THE INTERNATIONAL INSTITUTE OF REFRIGERATION

Design of Carton Air Blast Freezing Systems

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Air freezing of carton meat has been a feature of the meat industry for many years. Despite this and the fact that much practical research and development has been carried out some 30 years ago, the refrigeration industry is still designing freezing tunnels that are ineffective and do not provide the end user with what he wants. This paper summarises the information now available from this development programme and also compares the economic factors relating to one day as against two day turnaround cycles as well as automatic tunnels as against batch freezing units. With this summarised information, any good refrigeration company should be able to design and install effective systems.

Introduction

Air freezing of cartons of meat or other food substances has been carried out virtually since refrigeration began. However, the rapid freezing of such product came into its own in the 1960s and 1970s when the southern hemisphere countries in Australasia and South America started to bone meat carcasses into primal cuts for export. Previously the major export had been carcasses only.

Due to the size of the meat packing plants involved, the freezing of cartons became a science in terms of the most efficient and economical way to proceed. Much test data was accumulated particularly in New Zealand from research programmes by MIRINZ, the industry research body and further expertise built up in the meat plants themselves.

This paper compiles the most relevant information now available for operators and refrigeration designers to configure effective freezing tunnels to match the requirement of any particular operation and it also encompasses many years of our own practical experiences in these matters.

It should be noted that many UK and European carton freezing plants are being designed without using this knowledge today and it is hoped this paper will help those in the industry involved with these responsibilities to improve such designs for the benefit of the industry as a whole.

1. Heat Transfer Data

The most common method of freezing carton meat is the batch air blast freezer as diagrammatically shown on Figure 1. Cartons are placed onto pallets with air spaces between them, provided by corrugated sheeting or plastic “egg carton” spacers and air is circulated through the stow and over a suitable evaporator by means of powerful fans and closely fitted false ceilings. Much work has been carried out on freezing times for such tunnels and Figure 2 is the result of these many tests carried out in New Zealand and Australia during the 1960s and 1970s.

From Figure 2 it is possible to calculate the air velocities and temperatures necessary to arrive at a suitable freezing time for a specific type of cardboard carton. Due to the pattern of factory or cold store operating schedules, it is usual to design tunnels for either 24 or 48 hour turnaround times. The 24 hour design is expensive to operate due to the faster extraction of heat and the low refrigeration temperatures necessary.

In looking at the necessary requirements for a simple batch freezer as shown in Figure 1, the first requirement is to determine the worst type of carton from a heat transfer point of view expected for the long-term operation. Generally cartons are either made up in corrugated board or solid board, the latter having the far superior heat transfer value. Unfortunately it is usual for the general management of the factory to have chosen the carton type prior to asking the engineers to design the freezing tunnel. The advantage usually of the corrugated board is that it is cheaper to make and can sometimes be formed by bending layers over each other which can become disastrous from the heat transfer point of view.

