Non-traditional Refrigeration Technologies for Efficient Meat Processing

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ABSTRACT

Refrigeration has long been recognised as a high cost to meat processors, particularly in terms of equipment and energy costs. In recent yea however, more and more meat processors have recognised that not only is refrigeration essential to the preservation of meat products, but al the way it is applied to the product can have major effects on quality attributes such as tenderness and retail presentation. This paper discuss non-traditional chilling and freezing methods and process technologies that offer meat processors more direct control of product temperatures a quality attributes, as well as significant energy savings, when compared to conventional air-based cooling technologies. It also presents a visi of how boning, cooling, and packaging activities might work together in the future to streamline operations and reduce overall processing co

INTRODUCTION - REFRIGERATION FOR MEAT SAFETY AND QUALITY

Refrigeration systems are an integral part of meat processing plants. They are generally recognised as high cost operations, since they have hi installation costs and significant maintenance and running (particularly, energy and labour) costs. It is critical to make the right decisions at design stage to minimise refrigeration costs over the life time of the plant; however, all the purposes of refrigeration systems are not alwa suitably recognised or considered during design.

The key functions of a meat plant refrigeration system are:

- To provide temperature/time conditions that produce a safe food product and satisfy regulatory requirements.
- To provide temperature/time conditions that enhance or maintain product quality attributes (e.g. tenderness and colour for table cu functional properties for manufacturing meat).
- To satisfy production goals for cooling cycle times and product throughput.
- To provide cooling at the lowest possible cost in terms of carcass weight loss, energy and labour costs, etc.

The ordering of the above points is deliberate. Meat plant staff and refrigeration process designers must view refrigeration process technolog as existing first and foremost to manipulate product temperatures to produce a safe product with desirable eating and/or further processi characteristics. Equipment capital cost and energy consumption should take a lower priority. Figure 1 illustrates an appropriate "inside-out" "product first" approach to refrigeration process design.

A "product first" approach is essential since plant profitability hinges on having a safe and enjoyable product to sell. At the same time, it mak sense from an energy perspective: it is well known in the energy management field that reducing energy demand on the product side has far grea benefit than improving energy efficiency on the equipment side of the process.

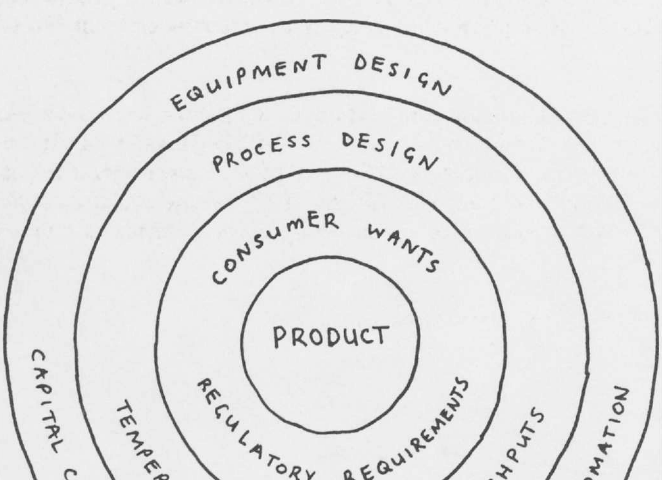

Figure 1.
Diagram illustrating a "product first" approach to refrigeration process design.

Once the product requirements have been defined to ensure product meets the market needs, the production goals can then considered in the design. Since labour is the largest operating cos a meat plant, the production goals often mean scheduling refrigerat processes to fit in with normal labour availability times for the carc boning, packaging and product handling operations. Ot production-driven goals may include getting the most out of refrigeration system (or, more realistically, pushing the most prod through it) and minimising product yield losses through moist evaporation from carcass surfaces or purge loss from packaged m

Once the process cooling conditions have been defined, based on product and production goals, it is then appropriate to consider h to deliver the cooling conditions in an energy-efficient mann Regardless of the product and production constraints, it is alm always possible to make significant differences to refrigerat process energy consumption through smart decision making at design stage. This paper will discuss technologies and processi changes that could play a big part in reducing meat plant energy co in the future.

