CARCASS CHILLING

Ian McNeil, Neil G. McPhail, David Macfarlane

The primary chilling of carcasses is the most important step in the cold-chain process for preserving meat.

Different chilling practices are adopted by individual processors, influenced by refrigeration facilities available and economic considerations, the type of animals being treated, and customer requirements. Obviously a chilling cycle adopted for light domestic-trade cattle would be entirely unsuitable for heavy Japanese-type ox.

The refrigeration conditions under which the initial meat chilling takes place influence the final meat quality as they affect shelf life, appearance, tenderness, weight loss and drip (purge).

1. Shelf Life

The moist, warm meat surface of a freshly slaughtered animal provides ideal conditions for microbial growth and this, if uncontrolled, can result in spoilage or food poisoning.

If fresh meat is chilled to a temperature below 7°C, mesophilic organisms (including most pathogens) will not grow, but psychrophilic organisms will continue to grow slowly and ultimately cause spoilage. Pseudomonads grow very slowly at 0°C but at 5°C the growth rate more than doubles and contaminated meat will spoil twice as fast.

2. Appearance

The purple colour of freshly killed meat is due to the myoglobin pigment which changes to bright red oxymyoglobin when oxygenated. After continued exposure to air, the exposed surface will eventually turn to brown metmyoglobin.

At lower temperatures the oxygen penetrates deeper into the meat and the oxymyoglobin layer thickens, whilst the conversion from oxymyoglobin to metmyoglobin accelerates at higher temperatures.

The bright red colour is desirable at the point of retail sale and the formation of metmyoglobin is therefore delayed by holding the meat at lower temperatures.

Meat colour is also influenced by the rate of cooling; slower cooling results in lighter-coloured meat. If cooling of very heavy, fat carcasses is delayed, then pale, watery regions occur, particularly in deep muscles. These regions brown faster in retail display. In heavy animals bone taint can occur under the same conditions.

3. Tenderness

The influence of chilling on the tenderness of meat is restricted to the effect of cold-shortening-induced toughness.

After slaughter, the glycogen in the muscles breaks down to form lactic acid in a process known as "glycolysis". The muscles become acidic and the pH falls. In healthy, rested animals the glycogen breaks down over a period of 48 hours, and the pH falls from 7.3 to about 5.4 - 5.6. When the glycogen is exhausted the muscle is in "rigor".

If muscle is cooled rapidly to below 10°C before it has set in rigor, "cold-shortening" toughness will occur due to muscle contraction.

This underlines the benefit of electrical stimulation (ES) which uses up the glycogen so that the onset of rigor is accelerated and faster chilling can be carried out without causing cold-shortening.

4. Refrigeration Equipment

Chilling is accomplished by circulating air through an evaporator or forced draught cooling (FDC) unit and then over the sides or carcasses. Fans, usually mounted on the FDC's, are used to create the air circulation (see Fig. 7). The air is cooled by the evaporation of a refrigerant, e.g. ammonia or "Freon" inside the tubing of the FDC. To reduce drying (shrink), the depth "D" of the FDC in the direction of the air flow should be small. If the air passing through the FDC reaches "dew point", moisture in the air will condense on the tubing. The drier air will collect more moisture from the meat and so on. This results in surface drying.

By keeping the temperature differential between the air on (returning to) and off (exiting from) the coils low, and the face area of the FDC high, fast chilling can be achieved without high weight loss.

The FDC's should incorporate controls for best results to enable the optimum refrigerant temperature and air distribution to be selected at various stages in the chilling cycle.

The chillers should not be operated with the refrigeration off and the fans on, unless the objective is to warm up the room.

As an illustration, if a chiller was fitted with a total of 6 fans each of 5 KW, i.e. 30 KW in all, the heat input from them would be equivalent to 20 domestic heaters of 1500 watts each.

Conversely, slow chilling will avoid the problem of cold-shortening, however this could be at the expense of shelf life, weight loss and meat colour.

5. Rapid Chilling

Export Meat Order 250 currently requires that active chillers be capable of reducing the deep-butt meat temperature of cattle and sheep to no more than 20°C within 20 hours and 8 hours respectively, from the time that they were first placed under refrigeration.

