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Rapid Carcass Chilling Plants Compared to Conventional Systems

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For many years the question of speed chilling of recently slaughtered carcasses has been a consideration for any cost conscious slaughterhouse operator. Thirty years ago most meatworks chilled their carcasses over a two day period which allowed for a flexibility of operation and simple low capacity refrigeration plant.

As meat products were further processed into cuts and retail products, the question of shelf-life became more important and with it the requirement to chill more rapidly to reduce bacterial growth.

The usual question nowadays is to chill all carcasses within a one day period at a faster rate to improve shelf-life, reduce working capital and cut back on building costs. However, chilling rates and performance varies significantly from plant to plant.

Over the last 15-20 years experimental chill tunnels have been developed to rapidly chill carcasses to further improve shelf-life and improve shrinkage of the carcass. Various combinations of air temperatures and air velocities have been advocated. Apart from the confusing claims from refrigeration contractors attempting to sell their equipment, other problems concerning meat quality, hygiene requirements and costs become evident, all of which must be addressed to arrive at the most suitable arrangement to provide good quality meat and economical operational procedures.

This paper looks at these conflicting requirements and separates the various elements so that a slaughterhouse operator can make a sensible decision as to which type of plant, conventional or blast chilling, will suit his operation best.

Conventional Carcass Chilling Systems

The EU requirement for carcass chilling stipulates that beef and sheep carcasses must leave the chilling rooms at a temperature no higher than 7°C. Pig carcasses must reach 4°C.

Thus the general practice for two day chilling was to design the refrigeration plant to extract the heat output of the carcasses over a steady 48 hours, and this was done by maintaining the chill room air temperature at around either 7°C or 4°C, depending upon whether pigs or other species were being chilled. For all intents and purposes, after 48 hours, the deep leg temperatures for the complied to the EU requirement.

The most common system for carcass chilling nowadays is a one day turnaround, Most slaughterhouses in Europe have refrigeration plant to achieve the EU temperatures for sheep and pigs, but inadequate plant for providing a satisfactory beef carcass temperature. However, due to inadequate authority control, the plants carry on operating with beef carcasses leaving the chillers with deep leg temperatures well in excess of 7°C.

In designing a good beef chilling plant to achieve 7°C deep leg temperatures after 24 hours, Figure 1 provides the basic information necessary for the refrigeration contractor to design his plant and equipment.

Form this graph produced by the Meat Research Institute in Bristol, it can be seen that with an air temperature of 0°C a deep leg temperature of 7°C can just be achieved within 24 hours for a light 100 kg beef side. Our own experience shows that a constant temperature of $^{-}$1°C throughout the 24 hour period is necessary to achieve

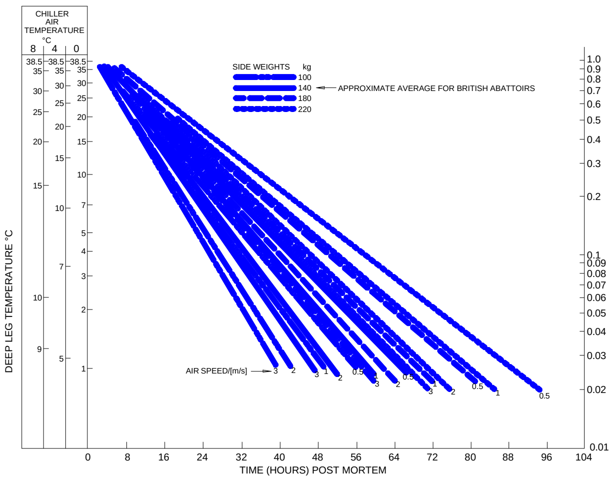

Figure 1 Air Velocity/Temperature Options for Beef Chilling

the requirements for larger more common stock together with an air velocity of at least 1-2 metres/sec across the hind quarter. Very few plants can achieve this requirement.

Apart from not meeting the official EU requirement, the shrinkage figure i.e. the water extraction element is higher than it should be.

The question of weight loss is extremely important. The old two day chill cycle will for beef end up with a shrink loss of some 2.4%, while a well designed 24 hour unit using $^{-}1^{o}$C air temperature and 2 metres/sec air velocity will give a shrinkage of approximately 1.2%. A poorly designed 24 hour unit could result in a shrink loss of some 1.8%.

