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# Refrigeration: underpinning the New Zealand economy for over 125 years

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***SUMMARY:*** *In 1882 the first refrigerated meat left New Zealand for London, the pioneering use of a technology that was to transform the New Zealand economy. Animals were no longer grown for wool only, and the wealth of the nation developed rapidly. From 1882 until as recently as the early 1990s refrigerated food has returned at least 30% of New Zealand's export income. Whilst much of the equipment has been imported, expertise in the application of refrigeration was developed in New Zealand. This paper describes some of the key engineering and technology developments through the history of the refrigerated food trade in this country. Examples include development of carcass freezers, boneless beef carton freezers, and systems development in the horticultural sector. It also identifies some of the iconic equipment systems used in the New Zealand industry, some of which have given reliable service for a century.*

## 1. FROM SUBSISTENCE TO PROSPERITY

In 1982, in a plenary presentation to the first conference of the International Institute of Refrigeration held in New Zealand (on the centenary of the first frozen meat trade), Professor Dick Earle wrote "Without refrigeration New Zealand would be a poor country in the South Pacific. Refrigeration gave New Zealand the opportunity to develop an extensive export economy, which has made possible a high standard of living for the population and the opportunity to be a world leader in social development. Refrigeration was, and continues to be, of utmost importance to the New Zealand economy and to the New Zealand people. It turned the blessing of a good climate for pastoral farming into a major economic resource" [1]. He went on to point out that New Zealand had the largest refrigerated storage volume per capita of any country, and that in 1980 36% of New Zealand's export earnings were from refrigerated food. For over a century refrigerated food was at least one-third of New Zealand's export earnings.

The earliest products were frozen meat, butter and cheese. There was considerable growth in animal numbers through the first half of the twentieth century, and then following World War II there were real boom times as New Zealand reached third place in the overall wealth rankings for nations. Our traditional trade partners (especially the United Kingdom) were short of food, and our part of the British Empire could supply it! With the ability to generate revenue from both wool and meat, the incentives to break in new land for sheep farming were considerable and large-scale land clearance occurred right through to the second half of the 20th century.

Somewhere in the 1970s or 1980s the peak importance of refrigerated food as an economic driver was reached. Sheep numbers peaked at about 70 million (they are now about half that number), and the dairy industry started to change with greater emphasis on protein-based rather than fat-based products. These declines were masked for a time through considerable growth of the beef industry and then venison, the fishing industry (following the declaration of a 200 mile economic exclusion zone), and the development of the apple and then the kiwifruit industries. Some of the newer food export industries (like the wine industry) and the food ingredient business of the dairy industry use considerable amounts of refrigeration, but their products leave our shores unrefrigerated.

In the 21st century, New Zealand has settled back to about 15th to 20th place in the world wealth rankings – about where we were prior to World War II. Looking at the profile of the food export trade in 2009, meat (lamb, mutton, beef and venison) is still very important, but much of this leaves chilled rather than frozen. Considerable volumes of apples and kiwifruit are still exported, along with small amounts of other fruit and vegetables. There is a considerable tonnage of frozen fish, and still butter and cheese (although much more of the milk fat ends up in whole milk powder than previously). There are also refrigerated food manufacturers for local consumption – including frozen vegetables, bakery products, ice cream and poultry. The service roles of refrigeration in the dairy, brewing and wine industries is significant.

We have a small manufacturing base for certain types of equipment (although perhaps less so than in the boom times), and like most countries have expanded the use of commercial air conditioning. However, the bulk of the equipment we now use is imported. The New Zealand refrigeration story is not so much about the equipment we used to make the "cold", but rather how we applied the "cold" to food products.

## 2. EARLY MEAT INDUSTRY REFRIGERATION

The first refrigeration was entirely on board ship. Sheep carcases were frozen using air cycle machines on the *Dunedin* (at Port Chalmers) which blew the cold air stream directly over the carcasses. About 300 carcasses could be frozen at once. A total of 4,909 carcasses made the first voyage so the loading and freezing process took some days, the ship eventually setting sail on 15 February 1882.

