# The prediction of freezing and thawing times of mutton carcasses

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## Introduction

Mutton production is seasonal and continuity of supply for processing can be achieved by frozen storage and subsequent thawing and boning. However, few data are available on freezing and thawing times to enable processing cycles to be optimised. A design nomogram produced by Fleming and Earle in 1966 has been extensively used but only gives freezing times of lambs and light mutton carcasses. They correlated experimental freezing times with predicted values using Plank's (1941) equation for a cylinder and obtained a relationship between carcass weight and cylinder diameter. Thawing has received very little attention since most frozen lamb and mutton is traditionally band-sawn into domestic joints. Haughey and Nottingham (1974) investigated the thawing of mutton for boning and subsequent export, but gave no details of thawing times, while the authors studied the thawing of 20 kg lamb carcasses (Creed et al., 1979). Both investigations showed that air temperatures between 7° and 10°C with a low air speed produced the optimum thawing system, giving low weight losses and insignificant increases in bacterial numbers.

This investigation aims to provide data on freezing and thawing times of mutton over a wide range of carcass weight for a practicable range of environmental conditions. The data have been compared with the results from a predictive mathematical model.

## Experimental materials and method

Thirty four mutton carcasses, with hot carcass weights between 25 and 50 kg obtained from either Cheviot, Scottish Blackface, Suffolk or Dorset Horn breeds were used. After conventional slaughter and chilling, the carcasses were stored under commercial conditions (4°C, 0.5 m/s and 95% RH). Following storage, pairs of carcasses (one wrapped in stockinette cloth, one unwrapped) were loaded into a wind tunnel previously described by Bailey & Cox (1976) and frozen at either -30°C, 0.5 m/s; -30°C, 4 m/s; or -20°C, 0.5 m/s. After freezing, the carcasses were stored at -30°C, 0.5 - 1 m/s. The pairs were then thawed in air at 10°C ± 0.5°C, 0.5 m/s ± 0.2 m/s, 85% ± 2% RH in an experimental room previously described by James et al. (1977).

## Measurements

Before freezing, two multi-point copper-constantan thermocouple probes (similar to those described by James et al., 1977) were inserted into each carcass in the thickest sections of the leg and shoulder. At a point 1 metre above the carcasses air temperatures were measured using copper-constantan thermocouples to an overall accuracy of ± 0.5°C, and relative humidities with 'Hygrodynamics' lithium chloride sensors to ± 2% RH. The air speed was monitored to ± 0.2 m/s at the mid-point of the carcass 10 cm away from the surface using a 'Wallac' hot-wire anemometer. The outputs from all the sensors were recorded at 0.5 hour intervals during freezing and thawing by a 'Solartron' computer-controlled data-logging system.

## Predictive method

There is no direct method of predicting the rate of heat flow during freezing and thawing in such an irregularly shaped non-homogeneous body as a mutton carcass. However, a number of theoretical methods can be used to calculate freezing and thawing times of homogeneous regularly-shaped bodies such as slabs, spheres and cylinders (Bakal & Hayakawa, 1973). Bailey et al. (1974) and James et al. (1977) have successfully predicted the thawing time of pork legs and beef quarters by deriving a relationship between leg weight and the diameter of a sphere; hindquarter weight and cylinder diameter, and forequarter weight and slab thickness. Fleming and Earle's (1966) relationship between carcass weight and cylinder radius could not be used directly in this work because their carcasses were far lighter than those used here. A new relationship has therefore been developed using a three time-level finite difference scheme devised by Cleland and Earle (1979) and is described in the Appendix.

## Results

Comparing the three freezing conditions, there was no significant difference between the freezing time from 4° to -7°C in the deep leg or deep shoulder of individual carcasses, so the longer time of the two was plotted against carcass weight in Figure 1 for unwrapped and Figure 2 for wrapped carcasses. Predicted relationships between carcass weight and freezing time using the method described in the Appendix, are shown in the same figures.