It further stipulates that after reaching 20°C, the surface temperature must not exceed:

- 12°C for mutton, fat class 4 or 5; or
- 10°C in all other cases;

for a period of more than 3 hours.

EMO 250 should be considered the minimum standard as there are many advantages to be achieved by increasing the cooling rate.

Rapid chilling to quickly reduce the meat surface temperature and achieve an "air on the coil" temperature of 0°C or less within 2 hours will minimise bacterial growth, improve shelf life, retain the meat and fat colour and reduce the amount of drip in vacuum-packed product. It will also reduce the evaporative weight loss in comparison to slow chilling to similar deep meat temperatures.

Moisture evaporation from the surface of meat is a function of the differential vapour pressure between the meat surface and the cooling air. It is at a maximum at commencement of the chilling cycle and gradually reduces as the meat temperature approaches that of the air. With slow chilling a larger temperature differential is maintained for longer periods and this accounts for the increased evaporative weight loss.

6. Chilled Quarter Beef

The majority of Australian quarter beef is chilled as "sides" prior to quartering, which provides for better utilisation of chiller space. It also avoids the "bone slump" (or "slip") which occurs if sides are quartered hot.

Herbert, in a summary on a study of chilling conditions in Australian abattoirs (1), reported weight losses of between 1.6 and 2.2% from "hot wet to cold dry" weight for four chilling regimes as summarised in Table 1. He also reported (2) that water uptake during final washing of the sides was less than 0.2%. Correcting his weight-loss findings to a "hot dry to cold dry" basis as per standard carcass specifications, gave amended results of between 1.4 and 2.0%.

During recent experimental chilling trials at a regional metropolitan abattoir we achieved "hot dry to cold dry" weight losses averaging less than 0.6% for quarter beef derived from carcasses with an average dressed weight of 212 kg over three differing chilling regimes as shown in Table 2. Although these conditions have not yet been subjected to scientific meat-quality assessment, there was no adverse report on the outturn of the chilled quarter beef from these experiments.

We attribute this low weight loss to the combination of low initial air temperatures and the reduction in fan speed once the thermal heat transfer rate of the muscle becomes the controlling factor in the rate of cooling. Typical cooling curves are shown in Figure 1.

***Table 1** Batch Chilling Procedures - beef sides, 140 kg, 20 h chill*

Procedure No.	Air Conditions			Total Weight	Final Deep-butt
	Velocity m/s	Temp. °C	Duration h	Loss	Temperature °C
1	1.0	0	10		
	0.1	0	10	1.8	10
2	1.0	0	10		
	0.1	10	10	2.0	15
3	1.0	10	10		
	0.1	10	10	2.2	20
4	2.0	-10	5		
	0	Rising to 10	15	1.6	10

Table 2 Experimental Chilling Results - 28 Beef Sides Per Test

Chill Cycle No.	Total Chill Time h	Air Conditions Veloc. m/s	Temp. °C	Durat. h	Side Weights Av kg	Min kg	Max kg	Weight Losses Av %	Min %	Max %	Final Deep-butt Temp. °C
1		1.5	-0.2	10							
		0.8	-0.2/+2.9	4							
	16.75	0.8	2.9	2.75	111.6	90.5	136.0	0.57	0.19	0.8	11.3-13.5
2		1.5	-0.2	6							
		0.8	-0.2/+6.9	6							
	40.0	0.8	6.9	28	103.8	76.7	134.5	0.53	0.4	0.72	6.7-7.1
3		1.5	-0.2	10							
		0.8	-0.2/+4.9	4							
	16.25	0.8	4.9	2.25	103.9	91.4	113.5	0.48	0.16	0.86	9-12.6

Refrigeration Conditions:

Phase	Fan Speed	Temperature
Loading Phase:	70% Fan Speed	10°C air-on-coil temperature
Quick Chill Phase	100%	-0.2°C
Holding Phase:	50%	Air temperature increments from -0.2°C to holding temperature over time as noted and then holds at this temperature until end of cycle

Carcasses air freighted to Japan as chilled quarters are usually cattle grain fed for between 220 to 300 days, with dressed carcass weights of 400 to 520 kg and P8 fat readings up to 50 mm. To achieve deep-butt temperatures approaching zero at load-out and still avoid surface freezing usually requires 72 hour chilling cycles with air temperatures of -1.5 ± 0.5°C. This can either be done in the primary beef-side chiller for the full period or, alternatively, the sides can be removed at some interim period (say after 48 hours, when deep-butt temperatures are between 2 and 5°C), quartered, and then transferred into a finishing chiller.

