Using Microwaves to Detect the Degree of Freezing of Individual Meat Cartons

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INTRODUCTION

The principle of using low level microwaves to indicate whether a block of product is frozen has been known for some years. Previous work at MIR in the mid 1980s, carried out and reported on by Tuan Pham (Pham, 1986), showed that the use of microwaves in this manner would be useful to New Zealand meat processing industry. Unfortunately, that work did not reach commercial application.

The NZ meat industry has gone through some significant changes over the past 10 years. One change has been the need to meet stricter temper monitoring requirements from customers and regulatory authorities. In general the industry has become a leaner and meaner machine that need produce consistent, high quality products for its markets. Associated with the drive to operating efficiently has been the move to push as much prod through the plant as possible, often without due regard to the capabilities of such things as the refrigeration systems and refrigerated room designs. this production push to occur at the same time as ensuring only quality product leaves the plant premises means that it has become increasin important for quality systems to be put in place.

Away from the meat processing plant, cold chain refrigeration systems are generally designed with sufficient refrigeration capacity to remove infiltr heat loads, but not to remove significant product heat load. Excess demand placed on these refrigeration systems by loading some under-frozen prod may increase the temperature of other initially well-frozen product. Additionally, uncontrolled temperature fluctuations during storage or trans can cause accidental thawing of frozen product (or freezing of chilled product). These effects can be avoided by applying quality assurance program both at the plant and in the transport cold chain. Unfortunately, current temperature checking methods are manual, invasive, and often inaccura

The New Zealand Meat Research and Development Council is funding MIRINZ to develop a rapid, non-invasive instrument to determine the de of freezing of cartoned meat products. Trials with a proof-of-concept prototype Microwave Freezing Detector (MFD) have successfully proven microwaves can be used to clearly differentiate frozen from unfrozen product. Such a tool used in quality assurance programmes could save processors and exporters $100,000's per year in reduced product losses and transport insurance claims, and improve the quality and consistency of c packed meat products.

THEORY

When a beam of microwave is shone through a slab of material, its intensity is reduced by an attenuation factor

$$A = \exp(t/d)$$

where:

t = the slab thickness

d = a quantity called "penetration depth", i.e. the thickness of material required to attenuate the intensity by a factor of 2.7.

The penetration depth, d, is a function of both frequency and product temperature. It increases steeply below the freezing point (-0.9°C for meat the product becomes "transparent" (Pham, 1986). For water containing products such as meat, the absorption of microwave radiation by liquid w is several hundred times that of ice. Trials carried out during Pham's work determined that a microwave frequency of 0.9 GHz was a reasonable for this application.

CURRENT STATUS

The need for meat plants to produce high quality, consistent and "safe" product, enhances the need for good quality management. The MFD wi a useful tool to help ensure that adequate freezing is taking place. The development of the proof-of-concept prototype was undertaken by Refrigeration and Energy Group at MIRINZ with design and construction carried out by the Electrical Engineering Group of MIRINZ and K Holdem Associates Ltd (Auckland). Initial trials have now been carried out to quantify the usefulness of this new and improved design, and th indicate that the MFD can be used to detect under-frozen cartons of product.

The trials included measurements during carton freezing of water bulk packed meat and individually wrapped meat cuts. The range of experim included monitoring the freezing of two sets of meat cartons, with temperature and transmittance measurements being taken at regular inter measuring the effect of the carton position between the antennae on transmittance (both rotational and longitudinal positions were considered); gathering data from a large number of cartons of a mixture of products (both fresh and frozen) in a meat processing plant.

RESULTS AND DISCUSSION

Baseline readings

A block of uniformly thick ice, simulating a meat carton in shape, was made and this was used to measure baseline readings for frozen, unfrozen partially frozen product. This was necessary because of the variable nature of meat in cartons, both in the composition of the meat itself and the manner in which it is packed with respect to air pockets and uneven thickness. The "ice" carton was equilibrated at -34°C before the measurem For the block of ice, the transmittance was the same (8.81 V) for both parallel positions.

Meat temperature/transmittance during freezing

The results of meat temperature/transmittance tests are represented graphically in Figure 1. Since for most of these tests the cartons of meat we the process of being frozen, and freezing occurs from the outside surface in towards the centre of the carton, ideally the transmittance would be portrayed with respect to the freezing front of the carton of meat. The freezing front is difficult to calculate, but since the total enthalpy of the ca also relates to the frozen state of the whole carton, this offers a possible alternative to calculating the freezing front. To consider this approach, the enthalpy was calculated using MIRINZ's Food Product Modeller finite difference calculation for a simulation that closely resembled the actual time/temperature of this trial. The resulting data may prove useful as a starting point for determining the practicality of using the MFD as an indicator for the freezing front in meat cartons. The indication is that whereas transmittance varies sharply with temperature around 0°C, total enthalpy produces a more gradual change. More data are needed from carefully monitored cartons to confirm this hypothesis.