The discussion will draw on the author's experience in the N Zealand and Australian meat industries when discussing refrigerat process technologies and meat processing operations. Neverthele many of the principles discussed will have applications in m processing plants with similar characteristics worldwide.

THE MEAT PROCESSING TEMPERATURE/TIME ENVELOPE

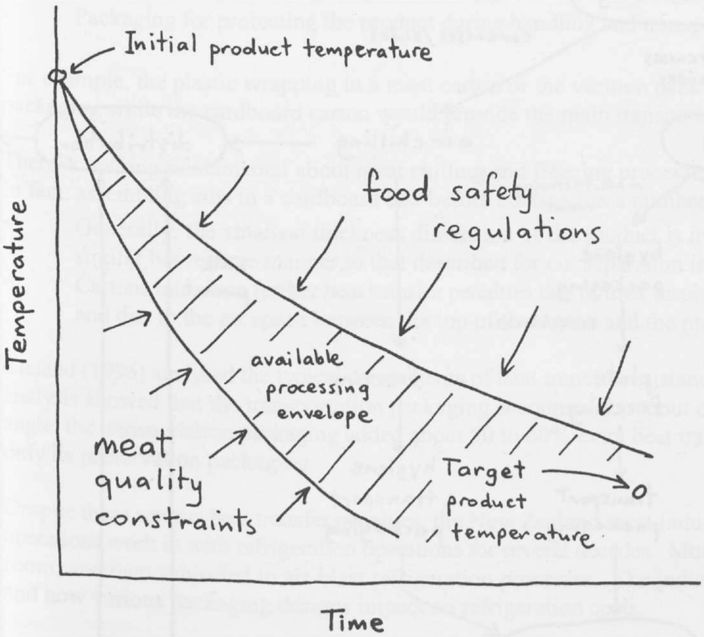

Figure 2.
Schematic of the available temperature/time envelope for meat processing and handling (after Fleming *et al.*, 1996).

Achieving the above-mentioned key functions of the refrigeration system can be a complicated task for the designer, especially when it is recognised that product safety and quality objectives often drive the product temperature/time requirements in opposing directions. Figure 2 illustrates how these two main objectives combine to form a defined product temperature/time envelope for meat processing.

In recent years, the available envelope size has diminished through pressure from both the upper and lower bounds. The upper bound has moved downwards as food safety regulations have become stricter, and it may continue to move downwards as consumers react to the occasional high profile food poisoning incident (e.g. the new USDA FSIS proposal for food transport and storage rules (USDA, 1996)). The lower bound has moved upwards from time to time, as cooling conditions have been specified to achieve a tender product (e.g. the Accelerated Conditioning & Aging process used in New Zealand for lamb). The narrowing envelope provides a challenge for meat processors and refrigeration process designers: designing refrigeration processes that meet both quality and safety requirements will probably become more difficult, so new approaches and process technologies will need to be developed.

NEW APPROACHES AND PROCESS TECHNOLOGIES FOR MEAT REFRIGERATION

Following on from the previous discussion, it is perhaps timely for the meat processing industry to take a fresh look at refrigeration process technologies, how to implement them, and how to integrate them with boning and packaging operations. Meat processors and refrigeration system designers need to start asking questions like: What temperature/time treatment does this product really need to meet the customer's quality needs? Can we chill or freeze this product in less time with less energy? Which chilling or freezing technology is the most appropriate and cost effective for this product?

The answers to such questions should be developed from a broad perspective, again driven initially by the regulatory and end-use requirements peculiar to the product. For instance, hot-boned manufacturing-grade boneless meat destined to be minced or ground can be frozen quickly because cold shortening is not usually a concern, whereas boneless primal cuts destined for the chilled market may need to be cooled according to a specified temperature/time process to achieve a tenderness standard without compromising hygiene regulations. While these are broad examples, they serve to illustrate that the appropriate refrigeration processes for different product types with different quality needs will almost certainly be quite different.