Staging in this manner may increase labour costs due to double handling of the product, however this will be partially offset by reducing the turn-around time of the side chiller, and the refrigeration load in the finishing chiller will be minimal.

It is known that storage life of chilled beef at -1.5°C is extended by maintaining an atmosphere containing approximately 25% CO_2 and that the benefit does not depend critically on the actual CO_2 level.

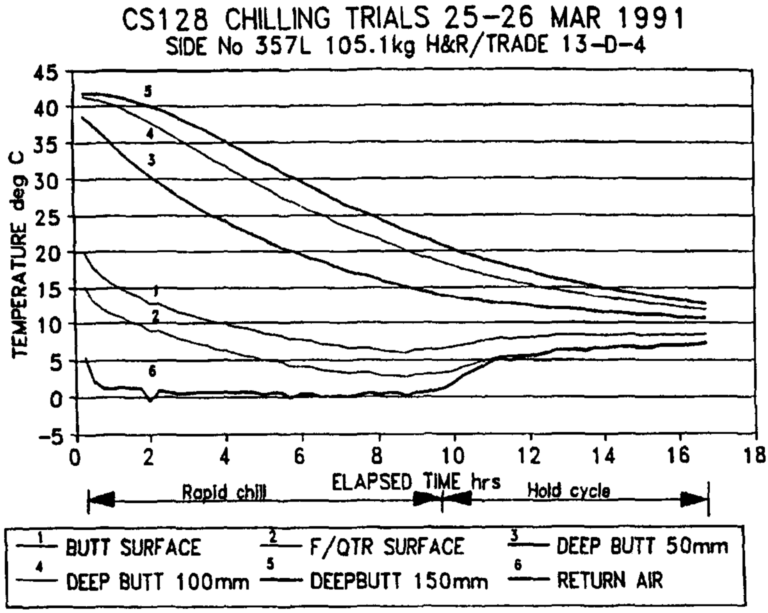

Figure 1 Chiller Trials - 25/26 March 1990

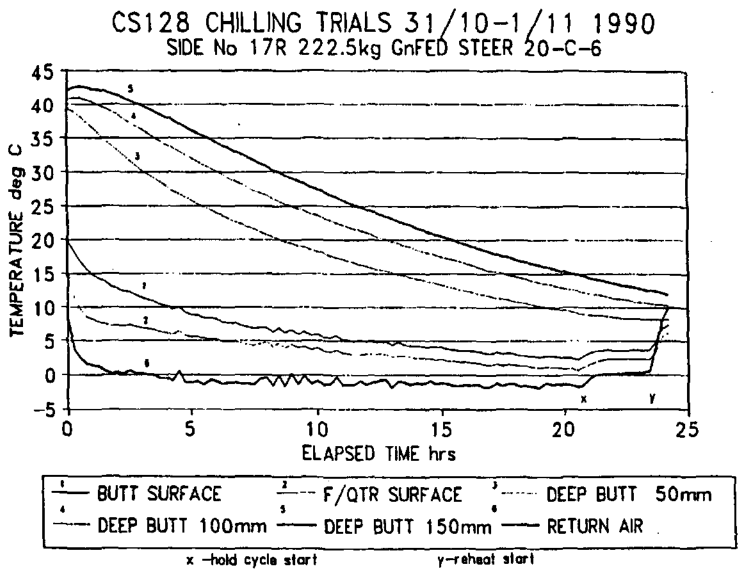

Figure 2 Chiller Trials - 31 October / 1 November 1990

Controlled-atmosphere containers, capable of maintaining 25% carbon dioxide, are prohibitively expensive, and are not available in sufficient quantity for trade requirements.

Commercial shipments of hung chilled meat under high levels of carbon dioxide have been conducted successfully by P&OCL for many years in unmodified refrigerated containers. Carbon dioxide gas (from gas cylinders) is added as required under manual control, so avoiding the need for an automatic controller.