Weight loss represents a large drop in revenue. For a beef slaughterhouse processing 500 cattle per day with an average weight of 600 keg per body and a selling price of 75 pence/lb., working 250 day per year, losing 1.2% of weight, the difference between two day chilling and 24 hour chilling will result in a loss of some £675,000 in revenue per year. With today's tight margins, this sort of money is critical to whether or not the operation stays in business.

It can be seen therefore that weight loss is a most important factor in the economics of chilling systems for carcasses. Generally speaking, the faster the carcass is chilled, the lower the weight loss becomes and the longer the shelf-life of the product. We have in our period as meat packing plant specialists obtained extensive experience of actual figures achievable from operational meatworks.

Rapid Carcass Chilling

Due to the very substantial savings achievable in reducing carcass weight loss achieved with effective 24 hour chilling, research has been carried out into systems for very rapid chilling to achieve further savings and to help in reducing bacterial contamination and extending shelf-life.

a) Beef Carcass Chilling

After substantial trials carried out in conjunction with the Meat Research Institute, we concluded that the most practicable system to develop for beef carcass chilling was one with initial air temperature of $^{-}15^{o}$C and a velocity of 3 metres/sec across the hind quarter for approximately 5 hours, and from this period onwards the refrigeration system was turned off and the air temperature and carcass temperature then allowed to equalised so that at the end of the 24 hour period, all elements of the carcass reached a temperature of 7^{o}C. Figure 2 provides the temperature curves for the various parts of the carcass.

These results were obtained form an actual operating chiller built in one the large Australian beef plants. The intention of the tests were to conclude once and for all the practical problems of operation such a system and to determine exactly the shrink savings possible under operational conditions. In this regard sample bodies of beef had their separate sides chilled conventionally while the other side was chilled in the new chiller.

The results from these tests concluded that the conventional chillers would achieve nearly 1.2% shrinkage, while the new rapid chill unit achieved 0.6%. This represented again with a plant processing 500 beef per day some additional £325,000 of revenue per year.

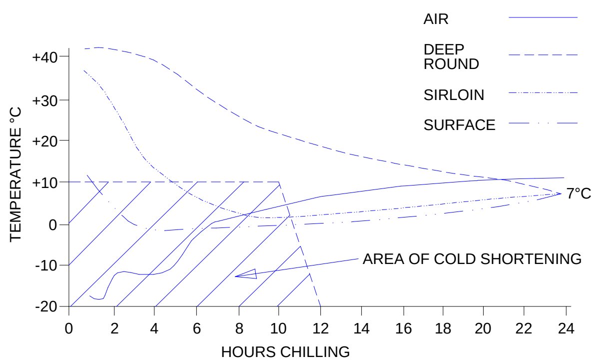

Figure 2 Rapid Beef Carcass Chilling

b) Pork Carcass Chilling

Considerable work has also been carried out on plant trials for pork chilling. In the case of pork where well designed 24 hour chilling produce shrinkage of 1.6% , blast chilling the carcasses for 3 hours at an air temperature of $^{-}15^{o}$C and then allowing temperatures to equalise at 3^{o}C for the remaining chill period will improve this figure to 0.9%. Thus similar revenue savings are possible with pork as with beef.

Practical Rapid Chill Problems

From the above the advantage of rapid chilling of beef and pork carcasses are clear. Firstly, there is a large revenue improvement to the business and also a significant improvement in shelf-life of the product which is important in today's climate of preparing chilled portions of ready to cook products compared with the old conventional practice of producing carcasses for butchers' shop use. However, these are some significant practical problems to be solved :

- Retention of good meat quality
- Slaughterhouse hygiene considerations
- Capital cost of rapid chill plant

Provided economic answers to these above points can be achieved, then the basis of rapid carcass chilling for introduction into meat processing establishments can be established.

Product Quality

The essential requirement for any meat product must be tenderness. In the past this has always been enhanced by ageing the meat. The problem that needs resolving with respect to any form of fast carcass chilling is meat toughening which comes about from a phenomenon called "cold shortening".