A matched-pairs T test showed that the shoulders took significantly longer (P<.001) to thaw than legs from the same carcasses, the magnitude of the difference being greater for wrapped than unwrapped carcasses. The thawing times from -30°C to 0°C in the deep leg and deep shoulder were therefore plotted against carcass weight separately in Figure 3 for unwrapped and Figure 4 for stockinette-wrapped carcasses. Predicted relationships between thawing time and carcass weight obtained as described before and the lines of best fit to thawing time in the shoulder are also drawn on the same figures.

The average absolute error between predicted and experimental values was 12.1% for freezing and 16.4% for thawing.

## Discussion and conclusion

During freezing, (Figures 1 and 2), it can be seen that any condition more severe than -20°C, 0.5 m/s would achieve a 24 hour cycle for unwrapped carcasses, but using -20°C, 0.5 m/s, heavy wrapped carcasses would require 30 hours. To guarantee an overnight (15 to 16 hour) freezing cycle for wrapped carcasses, conditions more severe than -30°C, 4 m/s would be required. It is clear from Figures 3 and 4 that a cycle of at least 36 hours is required to completely thaw unwrapped mutton carcasses, and a minimum of 2 days for stockinette-wrapped carcasses. In wrapped carcasses some parts of the shoulder of carcasses over 40 kg in weight could still be below 0°C.

Heat flow though mutton carcasses cannot be predicted using existing models because they are irregular in shape, inhomogeneous and have temperature-dependent thermal properties. Methods of obtaining design data that rely solely on experimental measurements are impracticable because of the wide range of processing conditions. Consequently, methods must be developed which combine predictions from simpler models with experimental results which are then extended to cover a wider range of conditions. Since carcass weight is the most important commercial variable and the easiest to measure, the requirement is to relate this to freezing and thawing times over a range of environmental conditions.

This method was used in this investigation and resulted in an average difference between the experimental and predicted freezing times of about 12% which is adequate for most commercial uses. The agreement was closest, as would be

