CARCASS CHILLING – PRINCIPLES

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The main reason for the post-mortem chilling of carcass meat is preservation. Modern production and distribution systems rely on preservation by refrigeration and the maintenance of the cold chain, for their existence. It is patently obvious that in today's environment, without refrigeration, even the small local operator would struggle to meet market expectations.

However, refrigeration cannot be thought of only as a means of preservation. Its effect on meat goes well beyond simply preventing spoilage. Refrigeration can affect meat in many ways. It can, for example:

- influence meat quality in respect of toughness and tenderness;
- affect product yield in relation to weight loss;
- determine the ultimate intensity and stability of meat colour;
- control the hardness or 'boneability' of fat, particularly where fat cover is heavy;
- as well, it is the most important element in the preservation process.

The principles of carcass chilling are governed by the above five features. Therefore, in order to understand carcass chilling, it is necessary to have an appreciation of the mechanisms of the above features.

During the first twenty-four to forty-eight hours post-mortem, muscle undergoes a bewildering array of biochemical and physiological changes in the process of becoming meat. It is during this period that refrigeration is applied to chill the carcass, so it is not surprising that the chilling process has a profound effect on these changes and therefore on the final product.

A great deal happens in that short time. At the end of the forty-eight hour period the die is cast in respect of four out of the five product attributes identified above. The only on-going task for the refrigeration system following the initial forty-eight hour chill, is the preservation of the meat.

This paper deals with the principles of carcass chilling from two view points. The first of these is centred on the post-mortem changes in meat and the influence of chilling on these changes. Discussion includes the effect of chillers on meat quality and on the growth of micro-organisms. The second aspect of this paper emphasises some of the practical aspects of chilling and freezing large carcasses. Discussion focuses on yield and meat colour, as well as problems associated with bone taint and hard fat. Together these will help put the responsibilities associated with refrigeration management into an appropriate perspective.

1. Post-mortem Changes in Meat

In order to understand how refrigeration affects meat in the manner alluded to above, it is necessary to understand the effects themselves. To do so, it is necessary to understand something of the structure of meat.

Meat Structure

Meat is made up of fibres that are bundled together and held intact by sheaths of connective tissue. Connective tissue is made up of the structural protein collagen. The fibres themselves are made up of the proteins actin and myosin that are linked together in an ordered repeating sequence.

The proteins actin and myosin, known as the contractile proteins, are responsible for muscle movement. When a muscle is flexed by the live animal, the actin and myosin filaments move in relation to each other. The same happens when the muscle is relaxed. Muscle structure is illustrated in Figure 1. This constant contraction and relaxation of the muscle is powered by energy derived from muscle starch, or glycogen, which is replenished by the animal during periods of rest.

Rigor

One of the many changes that take place during the rigor process is the linking of the actin and myosin filaments by a chemical bond. Once this bond is formed, the filaments can no longer move relative to each other and the muscle becomes inextensible. It is then said to be "in rigor".

Once the muscle is in rigor, the relative length of the actin-myosin unit, the sarcomere length, is fixed – Figure 2. This sarcomere length becomes a prime indicator of the tenderness or toughness of a piece of meat.

Meat Tenderness

In order for a piece of meat to be defined as tender, it must be possible to sever the bundle of fibres, by biting on the meat, without applying too much pressure. The extent to which pressure is necessary to sever the fibres will be influenced by the sarcomere length.

When the muscle goes into rigor with the filaments in the "at rest" position in relation to each other, the resulting sarcomere length will be of a suitable length consistent with tender meat. As a result, there will be no difficulty biting through the fibre bundles.

If there is any contraction of the muscle prior to rigor setting in, the fibres will still bond together in the usual way, but the sarcomere length will be shorter. This will result in tougher meat because the filaments will be bunched up and therefore more dense. They will be more difficult to bite through as a result – Figure 3.

Cold Shortening

When a muscle is chilled, there is a natural tendency for the fibres to contract if they are subjected to low temperatures before rigor is complete. This phenomenon is known as cold shortening, or cold toughening, and it is the most significant cause of toughness in meat from animals that are less than four years of age at slaughter.

The amount of contraction, and hence the amount of toughening, depends on the extent to which the muscle is allowed to contract.

A muscle can be prevented from contracting by one or more means:

(a) Conditioning, or controlled cooling;

(b) Physical restraint of the muscle;

(c) Electrical stimulation.