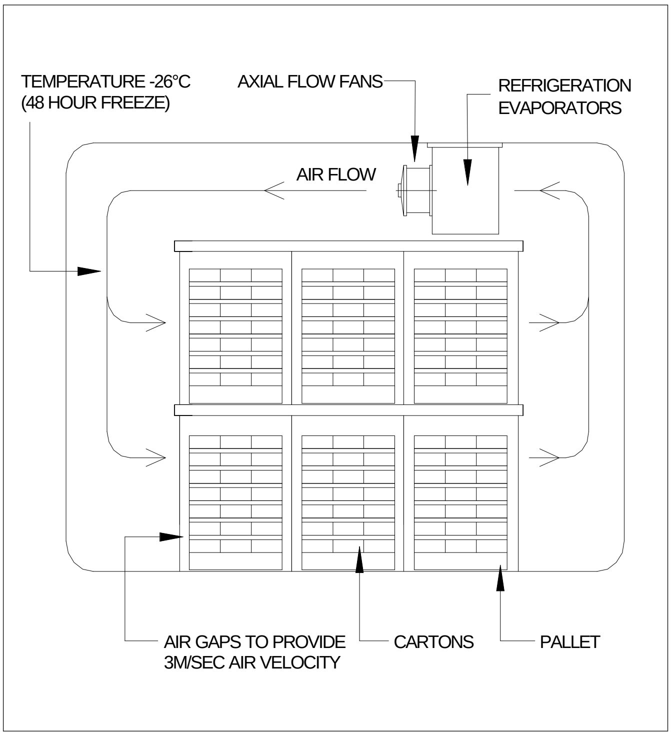

Figure 1 - Air Batch Freezer

Furthermore, some cartons are formed with lids which fit over the basic body of the carton resulting in two thicknesses of corrugated board through which the heat is to be extracted. One of the first such tunnels I personally designed many years ago in South America used double formed corrugated cartons with lids which resulted in a 24 hour cycle design freezing in 48 hours. Assuming fibreboard material with glued tops i.e. no lid, then for the normal 150 mm thick meat carton (27 kg) it can be seen from Figure 2 that an air velocity of 5 metres/second with an air temperature of -30^{0}C will be necessary to freeze the meat within 24 hours. These figures will change to a velocity of 7 metres/second and an air temperature of almost –40^{0}C to achieve the same results with a corrugated type carton. Thus consideration of carton type is of paramount importance.

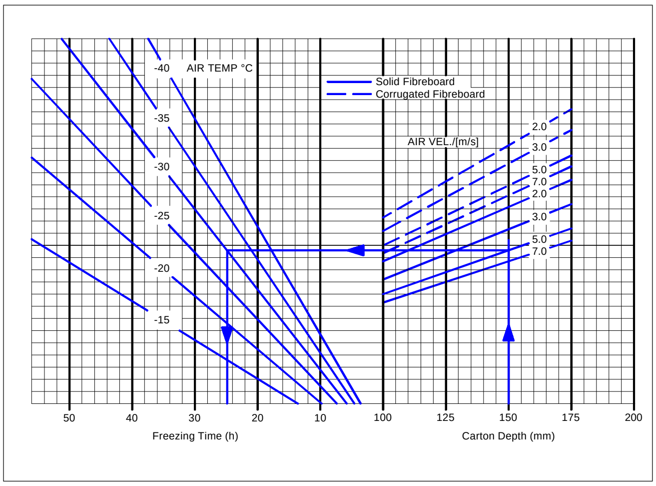

Figure 2 - Air Blast Carton Freezing Tunnels - Temperature/Time Relationships

2. Automatic & Batch Freezing Systems

In order to reduced the operational costs of loading batch tunnels with forklift trucks and eliminating the high labour costs of introducing spacers which requires double handling of pallet stacking, the automatic tunnel was introduced into high volume meat works in New Zealand in the late 1960s. Figure 3 gives a basic flow pattern showing how the system works.

Figure 3 shows an automatic loading model. The cartons arrive from the high volume boning room on conveyors and then by means of electronic eyes, when the load platform is full, a hydraulic ram pushes the cartons into the tunnel (in this case six cartons), which results in the six cartons at the far end being pushed out to the transfer annex, which in turn moves up to the return leg of the tunnel, when a further hydraulic ram pushes the cartons to allow the six frozen cartons to be discharged into a take-away conveyor. The tunnel shown shows a configuration of 72 cartons per 24 or 48 hour period, but can be made as long as required to meet the boning room output.

The top section of Figure 3 shows the refrigeration and air distribution system. The design requirements must conform to the air velocities and temperatures as indicated in Figure 2. No spacers are required because the freezing unit is made on steel frames with the cartons thus being separated for the correct sized air gap to obtain the necessary air velocities.

Figure 4 shows a general arrangement for a batch freezing operation.

