FREEZING AND THAWING TIMES OF A MEAT-LIKE SUBSTANCE IN AN AIR STREAM

Q.T. PHAM and J. WILLIX, Meat Industry Research Institute of New Zealand, Hamilton, New Zealand.

SUMMARY

Cartons of Tylose gel were frozen or thawed in a test air-blast tunnel. The effects of carton thickness, carton position in the row, shelf type and air velocity were investigated. Mesh shelves with flat tops gave shorter freezing/thawing times than corrugated shelves, as the former did not channel the air but stirred it up. Measured freezing times agreed with calculated times based on previously measured heat transfer coefficients. For thawing, an empirical factor had to be included to account for latent heat effects.

INTRODUCTION

Air-blast tunnels are frequently used to freeze cartoned meat. The heat transfer in these equipments is complicated by the interaction between air and product. There have been investigations on the freezing times of product in carton tunnels, but no attempt has been made to relate these to the heat transfer mechanism involved.

In a previous paper (Pham and Willix 1987) we gave some experimental results for the heat transfer coefficients (h.t.c.) in rows of cartons in an air stream. The results showed marked variations of the h.t.c. with carton position and the type of shelf used (mesh or corrugated). This paper shows how these variations affect the freezing and thawing times of cartoned products.

THEORY

Of the many methods available to predict freezing times, the best agree closely with each other, so the simplest one (Pham, 1986) will be used in this paper. Complications arise because of the difference in heat transfer rates between the top and bottom of a carton, considered as a slab. Pham (1987) derived a simple method to account for this asymmetry. The h.t.c. on the top, h1, is used and the thickness of the carton is multiplied by a factor $(B_1 + 2h_2/h_1)/(B_1 + h_2/h_1 + 1)$, where $B_1 = h_1 D/k$ is the Biot number, h_2 is the h.t.c. on the bottom, D is the slab (carton) thickness, and k is the thermal conductivity of the frozen food (for freezing) or unfrozen food (for thawing).

For thawing times, several prediction methods are also available (Cleland et al. 1986). We shall use that of Pham (1984) because it seems to be best for asymmetric freezing situations (Pham 1987). This method was originally derived for freezing; in thawing, the predicted time should be divided by an empirical factor 1.147 (Cleland et al. 1986).

MATERIALS AND METHOD

Rows of cartons were frozen or thawed on mesh or corrugated shelves. Three factors were varied: carton size, shelf type and air velocity.

Three carton types were used. The largest were 170 mm x 340 mm x 520 mm (external dimension) cartons, made of solid fibreboard 1.7 mm thick. Next in size were 78 mm x 170 mm x 325 mm cartons made of 0.69 mm-thick cardboard. The third type comprised 40 mm x 100 mm x 163 mm cartons made of 0.47 mm-thick cardboard. The cartons were lined with polyethylene and filled with Karlsruhe test substance, a 23% methylcellulose gel (Tylose) with thermal properties similar to those of lean meat (Riedel 1960).

Table 1. Freezing times of rows of Tylose cartons in air at -35°C.

Carton thickness mm	Air vel., m/s	Freezing times (in hours) to -18°C: Ctn 1	Ctn 3	Ctn 5	Ctn 6	Mean	Max/min
MESH SHELVES							
170	0.9	33.9	42.0	42.0	40.0	39.5	1.24
	1.8	29.0	35.9	34.8	33.3	33.3	1.24
	2.7	25.1	30.6	29.3	28.5	28.4	1.22
78	0.9	8.0	10.2	9.1	10.5	9.5	1.31
	1.8	8.5	8.7	8.1	9.6	8.7	1.19
	2.7	7.8	7.8	7.2	8.5	7.8	1.18
40	0.9	3.5	4.3	4.7	3.8	4.1	1.35
	1.8	3.2	3.8	4.1	3.7	3.7	1.28
	2.7	3.1	3.6	3.8	3.4	3.5	1.23
CORRUGATED SHELVES							
170	0.9	33.5	45.2	49.0	46.5	43.6	1.46
	1.8	30.0	39.0	40.0	39.0	37.0	1.33
	2.7	25.1	32.2	33.3	32.2	30.7	1.33
78	0.9	7.8	10.1	13.3	12.0	10.8	1.83
	1.8	7.5	8.6	12.0	10.0	9.5	1.60
	2.7	7.0	7.6	10.4	9.1	8.5	1.50
40	0.9	3.8	5.4	5.8	5.6	5.1	1.53
	1.8	3.4	4.7	5.3	5.2	4.6	1.57
	2.7	3.3	4.4	4.4	4.5	4.2	1.37