The filaments in a piece of cold-shortened muscle will yield a very dense structure that will be very difficult to sever and will therefore be very tough.

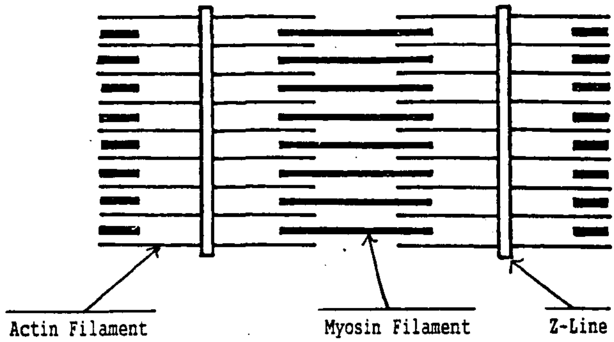

Figure 1: Muscle structure – actin and myosin filaments

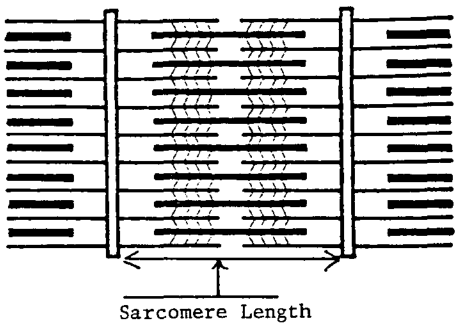

Figure 2: Muscle in rigor – sarcomere length

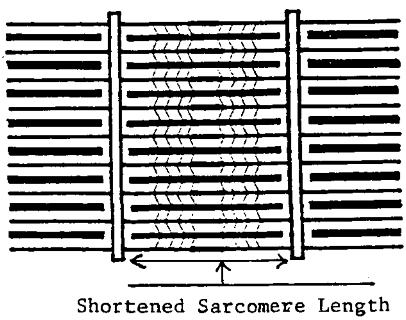

Figure 3: Cold shortened muscle

The extent to which the meat is tough will depend on the degree of shortening. Up to 20% shortening will not have any negative influence on tenderness. Shortening beyond 20% will yield meat of increased toughness. Maximum toughness occurs with muscle shortening of 40%, beyond which toughness actually starts to diminish.

Muscle which goes into rigor at too high a temperature will also contract to some extent; however, this degree of contraction is far less than that resulting from cold shortening. The optimum temperature for the transition into rigor is 15°C. Figure 4.

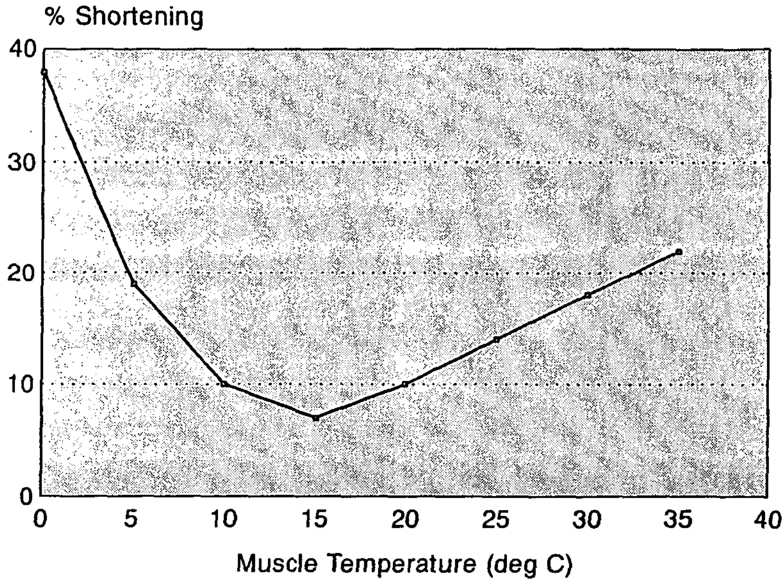

Figure 4: *Effect of pre-rigor temperature on muscle shortening (unrestrained muscle)*

Avoiding Cold Shortening

Conditioning

Cold shortening can be prevented by controlled cooling. The cooling rate of the carcass can be controlled such that the temperature of the pre-rigor muscle is prevented from going below the temperature at which the muscle fibres would shorten. An effective conditioning regime would not permit any muscle on the carcass to fall below 12°C within the first ten hours of slaughter.