In comparing this configuration with the automatic tunnel in Figure 3, it can be seen that a large palletising/depalletising area is required for building up freezer pallets with air spacers and then disassembling them after freezing and rebuilding onto cold store pallets. Thus labour costs are high but the fabrication of the tunnels is simple by

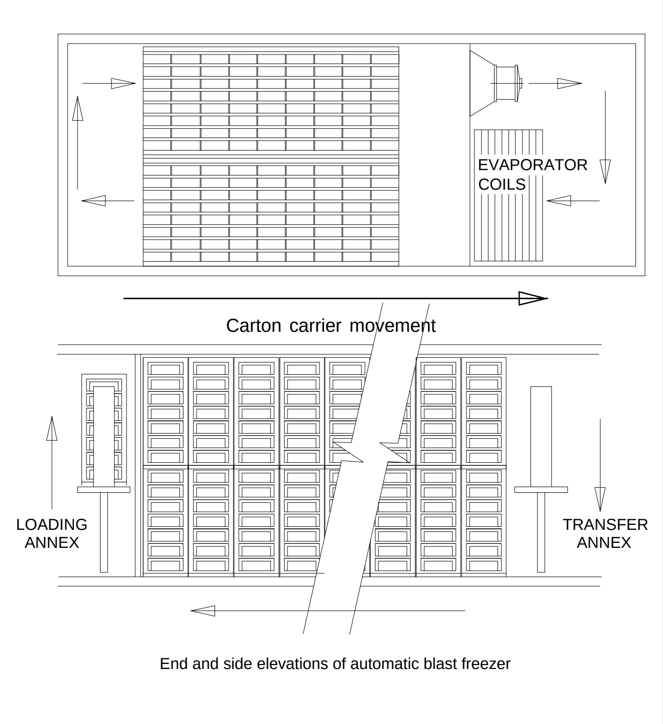

Figure 3 - Automatic Air Blast Continuous Tunnel

using insulation panels supported from the main building structures. The whole system is usually built into the works cold storage loading bays so that distribution to designated stores becomes easy. The air velocities and temperatures must conform to the Figure 2 heat exchange data.

3. Refrigeration System Design

It is essential that the air temperature chosen in Figure 2 for a specific duty is maintained throughout the freezing time. It is necessary therefore to size the evaporators to at least 50% larger than the average refrigeration load for one day turnaround units. In the case of 48 hour freezing, this requirement is not so critical. The reason why this evaporator oversizing is essential is to ensure that the air freezing temperature chosen is maintained over the full freezing period. The point here is that in the first few hours of freezing when the product is at a high temperature, the heat given off by the product is many times higher than in the last few hours. Thus the evaporators must be sized to take allowance for this high heat load. It is simply not good enough to size the units on an average heat rejection rate over the full freezing period.

In sizing the evaporators, a frost build-up factor must be considered and an average heat transfer rate of no higher than 2 watts/hr/^{0}C/m^2 should be used with fin spacing of no more than 4 fins per inch. Most refrigeration contractors undersize evaporators.

As far as the refrigeration system is concerned, a two stage pumped system should be employed for air temperatures below –30^{0}C, while a superfeed screw system could be used for temperatures between –20^{0}C and –30^{0}C. Both arrangements must be pumped so that a high wetted surface area within the evaporators is achieved.

