Research Branch
Technical Bulletin 1993-9E

Assessment of the preservative capabilities of storage and distribution processes

Canada

Cover illustration
The images represent the Research Branch's objective: to improve the long-term competitiveness of the Canadian agri-food sector through the development and transfer of new technologies.
Designed by Research Program Service.

Illustration de la couverture
Les dessins illustrent l'objectif de la Direction générale de la recherche : améliorer la compétitivité à long terme du secteur agro-alimentaire canadien grâce à la mise au point et au transfert de nouvelles technologies.
Conception par le Service aux programmes de recherches.

Assessment of the preservative capabilities of storage and distribution processes

C.O. GILL
Research Station
Lacombe, Alberta

D.M. PHILLIPS
Meat Industry Research Institute of New Zealand
Hamilton, New Zealand

Technical Bulletin 1993-9E
Lacombe Technical Bulletin No. 5

Research Branch
Agriculture Canada
1993

Copies of this publication are available from
The Information Officer
Research Station
Research Branch, Agriculture Canada
Bag Service 5000
Lacombe, Alberta
T0C 1S0

Cat. No. 54-8/1993-9E
ISBN 0-662-20964-8
Printed 1993

CONTENTS

SUMMARY

The storage life of raw meat is highly dependent on the temperatures that product experiences during storage and transport. Therefore, product temperatures must be controlled within a known and preferably narrow range if raw meat products are to demonstrate a consistent storage performance. The storage efficiency of a storage or distribution process can be assessed by the collection of temperature histories from a random sample of product units moving through the process; integration of the temperature history data with respect to appropriate models describing the effects of temperature on the growth of spoilage bacteria; and deriving a storage efficiency factor for each temperature history. The storage characteristic of the process are then described by the distribution of the values for the storage efficiency factors. The technique can be applied to identify causes of storage insufficiency, and in routine monitoring for Quality Management purposes. The application of the technique is illustrated by reference to assessments of commercial processes for the transport of hanging beef, and the storage and transport of boxed beef.

RESUMÉ

La durée de conservation de la viande fraîche est fortement influencée par la température pendant le transport et l'entreposage. Pour que le produit ait un rendement stable à l'entreposage, il faut que la température soit contrôlée à l'intérieur d'un intervalle étroit et connu. L'efficacité d'un procédé d'entreposage peut être évaluée à l'aide de la collecte de données thermales sur un échantillonnage aléatoire du produit, l'intégration de ces données thermales reliée à des modèles qui indiquent les effets de la température sur la croissance des bactéries, et l'établissement d'un coefficient d'efficacité pour chaque donnée thermale. La caractéristique d'entreposage du procédé est alors identifiée comme étant la distribution des valeurs des coefficients d'efficacité d'entreposage. Cette technique peut-être utilisée pour identifier les causes d'insuffisance en entrepôt et pour une surveillance systématique à des fins de gestion de la qualité. L'utilisation de cette technique est illustrée en référence à l'évaluation de procédés commerciaux pour le transport de carcasses de boeuf et l'entreposage ainsi que le transport du boeuf en caisse-carton.

INTRODUCTION

International standards for quality management require that Quality Managements Systems extend to processes for the storage and distribution of products (ISO, 1990). Therefore, meat packers who wish to demonstrate to their customs a commitment to product quality must seek means of assessing the integrity of their storage and distribution processes.

Modern quality management is based on the precept that if the quality of product entering a process is assuredly satisfactory, and the process is maintained within limits that assure that the product cannot be unacceptably degraded, then the quality of the product leaving the process must be acceptable. In the case of storage and transport processes for meat, it must be assumed that proper attention to live animal selection and handling, slaughtering, carcass dressing and meat fabrication have resulted in meat of known and intended quality being delivered to storage. The storage and distribution processes must then be managed so as to ensure that the product and its packaging, if any, are not physically damaged; that non-packaged product is not exposed to significant contamination from the environment; and that the storage life of the intrinsically perishable product is not so reduced during storage and transport as to compromise the customers' convenient use of the product.

The avoidance of damage and contamination during the handling of fresh meat is recognized as Good Practice throughout the meat industry. Most packing plants will therefore have appropriate procedures for handling their finished products, although often those procedures would be inadequately monitored and documented for a formally correct Quality Management System. Attention to those matters is therefore necessary, but unlikely to yield any substantial improvement in product quality.

In contrast, management of product with respect to time and temperature factors is commonly poor. That leads to product achieving a storage life that is at best much less than the possible maximum. Moreover, the storage life is often not only short but also uncertain. A shortened and variable storage life restricts the marketing possibilities for product, tightly constrains production and distribution schedules, and is a major cause of customer dissatisfaction or outright rejection of product. Proper management of time/temperature factors in storage and distribution will therefore substantially enhance product stability and reliability. As such gains in product quality can often be obtained with relatively little effort, the matter is one that should be addressed at an early stage in the development of a total Quality Management System.

This bulletin describes the procedures by which the time/temperature parameters of storage and distribution process can be appropriately monitored, and objectively assessed, for quality management purposes.

THE EFFECT OF TEMPERATURE ON THE STORAGE LIFE OF MEAT

Fresh meat is inevitably contaminated with a variety of bacteria. The bacteria are deposited on the meat surfaces during the dressing and fabrication of carcasses (Grau, 1987). A fraction of that bacterial flora will be capable of growth at chiller temperatures. Such bacteria are termed psychrotrophs. When meat is stored at any temperature at which it is not frozen, the psychrotrophic bacteria will proliferate to become the major component of the flora. Finally, they will reach such numbers that the byproducts of their activities become offensively evident as spoilage odours and flavours (Gill, 1986). The storage life of fresh meat is thus limited to the time required for the spoilage bacteria to multiply to those spoilage numbers.

The rates at which bacteria grow are highly dependent upon temperature, and all bacteria have a minimum and maximum temperature below and above which their growth will cease. Many of the bacteria initially found on meat have minimum temperatures for growth that are >5°C. Such mesophilic organisms will not grow on chilled meat. However, the minimum temperature for the growth of the psychrotrophic bacteria is about -3°C, while muscle tissue will begin to freeze at temperatures about -1°C (Lowry and Gill, 1985). It follows that meat spoilage cannot be prevented if the meat remains unfrozen, but that the maximum storage life for fresh meat will be obtained when the product is held at the lowest temperature that can maintained indefinitely without the muscle tissue freezing. In practice, it is found that muscle tissue directly exposed to refrigerated air will freeze if its temperature falls below -1°C, but that packaged meat in cartons can be held indefinitely without freezing at a temperature of -1.5°C (Gill *et al.* 1988a).

The small difference in the optimum temperatures for storage of packaged and non-packaged meats is of some practical importance, because of the large loss of storage life with small increases in temperature at the lower end of the chiller temperature range. Reducing the temperature of packaged meat from -1 to -1.5°C will increase the storage life by about 10%. The storage life of vacuum packaged meat is then extended by about a week, while that of meat packaged under a controlled atmosphere of oxygen-free carbon dioxide will be extended by 2 to 3 weeks (Gill, 1990). Such extensions of storage life cannot be neglected when chilled meat is freighted by surface for distribution in distant, overseas markets.

