Modelling Meat Processing Operations

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ABSTRACT

Design and control of meat processing operations can be made substantially easier through the use of both physical and mathematical mo This paper describes some physical and mathematical models of chilling and freezing processes that have been developed at MIRINZ and o organizations, and explores some case studies of their use in the New Zealand meat processing industry. Finally, it shows that packaging m results in unusual ways, such as on video tape, or including the models themselves in user-friendly computer software, can improve accessibility to industry users.

INTRODUCTION

The traditional method of designing a meat processing operation has been to rely on a combination of common sense and experience. Proc designed in this way have the virtue of easy predictability - they end up being similar to existing processes that have been used for decades so they produce outcomes that are little different from the outcomes that have been produced for decades. Where those previous outcomes and are still satisfactory, this is fine. Where those outcomes are now not satisfactory, because they are unnecessarily costly, the process unsafe, or they no longer meet the requirements of the modern consumer, the process designer must stray from the easily predictable path. At point, experience-based design techniques become a liability because the designer is operating in an area where experience is not applicab

Even when one is not designing a novel process, experience-based design techniques are still a liability. For one thing, they require the person doing the design have the required experience. This is a problem when the experience takes a long time to acquire, since it limits the nu of people who are qualified to do the design. When those people leave the organization, the experience, and thus the design capability, goes them. Further, even if one attempts to have experienced people train their replacements, the nature of experience-based design means that difficult for a designer to communicate a design procedure to his or her less-experienced colleagues by any means other than having the collea watch and learn while the experienced designer solves sample problems or carries out his or her designs.

Model-based process design, on the other hand, can resolve each of the difficulties identified above. A well-validated model will be cap of being applied to a wide range of conditions - far wider than the range typically encountered in a designer's experience. Furthermore, a model will include a clear description of the range of conditions where it is valid, thus preventing its use (or abuse) in situations where it is applicable. A model, in whatever form, is a tangible, objective, representation of the process to be designed. This means that it is not locked inside the head of the experienced designer, but is instead written down as a set of mathematical equations or lines of computer program or or is embedded in the physical structure of a scale model. When the experienced person leaves the organization, this objective representation s behind. Finally, because the model can be described in an objective and standardized way, it is relatively easy for a new designer to beco familiar with the model and to use it with a good chance of success.

ADVANTAGES OF INTEGRATED MODELLING

Although this paper will discuss models of processing operations, it is important to note that processing models should not be u independently of other models. Lovatt (1995) demonstrated how models of chilling and freezing rates could be combined with models of m aging and microbial growth. This integration allows the process designer not only to consider the engineering aspects of the process, but also optimize quality and hygiene aspects at the same time. On the other hand, integrated models allow scientists studying quality and hygiene iss to take the practicalities of implementation into account when they propose treatments to be included as part of the process.

Since the real objective of the process is often not (for instance) to "chill the carcass to 7°C in 24 hours", but to meet customer-specified tenderness and hygiene parameters, it is important to include models that predict the effect of the process on these parameters as early as possible in the design process. By allowing the process designer to focus directly on the real objective rather than on some intermediate goal (like a temperature vs. time profile), such models permit improved design flexibility; hence opportunities to reduce costs or improve reliability are made greater.

CASE STUDY: CHILLING AND FREEZING PROCESS DESIGN - A MODELLING APPROACH

Suppose that we are designing a new meat plant to process 500 head of beef per day in a single shift operation, as summarized in Figure 1. The objective is to design the chilling and freezing processes (while considering tenderness and

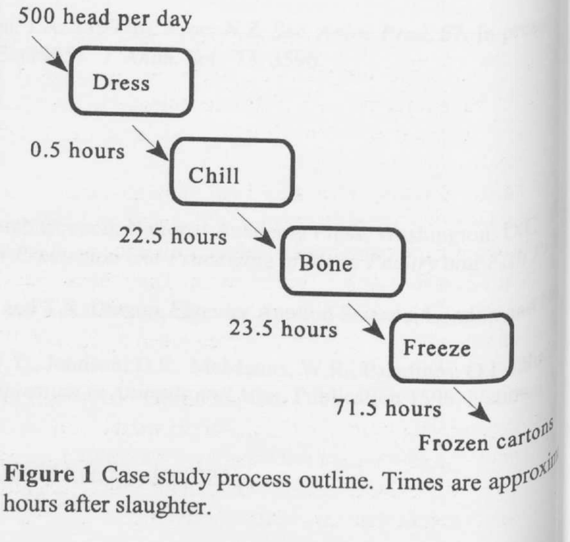

Figure 1 Case study process outline. Times are approxim hours after slaughter.

hygiene requirements), identify the times at which processes will be complete, and evaluate the amount of space and the refrigeration capacity required in the plant.