Heavy, well-finished beef carcasses cool more slowly than light carcasses; however it cannot be assumed that a slow-cooling heavy beef carcass is immune from cold shortening.

Some muscles, even on heavy beef carcasses, including the most commercially significant ones, may still fall below 12°C in ten hours during conventional chilling. These are the muscles that are thinnest in cross-section and most exposed, e.g. striploin and cube roll. Also, the surface muscles of some of the large cuts can fall below 12°C inside ten hours under normal circumstances and will suffer some degree of cold shortening as a result. Conditioning must therefore permit these muscles to remain above 12°C for ten hours with the result that the chilling of the butt of a heavy carcass may be prolonged to an undesirable extent. This may have implications for bone taint which will be discussed later.

Conditioning of small stock is feasible in terms of an overall acceptable chiller regime. However, space restrictions can be a limitation on effective conditioning of large numbers of carcasses.

Muscle restraint

Muscle can be prevented from shortening by physical restraint. The best way to restrain a muscle in a practical sense is over the skeletal frame of the carcass by hanging the carcass in such a way that the muscle is stretched and therefore physically unable to contract to any extent.

Muscle restraint is the principle of the tenderstretch technique for sustaining meat tenderness, which, although still used by a few operations, is not favoured by the industry at large.

Electrical stimulation

A modified pulsed electric current can be applied across a carcass to remove the driving energy necessary to cause cold shortening. A muscle effectively stimulated by such a current will go into rigor quickly as manifested by an accelerated fall in muscle pH. This process is often referred to as "accelerated conditioning", because the rapid drop in pH means that even under an efficient chilling regime, the temperature of the exposed muscle will not fall below 12°C before the pH has fallen below 6.0.

Electrical stimulation is widely used by industry as a means of preserving inherent meat tenderness. It will be described in more detail in a paper to follow.

Hot Boning

Hot boning of carcasses has been an option for meat processors for many years. Many are aware of its potential in terms of efficiency and there are a small number of operators presently hot boning. Some areas of the meat industry in other countries make extensive use of hot boning. The advantages are two-fold. The first is the continuity of the slaughter/boning operation without the need for intermediate chilling. The second is the saving on chilling facilities and the energy required to operate them. Carcass frames for example, represent some 30% of the weight of the beef carcass. Energy is used to cool them during conventional chilling, then more energy is used to heat them again during rendering the following day.

Unfortunately, hot boning has a major drawback in respect of cold shortening.

During conventional chilling the carcass frame provides the restraint that prevents excessive cold shortening of the muscles attached to it. When muscles are boned hot there is no physical mechanism to restrict cold shortening when the muscle is cooled. As a result, hot boned muscles will suffer extreme cold shortening, and toughening, if measures are not taken to prevent this.

Hot boning of manufacturing meat is not a source of major concern because comminution or blade tenderising effectively disrupts the muscle structure and overcomes the toughness problem. A mechanism for preventing cold shortening in these circumstances is therefore unnecessary. In the case where an operator removes valuable cuts from the manufacturing pack, markets will have to be found for these cuts where preparation and cooking methods are such that cold shortened is not an issue. If tenderness is important, it is essential that effective electrical stimulation be used in conjunction with a hot-boning operation.

2. Ageing

Ageing is another means of improving the tenderness of meat. Refrigeration in this instance is purely the vehicle which provides the shelf life and therefore the time necessary for the ageing process. In most cases, ageing of meat is done in conjunction with vacuum-packing, particularly with export shipment.

Ageing is an enzymic process which results in the severing of muscle fibres. Refrigeration per se does not have a role in the ageing process but temperature does influence the rate of ageing. Ageing is more rapid at higher temperatures.

Ageing however has little effect on very tough meat, irrespective of whether the toughness is a result of animal age, e.g. connective tissue induced, or a result of extreme cold shortening. Ageing will not effectively tenderise hot-boned meat that has not been electrically stimulated.

3. Freezing

If hot-boned, non-electrically stimulated meat is frozen pre-rigor, the cold shortening phenomenon is prevented because the muscle is restrained by the fact that it is in the frozen state. In frozen meat the rigor process will proceed, albeit very slowly, and if the frozen storage period is long enough, cold shortening and subsequent toughening will be prevented.