In each experiment twelve cartons were used, arranged in two rows of six in a wind tunnel (Fig. 1). Each row sat on a different shelf material, either corrugated iron (0.65 mm thick, 75 mm-pitch corrugations running parallel to the airflow) or expanded metal mesh (rhombic mesh 25 mm x 75 mm diagonals, approximately 9 mm wires). Sheet metal was laid on the mesh to prevent the cartons sinking into it. For each row, cartons no. 1, 3, 5 and 6 had thermocouples inserted into them at and about the geometric centre, so that the time taken for the thermal centre to reach a given temperature could be accurately determined.

Before each test, the cartons were equilibrated to a given temperature (+15°C before freezing, -35°C before thawing) in an air blast tunnel.

Table 2: Thawing times of 170-mm-thick Tylose cartons in air at +15°C.

Air velocity m/s	Thawing times (in hours) to 0°C					
	Ctn 1	Ctn 3	Ctn 5	Ctn 6	Mean	Max/min
MESH SHELVES						
0.9	46.0	56.0	52.5	54.5	52.3	1.22
1.8	42.0	50.7	45.9	48.5	46.8	1.21
2.7	40.6	48.1	44.6	44.8	44.5	1.18
CORRUGATED SHELVES						
0.9	48.0	60.0	58.8	62.2	57.3	1.30
1.8	43.9	53.0	52.9	55.0	51.2	1.25
2.7	41.4	49.8	49.3	52.3	48.2	1.26

Table 3. Error statistics for freezing and thawing time predictions (a positive error means that the predicted value is higher than the measured value).

	Mean	s.d.	Minimum	Maximum
Freezing time error (%)	-3.3	8.6	-15.5	+16.8
Thawing time error (%)	+17.0	6.8	+5.5	+27.6

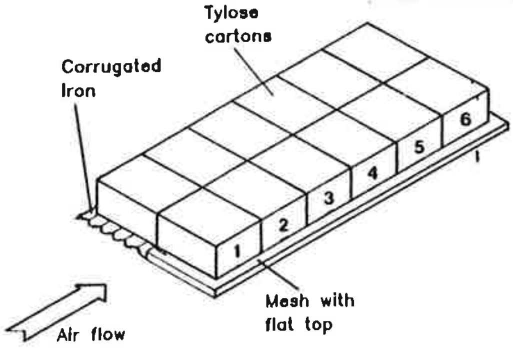

Figure 1. Layout for comparative freezing/thawing experiments.

The boxes were then fully insulated with slabs of polystyrene foam, and the tunnel was brought to a set air temperature (-35°C ± 0.5°C for freezing, + 15°C ± 0.5°C for thawing), which took about 30 to 60 minutes. The insulation was then removed and temperature recordings were started. The criterion for completion of freezing was -18°C maximum temperature and that for completion of thawing 0°C minimum temperature.

RESULTS

Experimental Freezing Times

Table 1 gives the experimental freezing times. Mesh shelves were markedly superior to corrugated shelves in terms of mean and maximum freezing times. For the 170-mm-thick cartons, improvements of 9 to 17% in the maximum freezing time and 8 to 11% in the mean freezing time were obtained by going from corrugated to mesh. (The maximum freezing time is perhaps a more important criterion for freezer design).

Table 1 also gives the ratio of longest to shortest freezing times for different types of shelves. A value close to 1 means that the freezer is efficient in terms of space and that cartons are frozen evenly. Mesh shelves were again markedly superior to corrugated shelves when this criterion is used.

Figure 2 illustrates why cartons in a row take different times to freeze. In carton 1 the high bottom h.t.c. causes the thermal centre to shift towards the top. In carton 5, the bottom h.t.c. is much lower due to air channelling and the boundary layer effect, and the thermal centre has moved back towards the middle.