There was clearly economic advantage in the freezing process being carried out on land, so that only storage was required on board ship at sea. A number of small freezing works were established in the three decades from 1882. In these plants, slaughtered sheep were moved into freezing rooms, and then dropped down a chute into cold stores below. At a later time they could be loaded out and transported to the port.

The freezing rooms typically had bare pipe grids in the ceiling over the top of rails on which sheep carcasses (or quarters of beef) hung (Figure 1). Natural convection heat transfer occurred (typically with air temperatures of the order of -15ºC), with freezing often taking three days.

*Figure 1: Carcass freezing room reliant on natural convection heat transfer to bare pipe evaporator overhead.*

*Figure 2: Cold store cooled by overhead bare pipe evaporator.*

Undoubtedly there was a fair degree of experimentation with different cooling systems. The open air cycle refrigeration was quickly replaced by carbon dioxide closed systems, and then by ammonia which became the dominant refrigerant of the 20th century New Zealand industrial food refrigeration industry. Some early systems cooled calcium chloride brine which circulated in the pipes, but eventually ammonia was used directly in the pipe grids.

Immediately following World War I, difficulties in procuring shipping led to the failure of a number of small meat companies, and there was a consolidation of meat freezing plants and companies – both local farmer cooperative companies and major United Kingdom companies emerged as multiple plant owners. As the scale increased, ammonia refrigeration became the dominant technology. However, the freezing rooms and cold stores (Figure 2) changed little in function.

After World War II systematic developments occurred leading to two notable technologies – the air-blast carcass freezer, and the carton freezer.

## 3. AIR-BLAST CARCASS FREEZING

### 3.1 The Dominance of Efficiency

As the size of meat plants grew (by the 1980s there were plants processing 25,000 animals per day), the demand for efficiency was strong. Commencing in the late 1940s, considerable development work was undertaken towards air-blast freezers for lamb and sheep carcasses. The concept was to use finned surface evaporators and large scale fans to cool and then direct the refrigerated air over the carcasses. A freezing time of less than 16 hours could be achieved, allowing overnight turnaround on the freezing rooms – perfect for mass production. There was also the potential to reduce product weight loss and to lift suction pressures, saving energy. Ellis Hardie Syminton Ltd patented the A189 air-blast freezer in about 1950 – it allowed for multiple air re-cooling between groups of carcasses. The local refrigeration engineering company worked with the development engineering group of Thomas Borthwick & Sons Ltd (a major plant owner) at the development laboratory of the latter at the Waingawa works near Masterton. Over the next 20-30 years, the air-blast freezer became universal in the New Zealand industry. Several variations were developed (Figures 3,4), and over time horizontal air flow was phased out in favour of vertical air flow as the latter gave better air distribution. Single storey was partly replaced by multi-storey (up to six storeys) in some of the larger plants in the 1980s. There was also a move from batch to continuous production.

There was also considerable automation – the batch rooms required labour to move carcasses in and out, the continuous freezers moved gantries along the freezer with one such gantry unloading and another loading at any time. In short, the industry applied all the principles of mass production.

*Figure 3: Cross-flow air-blast carcass freezer*

By the 1980s, energy efficiency became an important parameter, and means to minimise energy costs were explored. One of the most advanced systems was a predictive control system run on a PDP8 computer at the Pareora works of the then Canterbury Frozen Meat Company. As gantries of carcasses passed each fan zone, the computer determined the lowest possible velocity that would just freeze those carcasses before freezer exit – small carcasses passing would mean a drop in fan speed in the zone. Given the power law relationship of fan speed and power use, plus the reduced refrigeration load when the fans were slowed, the energy savings were considerable.

### 3.2 From Efficiency to Meat Quality

Although it was not realised at the time, the move to faster freezing times, and a desire to cool as rapidly after slaughter as possible to minimise microbial risks, led the meat industry to freeze meat carcasses too quickly – resulting in toughened product. Commencing in the 1970s, research at the Meat Industry Research Institute of New Zealand highlighted the need to control the temperature/time regime carefully, which was subsequently modified by the introduction of electrical stimulation. This new knowledge led initially to at least a proportion of the kill being held in chiller conditions for a period of time prior to freezing, and more latterly to a carefully controlled air temperature/air velocity regime. It became necessary to also differentiate on the basis of animal size lest small carcasses be allowed to cool too rapidly.