Cold shortening occurs in a carcass of on entering the chill room the pH of the meat is above 6.5 and the carcass in then rapidly chilled. Under normal processing, beef and lamb carcasses reach the chill room with pH reading well in excess of 6.2. Each species of meat is affected differently with beef and lamb the most seriously damaged with rapid temperature reduction. The following table highlights the differences:

	Temperature	**Time from Slaughter**
Beef	10^{o}C	10 hours
Lamb	10^{o}C	10 hours
Pork	10^{o}C	0.5 hours
Poultry	10^{o}C	0.3 hours

Table 1 Temperature/Time relationships for cold shortening

What Table 1 shows is that if a beef or lamb carcass is chilled below 10^{o}C in under 10 hours from slaughter, then part of the carcass so affected will become "cold shortened". Likewise, if a pork carcass was reduced to below 10^{o}C in under ½ hour from slaughter, then it would be toughened likewise. Thus we have a problem in achieving long shelf-life by fast chilling for beef and lamb by toughening the meat as shown in Figure 1, when the carcass is too rapidly chilled.

Fortunately, due to extensive work carried out in New Zealand in the early 1970s, a solution to this problem was developed by the application to the carcass of electrical currents. By passing these electrical currents through the carcass, commonly known as electrical stimulation, either shortly after slaughter or during dressing, the process of rigor mortis is accelerated and the pH of beef and lamb carcasses after 30-45 on the dressing floor can be reduced to below 6.2 prior to entering the chiller. This immediately allows rapid chilling to be carried out while preventing the toughening process taking place.

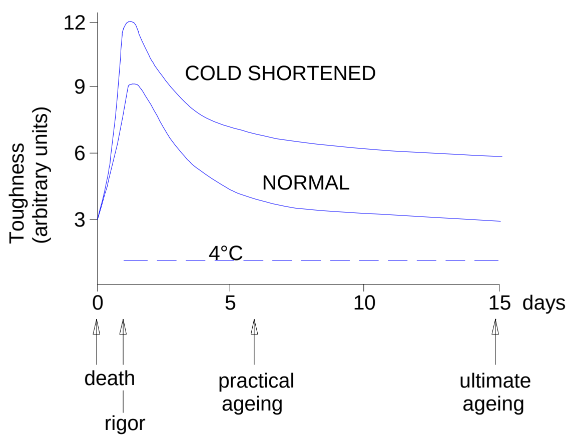

Figure 3 Changes in Toughness of meat after cooking during processing

Figure 3 explains the cold shortening phenomenon in relation to tenderness and meat quality and shows the toughness of meat on a time basis from slaughter. Meat cooked immediately after slaughter is tender – it has been given a rating of 3 toughness units on this graph. If handled normally and cooked in rigor (after 24 hours) it is excessively tough (up to 9 equivalent toughness units); after the resolution of rigor (2-3 days), the toughness will decrease rapidly to about 6 units and from then it will disappear slowly during ageing until, at about 14-20 days, it returns to the original value of 3.

Figure 3 show the same profile of toughness for cold shortened meat which comes about from fast chilling, and the toughness also reduces during the ageing process, as before, but the final aged product can end up with double the toughness factor of normal non-cold shortened product. This difference is unfortunately irreversible and the cold shortened product toughness cannot be further improved with ageing.

Thus, for today's high quality chilled product requirements, cold shortening meat products is simply not acceptable. However, as explained above, electrical stimulation of the carcass can and does eliminate this problem.

Thus, for lamb and beef plants operating with well designed 24 hour or blast chilling facilities, electrical stimulation is essential. Figure 2 shows the areas of the carcass where cold shortening is relevant, and the loin in particular can be badly affected which in practice is the most important part of the carcass.

Slaughterhouse Hygiene Considerations

The faster the carcass chilling the less bacteria build up on the carcass surface is evident and thus the longer the product shelf-life should be. Thus rapid chilling is most beneficial for improved shelf-life.

The worry that always exists in carcass chilling is the formation of condensation in the chillers when overhead drips take place from the ceiling and rail equipment onto the carcasses.

