Viewpoint

Package design for refrigerated food: The need for multidisciplinary project teams

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Consumer demands for fresh food are increasing; combined refrigeration and packaging systems are an effective means of achieving the required product shelf life for transportation over significant distances. Optimization of packaging systems for refrigerated food requires a multidisciplinary approach, drawing on a wide variety of skill areas. Examples of refrigerated packaging system designs are discussed in this article, to show how trends in societal organization and expectations may be having a negative effect on the formation of appropriate multidisciplinary teams for package design. Failure to form suitable teams may slow the uptake of new research results, and thus lead to less than optimal package designs.

The refrigeration of food to extend its shelf life so that it can be transported from agricultural production areas to urbanized consumers some distance away is a relatively old technology, dating from the late 1800s. Nevertheless, it is still one of major importance, and is likely to remain so for several reasons. First, the liberalization of the trading environment for agricultural products as part of recent changes to the General Agreement on Tariffs and Trade (GATT) is projected to increase the volumes of food that are transported internationally in refrigerated form. Second, consumer preferences for foods favour produce in fresh condition; refrigeration to chilled storage temperatures is a cost-effective means of extending the shelf life of such products. Third, packaging systems that modify the environment that a food is exposed to can significantly augment the effectiveness of the refrigeration process, increasing product shelf life still further.

Packaging performs three functions. The first function, which is usually met by the packaging layer in closest contact with the food, is to control the local environmental conditions to enhance storage life. Examples of packaging that performs this function are a sealed plastic film designed to exclude moisture, and the tin-plated can. The second function of packaging is display: presentation of the product in an attractive manner to the potential buyer. In the case of plastic films, the inclusion of an outer layer with enhanced printability is often necessary. The third function of packaging is to protect the product during transit to the consumer. Transport packaging is often made from paperboard. Economic considerations suggest that where possible all three functions should be met with a single layer of packaging, but sometimes several layers are required, each designed for a different purpose. Relatively sophisticated packaging designs for refrigerated food are frequently dictated by the use of low temperature and the often high relative humidity conditions as well as the increasing use of modified atmospheres.

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In the research and development phase, it is no longer enough to consider just refrigeration, or just packaging – it is the combinations that matter. Refrigerated package design requires a truly multidisciplinary approach, as illustrated in Table 1; there are needs for inputs by mechanical engineers (e.g. container strength), by process engineers (e.g. freezing and cooling processes), by physical chemists (e.g. polymer design, gas transmission), by food chemists and microbiologists (e.g. chemistry and microbiology of deteriorative change), and by physiologists (e.g. biological disorders in fresh

Table 1. Some disciplines and subject areas that are important in package design for refrigerated food

Packaging type	Discipline	Subject area
Transport and display packaging	Mechanical engineering	Compression strength Package shape retention Abrasion (rubbing) Puncture resistance Creep Shock and vibration Package handling
	Process engineering	Heat transfer Mass transfer Fluid flow and ventilation Psychrometry
	Chemistry	Additive performance
	Logistics	Ergonomics Transportation systems
	Marketing	Package presentation
Food-contact packaging	Process engineering	Heat transfer Mass transfer
	Physical chemistry	Polymer science Gas permeability Atmospheric modification
	Food chemistry	Deteriorative reactions
	Biology	Microbial spoilage Physiology of disorders Cell changes in bruising

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produce subjected to changes in environmental conditions), to name only the major disciplinary areas. The outcome from such combined efforts should be methodologies that enable effective and efficient packages to be designed to facilitate the transport of perishable food.

Changes in society

It might be said that the above view is very much stating the obvious, but changes are occurring in society that are making the process of package design much more difficult. First, there are the perceptions of consumers that environmental issues must be considered; consumers are not prepared to accept any lowering of product quality, yet the packaging system used must be demonstrably benign in environmental terms. A major mover in this respect was Germany which, following the so-called Topfer decree, introduced the Verpackungsverordnung (Verpac V) packaging ordinance on 12 June 1991. This legally required retailers and suppliers to take back all used shipping containers and to either reuse them or transmit them for recycling rather than dispose of them through the normal public waste collection and disposal system. Other countries have also moved along similar lines, and there are now common expectations that transport packaging materials are recyclable, and that the volumes of packaging materials are minimized. The requirement to use wood-fibre products without the addition of protectants that slow water-vapour absorption (so that fibre recycling is maximized) results in reduced container strength in the high relative humidity environment typical of refrigerated food storage.