On the other hand, if frozen pre-rigor, hot-boned meat is thawed in the short to medium term, the phenomenon of "thaw shortening" will occur. The resulting contraction is more severe than cold shortening and it is accompanied by excessive loss of moisture or weep. The resulting meat is likely to be extremely tough indeed. Thaw-shortening can result in greater than 40% shortening in which case the meat actually becomes more tender, however this scenario would be accompanied by a massive loss of moisture.

4. Micro-organisms and Meat

The other aspect of post-mortem changes to muscle that is of interest is the behaviour of micro-organisms. Muscle tissue is effectively sterile at the point at which the hide or pelt is removed. The bacteria that contaminate the carcass from that point onwards are transferred to the carcass: from the hide or pelt; from processing equipment; and from the hands of workers.

The extent to which a carcass becomes contaminated is dependent very much on work practices and on plant and operator hygiene. The extent to which the unavoidable background bacterial contamination is controlled, is dependent on the management and operation of the refrigeration system. Good refrigeration practice will ensure prolonged shelf life of meat. The question of bone taint in relation to refrigeration controls will be considered separately.

The extent of carcass contamination and the rate at which spoilage occurs will depend on several factors, each of which influence the growth of micro-organisms. Of these there are three that are influenced, to a large degree, by the refrigeration system, namely:

- temperature;
- water activity;
- numbers of micro-organisms.

As well as these factors, it is also worth considering the way micro-organisms actually grow. Micro-organisms (which include Bacteria, Yeast and Moulds) do not commence growing the instant they land on a new surface. There is a delay or lag phase while they adjust to the new environment, including the new nutrient source, moisture level, temperature and so on. Unfavourable conditions of temperature and moisture level will give rise to a prolonged lag phase as well as a lower ultimate growth rate thus contributing to prolonged shelf life (Figure 5).

Temperature

The extent to which temperature influences the growth of micro-organisms needs to be clearly understood in order to appreciate the relative importance of apparently small differences in temperature in the chiller environment.

At temperatures above 10°C, a change of (say) 2°C will have very little influence on the growth of micro-organisms, and therefore on shelf life. On the other hand a piece of meat that is supposed to be stored at 2°C will have its shelf life halved if it is instead stored at 4°C. The growth rate of the spoilage micro-organism actually doubles with a temperature rise from 2°C to 4°C. The effect of a temperature drop from 2°C to 0°C is even more pronounced and a further drop to -1°C will almost halve the rate of growth rate at 0°C. The effect of temperature change on the growth of spoilage micro-organisms is illustrated in Figure 5. Sub-zero chilling, as it is now known, is recommended by CSIRO as a means of ensuring optimum shelf life of vacuum-packed chilled meat for export.