Although the storage life of chilled meat can be greatly extended by vacuum, modified atmosphere or controlled atmosphere packagings, the proportional loss of storage life with increasing temperature is approximately the same for product that is stored without being packaged or in any of those packagings. Thus, at temperatures of 0, 2, 5, and 10°C the storage life of meat is approximately 70, 50, 30 and 15% of the storage life attained at -1.5°C (Fig. 1). Therefore, temperatures near the optimum must be sought if a long storage life is required, and product temperatures must be controlled within a narrow range if the product is to exhibit any consistent storage life performance.

MONITORING PRODUCT TEMPERATURES DURING STORAGE AND TRANSPORT

The temperatures of product units at the times they are loaded to storage or transport may vary considerably. Moreover, the speed and temperature of the air will vary at different locations within any chiller. Product units of the same type loaded to the same chilling facility are therefore likely to experience a range of chilling regimes (Wootton, 1986). Consequently, the effectiveness of processes for the storage and transport of chilled meat cannot be deduced with any certainty from the temperature of the refrigerated air leaving the coils of the refrigeration equipment. Instead, the processes must be characterized by representative temperature histories of product units.

The collection of product temperature histories requires a temperature logging device, of sufficient resolution and accuracy, which is small enough to travel conveniently with individual product units, is sufficiently rugged to withstand commercial conditions for meat handling, and which will log temperatures for extended periods (Phillips and Gill, 1986). A logger with those characteristics has been developed, and is available as a commercial device fitted with either an internal or an external temperature probe (See Appendix 1). The logger is set up and interrogated through a computer, with the collected data assured by a password against unwarranted interference. Analysis of the data by computer software yields a dated temperature history for the product, and values for appropriate parameters derived from the temperature history.

Obviously, a variety of temperature histories could be collected from any product unit. However, the product temperature history of relevance for characterizing the hygienic adequacy of a process is that obtained from the site in each unit which is the persistently warmest of sites likely to be contaminated with bacteria (Gill *et al.*, 1991). For whole carcasses, sides or quarters, that site is the most medial and caudal point within the aitch-bone pocket (Fig. 2). The temperatures of the deep tissues of carcasses are not directly relevant, because the deep tissues are sterile (Gill, 1979). The surface temperature is obtained by fixing a metal disc, of 4 cm diameter, to the carcass surface by means of a plastic staple. A cone-shaped slot running across the diameter of the disc fits to

Figure 1. The effect of temperature on the storage life of meat.

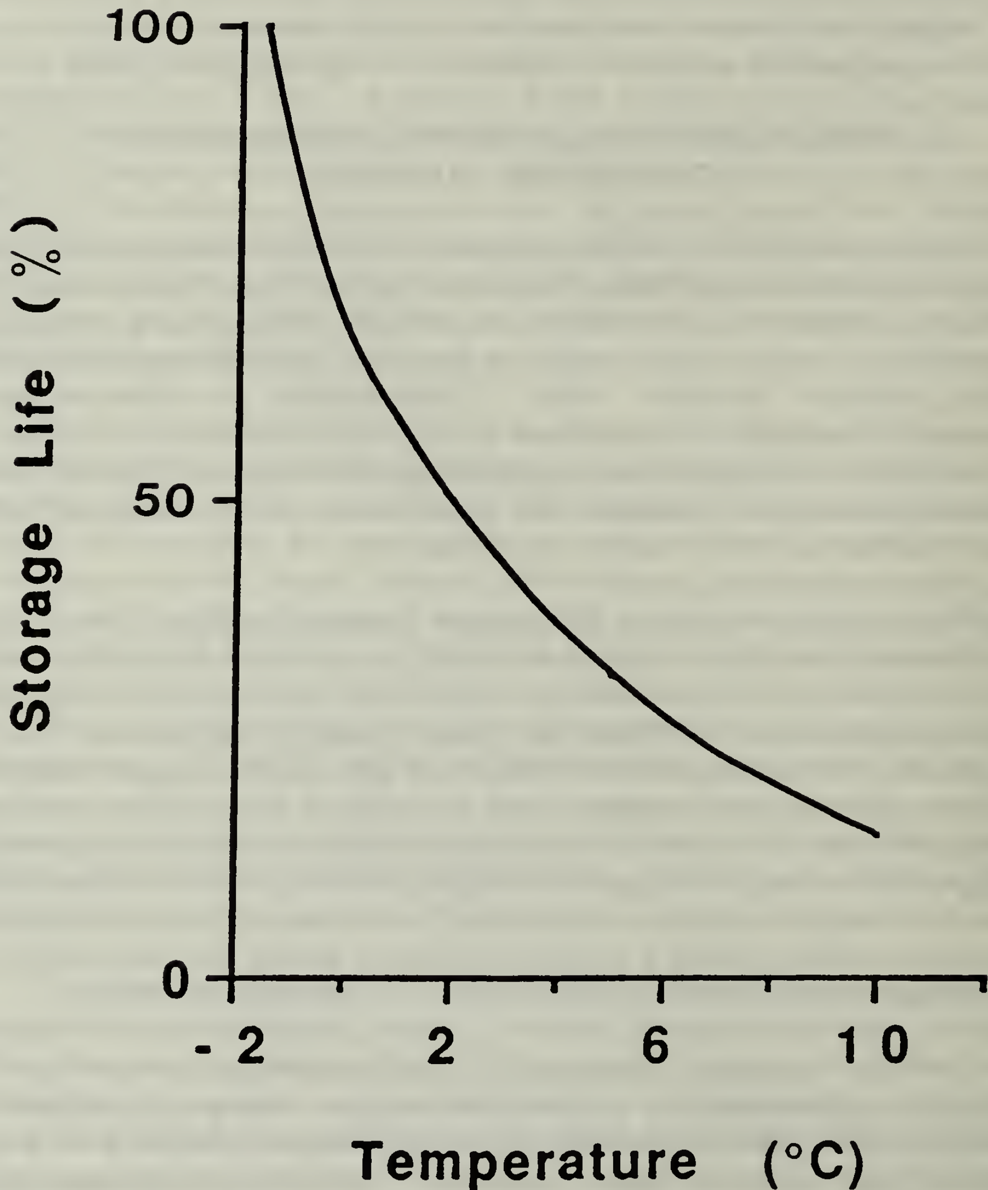
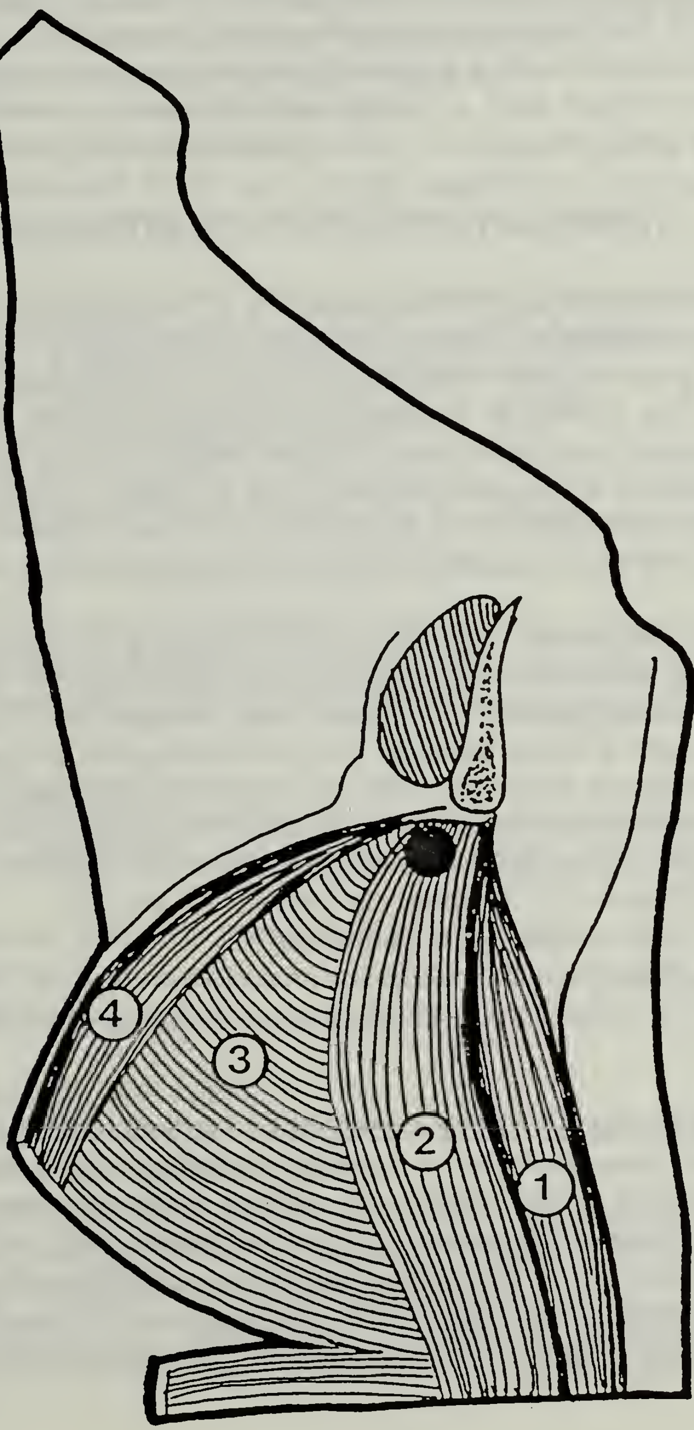