In order to maximise their control over product temperatures, processors need to follow four basic principles:

- Separate muscles with dissimilar cooling needs as soon as possible
- Minimise the product item size before cooling
- Maximise exposure of the product surface to the cooling medium
- Maximise the product surface heat transfer coefficient

Based on these principles, Figure 3 illustrates a futuristic abattoir with substantial changes to the basic design of and interactions between processing, refrigeration and packaging operations, when compared with existing plants.

This picture can be applied to domestic or export meat processing plants, regardless of how much further processing they do, by simply shifting the boundaries and following the same principles. In practical terms, the changes required to obtain greater control of the product (rather than cooling medium) temperature can be summarised in three basic rules:

- Cool after boning (e.g. after the "separation operation")
- Cool before bulk packing for transport
- Cool using direct contact refrigeration equipment

Each of these rules will be discussed in turn.

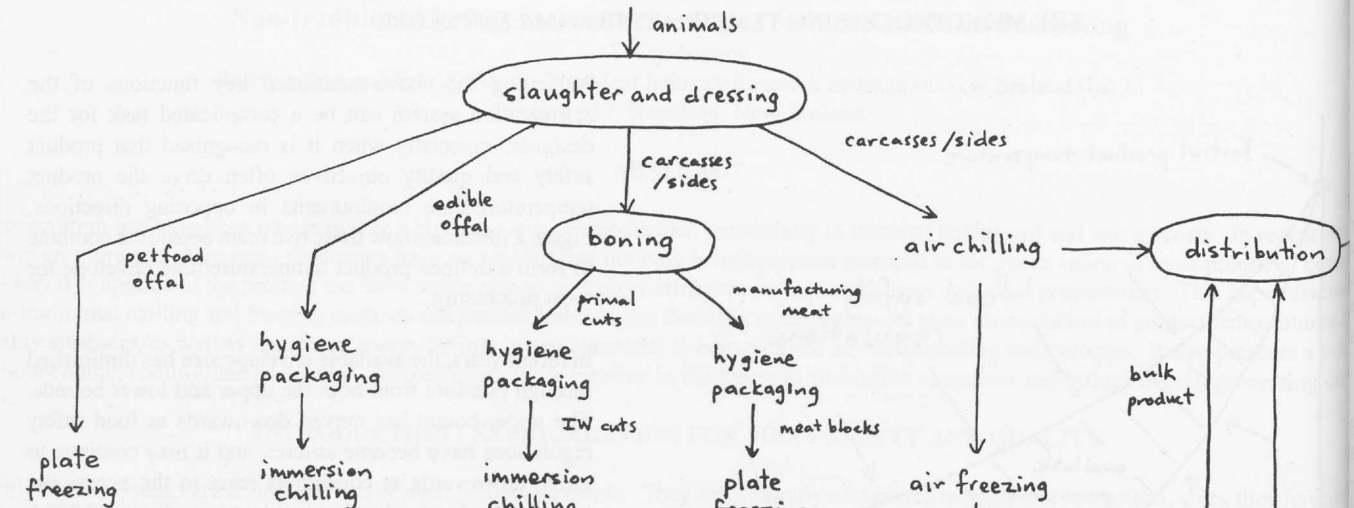

Figure 3.
A vision for a future beef and lamb abattoir, emphasising product cooling, packaging and handling operations (based on Chadderton & Cleland, 1993).

Cool after boning
Fast and efficient cooling can best be achieved by applying refrigeration to product items of the smallest possible size. On this basis, process should, whenever possible, schedule their cooling operations to occur after carcasses have been broken down into cuts (i.e. after carc disassembly or boning) and before packaging them for transport (i.e. before assembly of the product into cartons or other bulk packs).