In Australia, New Zealand and South America this has been a continual hygiene nightmare where visiting veterinarians condemn facilities due to condensation, with respect to the rapid beef chiller as represented on Figure 2 where freezing conditions are applicable for the first several hours, our concerns rested with the anticipated condensation that would occur when the 19 hours of temperature equalisation occurred. The operational chiller was set up with see-through inspection holes so that the whole process could take place with the doors permanently closed. To our surprise the initial formation of small areas of frost formed on the internal structures of the chiller gradually disappeared without water droplets forming. In fact the chiller had less problems with condensation than any we had encountered before. Our conclusion was that the ice went through a sublimation process where the ice evaporated to water vapour in one process. Thus our concerns relating to hygiene and condensation in particular were groundless.

Design of Rapid Chill Plant

Our last consideration to evaluate is the design and capital cost of the high speed chiller and refrigeration plant. Obviously the increased cost of the plant and its running costs must be significantly below the shrink savings to justify the process.

In order to achieve the exceptionally low weight loss of blast chilling, it is essential to hold the air temperatures at $^{-}10^{o}$C, or below, right from the beginning of the chilling cycle (see Figure 2). This low temperature together with an air velocity of over 2 metres / sec must be maintained until all the heat is removed from the carcass, which will be about 4-5 hours for beef and some 3 hours for pigs before minimal air velocities with no refrigeration equalise that carcass temperature over the remaining 19-21 hour period. This procedure requires a very large installed evaporator surface area. If each chiller fitted with this requirement, then the cost of the installation would be prohibitive. Thus for blast chilling it is essential to design a rail conveyor through a specially designed pre-chiller so that the carcasses achieve their first hour chill prior to moving onto batch units. See Figure 4.

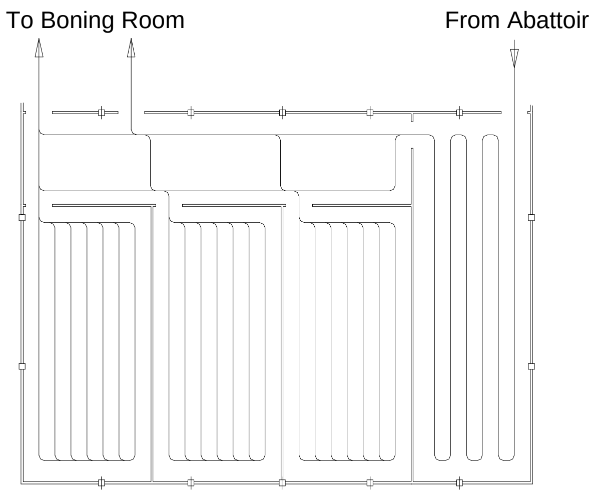

Figure 4 Blast Chilling Systems

The batch chillers, as shown on Figure 4, which complete the process can have conventional evaporator configurations with the necessary enhanced surface areas to deal with the maximum heat transfer requirement for the second and subsequent hours of chilling. The conveyorised first hour chiller must have the air flows directed down over the hindquarter of the carcass.

In order to understand the necessity of having continuous conveyored pre-chilling pre-chilling, we must consider the heat transfer from a hot carcass over the chilling period. Many designers not aware of the rate at which is extracted from a carcass, design evaporator surface areas on the basis of the total heat removal over the chilling period.

Newton's law of cooling tells us that the rate of cooling is proportional to the temperature difference between the cooling medium and the cooled product. Thus the average temperature difference between the carcass and the cooling air for a well designed 24 hour chiller may be some 18^{o}C, while the temperature difference in the first hour could be some 30^{o}C, giving a rate of cooling increase some 70%.

In case of blast chilling as defined by Figure 2, the evaporator surface area must be further increased in order to achieve the necessary constant air temperature. Our calculations and experience, taking into account the very large heat dissipation in the first hour of chilling compared with the average rate and the necessity to maintain a constant air temperature throughout the heat extraction period, have shown that the evaporator surface areas must be increased from approximately 9.5m^2/head chilled for 24 hours to 28m^2 fir a beef facility. Hence the very large increase in capital cost for the rapid chill plant.