Figure 2. The site within the aitch-bone pocket from which the temperature histories of the warmest area of carcass surfaces are recorded. 1, psoas minor muscle; 2, psoas major muscle; 3, external oblique abdominal muscle; 4, straight abdominal muscle. The abdominal muscles are shown as reflected from their position medial to the psoas muscles. (•), position of temperature probe.



the external, teflon probe of a logger, so that the probe tip lies at the centre of the disc (Gill *et al.*, 1991). The logger is wrapped in a plastic bag, which is secured to the carcass by means of a skewer.

For boxed product that is expected to cool in a refrigerated facility, a logger probe should be placed to record the temperature from the geometric centre of the box, unless the box contains only a single large cut. When boxed products is transferred from a chiller after it is known to have assuredly been equilibrated to the intended storage/transport temperature, then temperatures should be monitored using a logger with an internal probe, with the logger placed between the product and a carton wall (Gill and Jones, 1992). Such an arrangement should be used to monitor boxes containing single cuts.

TEMPERATURE FUNCTION INTEGRATION

The microbiological consequences of a temperature history often cannot be readily appreciated by simple inspection of the record. However, the extent of microbial growth can be assessed by use of temperature function integration technique. The technique involves the integration of the temperature history data with respect to models describing the effects of temperature on the growth of microorganisms of concern (McMeekin *et al.* 1988). Thus, each temperature history can be described by a single value for the increase in numbers of an indicator organism or organisms that the temperature history would permit.

The spoilage flora that develops on hanging carcass meat is inevitably dominated by *Pseudomonas* species, as those strictly aerobic organisms outgrow competing species on chilled meat exposed to air (Gill and Newton, 1978). As growth of those bacteria will commence while the carcasses are being cooled, temperature histories need be integrated with respect only to a model describing the dependency on temperature of the growth rate of psychrotrophic pseudomonads. The appropriate model has the form (Gill and Jones, 1992):

$y = (0.033x + 0.27)^2$, when x is between -2 and 25;

y = 1, when x is between 25 and 35;

and y = 0, when x is <-2 or >35;

where x is the temperature in °C and y is the growth rate expressed as generations h^{-1}.

For meat that is vacuum packaged, or bulked within a box, the growth of psychrotrophic enterobacteria is suitably indicative of the behaviour of the meat spoilage flora (Gill *et al.*, 1988b). Conditions within a vacuum pack, or at the centre of a box of meat pieces, will be anaerobic. The abrupt imposition of anaerobiosis imposes a lag on the facultative anaerobes that dominate in the spoilage of high-pH meat stored under anaerobic conditions. Thus, when boxed meat is passed to storage it is first necessary to calculate the resolution of that lag phase before calculating the growth of the psychrotrophic enterobacteria. The model used for that calculation described the relationship between temperature and a factor which converts the period during the lag phase at a given temperature to the equivalent fraction of the lag phase at 0°C. The duration of the lag at 0°C is taken to be 8 days. The equivalent lag factor at x°C then has the value:

8 (days) / observed lag at x°C (days).

The model relating the equivalent lag factor to temperature has the form:

y = 0.1304x - 0.0062, when x is between -3 and 10;
y = 0.034x - 0.96, when x is between 10 and 30;
y = 1.98, when x is between 30 and 35;
and y = infinity, when x is < -3 or >34;

where x is the temperature in °C and y is the logarithm to the base 10 of the equivalent lag factor.

When the lag phase is calculated to be resolved, the anaerobic growth of the psychrotrophic enterobacteria is calculated using the model:

y = (0.0265x + 0.1629)2, when x is between -3 and 10;
y = (0.0396x + 0.022)2, when x is between 10 and 25;
y = 1.04, when x is between 25 and 35;
and y = 0, when x is < -3 or >35;

where x is the temperature in °C and y is the growth rate expressed as generations h^{-1}.

Both the lag resolution and growth models must be applied to data for the first process for storing or transporting boxed product. However, only the growth model is applied to any subsequent transport or storage process (Gill and Jones, 1992).

The models are applied in a computer program that requires:

- definition of the times that temperature history recording began and ended;
- identification of the conditions for the product as aerobic or anaerobic;
- for boxed product, identification of whether the process is the first or a subsequent storage / transport process.

The program then calculates:

- For product stored/transported under aerobic conditions, the growth of psychrotrophic pseudomonads;
- For primary storage/transport processes for product experiencing anaerobic conditions, the fraction of lag resolution and any subsequent growth of the psychrotrophic enterobacteria;
- For secondary storage/transport process for product experiencing anaerobic conditions, the growth of psychrotrophic enterobacteria.

- For all types of process, a storage efficiency factor.

The storage efficiency factor is the percent ratio of the duration of the temperature history to the time calculated to be required for the calculated growth and/or lag resolution at the optimum storage temperature of -1°C, for aerobic conditions, or -1.5°C, for anaerobic conditions.

ASSESSMENT OF A PROCESS FOR TRANSPORTING BEEF SIDES BY RAIL

Background and Methods

Beef sides from animals slaughtered the previous day are unloaded from a carcass chiller, graded, and passed to a dock for loading into refrigerated railway wagons. The door of each wagon is sealed to the dock exit while the wagon is being loaded. The wagon refrigeration equipment is set to deliver air at 0°C.

Loggers were placed to record the deep leg temperature, and surface temperature in the aitch bone pocket, from three sides in each of ten consignments. In each consignment, the monitored units were respectively located in one of the rows bordering the central door aisle, and at the approximate centres of the areas between the aisle and the end walls of the wagon.