Experimental Thawing Times

Table 2 gives the thawing times for 170-mm-thick cartons on corrugated or mesh shelves. Because thermal conductivity is reduced during thawing, the internal resistance to heat transfer was the controlling factor, so that the percentage differences in thawing times were smaller than those in freezing (5 to 10% in thawing, 8 to 17% in freezing for 170-mm-thick cartons).

Calculated Freezing and Thawing Times

Complete data for the freezing/thawing time formulae are available for the freezing and thawing of 170-mm cartons of Tylose on corrugated or mesh shelves, at air velocities of 0.9, 1.8 or 2.7 m/s, for cartons 1, 3 and 5 in a row (Tables 1 and 2). The Tylose thickness, allowing for four layers of cardboard, is 165 mm. Tylose properties are given by Cleland and Earle (1984). The overall h.t.c., ho, is calculated by adding the surface resistance (i.e., the inverse of the surface h.t.c., measured by Pham and Willix 1987) and the cardboard thermal resistance, R. Values determined for the latter are 0.051 m2K/W during freezing and 0.044 m2K/W during thawing.

These data were used in conjunction with the method described in the "Theory" section to calculate freezing

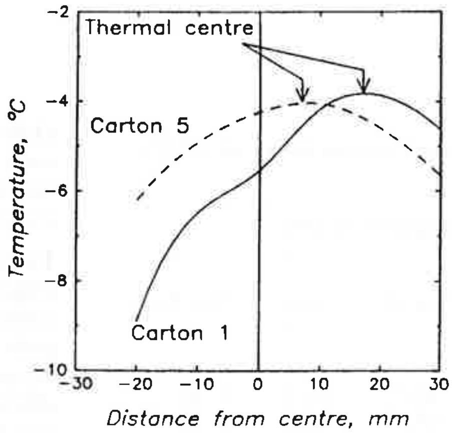

Figure 2. Temperature profile of 170-mm cartons of Tylose at the end of the latent heat phase. Corrugated shelf, air at -35°C and 2.5 m/s.

and thawing times. Discrepancies between calculated and experimental values are given in Table 3.

Reasonable agreement was obtained for freezing times, but for thawing times calculated values are consistently higher. This discrepancy is probably due to latent heat effects (frosting and condensation) which increases the surface h.t.c., at least during the early stages of thawing. An empirical latent heat factor of 1.72 applied to the surface h.t.c. results in a mean error of 0%, a standard deviation of 6.4% and a range of -12.8 to +10.0%.

DISCUSSION AND CONCLUSIONS

Corrugated shelves in air-blast freezers channel air that has been warmed by product upstream, thus reducing the h.t.c. for product downstream. A better alternative is to use shelves made of a mesh-type material, possibly with a flat metal top. Such shelving would increase the heat transfer and promote turbulence near the carton surface. These effects lead to significant decreases in the mean and especially the maximum freezing times. Alternatively, to keep the same freezing time, with such shelving the air flow could be reduced from say 2.7 m/s to 1.8 m/s, which corresponds to a 70% reduction in fan energy. The beneficial effect of mesh shelves was also observed in thawing trials, although the effect was less marked. A further consideration is the saving in vertical space when expanded metal is used instead of corrugated iron. This saving amounts to about 30 mm per shelf.

Measured freezing times agreed with calculations based on previously measured heat transfer coefficients. For thawing, the h.t.c. has to be multiplied by an empirical factor to account for latent heat effects.

REFERENCES

Cleland, A.C. and Earle, R.L. (1984). *J. Food Sci.* **49**:1034.

Cleland, D.J., Cleland, A.C., Earle, R.L. and Byrne, S.J. (1986). *Int. J. Refrig.* **9**:220.

Pham, Q.T. (1984) *Int. J. Refrig.* **7**:377.

Pham, Q.T. (1986). *J. Food Technol.* **21**:209.

Pham, Q.T. (1987). *J. Food Sci.* **52**:795.

Pham, Q.T. and Willix, J. (1987) Proc. 17th Int. Cong. Refrig., Vienna, p.350.

Riedel, L. (1960). *Kaltetechnik* **12**:222.