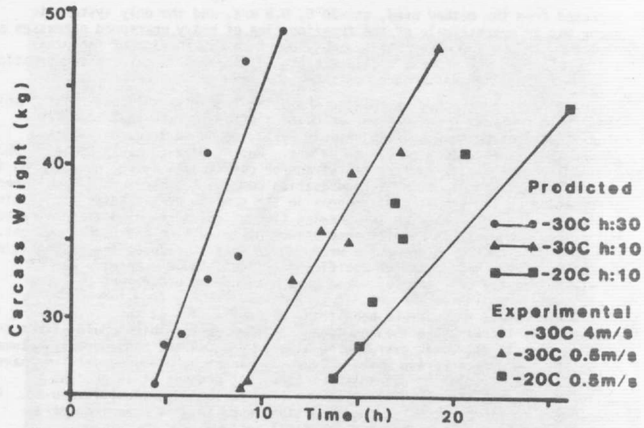


Fig.1 Freezing Time of Unwrapped Carcasses v Carcass Weight

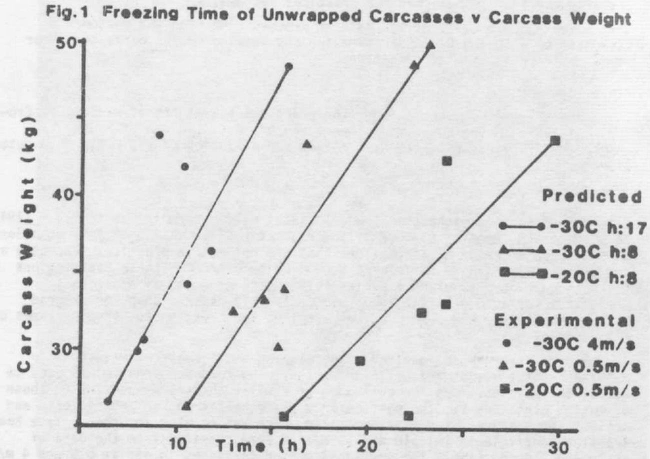


Fig.2 Freezing Time of Wrapped Carcasses v Carcass Weight

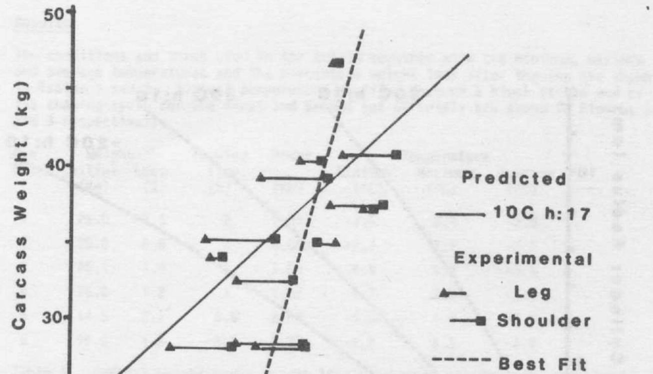


Fig.3 Thawing Time of Unwrapped Carcasses v Carcass Weight

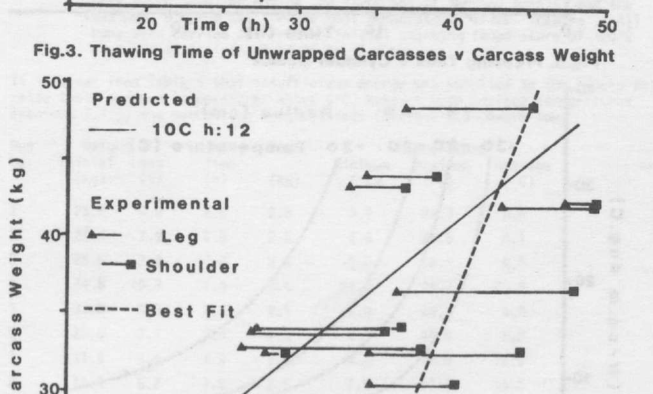


Fig.4 Thawing Time of Wrapped Carcasses v Carcass Weight

expected from the method used, at -30°C, 0.5 m/s, and the only systematic error was an overestimate of the freezing time of heavy unwrapped carcasses at -20°C, 0.5 m/s. The error was probably due to a combination of factors: failure to find the slowest cooling point, differences in carcass conformation and small localised differences in the air speed over the carcasses.

Extending the same method to thawing and using the only published relationship that could be located between air velocity and the surface heat transfer coefficient during thawing (Vanichseni, 1971), produced large differences between experimental and predicted values. Recent work (James & Bailey, 1982) has indicated that the surface heat transfer coefficient is not constant during thawing in air and has a large condensation component. There is no published information on the effect that changes in the surface heat transfer coefficient during thawing would have on the thawing time of cylinders of different radius, but it could modify the relationship between thawing time and carcass weight. One obvious effect of stockinette wrapping is that it reduced the condensation component of the heat transfer coefficient. Since the stockinette was stretched tightly over the leg, some condensation did occur, but as the stockinette wrapping became wet, it tended to fall away from the shoulder. This would reduce the surface heat transfer coefficient at this point and consequently increase the thawing time. Another factor which could affect the thawing time is fat cover over the shoulder, which varied considerably between carcasses. A more accurate model of thawing cannot be produced until we have a better understanding of all these factors. At present it is prudent to design commercial plants on the best fit line to the experimental results. As previously mentioned, the thawing conditions used in this experiment are probably the best combination for practical systems.

This investigation has provided data on process times for the engineer designing or adapting plant for freezing and thawing mutton carcasses under practicable environmental conditions.

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Appendix

Fleming and Earle's mathematical model (1966) used a formula due to Plank (1941) to predict the freezing time of cylinders, but the derivation of this equation depends upon a number of assumptions that are not met in practice. Recently a three time-level finite difference scheme which overcomes these restrictions has been developed (Cleland & Earle. 1979) which produces an accurate prediction for a foodstuff such as meat. In this paper a computer program written by Cleland has been used to calculate the freezing and thawing times of cylinders of meat.