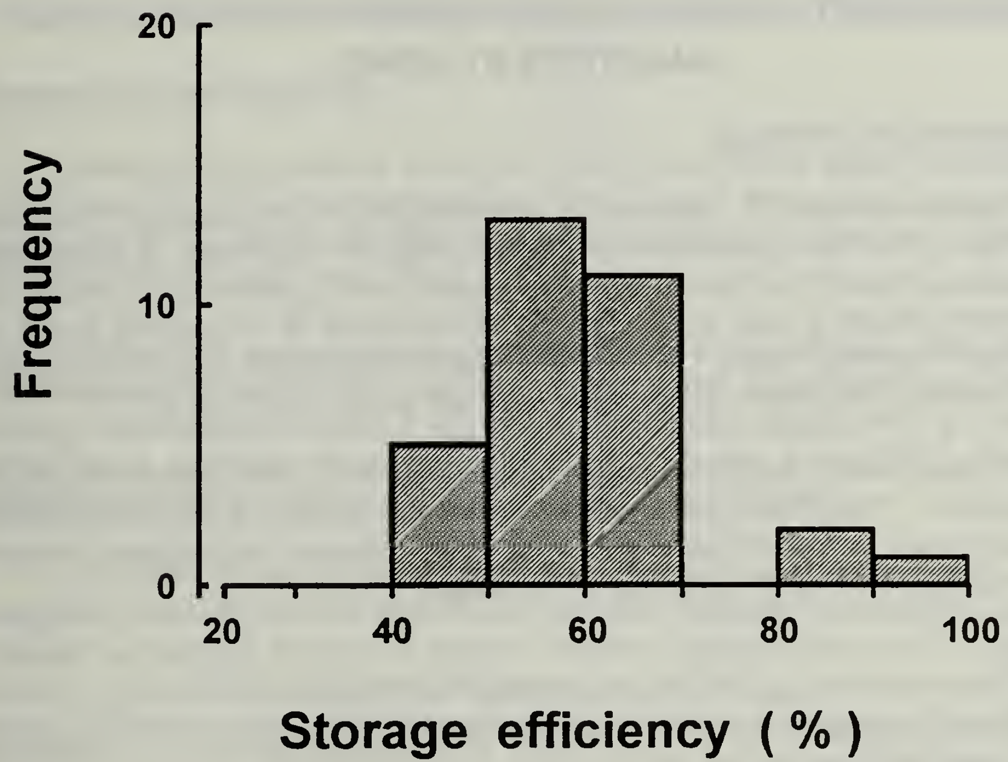
Results

The deep temperatures of beef sides at the times of their being loaded to transport varied from 6 to 18°C. At that time, the surface temperatures ranged from 0.5 to 5.5°C. There was no correlation between the deep and surface temperatures.

The times in transit varied form 4.3 to 6.9 days. The surface temperatures declined for the first 24 h, but subsequently a temperature of between +1 and -1°C was maintained, with fluctuations of no more than ± 0.5°C. When product was unloaded, the deep temperatures of most sides were between 0 and 1°C, and the deep and surface temperatures differed by no more than 0.5°C.

The proliferations of pseudomonads calculated from the surface temperature histories ranged from 8.4 to 19.3 generations. The three proliferation values from any consignment did not differ by more than one generation. The storage efficiency factors ranged from 43 to 94%, with 77% in the range 55 to 70% (Fig 3). The lower values were obtained from two

Figure 3. The frequency distribution of the storage efficiency factors calculated for three beef sides in each of ten consignments transported in refrigerated railway wagons.



consignments in which loss of temperature control was evident from the temperature histories (Gill and Phillips, 1992).

Those results show that refrigerated railway wagons have sufficient refrigerative capacity to rapidly reduce the surface temperatures of carcasses that are warm when they are loaded to the wagons. When the refrigeration units are operated to deliver air at -1°C, storage efficiencies in excess of 80% are reliably attained. However, it would seem that the delivered air temperature is commonly set too high. Action to remedy that matter would produce a transport process of reliably high storage efficiency.

ASSESSMENT OF PROCESSES FOR TRANSPORTING BEEF QUARTERS BY ROAD

Background and Methods

Two processes for transporting quartered beef carcasses by road were examined. The two processes are very similar, in that beef quarters from animals slaughtered the previous day are loaded to refrigerated road trailers that are sealed to loading dock exits. The air temperatures of the loading docks are maintained between 2 and 4°C, and the trailer refrigeration units are operated during loading. The trailer refrigeration units are set to deliver air at 0°C.

Loggers were placed to record surface and deep temperatures from beef hind quarters. Three beef quarters were monitored in each of five consignments from each plant. In each trailer, the monitored quarters respectively occupied position at the front, centre and rear of the trailer.

Results

The results from the two processes were closely similar, so the data can be considered together.

As with the beef sides loaded to railway wagons, the deep temperatures of the beef quarters ranged from 6 to 18°C. However, the surface temperatures of the beef quarters encompassed a range from 3.5 to 6.5°C. Again, there was no correlation between deep and surface temperatures.

The times in transit ranged from 3.8 to 6.7 days. The surface temperatures of the beef quarters declined progressively during the journeys, and did not attain a steady, minimum value. When they were unloaded, the temperatures of the beef quarters were between 1 and 2.5°C, with deep and surface temperatures differing by no more than 0.5°C.

The proliferations of pseudomonads calculated from the temperature histories ranged from 10.4 to 21.6 generations. The three proliferation values from a consignment differed by up to 3.6 generations. However, higher values were not associated with a particular location (front, centre or rear) within the road trailers. The storage efficiency factors that were calculated for the road consignments ranged from 33 to 55%, with 83% in the range 40 to 55% (Fig. 4).

Those results show that beef quarters in refrigerated road trailers are not exposed to a reliably high flow, and that trailer refrigeration cannot rapidly reduce the surface temperatures of warm beef quarters.

ASSESSMENT OF A PROCESS FOR STORING BOXED BEEF

Background and Methods

Beef sides are cooled overnight, then graded on a sales floor where the air temperature is maintained between 2 and 4°C. Most sides are passed to fabrication on the same day that they exit the chiller, but some may remain on the sales floor for up to three days.