These needs led to significant advances in control systems to adapt the carcass blast freezers to the new requirements. Fan speed controls to slow air velocity now had dual benefits – both improved product quality, and reduced energy costs.

By the 1970s, improvements in the dressing of product, and improvements in both packaging and air temperature control meant it was possible to export chilled product by surface freight systems. This, plus the general reduction in the number of lamb carcasses

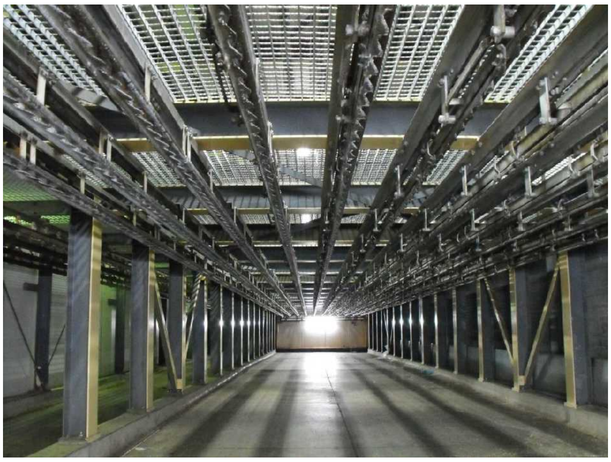

*Figure 4: Typical modern air-blast carcass freezer*

per year, has led to a significant shift away from the air-blast freezer as the dominant technology. Chillers for both carcasses and boned cuts, sophisticated packaging systems and closely controlled chill storage have become more important.

## 4. THE CARTON FREEZER

Prior to the 1950s the beef trade had been dominated by quarter beef. The emergence of the hamburger in the United States of America opened up a new product line – frozen boneless beef suitable to be processed directly. The New Zealand industry responded. The process involved an overnight chill of beef sides to 10ºC and then boning out of the sides to fill cartons to be frozen.

Working with Ellis Hardie Symington Ltd who did the refrigeration, Bill Freeman of the Cooperative Wholesale Society designed and constructed the world's first continuous carton freezer for cartons of beef at the company's Longburn freezing works near Palmerston North. The completion was during the 1959/60 processing season. Moveable racks were loaded at the entry, and then pushed progressively along to the other end of the freezer. They then dropped down to a second level and returned out to the entry end (Figure 5). Air was directed in cross flow across the tunnel – via large-scale fans. The carton held 27.2kg and was typically about 150mm thick. Solid wall fiberite was chosen to minimise insulation, and by using air temperatures as low as -40ºC and air velocities of the order of 3m/s a 24-hour freezing time was possible. Some companies preferred a higher air temperature and a 48-hour turnaround.

The range of cartons is much more diverse these days so some companies have chosen to return to smaller batch freezing rooms, sorting cartons by size and shape. There have been some variants of the continuous carton freezer, but the basic design is still in use in many countries 50 years later. This basic design which has endured to this day is a testament to the early engineering success of Bill Freeman.

*Figure 5: Load-in and load-out area of a continuous carton freezer – cartons are placed on the racks and transported along the freezer (with air cross-flow) to return on the upper level.*

## 5. METHODS OF REFRIGERATED ROOM CONSTRUCTION

The early insulation systems tended to fail eventually through vapour barrier penetration, and insulants like cork were not that effective. By the 1960s the expanded polystyrene sandwich panel and sprayed polyurethane had become the dominant insulants. Forced draught cooling units became the norm. New refrigerated rooms had to be added to the extremities of plants which in turn led to long pipe runs from centralised plant rooms, which created the need of a new set of expertise in controlling the systems (see below).

## 6. THE MEAT WORKS ENGINE ROOM

Powering the very large refrigeration systems was no small order. At the peak size of the industry there were plants generating more than 5MW of cooling effect, and because the load varied significantly during the working day, very flexible plant rooms were required.

As stated earlier, ammonia rapidly became the dominant refrigerant. Much of the first large scale equipment installed in the early 20th century is still capable of operating to this day, but as capacity was increased new technologies were adopted. The following compression equipment was widely applied:

Large horizontal-acting compressors circa 1910-1920 – these were low speed and often only a single cylinder (which may have been double acting). Early such compressors were driven by steam engine, but when electric motors were installed there was a need for large flywheels to balance the load (Figure 6). Hall and Haslam were common brands, and a few such machines are still in service.