A technique for the in-container disinfestation of grain by carbon dioxide was developed by CSIRO ten years ago, for use in general-purpose freight containers. This technique generates an initial level of approx 60% carbon dioxide from dry ice or cylinders of compressed gas, and maintains the level above 30% for ten days by the sublimation of dry ice held in an insulating box. Refrigerated containers are generally more gas tight than general purpose containers.

Recently a shipment of chilled quarter beef to Japan was monitored in which the CO_2 level was maintained by blocks of dry ice in thick-walled polystyrene sublimation boxes. The CO_2 level in the containers was measured daily by the ships officers and the meat and air temperatures recorded by portable data loggers inside the containers. The appearance of the meat on arrival in Japan was monitored by a CSIRO officer. Results of the trial are presently being collated.

7. Holding of Quarter Beef

Chilled quarter beef is sometimes "aged" by holding it in a chiller for several days. Improvement in the tenderness of the meat occurs by the natural muscle enzymes breaking down the muscle fibres, but the quarters lose weight and some spoilage will occur if the holding temperature is too high. The enzymes do not attack connective tissue and therefore muscles with a high connective tissue content will not tenderise to the same extent as those of lower content.

The effective shelf life of the meat after ageing is dependent upon the time/temperature conditions that it has been subjected to in the holding chiller. Shorthose (3) reported that "duration" had a greater influence on the tenderness than "temperature" per se. Therefore, to maximise shelf life and minimise weight loss, the quarters should be held at just above freezing temperature and with low air velocities of between 0.05 and 0.1 m/s measured over the meat surface.