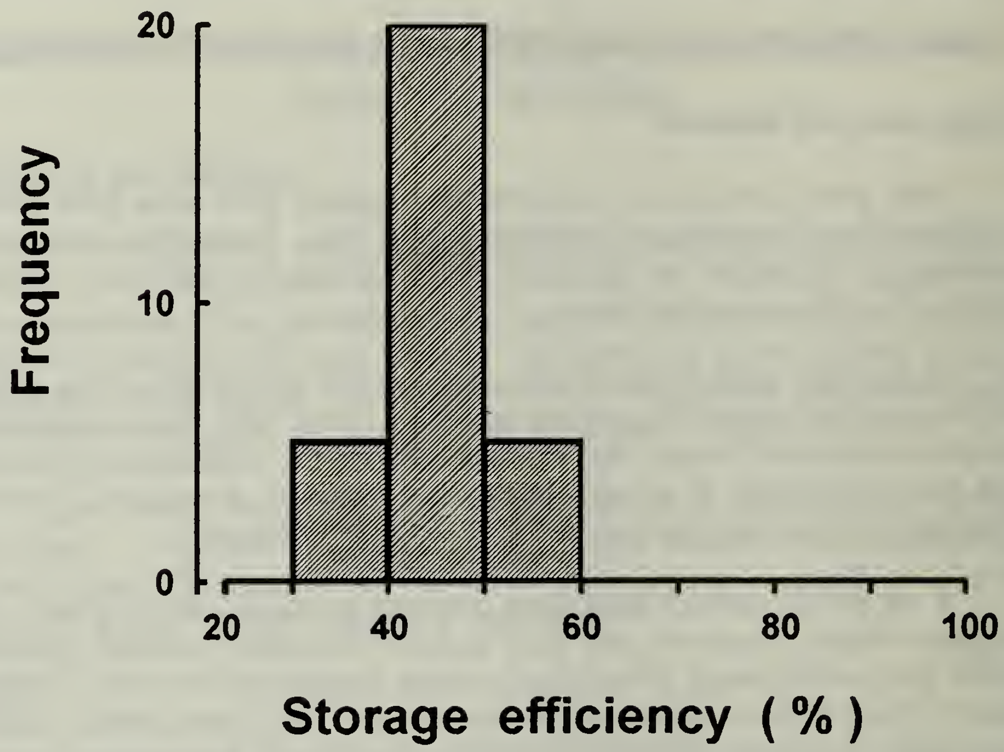
Fabricating operations are completed within 40 minutes. The product is then vacuum packaged and placed in boxes. The filled boxes are conveyed through an automatic sealer, and are then assorted to positions in a boxed beef store that is operated at an air temperature between 0 and 2°C. Product is withdrawn from the store as required for loading to transport.

A variety of vacuum-packaged cuts are produced at the plant. Large, irregularly shaped, bone-in cuts, such as hips (Canadian rounds), rounds, and chucks, are packed singly or in pairs in boxes measuring 545 x 425 x 165 mm (l x w x h). Such filled boxes weigh between 25 and 35 kg, and there is much free space within the boxes, both between pairs of cuts and between the cut or cuts and the box walls. Boneless cuts of more regular shape, such as bone-out loins or blades, are packed in smaller boxes measuring 450 x 380 x 100 mm (l x w xh). Such boxes weigh when filled approximately 20 kg, and within those boxes there is little air space.

Loggers fitted with external teflon probes were used for recording temperatures.

The loggers were placed in boxes of product immediately after they were filled. When the box contained more than one cut, the probe was placed between cuts with the temperature sensitive tip as near the geometric center of the box as was practicable. When the box contained only one cut, the probe was lodged between the cut and a box wall, with the tip as near as possible to

Figure 4. The frequency distribution of the storage efficiency factors calculated for three beef hind quarters in each of ten consignments transported in refrigerated road trailers.



the center of the box wall. Six loggers were placed with product on each of 18 days. On each occasion, the boxes that were monitored were selected to ensure that they would be distributed throughout a stack assembled in the storage chiller. Loggers were recovered when each stack containing monitored boxes was disassemble for dispatch.

Temperature histories were collected from 106 boxes of meat in the storage chiller. The types of packaged product monitored were inside rounds, 44 cartons; outside rounds, 21 cartons; hips, 17 cartons; bone-in chucks, 9 cartons; blades, 6 cartons; boneless loins, 6 cartons; and short ribs, 3 cartons.

Results

The initial temperatures recorded for the boxed product ranged from 14 to 2°C, mean 6.9°C. The highest temperatures were recorded from the round cuts. That would suggest that cut size substantially affected the product temperature at the time that cuts were packaged. However, the length of time that beef sides had remained on the sales floor before they were broken down would seem to be of greater importance, because boxes of inside rounds and blades known to be prepared from sides held on the sales floor for 3 and 2 days, respectively, all showed low initial temperature, but with a higher range of temperatures for the cuts from sides that were held for the shorter time. The data indicate that, given the current cooling conditions on the sales floor, sides would have to remain in that area for a least 2 days if all cuts were to be within a narrow range of low temperatures when they were packaged.

The majority of the monitored boxes (89/106) were held in the box chiller for periods between 18 to 25 h. The mean temperature of product in those boxes at the time of their dispatch was 4.4°C. Only two boxes of product were then at or above 7°C, but 14 boxes were at temperatures approaching 2°C. All but two of those latter boxes were filled with product derived from sides that had been held on the sales floor for 2 or 3 days.

The balance of the boxes that was monitored were held in the box chiller for periods between 62 and 68 h. When those were dispatched from the chiller, their mean temperature was 1.9°C. Most then had temperatures about 2°C, without the time/temperature traces showing constant, minimum temperatures. Minimum temperatures that remained stable for periods in excess of 20 h were attained by only one group of boxes. Those boxes contained product that had been prepared from sides held in the sales chiller for 3 days. The minimum temperatures recorded from those cartons were between 1 and <2°C.

During the residence of product in the boxed beef store, the mean resolution of the lag phase of the indicator organism, calculated for a reference temperature of 0°C, was 4.7 days. At 0°C, the duration of the lag phase is 8 days. The lag was calculated to be approaching resolution (>75% resolution) or resolved for the bacteria on product in 31% of the monitored cartons. The lag was calculated to be fully resolved on product in 12% of those cartons.

Storage efficiencies ranged from <5 to 46%. For product stored for about 1 days, 64% of the storage efficiency values were >15% (Fig. 5). The mean storage efficiency was 17.2%. Thus, on average, each day in the boxed beef store would be equivalent to about 5.5 d storage at the optimum storage temperature.

The results indicate that the average temperature of the air surrounding the boxes within the box chiller is between 1 and 2°C. However, because of weak movement of the refrigerated air in the chiller, and insulation provided by surrounding boxes of product, the boxed beef will cool only slowly to the air temperature of the facility. Unless the product has been cooled to within a degree or two of the box chiller air temperature before it enters that facility, a period in excess of 3 days will be required for the boxed product to equilibrate to the temperature of the chiller air. When most product is packed into boxes, its temperature is substantially above that of the chiller air, and most product remains in the box chiller for less than 24 h. Thus, control of product temperature adequate to assure a lengthy storage life for product is not attained before the product is transferred to transport facilities. The refrigerative capabilities of the boxed beef store would probably have to be upgraded to obtain a storage process that is satisfactory (Gill and Jones, 1992).

ASSESSMENT OF A PROCESS FOR TRANSPORTING BOXED BEEF

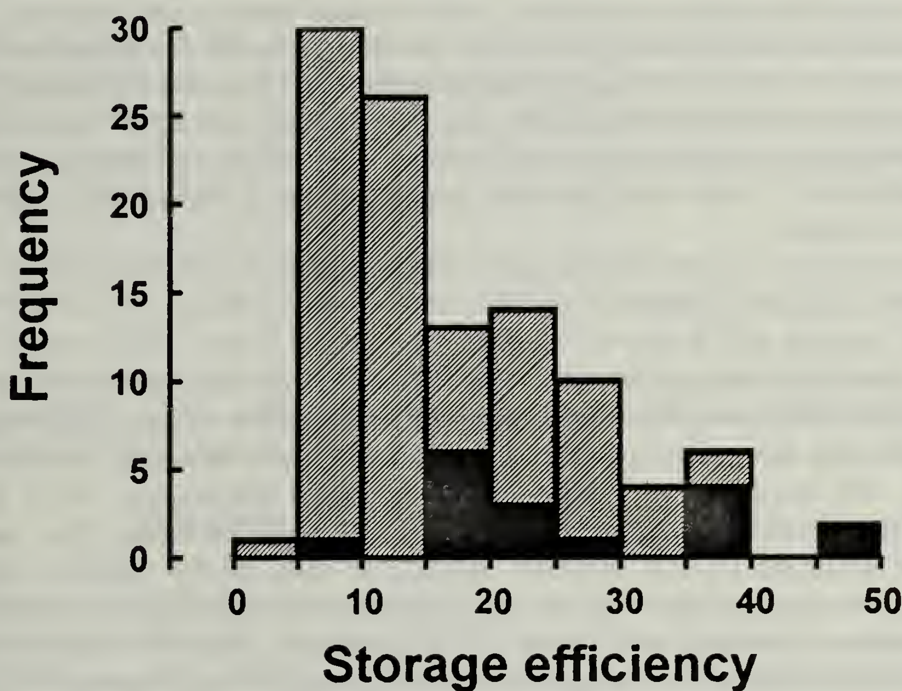
Background and Methods

Boxes are conveyed from a boxed beef store to an unrefrigerated but enclosed loading dock. Trailers seal to the loading dock exits.