The length of the cooling cycle is approximately proportional to the product's smallest thickness dimension, that is: the shortest distance thro the centre of the solid (Cleland & Earle, 1982). For example, the characteristic dimension of a 280 kg beef carcass is normally around 200 m whereas the characteristic dimensions of cuts derived from that carcass would normally be less than 100 mm. By cooling individual cuts inste of carcasses, a beef processor could reduce cooling cycle times from 24 or 48 hours to less than half that time with conventional air-blast syste The impacts of shorter cycle times on equipment space requirements and baseload energy usage are discussed by Cleland (1997).

This rule has important implications for boning practices. With cold boning, each carcass is subjected to the same cooling conditions as ev other carcass, but the temperature profiles for different cuts within a carcass can be quite different, since they depend on the depth of placem of the respective cuts within the carcass. Having some of the more valuable but sensitive (to cold shortening) cuts on the outside of the carc may therefore constrain the cooling regime for the entire carcass.

Hot boning separates carcasses into cuts prior to cooling, and thereby provides an opportunity to customise temperature/time treatments accord to the specific quality requirements of different cut types. While hot boning has often been promoted as a means of reducing processing co it may well turn out that the ability to manipulate individual meat cut temperatures for improved and more consistent end-point quality a functional characteristics will be its most valuable benefit.

Moving to faster cooling of individual hot-boned product items involves a number of potential benefits, as well as raising some potential proble that must be overcome. For instance:

- Microbial growth will be reduced and storage life could be extended (through rapid surface cooling).
- Moisture loss during carcass chilling is avoided.
- Moisture losses (purge) in packaging could be reduced, thus improving customer satisfaction.
- Tenderness must be assured for high value cuts, probably through new process cooling specifications.
- Cut shapes could be distorted by cooling cuts off the carcass, unless new packaging designs or refrigeration equipment can be develope

In New Zealand, many plants use hot boning, and so interest in faster cooling methods for meat cuts currently high. Consequently, research under way to quantify the impacts of faster cooling regimes on tenderness, colour and other properties that are important to high value red me products, as will be discussed later.

Cool before bulk packing for transport

For the purposes of this paper, it is useful to classify packaging into two main types:

- Packaging for preserving the product's hygiene and extending its storage life.
- Packaging for protecting the product during handling and transport.

For example, the plastic wrapping in a meat carton or the vacuum pack on a meat cut would be the primary preservation (hygiene and storage) packaging while the cardboard carton would provide the main transportation packaging.

There is nothing fundamental about meat chilling and freezing processes that locks the meat industry into cooling the product in 27 kg cartons. In fact, assembling cuts in a cardboard box before cooling has a number of distinct disadvantages:

- Generally, the smallest thickness dimension of the product is increased by almost a factor of two, which slows the cooling cycle (in a similar but reverse manner to that described for cut separation in the last section).
- Cartons introduce further heat transfer penalties due to their insulating cardboard layer, due to air voids that occur between product items, and due to the air space between the top of the carton and the product.

Cleland (1996) analysed the typical components of heat transfer resistance for beef frozen or chilled in cartons, as summarised in Table 1. That analysis showed that the transportation packaging accounted for about one-third of the heat transfer resistance during cooling, or, from another angle, the transportation packaging added about 50 to 60% extra heat transfer resistance over the resistance present if the product was cooled in only its preservation packaging.

Despite these serious heat transfer penalties, the New Zealand meat industry has made few changes to the basic carton design or how packaging operations work in with refrigeration operations for several decades. Most meat cuts continue to be sorted and packed into cartons in the boning room, and then subjected to air-blast refrigeration processes. The industry could benefit from considering the timing of packaging operations, and how various packaging designs impact on refrigeration costs.

In particular, opportunities exist for meat processors and equipment designers to look at ways to cool meat and offal contained in only their preservation packaging. A few possible alternatives are listed below, in order of change from existing practices:

- Air-blast cooling of product on flat plastic trays or conveyors.
- Dense spray cooling.
- Liquid immersion cooling.
- Cooling between flat refrigerated plates.
- Cooling in moulds, preferably designed to shape the product.

Table 1.
Typical components of the heat transfer resistance for an air-blast carton cooling process (after Cleland, 1996).