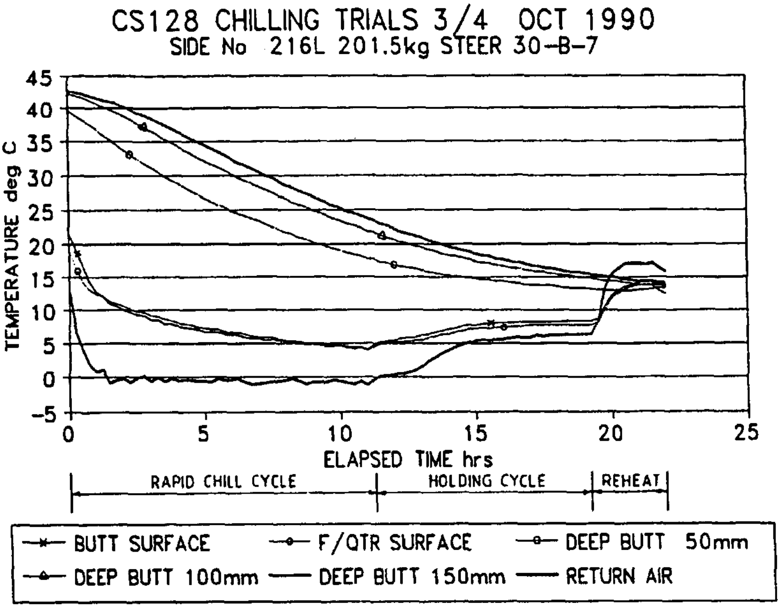

Figure 3 Chiller Trials - 3/4 October 1990

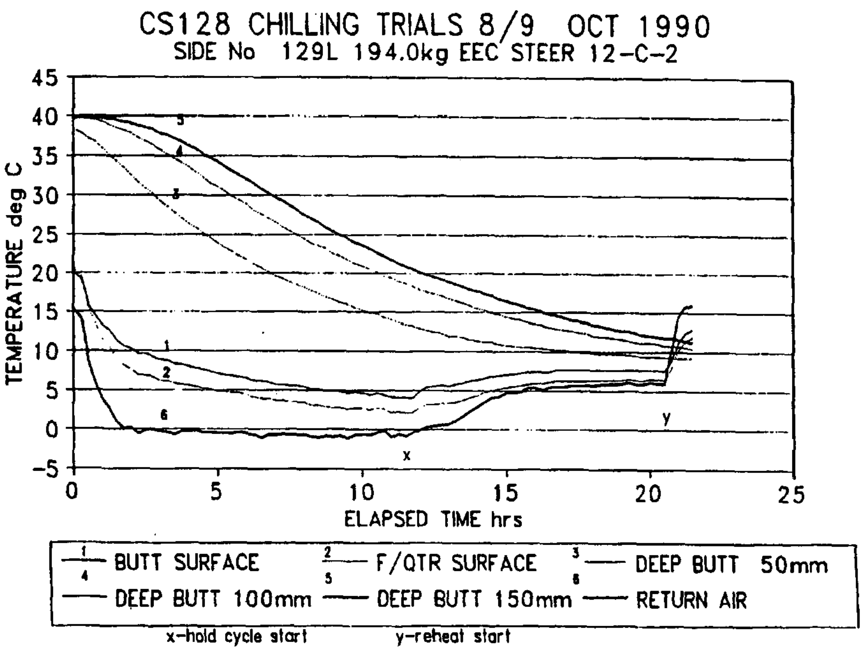

Figure 4 Chiller Trials - 8/9 October 1990

8. Primary Chilling of Boneless Beef

When considering the chilling of carcasses to be used for boneless production, an extra variable must be considered - HARD FAT.

Hard fat was not a significant problem prior to the development of quarter and side conveyorised boning systems in the mid to late 60's. With conventional table boning, meat temperatures under 5°C did not present much difficulty to the boners as they were able to use the table to exert leverage and cut the bones from the meat rather than meat from the bones.

However with the advent of the rail-boning techniques, the boners were required to cut through the surface fat first and this proved to be difficult (and to some degree dangerous), with surface temperatures close to 1.5°C.

Overnight chilling temperatures were amended to 10°C and this produced boneable meat, however with the subsequent development of the Japanese chilled, vacuum-packaged market that entailed increased carcass weights and grain-fed beef, the hard fat became a problem and resulted in industrial action by the boners. To alleviate the problems there has been a general relaxing on the boning temperature of vacuum-packaged product in contravention of AQIS EMO 250 to the extent that, in some instances, the chilled-meat quality could be compromised.

In an attempt to overcome the hard-fat problem some operators have introduced a hot-gas reheat cycle at the end of the chilling program, again in contravention of EMO 250. Unfortunately, lack of adequate controls can result in air temperatures exceeding 25°C during a 2½ to 3 hour reheat cycle, with the potential to reduce product shelf life. In some installations it has been necessary to artificially raise the refrigeration-system condensing temperature to provide an adequate supply of hot gas. The high-stage compressors are then required to operate at higher compression ratios, resulting in lower co-efficiency of performance (COP) and higher energy costs.

In the CSIRO experimental-chilling facility at the Metropolitan Regional Abattoir, Brisbane, we have utilised electrical heating elements in lieu of hot-gas reheat. The installed capacity is 3 KW per tonne of product and the elements are controlled by a programmable logic controller (PLC) to modulate the power output to achieve a regulated return-air temperature on to the coil.