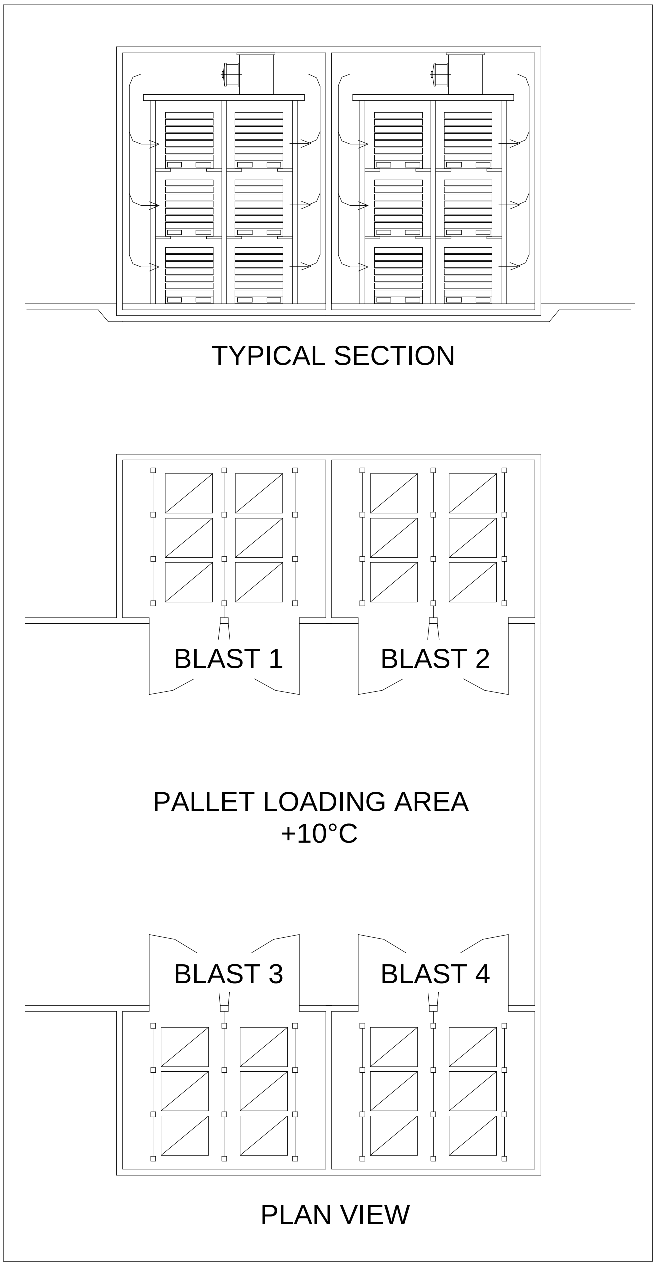

Figure 4 -Batch Freezing Tunnels

Our experience has shown over the years that high capacity outputs with a variable refrigeration requirement over the total freezing cycle, which will always be the case, means that direct expansion systems never provide the necessary performance.

Although direct expansion systems are officially only some 25% down on heat transfer rates, increasing the evaporator areas should result in similar refrigeration performance, but in practice I have never found direct expansion systems can provide the required evaporator performance for carton freezing. I can only assume that the reason for this is that the large refrigeration loads and larger evaporators required in the first hour of freezing just cannot be consistently managed with the type of direct expansion valve available on the market. This valve operation results in large areas of the evaporator becoming gas locked. A pumped system which keeps the coil surfaces continually wetted is the only system that can deliver the performance required for such freezing systems.

4. Economics of 24 and 48 hr Batch Freezing Systems

The comparative economics of installing 24 hour freezers as against 48 hour units rest on two specific factors, namely-

4.1 Operating cost
4.2 Capital cost.

4.1 Operating Cost

If we consider the two options for the batch freezer concept, the operating cost factor is related solely to the electrical consumption of the refrigeration plant. For both options the labour cost for palletising and depalletising so many tonnes of product per day are the same. It simply means that the 2 day turnaround option has two batch freezers with one freezer being loaded each day with the other being discharged.

The electricity consumption will be significantly less for the 48 hour units as the refrigeration plant will run with a compressor suction temperature of –32^{0}C rather than –40^{0}C. Furthermore, the fan loading will be less with a lower air velocity requirement, but two units will always be running rather than one. These factors of fan load balance out.

However, the operation at –40^{0}C will result in a COP of the plant at around 1.6 as against almost 2 for the 48 hour operation. Taking these factors into account, the 24 hour unit will consume approximately 4.1 kws electricity per tonne of product under refrigeration, while the 48 hour unit will consume approximately 3.3 kws per tonne, or 98 kw hrs/tonne and 79 kw hrs/tonne respectively of product frozen. On the basis of an electricity charge of 5.0 pence/kw hr, the electricity cost per tonne of product frozen will be £5.00 and £3.95 respectively. These cost differentials will be equally applicable for batch or automatic operation.