The second change in society is much more subtle. It is now well recognized that the industrialized nations have entered a so-called post-Fordist society, which is characterized by rejection of the 'production line' factory philosophy. Management structures have become much flatter, and the organization of employment is quite different. Many organizations now expect to buy in particular types of skills as they need them rather than to maintain skilled personnel on staff. In response, individuals are offering their skills on a short-term contractual basis, which they renegotiate for each new client. Such arrangements are the antithesis of the bulk labour supply agreements that characterized Fordism. Both within New Zealand and beyond, I have observed the shutdown, or at least the serious erosion, of research and development teams, and the emergence of a large number of consultants offering very specialized technical services, many of whom are operating internationally.

Consequences for refrigerated food package design

If the various skills needed to design a packaging system effectively must be purchased from several individual contractors, then communication in itself becomes a considerable component of the task. Not surprisingly, communication breakdowns occur, and these lead to poor designs. It is useful to look at some examples of packaging system development to see how the various disciplines need to interact. The examples chosen are typical of export food products from Australia and New Zealand to the northern hemisphere; such products travel the longest refrigerated food chain in the world.

It is common practice to chill or freeze meat or fish products in their transport packaging because this is usually the only packaging applied to the product that has the necessary rigidity. In the case of frozen products, the package is required only to have the strength to get the product to the freezer; thereafter the solid-frozen product itself holds the shape. Thus, it is often possible to use flexible solid-wall paperboards, which have relatively good heat transmission properties. In contrast, the chilled product carton must maintain its structural rigidity all the way to the market. It is usually made out of much more insulating, but stronger, corrugated-wall paperboard. This leads to the somewhat curious situation in which the normally lower-quality (frozen) product is more easily cooled to its storage temperature than is the higher-value but more sensitive (chilled) product. Worse, the tops of the plastic bags used to line the transport carton are often folded haphazardly in the top of the carton, thus creating highly insulating air pockets – an even better form of insulation than the corrugated-wall paperboard itself.

Table 2 contains the results of a typical heat transfer resistance analysis for the heat transfer pathway from the centre of a carton of meat or fish pieces to cooling air in an air-blast chiller or freezer. Such packs are normally regarded as 'solid' packs. The relative influences of the controllable factors – the packaging carton and the trapped air layer – are clearly seen.

It is relatively easy to assess the effects of different strategies for such a package design. A meat company in New Zealand, using the skills of its own personnel in its core competency areas of marketing and logistics, decided that the base dimensions of all of their meat cartons should be the same. Different product densities and container loads would be accommodated by varying the container height. The downstream consequences were quite serious: the freezing or chilling time varied by between a linear and a quadratic relationship with height if the air convection heat transfer coefficient was not changed. Tall cartons obstructed the air flow channels in the freezers and chillers more than short cartons did; thus, the tallest cartons had the least air flow over them, increasing the associated convection heat transfer resistance and the process time still further. For example, in changing from a 180-mm-thick solid-wall carton with an air flow of 2 m/s over the surface to a 165-mm-thick carton with an air flow of 3 m/s, the heat transfer resistance increased by 20%, from $\sim 0.16\ m^2K/W$ to $0.19\ m^2K/W$.

Another weakness of this type of packaging system when applied to an air-blast-frozen product is that the resulting frozen product cartons are difficult to stack as the faces of the cartons expand (as a result of ice formation), thus leading to a safety problem (tipping over of stacks) and to poor use of shipping space. Furthermore, the plastic liner within the carton may become frozen in between pieces of meat and thus thawing (usually by microwave) is required before the product can be separated from the packaging. Neither the package itself nor the packaging process should be considered to be at fault in isolation from the other – the system as a whole needs re-evaluation.