Multi-cylinder vertical compressors – these were typically installed between the two World Wars – slightly faster and generally with an enclosed crankcase (Figure 7). Again, many (including Halls and Sternes) were still in action fifty years later. Some of these were compound compressors accomplishing two compression stages in different cylinders in the same machine.


*Figure 6: A horizontal open compressor with flywheel.*

*Figure 7: A typical vertical cylinder compressor with enclosed crankcase.*

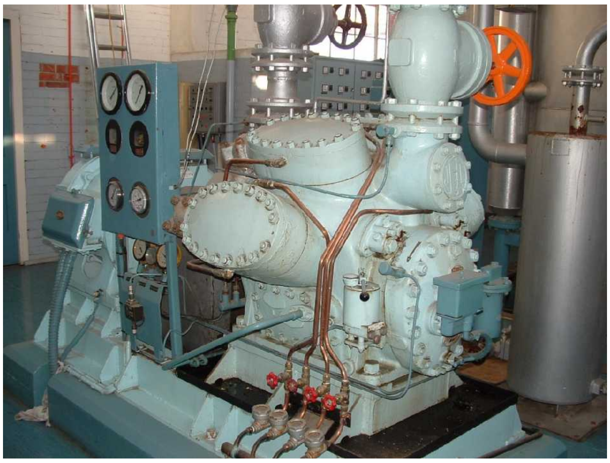

*Figure 8: A typical Vee block compressor used both within and outside the meat industry.*

Vee block reciprocating compressors – typically installed after World War II. These were electrically driven and used largely as the high stage on multiple stage compression systems. The most common were Hall 5x4 and 7x5.5inch machines, driven by 125HP or 250HP motors respectively (Figure 8).

*Figure 9: A typical rotary vane booster compressor.*

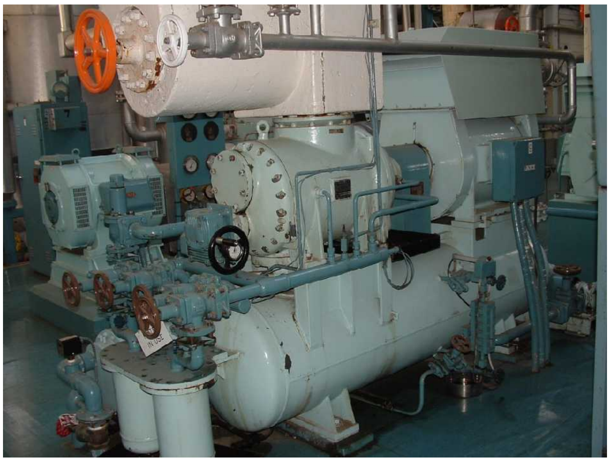

*Figure 10: A relatively early model twin screw compressor*

Rotary vane compressors – typically used as boosters on multi-stage systems, after World War II – the Fuller brand was common (Figure 9).

Twin screw compressors – installation commenced in the 1970s (mainly Howden machines in the early days), and these machines were widely applied thereafter (Figure 10). These machines could be very large – up to 1000HP required to drive the largest. The monoscrew compressor never really took off in New Zealand.

Condensers were often locally made – early systems used evaporative cooling reliant on natural air flow over large-scale pipe grids, but with a water spray over the top. The next stage was the wide-scale use of both horizontal and vertical shell and tube condensers, sometimes with evaporative cooling systems to re-cool the cooling water (Figure 11). Whereas evaporative condensers were widely applied in Australia at the same time, in New Zealand the plentiful water supply led to a different approach. Only in the last 20-30 years have evaporative condensers (Figure 12), plate heat exchangers and imported water cooling towers been widely applied.