A number of stages were involved in developing a mathematical relationship between carcass weight and cylinder radius. The computer program was used to calculate freezing times for cylinders of similar thermal properties to those of mutton carcasses for the particular surface heat transfer coefficients and ambient temperatures used experimentally. The values used for the surface heat transfer coefficients (h), 10 and 30 W/m²°C were obtained from the data of Earle and Fleming (1967) for unwrapped mutton carcasses in air at 0.5 and 4 m/s respectively. This provided the curves of freezing time against cylinder radius shown in Figure 5. A least-squares fitting technique was then used to obtain the best fits to the three sets of experimental freezing data for unwrapped carcasses. The line for -30°C, 0.5 m/s had the highest correlation coefficient of r = 0.94. From this line the freezing times for 25 and 40 kg carcasses were calculated. These times were used with the line for h = 10 W/m²°C at -30°C in Figure 5 to obtain related cylinder radii of 5.75 and 9 cm respectively. The two radii values were then used in conjunction with Figure 5 to obtain predicted freezing times for 25 and 40 kg unwrapped carcasses at the two other experimental conditions and the points transferred to Figure 1. Straight lines were then drawn through the pairs of points since earlier work (Bailey et al., 1974) had shown that the relationship between weight and freezing time was substantially linear over a limited weight range.

To predict freezing times for the wrapped carcasses, the computer program was used to produce the relationship shown in Figure 6 between freezing time and h for cylinders of 5.75 and 9 cm radius frozen at -20°C and -30°C. The freezing times for 25 and 40 kg wrapped carcasses were obtained from the best-fit lines to the experimental data (r = 0.88 at -30°C, 0.5 m/s). Using Figure 6 and these two freezing times, values of h of 7 and 8.9 W/m²°C (average h = 8) were required to give agreement. Earle and Fleming (1967) stated that the overall surface heat transfer coefficient is related to its convective and wrapping components by the equation:-

$$1/h = 1/hc + 1/hw \qquad (1)$$

where h = overall surface heat transfer coefficient (W/m²°C), hc = convective component (W/m²°C) and 1/hw = thermal resistance of the wrapping (m²°C/W). If h = 8 W/m²°C and hc = 10 W/m²°C (for air at 0.5 m/s) then hw = 40 W/m²°C. Substituting this value back into Equation 1 with hc = 30 W/m²°C, a value of h = 17 W/m²°C is arrived at for wrapped carcasses in air at 4 m/s. The values were then used to obtain the predicted lines shown in Figure 2.

The only published data located relating air speed to h during thawing is that of Vanichseni (1971), who gave a value of hc = 17 W/m²°C for thawing in air at 0.5 m/s, 10°C. This value of h for unwrapped carcasses and h = 12 W/m²°C for wrapped carcasses, (from equation 1 using hc = 17 W/m²°C and hw = 40 W/m²°C) were used with cylinder radii of 5.75 and 9 cm to predict thawing times for 25 and 40 kg mutton carcasses shown in Figures 3 and 4.

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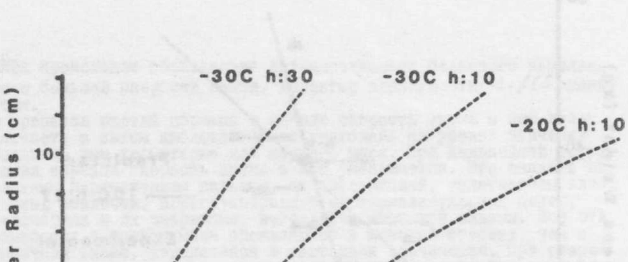


Fig.5. Freezing Time v Cylinder Radius

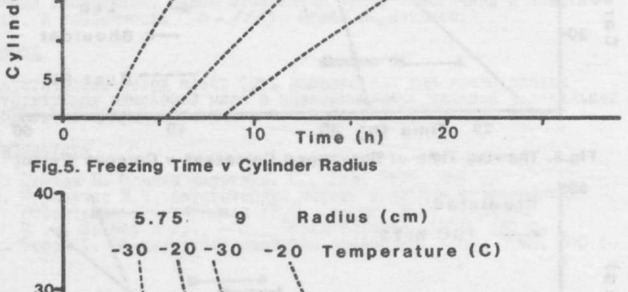


Fig.6. Freezing Time v Heat Transfer Coefficient