Chilling and freezing time

The full range of chilling and freezing time models available for application to meat products has been surveyed by Cleland (1990). These methods range from simplified methods that predict single chilling or freezing times for specific points in the product (e.g. the freezing time for the thermal centre as calculated by the method of Pham, 1986), to finite difference methods that can readily be applied to specific simple shapes (slab, cylinder, sphere, rod, short cylinder, and brick, e.g. the method of Pham, 1985), and to finite element methods that consider the full shape of a piece of meat (e.g. Pham *et al.*, 1991).

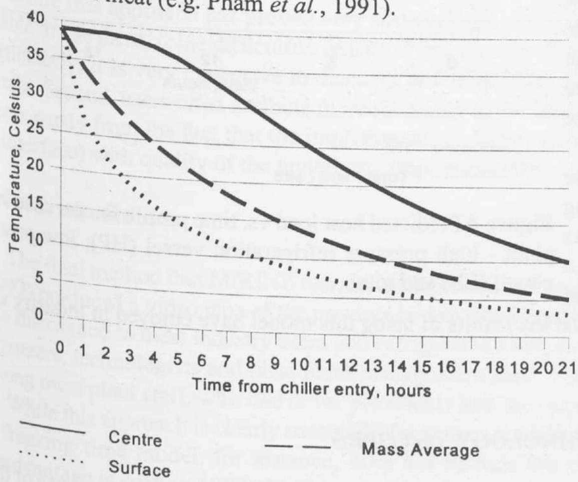

Figure 2 Predicted temperature vs. time profiles for the case study process. Air temperature 0°C, air velocity 1 m/s.

To design the chilling and freezing processes, we will need to know the temperature vs. time profiles at several points in the product, so the simpler methods are not sufficient. Since it is difficult to specify a meat temperature vs. time profile, and automatically calculate the required chiller conditions from that (this would amount to the problem known as the "inverse heat conduction problem"), a trial and error procedure is followed until a set of conditions is found where the product chills within the time required. Figure 2 shows the temperature vs. time profiles for the centre and surface of a 150 kg beef side as predicted by MIRINZ's "Food Product Modeller" software (FPM) for an air temperature of 0°C and an air velocity of 1 m/s.

This software is based on the work of Pham (1985), but it extends the applicability of the finite difference method to complex shapes through the use of mapping functions that relate complex shapes such as meat carcasses to simple shapes such as slabs, cylinders or spheres. The mapping function used for the beef side is intended to predict the thermal centre (deep butt) temperature profile most accurately (approximately ±10% error in predicting chilling time), while the surface temperature is predicted less accurately than this.

FPM calculates the value of the Process Hygiene Index (PHI), as described by Gill *et al.* (1991), so PHI can be used to evaluate the relative hygienic quality of the process. For the surface, the calculated PHI for this process is 5.8, which is well within acceptable guidelines. The PHI at the centre is much higher, but one can assume that the thermal centre of an uncut beef side is sterile (Gill *et al.*, 1991), so the PHI value at the centre will not reflect any real hygienic consequences.

If we assume that the meat temperature does not change significantly during boning, and that the process of packing the meat into cartons mixes up cuts of different temperature, the freezing process will commence with meat at 5°C. Assuming 160 mm deep by 540 mm wide cartons arranged in rows (so that there is no heat transfer on the leading and trailing surfaces), cartons constructed of E-flute cardboard, and a 4 mm air gap at the top of the cartoned meat (to allow for expansion during freezing), we can then use FPM to simulate the freezing process. As with the chilling phase, trial and error can be used to discover a suitable process, as shown in Figure 3.

The "Surface - Top" line and the "Geometric centre" line in Figure 3 intersect because the thermal resistance due to the air gap in the top of the carton means that the geometric centre is not at the thermal centre. Most of the heat in the carton therefore passes out through its bottom surface.