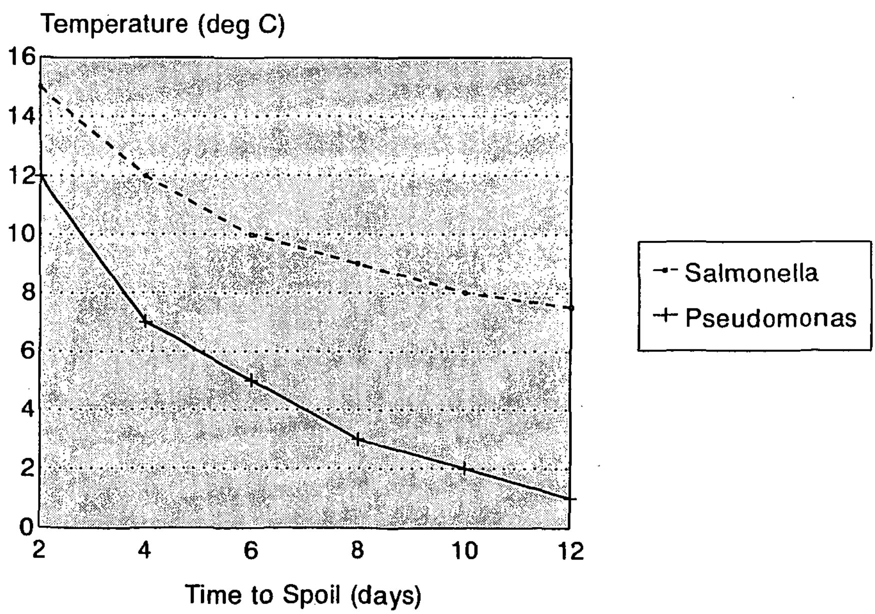

Figure 5: Effect of temperature on the growth of Pseudomonas and Salmonella

The other important aspect of temperature in relation to meat chilling is that most of the pathogenic micro-organisms commonly associated with meat are inhibited in some way by temperature control. Salmonella and *E.Coli* for instance do not grow below 8°C (Figure 5). *Staphylococcus*, whilst it can grow at low chiller temperature, is unable to produce toxins at less than 10°C.

Water activity

Moisture content *per se* is not a factor that affects the growth of micro-organisms. Rather, it is the availability of moisture, namely the water activity, that is important. Either way a moist surface will support the growth of micro-organisms far better than one that is dry. The influence of water activity is on both the length of the lag phase and the subsequent rate of growth and is similar to the influence of temperature.

In order to prolong shelf life, the surface of a carcass or piece of meat should ideally be dry. Unfortunately, excessive drying is unacceptable for several reasons. Drying represents a direct loss of yield, and the dried-out surface of a piece of meat is dark and unsightly.

Good chilling practice therefore demands a balance. Excess moisture needs to be dried from the meat surface; however, care needs to be exercised to ensure that drying is not excessive.

Number of micro-organisms

There will inevitably be a number of micro-organisms on the surface of a carcass when it enters the chiller. Correct chiller practice can keep these numbers in check. In fact, an effective chilling program will result in a reduction in micro-organisms on the carcass surface following a twenty-four hour chill.

This will not be the case; however, if chiller hygiene is not properly managed. Areas such as plenums and the coils of FDC units can become heavily contaminated with micro-organisms, particularly some moulds. These can be transferred to carcass surfaces by air currents and/or condensation droplets blown from FDC units.

Carcass washing

One source of moisture on carcass surfaces that should be at least minimised, or better still, eliminated if possible, is the carcass wash. Washing has been an integral part of the dressing operation, especially on export plants, for many years, however, it can have a retrograde effect. The reason for washing is to facilitate the removal of surface contamination. In reality, washing may spread any isolated contamination and provide a uniformly moist surface which will facilitate growth of micro-organisms. Trends in recent years towards automatic (so called) carcass wash cabinets are often associated with excessive water usage, with its accompanying environmental implications as well as carcass contamination problems.

Washing should be restricted to the areas of the carcass that need it most; namely, those areas affected by bone dust from the splitting saw. Choice of the saw itself can have a marked effect on the need to wash, with low-speed circular saws and bandsaws being better than recipricating saws and high-speed circular saws. Band saws in fact produce a bone "paste" rather than bone "dust" which is far easier to remove and therefore requires less washing.

5. Chilling and Freezing of Large Carcasses

The chilling and freezing of large carcasses presents special problems for the refrigeration system and those who manage it. The conditions required to adequately chill a large beef carcass are extreme. As a result, some of the problems that arise from chilling under these circumstances are also extreme.

Shrink and Weep

Loss of moisture in the form of both shrink and weep are influenced by chilling rate. Hot carcasses and sides must be chilled quickly if both shrink and weep are to be minimised during chilling. Also, chilling rates will pre-dispose meat to some extent to subsequent weep loss. Slow cooled carcasses will yield cuts that will suffer excessive weep loss especially if they are subsequently vacuum-packed.

Sides should be chilled as quickly as possible, at least until the deep muscle temperature has been reduced to 25°C or lower. In the process the deep butt should be down to at least 30°C within the first 10 hours post-slaughter. This latter point also has implications for bone taint.

Electrical stimulation may or may not be necessary to preserve tenderness in very heavy sides of beef. If electrical stimulation is used, the problem of weep loss is likely to be exacerbated if, for any reason, the chilling rate is not as rapid as it should be. Slow chilling of heavy carcasses, in conjunction with electrical stimulation, will give rise to a "PSE effect" in the deep muscle of the butt. This will result in excessive loss of moisture as weep, as well as having implications for meat colour.

A balance is necessary, based on the capacity of the refrigeration facilities on the plant; the best possible result being achieved by rapid chilling together with electrical stimulation to prevent toughening of the more exposed muscles.