Perhaps the major New Zealand contribution to engine room engineering was in pump circulation of ammonia. Due to the very large scale of meat plants, very large pipe runs were needed, and the volumes of refrigerant were substantial. Commencing prior to World War II, New Zealand refrigeration companies like Ellis Hardie Syminton and then later Refrigeration Engineering Ltd developed the expertise to design, build and then control large-scale pump circulation systems. Low-pressure liquid accumulators (called “pots”) were placed in the engine room, and from these liquid was pumped out to a variety of applications. The return stream was separated in the pot upon its return and the vapour drawn off to compression. Given that the loads were highly variable there was a considerable control problem – the plant operators had the expertise to ensure major liquid flood backs did not occur. Typically there were two to four such pots in a large meat works, although very complex plants could have more.

*Figure 11: Typical vertical shell and tube condensers used in the meat industry.*

*Figure 12: An evaporative condenser in service at a meat freezing plant.*

## 7. THE DAIRY INDUSTRY

The early dairy industry was characterised by a large number of small local factories. Farmers would separate cream from skim milk on farm and take the cream by horse and cart to the factory. There, the initial product was butter, but cheese was also important. Farmers were paid for many decades on the basis of the fat supplied, ignoring the protein component of the milk. With the development of refrigeration and mechanised transport bulk milk collection was able to commence. Stainless steel dairy vats with refrigerated pads were made locally and milk was cooled on farm, to be collected daily. In contrast to the use of natural refrigerants in the meat industry, this on-farm development applied synthetic refrigerants (CFCs) in the main. Consequently, the number of dairy factories rapidly reduced.

By the 1980s the increasing efficiency of the on-farm systems and improvement in hygiene meant that less frequent tanker collections were possible. With mechanisation the average dairy herd size rose rapidly, and the age of the mega-factory supplied over very long distances was born. This is the dairy industry New Zealand has today.

On-plant there is also a need for cooling – large quantities of chilled water are used and direct refrigeration is used in continuous butter makers as well. There has always been refrigerated servicing of cheese making e.g. curing rooms. Mechanical vapour recompression has become the norm in evaporation of milk towards milk powder.

In terms of New Zealand innovation, the local design and manufacture of the refrigerated dairy vats was significant. There was also some New Zealand-designed equipment for cheese making. However, the other technologies, including the cold stores for butter and cheese, were relatively standard.

## 8. THE FRUIT INDUSTRY

The export apple industry started to gain scale in the 1970s and rapidly expanded in the two decades thereafter. The building technology evolved into relatively simple but massive cool stores, which had pre-cooling areas in which the initial field heat could be withdrawn from the product. Where New Zealand was innovative was in the control of relative humidity of the air. As the fruit was unwrapped it was desirable to minimise water loss, but a high relative humidity would reduce the strength of the fiberite cartons. Through research, process understanding was developed to enable high relative humidity to be obtained, as well as ensuring tight temperature control. This lengthened the storage life and enabled transportation to distant markets.

New Zealand also took up controlled atmosphere storage, but made limited use of modified atmosphere packs. It developed expertise in the mathematical modelling of the heat and mass transfer processes which could be applied to ensure that the local relative humidity established in the pack around the fruit was controlled to the optimum level by setting the perforation size and number.

From the 1980s the kiwifruit industry developed in parallel. The scale of the storage facilities was smaller initially, but the industry evolved in scale and technology to parallel the apple industry. The know-how for using temperature, packaging and gas composition to maximise product quality has been central to the success of these industries.

There is also a small frozen vegetable industry – potato products, peas, beans and corn. This has always tended to use imported freezing technology, but ammonia refrigeration.

## 9. OTHER INDUSTRIES

The other notable food refrigeration export industry was the fishing industry. This now has a high proportion of off-shore processing on factory ships. The on-shore technology tended to draw on the experiences from the meat industry. Hence there is little of engineering heritage significance in the industry.

Likewise, the brewing, ice cream, bakery products, wine making, confectionary and poultry industries also use significant amounts of refrigeration, but in their history there is nothing particular to New Zealand engineering heritage.

New Zealand has had commercial display cabinet manufacturing (including for export) over several decades but on a modest scale. McAlpine Industries (later McAlpine Hussman) was the initial major player, but more recently Skope Industries has also become a significant-size manufacturer. There has been a single manufacturer of domestic equipment (Fisher and Paykel) for the last 70 years, initially manufacturing under licence, but now using its own designs.

