REFRIGERATION, FREEZING AND THAWING

A RE-EXAMINATION OF THE FACTORS AFFECTING THE CHILLING OF BEEF CARCASSES

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Many publications on the chilling of carcass meat have appeared over the last 40 years, but the large number of enquiries received by the Meat Research Institute show that the U.K. industry still does not have access to design information in a form that it can readily use. Reasonably well established data on pig chilling is available; information on lamb chilling is also available in some depth although more work is necessary to establish optimum environmental conditions to produce acceptable tenderness with maximum economy. Greatest discrepancies and confusion exist in the information on beef chilling.

A research programme was therefore initiated to clarify the situation by investigating the effect of air temperature, velocity and relative humidity on the cooling rate of and evaporation from beef sides of different weight and fat cover. This paper describes the chilling systems used, reports the findings to-date, and outlines the plans for the continuation of the experimental work and the analysis of the data.

REEXAMEN DES FACTEURS TOUCHANT LA FRIGORIFICATION DES BOEUFS ENTIERS

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Au cours des 40 dernières années on a vu de nombreuses publications concernant la frigorification des bêtes entières, mais le grand nombre de demandes de renseignements reçues par le Meat Research Institute montre qu'au Royaume Uni l'industrie ne trouve toujours pas les renseignements détaillés dont elle a besoin sous une forme qu'elle peut facilement utiliser. On trouve des données assez bien établies au sujet de la frigorification du porc; on trouve également des renseignements assez complets concernant la frigorification de l'agneau, bien que des études supplémentaires soient nécessaires pour déterminer les conditions optimums d'environnement pour allier une tendreté acceptable avec un maximum de rentabilité. Dans le domaine de la frigorification du boeuf, il existe de la confusion et des opinions extrêmement divergentes.

Un projet de recherches fut donc entrepris pour clarifier la situation au moyen d'une enquête concernant l'effet de la température, la vitesse et l'humidité relative de l'air sur le taux de refroidissement et l'évaporation des moitiés de boeuf de poids et d'épaisseur de graisse différents. Ce document décrit les procédés de frigorification utilisés, présente les résultats obtenus jusqu'ici, et donne un résumé des projets de continuation des expériences et de l'analyse des données.

EINE NACHPRÜFUNG DER FAKTOREN, DIE AUF DAS KÜHLEN VON FRISCHRINDFLEISCH EINWIRKEN

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In den letzten 40 Jahren gab es viele Veröffentlichungen über die Kühlung von Frischfleisch, aber die große Zahl von Anfragen an das Meat Research Institute zeigt, daβ die britische Industrie immer noch keinen Zugang zur Information über dieses Verfahren hat in einer Form, die sie übernehmen kann. Einigermaβen fundierte Daten über die Schweinefleischkuhlung stehen zur Verfügung; auch über die Kühlung von Hammelfleisch ist mehr oder weniger fundiertes Informations-material vorhanden, jedoch sind weitere Arbeiten notwendig, um optimale Umgebungsbedingungen zu schaffen, die zu einer akzeptablen Zartheit bei maximaler Sparsamkeit beitragen können. Was das Kühlen von Rindfleisch anbelangt, so gibt es ein Höchstmaβ an Diskrepanz und Verwirrung.

Deshalb wurde ein Forschungsprogramm ins Leben gerufen, um die Situation zu klären und zwar durch die Untersuchung der Wirkung der Lufttemperatur, der Geschwindigkeit und der relativen Feuchtigkeit auf die Kühlgeschwindigkeit und die Verdampfung von Rindfleischseitenstücken verschiedenen Gewichts und mit unterschiedlichen Fettschichten. Die Untersuchung beschreibt die verwendeten Kühlungssysteme, berichtet über bisherige Ergebnisse und umreiβt die Pläne für die Weiterführung der Experimente und die Analyse der daraus gewonnenen Daten.

ПЕРЕСМОТР ФАКТОРОВ ВЛИЯЮЩИХ НА ОХЛАЖДЕНИЕ ТУШ КРУПНОГО РОГАТОГО СКОТА

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За последние 40 лет был опубликован целый ряд работ, посвященных проблемам охлаждения мяса в тушах, однако большое число запросов, получаемых Мясным научно-исследовательским институтом, свидетельствуют о том, что промышленность Соединенного Королевства еще не имеет доступа к поддающейся учвоению проектировочной информации. Имеются уже достаточно установленные данные относительно свиных туш. Имеются и довольно глубоко разработанные данные относительно охлаждения бараньих туш, хотя здесь еще надо будет провести много исследований для определения оптимальных условий окружающей среды для обеспечения приемлемой нежности при максимальной экономии. Крупнейшие несогласия и запутанность характеризуют информацию относительно охлаждения туш крупного рогатого скота.