4.2 Capital Cost

Again looking at the batch freezer operation only, the capital cost of the refrigeration plant will be lower for 48 hour freezing, as discussed above, but 2 tunnels will have to be built rather than one so that the building costs and the plant area will be larger.

In viewing Figure 4 which shows 2-10 tonne tunnels, if 10 tonnes of product was required per day, then one tunnel with 24 hour freezing would be sufficient while 2 would be necessary for a 2 day turnaround. Each tunnel would cost approximately £22,000 to build, including palletising space, which would mean a capital cost of £44,000 for the 2 day turnaround as against £22,000 for the 1 day option, or £2200/tonne frozen. However, the refrigeration plant for the faster freezer would cost approximately £25,000 more, or £2,500 per tonne frozen. Thus for the batch tunnels, there would be virtually no difference overall in capital cost. Table 1 gives a rough guide to calculating the costs involved:

	24 hour cycle	48 hour cycle
Electricity	£ 5.00	£ 3.95
Refrig. Capital	£5000	£3700
Building Works	£2200	£4400

Table 1 – Comparative Costs for 1 & 2 Day Cycles per 1 Tonne Product/Day

5. Economics of 24 and 48 Hour Automatic Freezing Tunnels

Due to the large cost of building small automatic air freezing tunnels, this high capital cost excludes the economic use of such tunnels unless the throughput of the tunnels reaches some 2000 cartons per day or some 54 tonnes per day where the capital building costs of the 24 hour turnaround tunnels, excluding refrigeration, would be in the order of £400,000 as against some £120,000 for the previously discussed batch tunnels. Refrigeration capital charges would be approximately the same for each tunnel type at approximately £380,000 and the electricity cost again would be similar.

The advantage of spending this additional £280,000 excluding refrigeration comes in the labour saving possible. To palletise and de-palletise some 60-80 pallets per shift or building and restacking some 120-160 pallets (18-23 pallets per hour) would require at least 4 extra employees or some £75,000 per year in employment costs. Under these circumstances, a three and three quarter year payback would be possible on the extra £280,000 for building the tunnels in the first instance. Bearing in mind that the automated tunnel starts becoming effective at some 50-60 tonne of product per day, then Table 1 will turn into Table 2 below, but again these figures are a rough guide and each project needs careful analysis to conclude the right course of action: -

	24 hour cycle	48 hour cycle
Electricity	£ 5.00	£ 3.95
Refrig Capital	£5000	£ 3700
Building Works	£7500	£15000

Table 2 - Comparative Costs for 1 & 2 Day Cycles per 1 Tonne Product/Day

CONCLUSION

Rapid air blast freezers for carton meat became commonly used in the late 1960s when the southern hemisphere meatworks started to bone carcasses to ship frozen primal cuts and manufacturing meat.

At this stage extensive research went into the heat transfer rates between the cooling air and the cardboard cartons. MIRINZ, the New Zealand research body provided detailed data for designing freezing tunnels.

Shortly after this period the New Zealanders developed automatic freezing tunnels to eliminate labour costs compared with the accepted batch freezing tunnels.

Much experience has been accumulated with respect to the most effective refrigeration plant to service these tunnels. Pumped refrigerant systems are essential and generous evaporator sizing necessary for effective performance.

The tunnels are usually designed on the basis of one or two day turnaround cycles to fit into the factory or cold storage routines. The question of the economies of one option as against the other needs concluding for each individual plant. However in general terms, provided electricity costs are reasonable, the one day turnaround cycle is the most economic while the application of automatic tunnels which eliminates much of the double handling costs of the batch tunnel can only be justified with a regular daily freezing requirement of at least 50 or 60 tonnes of product per day.

REFERENCES

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