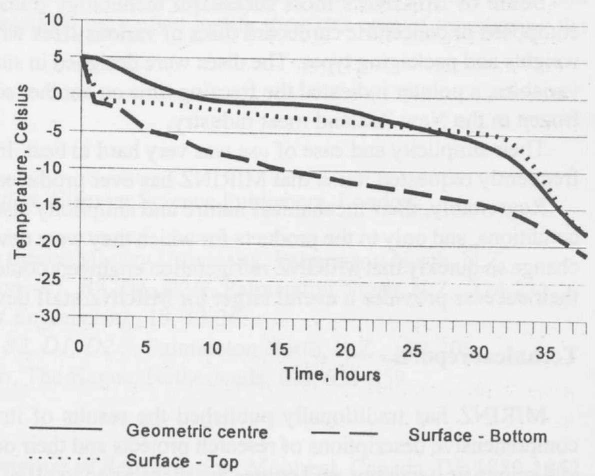

Figure 3 Predicted temperature vs. time profiles during carton freezing for an air temperature of -28°C and an air velocity of 3 m/s.

Chilling and freezing heat load models

Having discovered a process that cools the product in the time available, we now need to size the refrigeration system. For the product heat load, this can be calculated from the same finite difference models as were used for the temperature profiles, or alternatively from simpler models such as those proposed by Lovatt *et al.* (1992).

The next most important heat load in an air-blast chiller or freezer is typically that due to the electrical power driving the fans. This was modelled for typical New Zealand meat industry chillers and freezers by Kallu *et al.* (1993). These workers proposed that the required fan power could be calculated from the air velocity over the product, the number of product items, the cross-sectional free air flow area for each product, and the air pressure drop over the room. They found that the cross-sectional free air flow area depended on the product type, and that the air pressure drop depended on the room configuration and the pressure drop through the refrigeration coil. Using the models given by Kallu *et al* (1993) and the relationship for free area given by Kallu (1993) for beef sides, we can calculate the amount of fan power required in the chillers and blast freezers.

If we assume that 100 carcasses per chiller is a reasonable size, then the plant will require five side chillers to deal with its daily throughput. Assuming a boning yield of 67%, this plant would produce 3700 27.2 kg cartons of meat per day (offal would be additional, and is not considered in this analysis), so the required capacity for a continuous carton freezer would be 7400 cartons. Assuming a fan efficiency of 70% and a motor efficiency of 90%, Kallu's models predict a required fan power of 32 kW in each chiller and 116 kW in the carton freezer. The figure of 32 kW per chiller is higher than usual New Zealand practice, and is a consequence of the relatively high air velocity of 1 m/s.

Combining the heat loads from the fans and product, and some miscellaneous loads resulting from heat infiltration through walls, we can now predict a load profile for the whole refrigeration system, as shown in Figure 4.

From the load profile shown in Figure 4, we could proceed to size the refrigeration plant using further models of the refrigeration process, but the technique is very similar to that just discussed above.

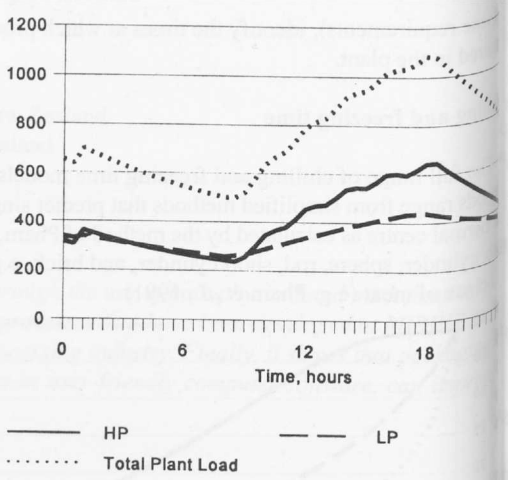

Figure 4 Predicted heat load vs. time profile for the case s plant - high pressure refrigeration vessel (HP), low pre vessel (LP) and total.

Air flow distribution models

Not all of the models developed for use in refrigeration design have been of the mathematical variety. Lovatt *et al.* (1993) developed a two-dimensional 1:10 scale model of a beef chiller by using water to represent flowing air and visualizing that flow by generating hydrogen bubbles in the water. Meat carcass shapes were placed inside the chiller model and the effects of various flow regimes were studied.

The physical modelling technique was originally selected in this case because the alternative method (computational fluid dynamics) required computing resources that were not available to the model's developers. However, it was subsequently found that the tangibility of the physical model seemed to give it a greater intrinsic credibility among industry users than many of the mathematical models have had. This may well have influenced the fairly high rate of uptake that the results of using this model have enjoyed in industry s it was developed.

TRANSFERRING MODELLING TECHNOLOGY TO USERS

The process models described above are typically not accessible enough in their published form for users in industry to make good use of t It is therefore important to select technology transfer methods that give the meat plant staff who need the models the ability to use them o results most effectively. Methods that have been used by the author's institute to make processing model results useful to industry in mechanical calculators, technical reports, user-friendly bulletins, computer software, and video presentations.