Meat Colour

Meat colour, together with fat colour, is possibly the single, most important, attribute of meat quality in terms of visual appraisal. Fat colour is determined largely by the animal itself, whereas the chilling environment has a profound effect on the colour of red meat tissue.

In the absence of oxygen, meat is purple-red in colour. This is the colour of freshly-sliced meat and it is due to the pigment myoglobin. On exposure to air the myoglobin absorbs oxygen and is converted to its bright red form, oxymyoglobin. This is the colour we associate with fresh meat that has had time to bloom. Prolonged exposure to air produces the oxidised form of the pigment, metmyoglobin, which is brown to grey and is the colour we associate with stale meat near the end of its shelf life. The relationship between these pigments is illustrated in Figure 6.

The rate at which these pigments change and the intensity of the end result depends to a large extent on temperature. In the case of the oxygenation of myoglobin to oxymyoglobin, low temperature will slow down rates of the change, but will enhance the intensity of the end result. At least 30 minutes is necessary to achieve a fully bloomed colour with well-chilled meat at 0°C. As well, the oxymyoglobin pigment extends to a depth of 5 mm in meat at this temperature, thus enhancing the intensity of the colour.

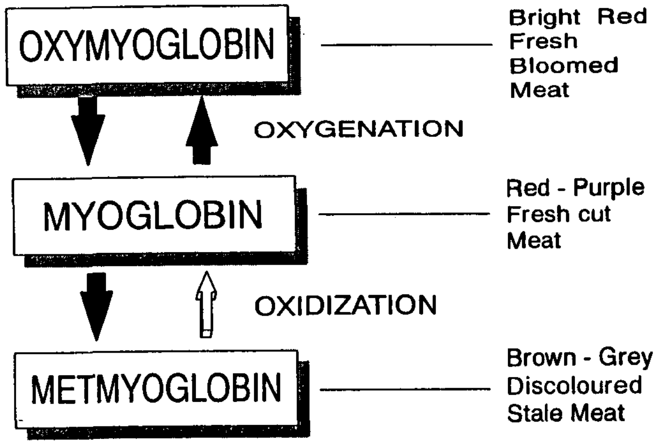

Figure 6: Meat colour

When meat is exposed to oxygen, there is a tendency for the myoglobin to oxidise to metmyoglobin. This should not be confused with oxygenation to oxymyoglobin because whilst the latter is a reversible reaction, the former is not necessarily so. Early resistance to the tendency to form the brown/grey metmyoglobin is provided by the enzyme reducing capacity of the meat. Whilst this capacity exists the meat will remain red; however, once it is exhausted, the irreversible browning reaction will take over.

The reductive enzyme capacity of the meat, like all positive attributes, is prolonged by low temperatures, but it is finite. Rapid chilling in the first instance followed by sustained low storage temperature will preserve the attractive visual appeal of meat for an extended period. It will certainly influence grading scores where colour is an important criteria.

Two-toning

The "redness" of meat colour and its intensity is influenced to a very large extent by the condition of the meat proteins. If the proteins are denatured to any extent, the meat will have its reflective capacity altered and the colour will tend to be pale.

The best illustration of this phenomenon is pale and watery (PSE) pork. PSE is the result of a stress-induced problem in pigs, but it is the effect that is of interest here. The muscle pH drops very quickly post-slaughter and a combination of high muscle temperature and low pH causes the meat proteins to denature. In the extreme, this causes loss of colour and loss of water holding capacity, hence "pale and watery".

If heavy beef is electrically stimulated, then not chilled as rapidly as it should be, the accelerated drop in pH resulting from electrical stimulation, coupled with higher than desired butt temperatures, can cause some degree of protein denaturation. The effect is greater towards the centre, i.e. warmer, part of the muscle, and the result is a two-tone effect when the meat is sliced.

The two-toning effect is compounded by an accelerated loss of enzyme reducing capacity in the meat, with the result that browning will occur more quickly in the pale muscle. The problem is further compounded by the fact that the browning is more obvious against the pale background colour.

It is a question for management then, if a plant's refrigeration is, say, adequate but stretched to capacity in respect of heavy beef, as to whether electrical stimulation should be used. There is no simple answer to this dilemma. It is a case of weighing up the relative merits of the options in terms of the required end result, giving due consideration to tenderness, bone taint and meat colour, as well as the usual considerations that include shrink loss, chiller capacity and production level.