The trailers' refrigeration units are operated during loading. The product may be block stacked within a trailer, or assorted to pallets on the loading dock, the palletized stacks then being transferred to a trailer. Because of weight constraints on trailer loads, the trailers are never filled with boxes. Instead, they occupy little over half the available trailer volume. For both block stacks and pallatized loads, the gap between the trailer ceiling and any box is at least 0.5 m. Additionally, palletized stacks are placed against the trailer walls, leaving a central gap of about 0.4 m between the two rows of palletized product.

A trailer can be fully loaded, and the doors closed, within 1 h of the commencement of loading. However, commercial circumstances may extend the loading period for up to 4 h. When sufficient product is not available to

Figure 5. The frequency distribution of the storage efficiency factors calculated for 106 boxes of vacuum packed beef stored in a chiller at a beef packing plant. Product was stored before dispatch for about one day ( ) or about three days ( ).



complete a load, it is the practice to part load, then close trailers, and complete the loading on the following day.

The trailer refrigeration unit is switched on a least 1 h before loading commences. The units operate at a set temperature of 0°C throughout the loading of product. However, the air temperatures to which product is exposed during loading are between 10 and 20°C on the loading dock and between 5 and 10°C within the trailer, because of the exchange of air between the trailer and the loading dock.

After trailers are closed, the refrigeration unit controls are set to -1°C.

Loggers fitted with internal temperature sensors were placed with product as consignments were assembled. Each logger was placed between a product unit and a box wall. Two loggers were placed with each monitored consignment, one being in a box at the approximate center, and the other occupying a box at an upper rear corner of the trailer load. At those positions, the boxes would respectively be insulated from the trailer air flow or be optimally exposed to the refrigerated air. Only consignments that would be in transit for 2 days or more were monitored.

Results

During transport, the temperatures of most product fell, but in 10 of the 60 boxes the final temperatures were higher than the initial temperatures. In consignments where temperatures had risen only in product at the centers of trailers, the temperature history traces showed continuous rises in product temperature following trailer loading. Such traces indicate the warming of product surfaces by the warmer centers of cuts or by warmer surrounding product. In the consignment where temperatures had risen in product at both the rears and centers of trailers, the temperature history traces showed that temperatures rose after some minimum temperature was attained. Such traces indicate failures to maintain truck air at the stipulated temperature.

The distribution of temperatures in monitored boxes at the times they were loaded to road trailers was similar to the distribution of temperatures in monitored product unloaded from the boxed beef store. The mean temperature measured for product at the time of its loading to trailers was 4.8°C. That mean temperature was the same for each of the groups of boxes loaded to central or rear positions in trailers. However, when trailers were unloaded, the distributions of temperatures in the group of cartons carried at the rears or centers of trailers differed distinctly. The mean temperatures of the two groups at that time were 1.7°C and 2.6°C for the rear and central groups, respectively. The mean temperatures during transport for the rear and central groups were, respectively, 2.4°C, range 4.7 to -0.6°C, and 3.0°C, range 7.4 to 0.8°C.

The times product was in transit ranged from 2.3 to 5.9 days for most product. However, three temperature histories for centrally located boxes extended to between 7 and 9 days. From the dates on the temperature history traces, it was evident that those extended temperature histories were the results of delays in completing either the loading or unloading of trailers.

As would be expected from the temperature differences experienced during transport, the mean proliferation calculated for the group of boxes at the rears of trucks was less than the mean calculated for boxes at truck centers, the two values being, respectively, 5.2 generations and 6.9 generations. Moreover, the range of proliferations extended to higher values for the cartons carried at trailer centers.

The lowest storage efficiency (11.5%) was calculated for a carton at a trailer center, while storage efficiency values exceeding 40% were obtained only for some cartons loaded at the rears of trailers (Fig. 6). The mean storage efficiency values for cartons at the rears and centers of trailers were, respectively, 31% and 26%.

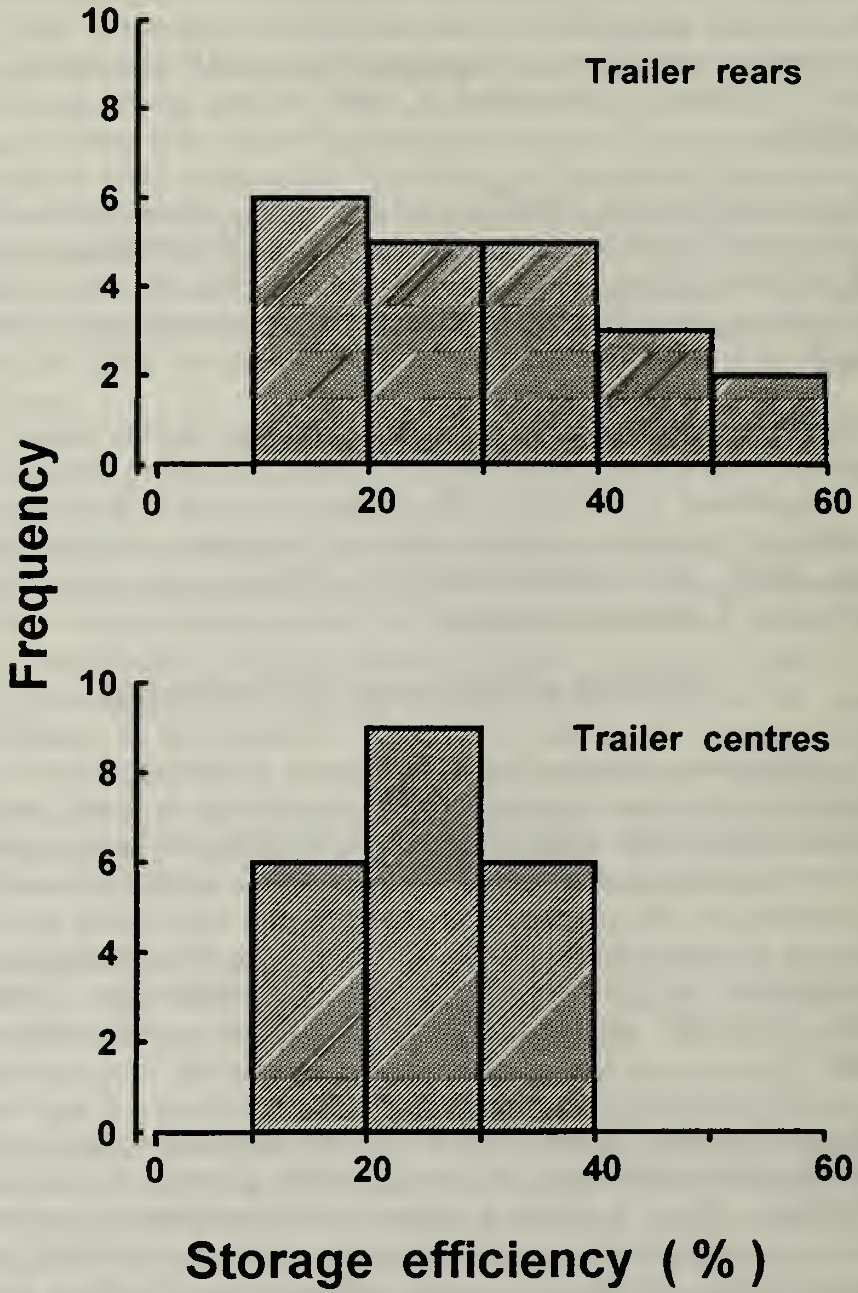
From those results it is very evident that boxed beef is cooled ineffectively in refrigerated road trailers, and that the practice of loading product to transport while its temperature is well above the optimum results in the product having a reliable storage life which is only a quarter of that which could be attained (Gill and Jones, 1992). The matter could be remedied only by proper cooling of the product before it is loaded to transport.