The effect of longitudinal positioning and transition

A block of ice was used to consider the effect of the transition of the block through the microwave beam. The steps between readings were 25 mm. The data are presented graphically in Figure 2. The width of the plateau indicates that, for a carton that is full to an even depth with a homogenous product, longitudinal placement to ±100 mm of the central point will provide a satisfactory reading. The results for individually packed meat cartons would be less reliable.

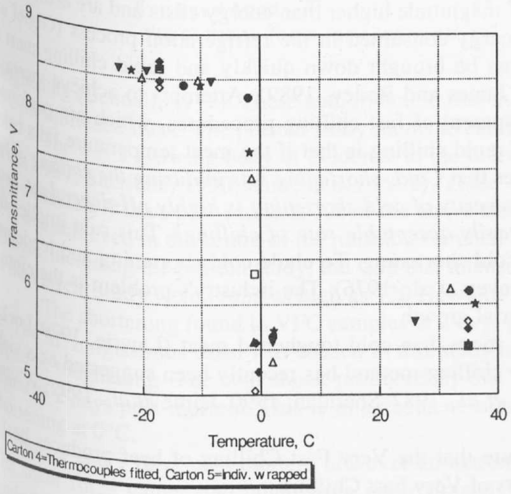

Figure 1.
Effect of carbon centre temperature on microwave transmittance.

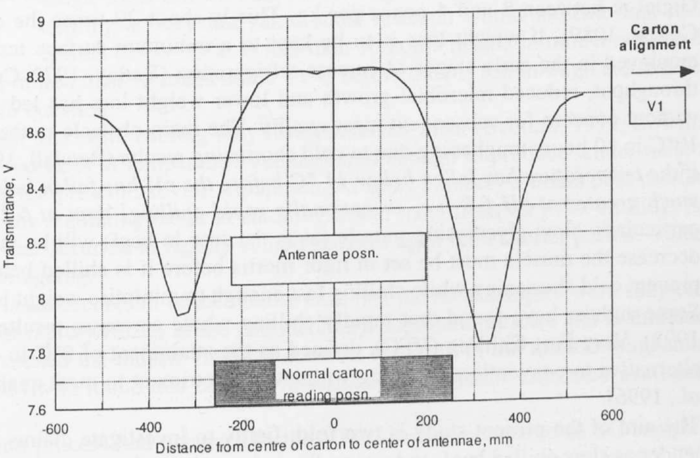

Figure 2.
Effect of carton position on microwave transmittance.

Some preliminary analysis has been carried out on all the data collected to date and in general the consistency of the results for each product type give a clear differentiation between fresh hot cartons and frozen cartons of meat. Table 1 shows a breakdown of the data, and it can be seen that for individually wrapped frozen product the variance is greater, but in all cases there is a clear differentiation between fresh product with a transmittance of about 6.8 V, and frozen product, at about 8.5 V.

Table 1.
Transmittance for position (v)

	Frozen bulk (-14°C)	Frozen IW (-20°C)	Fresh bulk (+30°C)
Maximum	8.82	8.68	7.09
Minimum	8.45	7.84	6.54
Range	0.37	0.84	0.55
Average	8.67	8.36	6.88
Standard Dev.	0.08	0.21	0.12

IW = Individually wrapped.

These trials demonstrated the effect of the carton contents and their conformation on the MFD readings. Invariably the end-for-end readings for each meat carton were different. These differences are most likely due to:

- Variable thickness of the carton due to (i) packing of the meat (especially individually wrapped, IW, cuts), (ii) stage of freezing (which also creates an increase in carton depth of 20 mm or more when frozen) or (iii) air voids between lumps of meat.
- Variation in freezing front due to differing sizes of meat lumps in the carton and associated air voids.

Even without data for unfrozen, individually wrapped product cartons, it appears clear that about 7.5 V would be an appropriate cut-off point to separate fresh and frozen carton product.

A regulation currently exists for cartons to be removed before the temperature at the centre reaches the desired level, and for the carton to be equilibrated over a period of time to reach that level. Unfortunately, this operational flexibility practice is fraught with problems due to the difficulty of accurately determining the degree of freezing that has taken place throughout the carton. If the MFD can be "tuned" to provide information relating to the freezing front of a carton, this will allow MAF and processors to consider equilibration seriously and safely as a normal process.

CONCLUSIONS

This stage of the project has shown that there is a useable voltage difference in microwave transmittance between unfrozen and frozen meat packed in cartons. Current work is now focussing on how this difference can be best used and developed to fit into good quality management for the meat industry. This includes how the MFD can be used to streamline processes in the future, with the possibility of allowing for cartons to be equilibrated with confidence. Other factors that need to be addressed include the mechanical requirements for a commercial model that will fit into a plant situation and meet MAF regulations. At the other end of the scale is the potential of the MFD to be used for determining the end-point for thawing/tempering processes and chilling processes.

REFERENCES

Pham, Q.T. (1986) "Microwaves measure degree of freezing" in Automation and Control, March 1986.