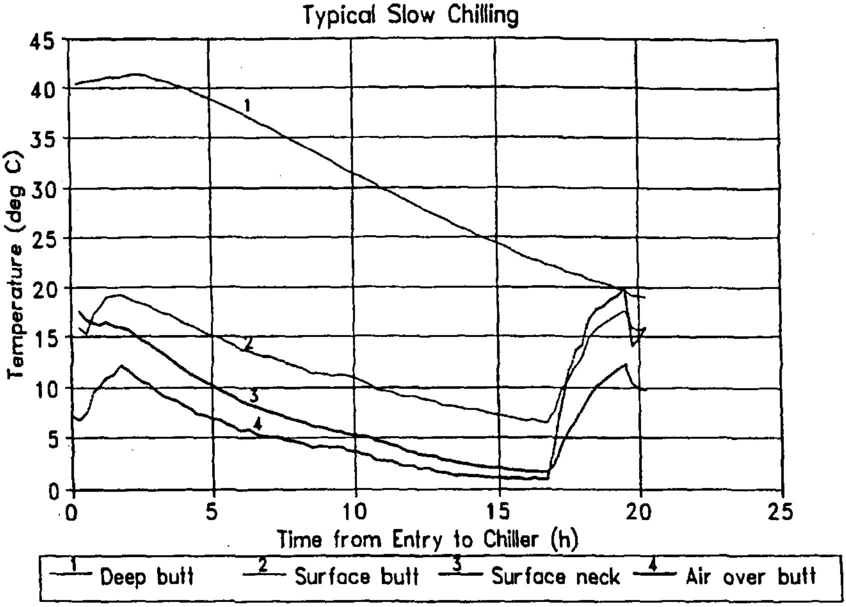

Figure 5 Typical slow chilling

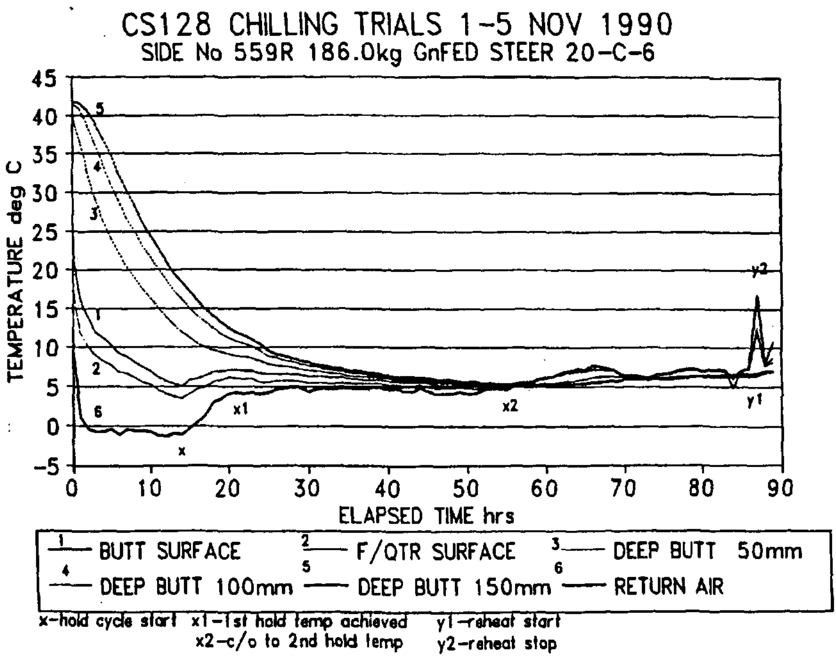

Figure 6 Chiller trial - 1/5 November 1990

With this system it has been possible to effectively temper hard fat in as little as 40 minutes and at a maximum air temperature of 10°C (see Fig. 2). However since this will vary with product type, chiller load, fat composition, and temperature, a return-air temperature of circa 15°C for between 1 and 1½ hours may be required.

The electrical reheat elements can be readily retrofitted to existing evaporators by mounting them on the discharge face of the coil block. At the start of the reheat cycle the power output of the elements will be at maximum and will reduce as the air temperature reaches set point.

The combination of electrical stimulation and chiller reheat facilities has effectively eliminated the problems previously associated with quick chilling of beef sides, that is, cold-shortening and hard fat. Tests carried out at an export works with AQIS dispensation from EMO 250 have verified that there are no adverse microbiological consequences in using reheat, provided that a rapid pull down of meat temperature is achieved at the beginning of the chill cycle.

Further work will be carried out at MRA to establish the minimum chilling conditions which CSIRO can recommend to AQIS for dispensation from EMO 250.

Providing there is sufficient refrigeration capacity and adequately sized evaporator units, controls and instrumentation, works will be able to obtain the following benefits from faster chilling rates and lower meat temperatures:

- improved shelf life due to enhanced bacteriological quality;
- reduced weight loss;
- retention of meat and fat colour;
- reduced drip in vacuum-packaged product.

To achieve these benefits we recommend the following chilling procedures:

- pre-grading of carcasses or sides to obviate the mixing of heavy and light animals in the same chiller;
- air on (return air) set point at 10°C during loading with sufficient air velocity to prevent condensation;
- complete the loading as quickly as possible, close the doors and commence the full chilling cycle;

- chilling cycle - run evaporator fans at maximum speed with the air on temperature set point at 0°C or just below;
- maintain these conditions for sufficient time to extract enough heat energy to ensure that the surface temperature of the meat does not rise above 8°C during the subsequent equilibration and holding cycles;
- to prevent secondary condensation forming on the chiller steelwork, the air temperature should rise gradually at no more than 2°C per hour (following the completion of rapid chilling) until the holding cycle set point is reached.

Typical cooling curves achievable with this method are shown in Figures 3 and 4 for two classes of livestock and these can be compared with Figure 5 which is representative of the slower chilling rates common in the industry. Hot-gas reheat was included in the Figure 5 cycle, despite the fact that 20°C deep-butt temperature was barely achieved in 20 hours.