ROUTINE MONITORING OF PROCESSES

The initial assessment of a storage and/or transport process should allow establishment of the type of product unit that will be routinely monitored, the region of the product from which temperature histories will be obtained, the basis on which product units of the appropriate type are selected for monitoring, and a working criterion for the process. In selecting the monitoring procedures, the objective is to ensure that the product units with the worst storage performance are encompassed in routine monitoring, as if that worst performance is acceptable, then the storage performance of all other product must be satisfactory.

When a process involves units of more than one type, the type to be monitored should be that which will remain at the warmest temperatures for the longest periods. Thus, beef hind- rather than fore-quarters are monitored in shipments of quartered beef, and the largest cuts are monitored in processes where boxed beef is cooling to storage temperatures. Similarly, the site from which temperatures are collected will be the microbiologically contaminated site that will remain at the highest temperatures for the longest periods.

Figure 6. The storage efficiency factors calculated for boxes of vacuum packaged beef in 21 consignments transported from a packing plant to customers.



For plant chillers, units of the identified product should be monitored on a random basis. That is readily achieved by monitoring one unit each day, but with random selection of the time for placing a logger with a product unit entering the process.

With consignments of meat, a consignment may be selected for monitoring at random each day. Such monitoring will allow characterization of the process, but will, of course, not identify the individual unmonitored consignments that are subjected to temperature abuse during transportation. As delivery of spoiling product usually leads to extended argument concerning who should bear the responsibility for the consequent losses, routine monitoring of all consignments is worth considering. Then, examination of dated temperature histories will reveal when temperature control was lost, and so establish the responsibilities in the matter.

With hanging meat, the position of a product unit within a consignment apparently does not affect the product temperature history. Thus, the unit to be monitored can be selected at random. The temperature of the air at the rear of the truck, or in the aisle of a railway wagon, should also be monitored, as that temperature history will establish unequivocally the control that is exercised over the truck or wagon refrigeration.

With boxed meat, a logger should be placed with a unit of the selected type that occupies a position within a stack. Again, the trailer or wagon air temperature should be monitored.

The criterion for the process should be set on the basis of attainable storage efficiencies. The criterion should be based on a random sample of 21 units and should stipulate the minimum storage efficiency that is associated with satisfactory storage conditions (**m**), the storage efficiency below which storage conditions for the product unit are unacceptable (**M**), the proportion of units with efficiencies between **m** and **M** that can be tolerated (**c**), and the average storage efficiency (**a**). The criterion is in the form of a three point attributes acceptance plan, which is an appropriate form for decisions with respect to the microbiological condition of raw products (Jarvis, 1989).

The values for the fraction of storage efficiencies that are less than **M**, the minimum storage efficiency and the average storage efficiency should be determined from the first 21 routine monitorings. Subsequently, those values should be recalculated for the last 21 temperature histories each time that five or six temperature histories are accumulated following a previous calculation of the values. The values for those factors should be plotted on a suitable graph maintained for that purpose . Then, any drifts in the process can be identified, and movement towards decreasing storage efficiency corrected before the efficiency falls below the criterion values.

The storage efficiency data should be used to calculate the reliable storage life of product. The storage life of product units held under constant temperature conditions should be determined. Ideally, two or three product units should be withdrawn weekly, and stored until spoilage at a steady, known temperature. However, such a procedure would be impracticable with large units such as beef sides. For that type of product, an estimate must be made of the numbers of the relevant spoilage bacteria that contaminate the product at the start of the process. That will allow calculation of the storage life attainable at the optimum storage temperature. Similarly, the storage life at the optimum temperature can be calculated from the storage life determined at any constant chiller temperature.

With a value for the maximum storage life attainable, the actual storage life achieved in a storage or distribution process can be derived from the information on the storage efficiency of the process. The duration of a storage or distribution process should never be extended beyond the time that is obtained by multiplying the maximum storage life by the minimum storage efficiency value derived for the process. In most circumstances, that time will have to be reduced by between 25 and 50%, to allow for the convenient use of the product by the customer.

CONCLUSIONS

The storage life of all chilled meat is highly dependent upon the temperatures that the product experiences during storage. Therefore, a storage life ascribed to a chilled meat product is essentially meaningless unless the temperature at which that storage life is attained is known and stated. Unfortunately, many in the meat industry do not appreciate the extreme temperature dependence of their products' storage life, and so are disappointedly surprised when product in commercial trade does not have the expected stability.

Such misunderstanding can be remedied by the described temperature function integration assessment of the storage efficiencies of storage and distribution processes. With that knowledge, meat packers can at least avoid distributing meat through processes having storage efficiencies that are inadequate to preserve meat for required times. More positively, a proper assessment will allow identification of the factors in a process that limit the storage efficiency, and so allow effective decision on how the process can be improved. Optimization of storage and distribution processes will allow meat packers greater flexibility and range in the distribution of their products.

ACKNOWLEDGMENTS

The technique of temperature function integration analysis was developed over several years with the assistance of members of the staff of the Meat Industry Research Institute of New Zealand and the Agriculture Canada Research Station, Lacombe. Work in Canada has been supported financially by the Alberta Agricultural Research Institute through their grant No. 990M221.

REFERENCES

Bogh-Sorensen, L. and Olsson, P. (1990). The chill chain. Pages 245-268 *in* Chilled Foods, The State of the Art. Ed, Gormely, T.R. Elsevier Applied Science, London, U.K.

Gill, C.O. (1979). Intrinsic bacteria in meat. J. Appl. Bacteriol. 47, 367-378.

Gill, C.O. (1986). The control of microbiol spoilage in fresh meats. Pages 49-88 *in* Advances in Meat Research, vol. 2. Eds, Pearson, A.M. and Dutson, T.R. AVI Publishing Co., Westport, CT. U.S.A.

Gill, C.O. (1990). Controlled atmosphere packaging of chilled meat. Food Control 1., 74-78.

Gill, C.O. and Jones, S.D.M. (1992). Efficiency of a commercial process for the storage and distribution of vacuum packaged beef. J. Food Protect. 55, 880-888.