Mechanical calculators

Some of MIRINZ's most successful technology transfer efforts have been the so-called "MIRINZ freezing wheels". These device composed of concentric cardboard discs of various sizes with markings on their outer edges to represent air velocities, air temperatures, pro weights and packaging types. The discs were designed in such a way that when they were aligned to indicate a particular combination of the ab variables, a pointer indicated the freezing time on another scale. Several calculators were developed - one for each of the product types comm frozen in the New Zealand meat industry.

Their simplicity and ease of use was very hard to beat. Indeed, even though they were developed many years ago, they are still among the m frequently requested items that MIRINZ has ever produced.

Regrettably, their mechanical nature and simplicity also makes them inflexible. The calculators can be applied only over a limited rang conditions, and only to the products for which they were developed. In the modern New Zealand meat industry, products and processing condi change so quickly that MIRINZ refrigeration engineers could easily spend their time doing nothing but devising new freezing wheels. Neverthe their success provides a useful target for MIRINZ staff developing other technology transfer media.

Technical reports

MIRINZ has traditionally published the results of its industry-oriented research in the form of technical reports. These document comprehensive descriptions of research projects and their outcomes. They are reviewed within MIRINZ to achieve a high quality of present and scientific accuracy, and copies are distributed to all of MIRINZ's subscribing members.

Unfortunately, it is the author's experience that process models and their outcomes presented in the form of technical reports tend to intim all but a few of the people that they reach in industry.

User-friendly bulletins

MIRINZ also produces a series of "bulletins" that are intended to be more accessible than its technical reports. Bulletins are typically four p in length and present the outcomes of research projects without the rigorous justification that one finds in technical reports. Through the auth contact with meat plant staff, there is considerable anecdotal evidence that plant staff find the bulletins much easier to use than the techn reports.

While model outcomes can be presented in bulletins, lack of space prevents a bulletin from including more than the highlights of the mode work. Furthermore, simplifying the report by eliding justifications and assumptions makes it easier for a user to apply the model res inappropriately.

As a trial, MIRINZ has produced a recent bulletin that uses a "recipe" formulation to present a fairly sophisticated model of the freezing process (that of Pham, 1986) in a form that a computer-literate user could implement in a spreadsheet, or that could be used for hand calculations with the aid of a pocket calculator. This bulletin has not been released for long enough for its effectiveness to be assessed.

Computer software

The most successful method that MIRINZ has used in the last 10 years for transferring sophisticated modelling technology to the meat industry has been to embed the models in user-friendly computer software. By this method, the complexity of a partial differential equation or ordinary differential equation-based model can be concealed from the user. The user provides input data that the program can check for reasonableness, and then the program responds with outputs resulting from the model as if by magic.

While this approach has proved very successful in putting powerful modelling techniques into the hands of users who would otherwise be unable to use them, some difficulties remain. First, the cost of developing software that is sufficiently user-friendly for industry staff is high. More particularly, it is very expensive to discover and then block all the ways in which such users could misuse the software to obtain nonsensical results. Second, users often attribute more reliability to the model results than is justified by the input data or the accuracy of the model itself. This stems partly from the fact that the implementation details are hidden, and partly from the way in which users associate ease of use (i.e. quality of interface) with quality of the underlying implementation.

Video presentations

The final method that MIRINZ researchers have used to transfer process model outcomes to industry has been the video presentation. Willix (1993) produced a video tape of the previously described beef chiller scale model, while it was operating in a range of configurations. This tape was distributed to meat industry users and refrigerated room designers around Australasia. It has also been used by several educators in training engineers, technologists and meat plant management staff. The visual impact of the flow model video has engendered many positive reactions among meat plant staff, who had never previously had the opportunity to observe how air actually flowed around the carcasses in their chillers.

While this approach is clearly successful for certain models, there are other models for which a video presentation would be much less effective. A freezing time model, for instance, does not include the visual elements that make the flow model so appealing to the viewer. Another disadvantage is cost: in 1993, the flow model video cost about $US700 per minute of finished presentation.

CONCLUSIONS

Modelling techniques, both mathematical and physical, have real advantages when used in meat plant process design, including their objectivity, portability and independence from the skills of particular experts. If they are to be of real use to industry after development, however, it is vital to develop methods for transferring their results effectively. While passive methods of technology transfer such as written reports and bulletins have their place, the effectiveness of computer software and video presentations may often justify the extra cost of transferring the technology by these means.

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