Source of heat transfer resistance	Frozen beef	Chilled beef
1. Convection boundary layer	0.04	0.04
2. Carton wall	0.02	0.06
3. Trapped air between carton and product	0.04	0.04
4. Product internal conduction	0.06	0.17
Total	0.16	0.31
Packaging effect (2 + 3)	38%	32%

The key result for all of these options is that they would provide faster heat transfer and more direct product temperature control by getting away from the insulating carton during cooling. Packaging for transport would occur only after the product has been cooled to its required storage temperature.

A number of New Zealand processors have investigated the use of bulk bins as an alternative transportation packaging. From the perspectives of market opportunity, packaging cost and waste minimisation, this may be a step forward. However, for this approach to succeed, it is extremely critical that the individual product items are cooled to (slightly below) their final storage temperature before they are packed in the bulk bin. If the product is not properly cooled before packaging it in the bin, the processor will end up with either a costly product disposal problem or a costly re-packaging exercise, since it impractical to cool product items with such a large thickness dimension (normally 500 mm to 1 m).

Cool using direct contact refrigeration systems

The refrigeration systems used today in the meat industry differ very little from those used thirty years ago. Meat processors still predominantly use air-blast refrigeration systems to cool meat carcasses and cartoned product. Times are changing though: with growing end-user interest in product quality attributes, and stricter market requirements for cooling regimes, some meat processors are starting to seriously investigate the opportunities presented by direct contact cooling systems.

Figure 3 attempts to match appropriate refrigeration process technologies to common beef and lamb product types. Its vision for the future involves using immersion or plate contact cooling systems for most meat and offal refrigeration processes, with air-blast cooling retained only for refrigerated storage and for a few applications that do not suit contact refrigeration systems due to shape or packaging constraints.

<u>Immersion contact refrigeration</u> should be considered where the product shape is non-uniform and after the product has been wrapped in its preservation packaging. Immersion refrigeration units normally use relatively inexpensive fluids like water or brine, which are cooled and circulated around the immersed product in a large bath or tank. This type of technology is well-used in other food industries - e.g. hydrocoolers for stonefruit, and spin chillers for poultry. In the meat industry, immersion chilling has been applied (without sophisticated temperature/time regimes) for some products that do not need to achieve tenderness criteria by avoiding cold shortening.

The potential advantages of immersion chilling over air-blast chilling include:

- Faster cooling times.
- Rapid surface temperature drop (and hence lower microbial growth).
- Ability to manipulate product temperatures directly.
- Less moisture loss in wrapped cuts.
- A physically compact refrigeration process.

For red meat applications, the faster temperature/time regimes possible by using immersion chilling will affect meat tenderness and other qu attributes - particularly for hot-boned meat. Over the last two years, MIRINZ meat scientists and refrigeration engineers, and Massey Unive food technologists, have been working together on a project funded by the New Zealand Meat Research and Development Council (MRDC, 19 to design and demonstrate an immersion chilling system for hot-boned meat cuts. This work has shown that individual cuts chilled rapidly i immersion chiller can achieve similar meat tenderness scores to conventionally cooled meat provided that appropriate processing specificat are followed.

Figure 4 shows temperature/time profiles for hot-boned primal cuts cooled using immersion or air-blast chilling technologies, as predicted u computer software (MIRINZ, 1994). Based on the temperature profiles in Figure 4, the predicted hygiene results for the faster cooling regi were superior to those expected for cartoned hot-boned product cooled in air-blast chillers, but the predicted tenderness scores for immers chilled product were somewhat poorer, based on standard equipment operating practices. To achieve desired tenderness criteria, diff combinations of electrical stimulation, pre-rigor aging, and post-cooling aging parameters have been determined for meat destined for consumption (e.g. domestic market or air freight transport) and for consumption after extended storage (e.g. sea freight transport to export mark

Using the results of the meat science research, MIRINZ engineers designed immersion chilling equipment that promised economic advant over air-blast systems, as long as the immersion chiller could be utilised for two or more product batches per day. Although the en consumption of the immersion chiller was estimated to be only about one-third that of an air-blast system, the estimated capital cost o prototype equipment was about 50% higher. Since then, MIRINZ has worked with a meat company to design and evaluate a cheaper and m automated design of immersion chiller that should achieve significant cost reductions compared with air-blast chillers if it meets its meat qu and engineering objectives.