In the case of chilled products there are other consequences. It is well known that psychrotropic bacteria grow much faster on meat at 5–10°C than at ~0°C; various published data are available, of which those of Gill[3] are a good example. By slowing the carton cooling process significantly, the corrugated-wall carton reduces the subsequent shelf life of meat at 0°C; the initial loading of bacteria at the time that the product reaches 0°C is higher than if a quicker cooling process could be used. Much research has been conducted into the injection of gases such as CO_2 into plastic liners before sealing to reduce the growth rate of spoilage microorganisms (and thus prolong shelf life) at cool storage temperatures[4]. However, one might question whether the correct balance between efforts aimed at developing modified-atmosphere packaging systems versus designing a pack with better heat transfer characteristics (which might take a few hours off the cooling time) has been achieved. One suspects that the right research and development team that is capable of answering this type of question is rarely formed.

Table 2. Typical components of the heat transfer resistance between the geometric centre of a carton and cooling air flowing over the carton top and bottom

Source of heat transfer resistance	Heat transfer resistance (m^2K/W)		
	Frozen fish[a]	Frozen beef[b]	Chilled beef[c]
Convection boundary layer external to carton[d]	0.04	0.04	0.04
Carton wall[e]	0.06	0.02	0.06
Nominal 1 mm layer of trapped air between carton and product[f]	0.04	0.04	0.04
Product itself between surface and geometric centre[g]	0.03	0.06	0.17
Total	0.17	0.16	0.31
Heat transfer resistance attributable to packaging system (%)	59	38	32

[a]Nominal 10 kg corrugated-wall carton of fish fillets to be frozen; carton height of 100 mm
[b]Nominal 27 kg solid-wall carton of boneless beef to be frozen; carton height of 165 mm
[c]Nominal 27 kg corrugated-wall carton of boneless beef to be chilled; carton height of 180 mm
[d]Data taken from the mid-range of values given in Ref. 1
[e]Data taken from Ref. 2
[f]Calculated from the thermal conductivity of air (~0.025 W/mK)
[g]Calculation based on the thermal conductivity of frozen fish and beef (~1.5 W/mK) and the thermal conductivity of chilled beef (~0.5 W/mK)

In the case of many horticultural products, it is desirable to ventilate the package to permit gas transfer from the respiring product. If weight reduction owing to water loss from the product is to be minimized in such situations, the maintenance of an environment with a high relative humidity is required. Such an environment can be disastrous for the strength of paperboard cartons, particularly when the position of ventilation holes in the carton must be selected to avoid marketing logos on the carton walls. Examples of the necessary compromises are demonstrated by the work of Peleg[5], who showed that the compression strength of paperboard products was generally halved on transfer from a test environment of 22.8°C, 50% relative humidity to one of 3.3°C, 92% relative humidity. Also, the process of cutting hand holes in the cartons reduced the compression strength by 15–20%. In a recent study [N.T. Amos (1995) *Mathematical Modelling of Heat Transfer and Water Vapour Transport in Apple Coolstores* (PhD thesis), Massey University, Palmerston North, New Zealand], it was shown that the paperboard in the cartons within an apple coolstore was a major source of moisture storage, typically holding more than 100 times as much free moisture as the store air, even when the relative humidity of store air exceeded 90%. Amos found that the rates of moisture transfer processes were very rapid, and that predicting the local relative humidity required detailed knowledge of water-vapour absorption or desorption characteristics of the paperboard as well as of carton air flow characteristics. This study still fell well short of package optimization.

Conclusions

In order to develop optimized food package designs it is vital to recognize the characteristics of industrial organizations in present day society that impede the formation of appropriately skilled project teams. Teams must balance the needs of marketing staff, for whom packaging represents an important interface with the customer; the needs of the quality assurance staff, who require the package to maintain an environment around the product that enhances quality and shelf life; the needs of the process engineering staff, who require the package to be sensibly handled through the refrigerated processing systems; and the needs of the mechanical engineering and distribution system staff, for whom the strength of the package for survival during the transport and distribution system is most important. Organizations that fail to form appropriate multidisciplinary teams for refrigerated food package design risk being unable to take full advantage of new research and development, and thus may be forced to accept package designs that are less than optimal.

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