Для разъяснения этой проблемы была предпринята исследовательская программа с целью расследования влияния температуры воздуха, скорости и относительной влажности на скорость охлаждения и на испарение говяжьих полутуш разного веса и разных жировых покровов. В настоящем труде описываются разные использованные системы охлаждения, изложены полученные до сих пор результаты и очерчены планы для продолжения опытных работ и для анализа данных.

REFRIGERATION, FREEZING AND THAWING

A RE-EXAMINATION OF THE FACTORS AFFECTING THE CHILLING OF BEEF CARCASSES

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INTRODUCTION

A large number of publications relating to the chilling of meat in carcass form have appeared in the literature over the last 40 years, but the evidence of the many hundreds of enquiries received by the Meat Research Institute shows that the U.K. industry still does not have access to design information in a form that it can readily use.

In an earlier analysis (Bailey, 1972) it was pointed out that a considerable part of the problem is caused by the fact that much of the available information is in direct conflict. It is possible to find recommendations for almost any combination of high or low air velocity, temperature and relative humidity. This situation probably exists because experimental measurements to date have been made in commercial abattoirs where inability to vary process conditions, inadequate instrumentation, and the neglect of factors such as fat cover have led to erroneous conclusions.

However, up to a few years ago a certain uniformity had started to appear in recommendations for chilling procedures. Arguments were based primarily on economics where it was generally agreed that rapid chilling could produce significant savings in evaporative weight loss. Chilling air temperatures in the case of lamb or beef were maintained as low as possible short of freezing the meat in order to minimise the surface temperature and consequently reduce the vapour pressure available for mass transfer. Even greater savings were obtained with pork by using the lower air temperatures justified by the protective layer of fat on the carcasses.

Considerable investments were made in plants designed on this basis before problems of quality became apparent in the form of toughness, caused, it was later discovered (Locker and Hagyard, 1963), by the phenomenon of "cold shortening" which occurs if the carcass is rapidly chilled before the pH of the muscles has fallen below 6.2. This problem was particularly serious in the case of lambs where the small carcasses could be cooled very quickly with the consequent production of some extremely tough meat. The biochemical relationships are very similar in beef but the inability to rapidly chill the greater part of these much larger carcasses has resulted in conflicting statements on the degree of toughening produced. There are no reported problems of toughening in pork carcasses as the more rapid fall in pH post slaughter generally obviates any risk of "cold shortening".

Current chilling procedures with lambs have therefore recently reverted to much slower rates of cooling. New Zealand research workers, for example, now recommend that for maximum tenderness after freezing and thawing, lambs should be held for 24 hours at +18°C before subsequently chilling for 40 hours at +3°C (Haughey and Frazerhurst, 1972). Recent investigations at the Meat Research Institute (Dransfield, 1973) have shown that such high temperatures are probably unnecessary for distributing in the chilled state as lambs of good texture can be obtained by holding at ambient conditions (15°C) for 6 hours before chilling at +2°C.

Considerable disagreement exists over the extent of the problem of "cold-shortening" in beef carcasses. New Zealand specifications to offset "cold shortening" require the air temperature to be held at +10°C for the first 24 hours (Haughey and Frazerhurst, 1972). Buchter (1969) reported toughness in calves chilled at temperatures below 6°C and in young bulls chilled below 4° to 6°, whilst Sulzbacher (1972) recorded no evidence of toughness in beef from American meat plants operating rapid chill systems.

The availability of useful design information for the refrigeration engineer is thus currently related to the species in question. Reasonably well established data on pig chilling can be obtained from the work of such people as Cooper (1967, 1968), Møller (1967), and Westerling (1966, 1967, 1968) where weight saving is still the principal factor to be considered. Information on lamb chilling is also available in some depth from investigations carried out in the research institutes in Australia and New Zealand (Earle & Fleming, 1967, 1968), although more work is necessary to establish the optimum combination of temperatures and air velocities required to produce acceptable tenderness with maximum economy. Greatest discrepancies and confusion exist in the available information on beef chilling. Apart from the aforementioned considerations of texture, Swenson et al (1969) have pointed out that nowhere in the literature are there reported conclusive experimental results of the variation of carcass cooling rate and weight loss with air temperature, or the extent to which relative humidity affects cooling rate and weight loss.