To date, MIRINZ's recent work has focussed on immersion chilling of pre-packed hot-boned meat cuts, since this is probably the most challen application in the red meat industry from the point-of-view of product issues. Immersion freezing systems using low temperature glycol f on the other hand, have been commercially available for some years. Frazerhurst *et al.* (1971) and Downey (1988) showed that immersion free of packaged offal is a viable process from an economic and product quality perspective, but even so the technology has not yet been taken u New Zealand meat processors.

Plate contact refrigeration should be considered where the product is slab-shaped or can be fitted between or deformed under parallel flat surf without affecting its value. Plate refrigeration units evaporate cold refrigerant (normally ammonia) inside metal plates placed on either sid the product. In the meat industry, plate technology has been most commonly applied to freezing cartoned meat. It has occasionally been u for freezing bare offal destined for petfood processing.

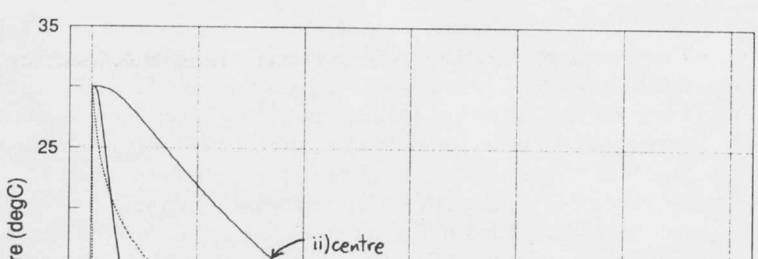

Figure 4.
Predicted meat centre and surface temperatures for: i) immersion chilling of packaged cuts; ii) air-blast chilling of meat cartons.

The advantages of plate freezing over batch air-b freezing include:

- Faster cooling times (and hence lower micro growth).
- Ability to manipulate product temperatures dire
- A physically compact refrigeration process.
- 30 to 45% lower energy consumption (as there no air-circulating fans and cycle times are shor
- Less carton bulging, which can lead to up to 3 greater space utilisation in cold stores and u 10% higher payload in refrigerated contai (Visser, 1995).

The disadvantages compared to manual air-blast free can include:

- 20 to 30% higher capital costs for manual p freezers, higher still for automatic freezers.
- Higher labour costs (for manual freezers).
- Need for cartons between adjacent plates to b the same thickness.
- Damage to cartons due to ice build-up on plate

Some of these issues do not always apply. For instance, some hot-boning plants claim that they have overcome the carton bulging problem with air-blast systems, and users of plate freezers should be able to minimise carton damage through appropriate design and work practices.

de Jong (1994) did an economic analysis of the potential benefits of plate freezing versus manual or automatic air-blast freezing of meat cartons, from the perspective of the entire plant refrigeration system, and Fleming *et al.* (1996) produced a modified analysis that accounted for labour cost differences between the three options. Table 2 presents a reworked economic analysis from the perspective of the freezing operations only, and with the addition of a fourth option for plate freezing of bare meat.

Table 2.
Energy and cost analysis for the refrigeration requirements of a beef plant using plate or air-blast freezing options for 3,000 cartons per day.

	Four batch air-blast cabinets	Automatic air-blast tunnel	Manual plate freezers with cartons[1]	Manual plate freezers without cartons[1]
Energy analysis				
Freezing time, h	38	38	17	8
Freezing refrigeration load, kW	573	477	400	400
Power consumption[2], kW	480	360	250	240
Economic analysis[3]				
Capital cost, $'000	800	1,500	1,300	1,000
Annual capital charges, $'000	142	266	231	177
Annual energy costs, $'000	323	242	168	160
Annual labour cost, $'000	60	0	90	90
Total annual costs, $'000	525	508	489	427

[1] Assumes a carton height of 160 mm.
[2] Includes power used by compressors, fans and pumps for the freezers.
[3] Assumes a net electricity cost of $0.10/kWh, capital recovery over 10 years, and an interest rate of 12%.