## 10. NEW ZEALAND CONTRIBUTION TO RESEARCH AND DEVELOPMENT

By the 1960s, New Zealand started to publicise its research into refrigeration on the national stage. The main contributors were the Meat Industry Research Institute and Massey University, both reliant on Professor Dick Earle to pioneer their initiatives.

The best-known research that established New Zealand's reputation, and forms part of our refrigeration engineering heritage, was the development of highly sophisticated mathematical models of food refrigeration processes and systems, particularly as applied for food freezing and chilling. We led the world on development of methods to predict freezing times, and then the modelling of simultaneous heat and mass transfer in the horticultural industry. We also did considerable pioneering work on measurement and later modelling of overall refrigeration system performance, particularly looking to improve process control and energy efficiency. This was not a small undertaking as several megawatts of refrigeration effect was not uncommon on large freezing plants. New Zealand-developed software to apply the models was used in a number of countries.

Heat pump technology has also been developed by New Zealand researchers. Through the University of Otago a domestic hot water heating system, and through Massey University a trans-critical carbon dioxide system were developed, both in the last decade.

By the 1970s, New Zealand had started to become active in the International Institute of Refrigeration (IIR) – an intergovernmental organisation to promote the wide application of refrigeration. New Zealand hosted major international research conferences in 1982, 1993 and 2006, and co-hosted the four-yearly International Congress of Refrigeration with Australia in Sydney in 1999, a massive undertaking with over 500 technical papers presented.

A local learned society (initially the Institute of Refrigeration and Air Conditioning Engineers, but later to become IRHACE through the addition of "Heating" to the name) was also established. This tended to gather the refrigeration engineers operating with synthetic refrigerants more than those applying ammonia in its early life, but by the 1990s it was operating across the whole industry and there were close links with the IIR and local research groups. IRHACE and the New Zealand National Committee of the IIR now act as the hubs for distributing new knowledge in the industrial food refrigeration sector.

## 11. SOME PERSONAL MEMORIES

My own memories commenced in 1974 when I took up my first holiday job at a meat plant – it had a horizontal-acting Haslam compressor operating on a flywheel rope drive system. I had considerable involvement from then until the turn of the century.

Failure of insulation systems was a major problem I experienced at first hand. Over many decades ice build-up in the underfloor region would occur. In most parts of New Zealand the permafrost layer underneath was of the order of 10-12m, so the floor in the middle of an old meat works cold store could have a heave of up to one metre in the middle – I recall entering many such stores. Fortunately (I think) I never came across one of the feared freezer rats – rats that had adapted and lived in the central hollow of a meat carcass in cold store – reputedly, if disturbed, their eyes could not cope with bright light and they could be quite dangerous.

I recall doing a refrigeration survey at the Ocean Beach freezing works at Bluff – its condensers were cooled by sea water, trapped by a one-way gate which closed off at high tide, entrapping sufficient coolant until the next high tide. Sea life getting into the water pumps was an ongoing issue.

Then there were the tough shift engineers who manned and controlled the plants. Some of their control expertise was brilliant – there was an old saying – "if you had 10lb by 10 at night you would be alright" – if the suction pressure at 10pm had dropped to 10lb/sq inch then the meat would be frozen by morning – a rule of thumb that meant the engineers could operate a variable set point control system. Their replacement by early automatic control systems with fixed set points dramatically increased (and even doubled) the energy required to freeze meat until the control systems could be improved.

Whilst the memories are strong for me, too much of the story of the technology development remains untold in New Zealand. I hope this paper goes some small way to tell some of the important stories.

## 12. CONCLUSIONS

New Zealand has a rich heritage of innovation on refrigeration engineering as it pertains to the frozen and chilled food industry. The major innovations are in process technology rather than in equipment systems, and this heritage is difficult to preserve in the form of artefacts.

This paper sets out some of the important advances that form part of our refrigeration engineering heritage. Without those advances New Zealand may have taken a much less prosperous journey through its economic development over the last 125+ years.

## 13. REFERENCE


1. Earle, R.L. (1982). Refrigeration and New Zealand. In *Refrigeration Science and Technology Proceedings* (1982-1).


## 14. ACKNOWLEDGEMENTS


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