Bone Taint

Bone taint is a problem that has been experienced by various operators at different times. In the past, the problem has been manageable because most product was boned and any evidence of taint was detected in the boning room. If the incidence was unacceptable, the problem would usually be traced to some form of refrigeration problem and corrective measures could be taken.

The trend in recent years towards heavier bodies, both grain-fed and grass-fed, for certain markets has led to the risk of an increased incidence of bone taint if chilling practices are inadequate. This issue is compounded by markets such as Korea which take bone-in quarter beef. It is not possible to detect the presence of bone taint in this product prior to load-out, except by drilling or knifing every quarter to the deep muscle/bone interface. The risk of bone taint is exacerbated by carcass weights of 300 kg and over that are required by the market and it is therefore imperative that appropriate measures are taken to ensure adequate chilling.

Code of Practice – Korean Beef

Given the size of the carcasses in question, and the implications of a bone taint problem in the Korean market, the basic requirements of Export Meat Order No. 250 are not sufficient to provide adequate safeguards.

AQIS have developed the following:

> *"Code of Practice for the production of Grass-fed bone-in Quarter Beef for export to the Republic of Korea – Minimum Guidelines".*

In respect of chilling, this document recommends:

The following requirements shall apply in place of EMO 250(a):

(a) a deep-butt temperature of 16°C must be achieved within 20 hours of slaughter; or

(b) a deep butt temperature of 20°C within 20 hours of slaughter shall be achieved and when option 2(b) is utilised, all chilled hindquarters must be examined for the presence of bone odour by deep muscle incision into the acetabular area or by core testing of the proximal femur (see attached diagram).

The full Code of Practice, which includes details of the drilling technique to test for bone taint, is available from AQIS.

Initial Cooling Rate

A further recommendation is made by CSIRO, in addition to those outlined in the AQIS Code of Practice. That is, that the initial chilling rate should ensure that the deep-butt temperature is reduced to below 30°C within the first 10 hours post-slaughter. If sides are chilled so that the deep butt is below 30°C within 10 hours and below 16°C within 20 hours, the risk of conventional bone taint is very much reduced.

Korean Bone Taint Test

Recently, Korea has adopted a new, more radical means of testing for bone taint in quarter beef. A chain-saw cut is made through the butt above the liaich bone and a sample of femur bone marrow is taken, warmed and evaluated by smelling. This has added a new dimension to the bone taint issue and has posed new questions for the Australian meat industry.

The root cause of bone taint in muscle is not fully understood, so the addition of the bone marrow question has added to the issues that need to be addressed by research.

A recent preliminary, and necessarily limited, investigation was undertaken with a view to throwing more light on this subject and making recommendations to industry that would significantly reduce the risk of odours at the bone/muscle interface and in bone marrow.

The incidence of bone taint in bone marrow is higher than in meat. However, the faster the temperature is reduced in the deep butt of heavy Korean-type beef, the lower the incidence of taint in both muscle and bone marrow. In order to significantly reduce the risk of taint in muscle and marrow, the deep but temperature should be reduced to below 30°C within 10 hours of slaughter and below 16°C within 20 hours of slaughter.

This time/temperature relationship is necessary for both grain-fed and grass-fed beef because there is no difference in the incidence of taint between the two types with similar carcass weights.

Hard Fat

The issue of hard fat has been one of concern to industry for many years. The workplace safety implications in today's industry have heightened the profile of this problem and increased the demands for some permanent solution. Apart from the development of the fat hardness gun (the Sliding Pin Consistometer) which is at the stage of perfecting a prototype commercial unit, there have been efforts to develop refrigeration management measures. These measures involve monitoring and managing the chilling cycle. The details of this work, together with recommendations, are outlined in a separate paper.

6. Conclusion

The principles of carcass chilling go well beyond the need to chill meat in order to prolong its shelf life. Chilling, and refrigeration generally, has implications for many attributes of meat that influence it's quality. As the complexity of the Australian meat industry increases, there are now demands for processors to meet increasingly stringent criteria for hygiene and meat quality, and to meet these demands it is necessary to understand the factors involved. The papers that follow deal with the whole range of chilling considerations, with an emphasis on engineering aspects. This paper, by way of an introduction, has set the ground rules.