Table 2 indicates that plate freezers are likely to be at least as economical as air-blast refrigeration systems for freezing cartoned product, but with only a 5% difference in the estimated annual ownership cost, it is not possible to say more than that. More importantly, it illustrates that plate freezing without cartons is potentially the most economic way to freeze meat blocks. By eliminating the carton, it is possible to at least double the product throughput per day, which should mean that this approach would require only half the amount of equipment used for plate freezing with cartons. The electricity consumption would be similar to that for plate freezing with cartons (although perhaps with higher peak demand charges), but the overall annual cost would be significantly lower than the other options. Cleland (1997) considers the energy consequences of plate freezing from a different angle, but with similar conclusions.

Equipment to freeze bulk meat without cartons is not yet commercially available. The Meat Research Corporation (Australia) is funding a project to develop "mould" freezers for freezing uncartoned manufacturing-grade meat (MRC, 1996), following on from work done in that country to develop large automatic plate freezers.

In summary

Whether or not the vision presented in Figure 3 eventuates in its entirety, several important technological changes are desirable from the point of view of refrigerated meat safety, quality and processing efficiency:

- Separate meat into individual cuts before cooling it.
- Cool meat before bulk packing it for transport.
- Cool manufacturing meat and low value offal with plate freezers.
- Cool high value chilled meat cuts and offal with immersion chillers.

Air-based cooling technology should be retained only for refrigerated stores, and for product sold in carcass form.

ENERGY AND REFRIGERATION PROCESS TECHNOLOGY

Energy comprises one of the most important operating costs to a meat processing plant. It is typically the third largest cost after stock procurement and labour, and is of about the same magnitude as repairs and maintenance (R&M) and packaging. This section assesses the likely impact of introducing non-traditional refrigeration process technologies on energy demands, with reference to the New Zealand situation.

Trends in specific electricity consumption

MIRINZ has surveyed energy consumption by the New Zealand meat industry about once every five years since the 1979/80 season. Figure 5 illustrates trends in specific electricity consumption (SEC), using data from Lovatt & Chadderton (1996)

In recent years, SEC has fallen. However, it is unlikely that much of this SEC improvement can be attributed to refrigeration technology changes. Limited capital available for investment has meant that generally only incremental improvements have been made to the design and control of refrigeration systems. When equipment has been bought, it has often been purchased from older plants that have closed, so the second hand equipment probably has inferior energy efficiency performance to brand new equipment. The improvement in SEC during the last ten to twelve years probably has more to do with logistical and baseload issues than it does with improvements to actual energy-using technologies. Some likel contributing factors include:

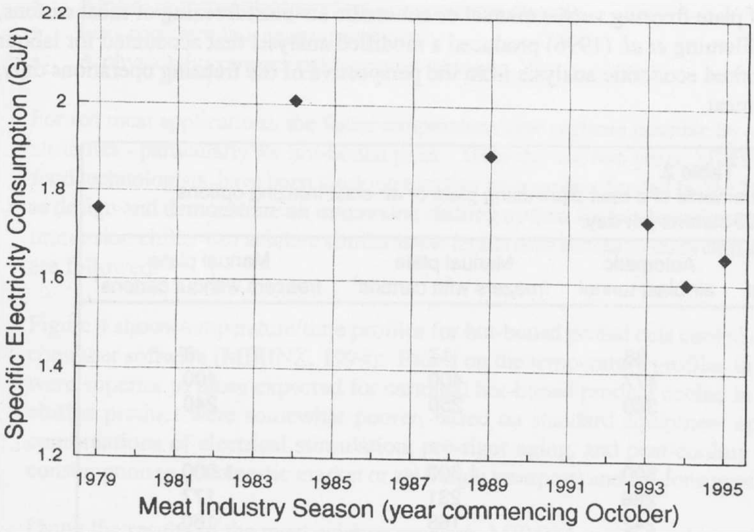

Figure 5.
Specific electricity consumption data for the New Zealand meat export industry, for October to September years between 1979 and 1995.