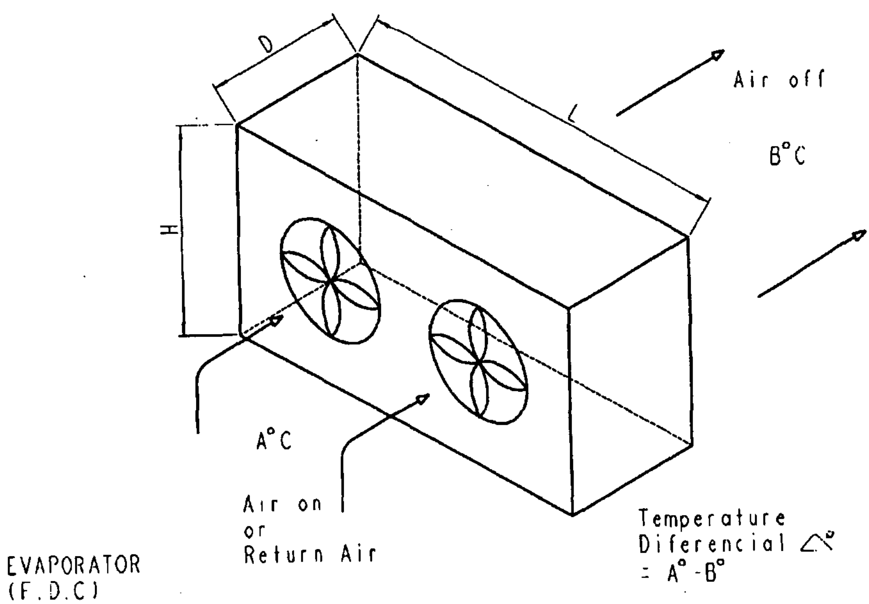

Figure 7 Air circulation diagram

Similar quick chill strategy was employed during a long weekend test run, see Fig. 6, which achieved a deep butt temperature of 20°C within 13 hours. A favourable out-turn was achieved at the end of the 88 hour chilling cycle:

- there was no drying out of the forequarter meat;
- the loin fat was noticeably soft;
- the boners' comments were favourable despite a 7°C deep-butt temperature.

9. Lamb Carcasses

Lamb produced for export chilled markets should be cooled rapidly to maximise shelf life, retain bloom, and reduce the weight loss.

Non-stimulated lamb muscles chilled below 10°C within 10 hours of slaughter will cold-shorten.

Shorthose (3) has shown that, unless very rapid chilling is used, the shear force values of the muscles will decrease with ageing and that most non-stimulated lamb would be acceptably tender after 3 days.

Since the majority of chilled lamb is exported as either vacuum packaged (VP) or, controlled-atmosphere packaged (CAP) in full carcass form or, as individual cuts, it is desirable to reduce the meat temperature to 0 0.5°C within 24 hours of slaughter.

This can be achieved by operating the chillers under the following conditions for unstimulated carcasses.

1. Return air temperature set point at 8 to 9°C during loading, with the evaporator fans providing sufficient air velocity to prevent fogging or condensation. If a chiller has both entry and exit doors, avoid opening them both simultaneously.

2. On completion of loading, close up the chiller, run the evaporator fans at sufficient capacity to achieve an air velocity of about 1.0 m/s, with the air-on temperature set point at 3 to 4°C.

3. After 5 hours, lower the air-on temperature set point to 0°C and maintain these conditions for the balance of the chilling period.

Stimulated lamb carcasses can be chilled with an air temperature of 0°C from the commencement of active chilling.

10. References

1. Herbert, L.S. 1977, "Carcass chilling in Australian abattoirs - summary of survey", *CSIRO Meat Research Report 9/77.*

2. Herbert, L.S. Anderson, J. & Larnach, W.K. 1977, "Carcass chilling in Australian abattoirs" *CSIRO MRR* July 1977, p. 42.

3. Shorthose, W.R., Powell, V.H. & Harris, P.V. 1986, "Influence of electrical stimulation, cooling rates and ageing on the shear force values of chilled lamb", *J. Food Sci.* vol. 51 (4), pp. 889, 892, 928.