Finally, we must look at the plant room requirement. Figure 5 shows the vastly increased size of plant room necessary for the blast chill option which, as the daily processing builds up, requires some 2kW/head of beef/day. Similar figures would apply for pork.

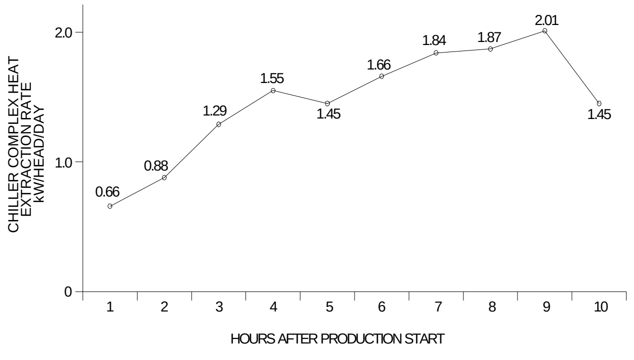

Figure 5 Plant Room Refrigeration Loads vs Time

The point here is that to determine the evaporator sizing is straightforward once the data has been provided, but when it comes to plant room sizing, the maximum daily loading which is needed to size the plant is not so easy to determine.

The graph (Figure 5) is of a one shift beef operation with the worst situation occurring in the 9th hour after processing starts. The maximum extraction rate of 2.01 kW/head/day compares with a maximum requirement of only 0.9kWs for the usual 24 hours chilling cycle and when the high capacity requirement for blast chilling is also equated to the machinery having to operate at a suction pressure $^{-}$25^{o}C for the blast chiller, as against $^{-}$10^{o}C for conventional 24 hour beef chilling, the enormously increased plant room refrigeration capital and electricity costs can be better understood.

Economic Evaluation

The conclusions we reached from our extensive experience and operating tests on the economies of beef carcass chiller design, Table 2 shows the relevant cost differences of capital costs, electricity consumptions and weight losses for each of the two chilling options

	Capital Cost	**Electricity Cost**	**Weight Loss**	**Total**
24 hour	£1.67	£0.22	£7.92	£9.81
Rapid Chill	£3.20	£0.48	£3.96	£7.64

Table 2 Production cost/head of beef for different systems

These beef figures have been assessed from an actual operating plant and show how the rapid chiller could save overall some £2.20 per carcass processed over the 24 hour chill or, for a medium sized beef factory processing 125,000 head/year, approximately £275,000/year.

Adequate evaporator surface areas and fan capacities must be installed to achieve the required air temperature for the whole heat removal cycle time with the most suitable configuration of rails, carcass hanging position and evaporator location to obtain the required air velocities across the carcasses and achieve the necessary heat extraction rates.

The details shown in Table 2 are related to beef chilling. The same principles apply to pork, and again the most economic design solution should be chosen. In the case of pork carcasses, the blast chiller will save approximately

0.7% in weight over conventional 24 hour chilling and with a plant processing say 3000 pigs / day, a yearly saving in revenue of around £500,000 will be achievable from weight loss alone.

Conclusion

The chilling of carcasses used to be carried out in a two day cycle. Due to the development of prepared cut and meats offered in the supermarkets the question of shelf-life and its extension has become a priority. In general terms, the more rapid the chilling time of a carcass, the longer the shelf-life of the final meat product becomes and the less weight loss occurs during the chilling process. Thus nowadays most slaughterhouses chill carcasses on a one day cycle.

More recently, the rapid chilling of beef and pork carcasses has been assess with the object of reducing weight loss and increasing revenue. Weight gains of some 0.6% can be achieved for beef and similar gains for pork. However, rapid chilling results in high capital and electrical costs. It also can result in toughening of the final product but this has mainly been eliminated by the process of electrical stimulation on the slaughterfloor. This paper has covered some of the design requirements for rapid chilling of carcasses and particularly beef carcasses and, having carried out on plant trials with rapid chill rooms operating on a day to day basis, the overall conclusion is that after taking into account capital costs, electricity charges and weight savings, a properly designed rapid beef chiller could save about £2.20 per carcass processed or some £275,000 per year in a medium sized beef processing factory. Similar figures are applicable for rapid pork chilling.

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