- An increased emphasis on chilled meat has reduce refrigeration running costs in accordance with change in the chilled-to-frozen product mix (although, th energy saving benefit may be counteracted to som extent by higher packaging costs).
- Many older plants have been closed and replaced b newer plants that have lower baseloads (as referred t by Cleland, 1997).
- Many meat plants have altered their procedures to foc only on meat processing operations (e.g. some new an existing meat plants do not carry out rendering or c products processing and some contract out cold storag to third parties.)

The consequences of other trends are less definite. F example, some meat industry designers have proposed that o of the main drives for moving from cold to hot boning energy savings "through not cooling the bones". In realit packaging the meat in cartons and cooling it under freezin (rather than chilling) conditions adds expense to th refrigeration process despite the fact that bones (and other lo heat capacity components) have been removed prior to coolin (Pham *et al.*, 1993). Ignoring the second and third rul discussed earlier (cool before bulk packing; cool using conta refrigeration) has probably diluted the energy efficienc improvements that might have been expected from hot bonin

In the last year or two, profitability has started to return to the New Zealand meat industry. Companies are looking to invest in projects that w enable them to meet stricter regulations for food safety and environmental discharges. Companies are also becoming conscious of energy cos and especially the possible added costs of carbon taxes or other charges that may be imposed by Government to reduce energy-related C emissions. Notably, plant managers and designers, who have been focussing their efforts on labour saving for the last decade or so, are no suggesting that further gains in that arena may be limited for the medium term, and that energy efficient technology will be the next area to targ for cost savings when modernising or building new meat processing plants.

Potential savings through refrigeration technology change

According to Lovatt & Chadderton (1996), energy currently accounts for about 5 to 10% of processing cost for a meat plant, depending on pla age, product types and other factors. On an industry basis, about 70% of the energy cost is for purchased electricity and about 70% of th electricity is used for refrigeration and air-conditioning applications. Published profit margins for New Zealand meat companies average abo 3% of turnover (NZMPB, 1997), which equates to about 12% of processing cost. Reductions in refrigeration-related energy consumption as function of product throughput are therefore valuable in terms of plant and industry profitability.

The refrigeration process technologies discussed in this paper have the potential to significantly reduce process energy demands. By eliminatin air-circulating fans and reducing cycle times (and consequent baseloads), contact refrigeration technologies offer 30 to 50% energy savings ove air-blast chillers and freezers. Considering that refrigeration accounts for about half the plant energy cost, and that air-blast chilling and freezin processes are easily the largest refrigeration loads, moving to contact cooling of individual product items could reduce energy costs by 10 to 15 for meat processors - equivalent to a 10% increase in profit margins.

It is possible that stricter cooling regulations, such as introduction of the recently-proposed USDA FSIS refrigerated temperatures proposal (USDA 1996), could necessitate a rapid uptake of contact refrigeration technologies in the near future. If not, then widespread adoption of the ideas an technologies presented in this paper will depend largely on the financial position of the meat industry, and on whether the various product quali and energy saving benefits can be demonstrated in practice.

CONCLUSIONS

When building new refrigeration processes, meat processors and designers should consider chilling and freezing technologies that are appropria to each product type and value. If there are product quality advantages to be gained from direct manipulation of product temperatures, or throug faster cooling for food safety, then processors should seriously consider contact cooling of individual product items (meat cuts and offal) afte boning and before bulk packing for transport.

Plate and immersion contact refrigeration technologies are not widely used in New Zealand meat plants at present, although interest is growin and some initial installations are in place or underway. With further meat science and engineering development, it should be possible to implemen chilling and freezing technologies that consume significantly less energy and give processors greater control of end-point product quality than is possible with current air-based cooling processes.

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