Gill, C.O. and Newton, K.G. (1978). The ecology of bacterial spoilage of fresh meat at chiller temperatures. Meat Sci. 3, 207-217.

Gill, C.O. and Phillips, D.M. (1992). The efficiency of storage during distant continental transportation of beef sides and quarters. Food Res. Internat. (in press).

Gill, C.O., Phillips, D.M. and Harrison, J.C.L. (1988a). Product temperature criteria for shipment of chilled meats to distant markets. Pages 40-47 *in* Refrigeration for Food and People. International Institute of Refrigeration, Paris, France.

Gill, C.O., Phillips, D.M. and Harrison, J.C.L. (1988b). A computer program for assessing the remaining storage life of chilled red meats from product temperature histories. Pages 35-39 *in* Refrigeration for Food and People. International Institute of Refrigeration, Paris, France.

Gill, C.O., Harrison, J.C.L. and Phillips, D.M. (1991). Use of a temperature function integration technique to assess the hygienic adequacy of a beef carcass cooling process. Food Microbiol 8, 83-94.

Grau, F.M. (1987). Prevention of microbiol contamination in the export beef abattoir. Pages 221-233 *in* Elimination of Pathogenic Organisms from Meat and Poultry. Ed, Smulders,. F.J.M., Elsevier Science, Amsterdam, The Netherlands.

ISO (1990). ISO 9000, International standards for quality management, 2nd ed. International Organization for Standardization, Geneve, Switzerland.

Jarvis, B. (1989). Statistical aspects of sampling for microbiological analysis. Pages 59-86 *in* Statistical Aspects of the Microbiological Analysis of Foods. Elsevier Science Publishers, Amsterdam, The Netherlands.

Lowry, P.D. and Gill, C.O. (1985). Microbiology of frozen meat and meat products. Pages 109-168 *in* Microbiology of Frozen Foods. Ed, Robinson, R.K., Elsevier Applied Science, Barking, Essex, U.K.

McMeekin, T.A. Olley, A.J. and Ratkowsky, D.A. (1988). Temperature effects on bacterial growth rates. Pages 75-89 *in* Physiological Models in Microbiology, vol. 2 Eds. Bazin, M.J. and Prosser, J.L., CRC Press, Boca Raton, FL, U.S.A.

Phillips, D.M. and Gill, C.O. (1986). Routine collection of product temperature history during storage and transport of chilled, packaged meat. Pages 527-537 *in* Recent Advances and Developments in the Refrigeration of Meat by Chilling. International Institute of Refrigeration, Paris, France.

APPENDIX 1. EQUIPMENT FOR TEMPERATURE HISTORY COLLECTION

Development of the temperature function integration technique required the availability of a temperature data logging device that was; sufficiently rugged to withstand the meat plant environment; of a conveniently small size, so that the logger could be placed with product without interfering with normal processing; accurate, reliable and secure against unauthorized interference with the data it collects; and capable of being interfaced with a computer, for convenient analysis of the data.

At the time that work was initiated, no such instrument existed. It was therefore necessary to design a temperature data logger, and computer software for setting the logging functions and retrieving collected data. That system is now licensed, by the Meat Industry Research Institute of New Zealand, for manufactured by Tru Test Distributors Ltd., Auckland, New Zealand. A number of similar instruments are now available from various suppliers. However, those other instruments are not compatible with the analytical software (see Appendix 2) that has been developed for the MIRINZ/Delphi temperature data logging system.

The characteristics of the MIRINZ/Delphi temperature logging system are:

Temperature Logger:

Physical Characteristics

- Compact Size: 160mm x 96mm x 22mm
- Weight: 204.5 grams
- Power Supply: Lithium cell, meeting US Fed Reg CFR 173.206
- Battery Life: Approximately 5 years
- For in-plant monitoring of product temperatures the model fitted with an external, Teflon probe should be specified.

Recording Characteristics

- Temperature Range: -20 °C to + 40 °C
- Accuracy: ± 0.25 °C over operating range
- Resolution: 0.25 °C
- Start delay: up to 85 days
- Data Security: 4 Character Password
- Number of Temperature Recordings: 8000 8-bit logs
- Recording Time Intervals: Min. 1/32 hour, Max. 7.96 hour
- Recording period (Interval x 8000)
  10 Days if recording interval is 1/32 hour
  333 Days if recording interval is 1 hour
  667 Days if recording interval is 2 hours

- Downloading time: 64 seconds

Logger to Computer Interface:

- Communications : Utilises RS 232c Serial Link
  : Data format : 8 bits plus 1 stop bit at 1200 baud
- Power Supply: Internal, 9V cell type 216
- Size: 120mm x 68mm x 34mm
- Weight: 216 Grams
- Cable Length: 1.5 metres
- Terminating Connector : For PC: 25 pin D type female
  : For Epson HX-20: 3 pin DIN
- Battery Failure Indicator for Logger and Interface

Controlling Software

Capabilities

- Set up logger for recording
- Read logger data and summary
- Display of logger status
- Graphics display of logger data
- Printed report on logger status, tabulated data and graph data
- Database version (Optional)

Features

- Menu driven, function key control
- Multiple display windows
- On-screen status and data summary
- Expanded on-screen data plot
- Automatic alarm indication for temperature outside preselectable range
- Selection of limits on data of interest
- Data storing on disk and loading from disk
- Customized report selection
- Installation program to set custom options
- Automatic logger error detection
- Fail safe against user errors
- Compensated for Time Zone differences
- Operates in degrees Centigrade or Fahrenheit

Compatible Computer and Printer Systems

The recommended computer system is IBM PC or compatible.

- MS-DOS or PC-DOS Version 2.0 or later
- 640 KByte RAM

- 640 x 200 resolution graphics controller and monitor
- Minimum of 2 x 360 KByte floppy disk drives
- Hard disk optional but highly recommended
- RS 232 serial interface
- Printer interface

Any printer can be used but it must have graphics capability. Currently supported are IBM, EPSON and Printek. Others can be adopted as required.

APPENDIX 2. SOFTWARE FOR TEMPERATURE HISTORY ANALYSIS

Software for temperature history analysis is available from The Meat Industry Research Institute of New Zealand, Hamilton, New Zealand. The software allows set up of the MIRINZ/Delphi data logger. With the analytical software, the logger is associated with a particular process to be monitored, and an appropriate recording interval is automatically set, during the set up procedures. Data is also retrieved by the software by the software, with graphical presentation of the temperature history, times of history beginning and ending, and the minimum, maximum and average temperatures for the history. With the analytical software, the program will run only if the temperature history meets with a number of checks that identify it as having the form expected for the process that was identified for monitoring at logger set-up. If those checks are met, a report will be printed which details the process which was monitored, the temperature history, and the calculated growth of an appropriate indicator organism. The available programs are:

DLOG - Controlling software for the MIRINZ/Delphi temperature data logger, with facilities for data manipulation and analysis.

API - Analytical software for meat cooling processes in slaughtering plants. Temperature history data is analysed with respect to the growth of *Escherichia coli.*

AP2 - Analytical software for the storage and transport of chilled carcasses, and chilled meats that are not packed in a preservative packaging. Temperature history data is analysed with respect to the growth of psychrotrophic pseudomonads.

AP3 - Analytical software for the storage and transport of vacuum packaged meat. Temperature history data is analysed with respect to the growth of psychrotrophic enterobacteria.

The compatible computer and printer systems are those specified in Appendix 1.