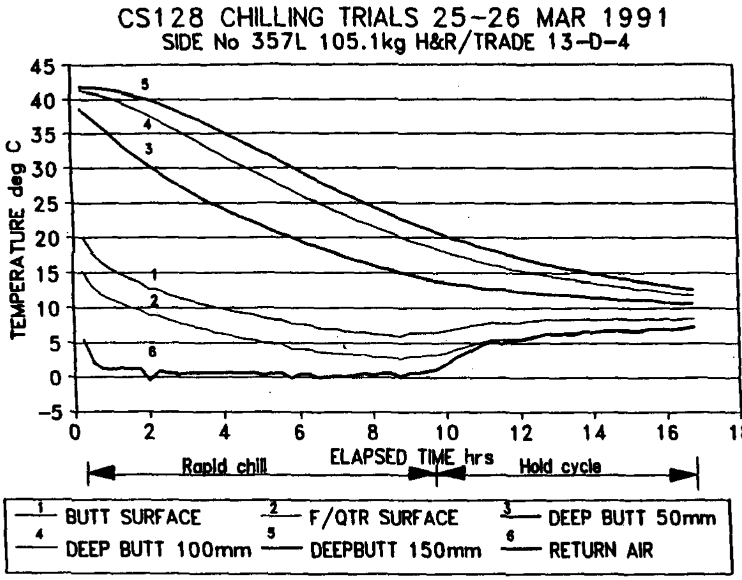

Figure 4: Temperature profiles for chilled domestic beef sides

- it is not free, as is popularly supposed. The engine room compressors supply the energy to push the hot gas round the pipework and this cancels out the benefit of using the evaporator as a condenser. Some plants have had to shut down condensers, or close in the hot gas discharge valves in order to achieve hot gas defrosting in an acceptable length of time. A satisfactory electrical re-heat system has the following characteristics:
  - sufficient capacity to rapidly raise the chiller air temperature to the set-point;
  - automatic control of capacity so only sufficient heat is applied to maintain re-heat set point temperature;
  - safeguards which will only allow re-heat to be initiated if the evaporator refrigeration system is immobilised, and which will terminate re-heat if time and temperature set points are exceeded;
  - components suitable for the rigorous conditions of a chiller environment.

Quarter Beef

Satisfactory chilling of sides destined for sale as quarter beef has most of the same requirements as for boneless, with the exception of avoidance of bone taint, and no requirement to have the surface fat suitable for boning. While avoidance of bone taint in boneless beef is highly desirable, its incidence is not of as great economic significance as in quarter beef as it will be detected in the boning room before it has progressed too far and any affected tissue trimmed off. Bone taint is still not fully understood, but sufficient is known to limit its incidence to an insignificant level. The key is to reduce the deep muscle temperature surrounding the major bones in the hind and fore quarters to below 20°C as rapidly as possible. Researchers at the UK Meat Institute at Bristol determined that bone taint does not progress below this temperature.

Many people are of the opinion that knifing open the stifle will reduce the risk of bone taint by exposing the deep muscle for faster cooling. Preliminary tests carried out by MRL do not support this idea.

As surface fat hardness is not a significant factor in export quarter beef the high intensity chilling phase should be maintained right through to removal from the chiller, or to the deep butt temperature reaching circa 2°C, whichever occurs first.

With domestic quarter beef there is not much point in achieving such a low temperature, unless the refrigeration conditions which follow active chilling are equally stringent. If the holding and transportation temperatures are higher than those achieved during active chilling the weight loss saved will be lost subsequently.

The temperature must be maintained below 8°C, however, in order to control bacterial growth so a deep butt and room temperature of no higher than 7°C should be the goal. One trader operates the active chillers at 0°C for about 5 hours then ramps up to 3°C and achieves a deep butt temperature on 90 kg sides of 7°C in ca. 17 hours.

3. Chilling Cycles for Sheep, Goats and Pigs

General

The same principles apply as for beef but the carcass weights are lighter. The surface area of a carcass varies as the square of its dimensions but the weight (volume) varies as the cube. Thus the surface area per kg of carcass weight of a lamb is much higher than that for beef. The ratio of surface area to weight has an important influence on both the speed of chilling and weight loss during chilling. This means that the smaller the animal the higher percentage the weight loss will be unless some factor is introduced to prevent evaporation of water from the carcass. Some such factors are:

- an impervious covering
  - OK for freezing but microbiologically unsound for conventional chilling;
- surface coatings
  - probably the best option currently available. They were devised by MRL. The one which has been commercialised is an acetyl alcohol applied by spraying. Presently this is only approved for domestic carcasses;
- spray chilling
  - OK for domestic meat but there appear to be microbiological problems in the shelf life of vacuum packaged beef which are associated with long term holding. There is also some doubt as to whether the weight loss saved ends up in the carton when heavy fat trimming occurs;
- ultra-low temperature chilling (ca. -25°C for some 2 hours followed by equilibration to 4°C)
  - achieves low (ca. 1%) weight loss for pigs and is satisfactory when they will be further processed, but can cause toughening of fresh pork. Animals which have the skin removed during dressing, such as cattle, calves and sheep, will lose weight through weep when the frozen meat thaws.

Lamb Tenderness

Because of their small dimensions lamb carcasses are particularly prone to cold shortening but, as explained earlier, this will only be a problem under certain circumstances. It can be avoided by keeping the loin muscle temperature above 10°C until full rigor has been reached. Ideally either a pre-chill room operating at no lower than 8°C should precede the active chiller or, better still, conveyorised storage at this temperature for some two hours should be provided.

4. Holding in Active Chiller after Programmed Deep-butt Temperature is Achieved

When sides or carcasses are held in the active chiller after the desired deep butt temperature is achieved (weekends, public holidays and no kill days) the air velocity can be reduced to 0.5 m s^{-1} and the refrigerant temperature raised to within 2°C of the set temperature. This will reduce variations in the chiller temperature and minimise shrinkage. Note that reducing the air velocity without reducing the approach temperature (the amount by which the refrigerant temperature is less than the circulating air temperature) may increase weight loss as the temperature differential (TD or $t\Delta$) across the evaporator coils will be greater. If dew point is reached, moisture will condense on the evaporator coils and the air coming off will be drier. Equipment is available which can be programmed via a computer or programmable logic controller (PLC) to carry out these functions automatically according to the programme selected.