A research programme was therefore initiated to clarify the situation by investigating the effect of air temperature, velocity and relative humidity on the cooling rate of and evaporation from beef sides of different weight and fat cover. Experimental chilling systems were designed to obviate the problems of lack of control and inadequate instrumentation mentioned earlier. This paper describes the chilling systems used, reports the findings to date, and outlines the plans for the continuation of the experimental work and the analysis of the data.

MATERIALS AND METHODS

Meat Beef sides of different fatness gradings (see results) in the weight range 100 to 250 kg were obtained from animals slaughtered either in the Meat Research Institute abattoir for chilling in the wind tunnel, or in a commercial abattoir for chilling at the Institute's out-station laboratory. In both cases the sides, fitted with thermocouples, were normally loaded into the chilling system within 40 minutes of leaving the slaughter line.

Equipment

(a) Experimental carcass cooling tunnel

The tunnel is arranged as a vertical closed quadrilateral loop, with sides 5.5m in external length, providing a working cross-section of 1.52m x 1.14m internal, and of sufficient height to accommodate complete sides of beef in the normal hanging position. Air is driven from a 0.97m centrifugal fan via a diffuser section and corner vanes vertically downward over the carcass at velocities of up to 8 m/s. A thyristor controller and tachometer feedback system ensure that velocity is maintained constant at any set point. The refrigeration system allows tunnel air temperatures to be set between +10° and -40° ± 0.25°C. The air is cooled by a large evaporator operating on a small refrigerant/air temperature difference with a consequent average equilibrium relative humidity of 94%.

(b) Out-station laboratory chillroom

This unit was designed to provide a more conventional chillroom in which up to 8 sides of beef could be hung and cooled uniformly by a downward draught of air from an overhead plenum. Adjustable ports in this plenum enabled air velocity to be "zoned" over any part of the room or maintained at a uniform value throughout the room. Air velocities could be varied between 0.1 and 3 m/s and air temperatures set between +5° and -5° ± 1°C. The average equilibrium relative humidity in this room was 88%.

Measurements

Meat temperatures were measured to ± 0.5°C with insulated copper-constantan probes inserted into the carcasses at the deep leg, centre l.d., deep shoulder and rear kidney knob positions. Surface temperatures were measured at points corresponding to these positions by inserting thermocouples immediately under the vellum. Air temperatures were measured with similar thermocouples located above, to the side of, and below the hanging carcasses.

Air velocities were measured to ± 0.2 m/s with "DISA" hot wire anemometers, and relative humidities to ± 1% with "Hygrodynamics" temperature compensated LiCl hygrometers. Carcass weights were recorded on "Berkell" mechanical balance systems fitted with converters to give BCD analogue outputs to ± 20g. All of the above variables were recorded on 20 channel "Solartron" data loggers outputting simultaneously onto electric printers and paper tape punch units. Carcasses were graded for increasing subcutaneous fat and kidney knob fat using a 1-7 point scale as described in the visual appraisal technique of Williams (1972).

The extent of radiation losses was determined by a series of measurements comparing the cooling of one side of a carcass fully exposed to the radiating walls of the chillroom, with the other side located in the same chillroom but flanked by two further sides at the same carcass temperature.

RESULTS

In the experiments in the wind tunnel to date carcass sides in the weight range 100 to 250 kg and fatness gradings from 1 to 7 have been chilled in air at temperatures of 0° and +4°C and at velocities of 0.5, 1, 2 and 3 m/s. Relative humidities have been maintained constant at 94% (±2%).

(i) Effect of air temperature, velocity, carcass weight and fatness on cooling time

The effect of air velocity on the average cooling time to 10°C at the surface and deep leg positions for air temperatures of 0°C and +4°C is shown in Figure 1. As far as possible care has been taken to obtain an equal number of replicates over the range of weights and fatness gradings to ensure relatively constant average values of these variables at each point. However, there are inevitably slight differences from point to point and between the values at 0°C and +4°C air temperature, the latter attributable in part to the smaller number of experiments to date at +4°C. It is clear that air temperature has a significant effect on cooling time, whereas increasing air velocity above 1 m/s causes little further reduction in the time to chill the deep leg to 10°C. Equivalent cooling curves for the centre and surface of the longissimus dorsi muscle of the same samples are shown in Figure 2.

Figure 3 shows the relationship between carcass side weight and cooling time to 10°C for both the deep leg and centre l.d. for air velocities of 0.5, 1, 2 and 3 m/s and temperatures of 0° and +4°C. The results of replicate experiments at each weight were combined to give cooling times for average fatness gradings. It has not been possible to provide an accurate quantitative assessment of the effect of fatness on cooling time because of the interaction between fatness and weight. A total of approximately 400 separate experiments would be required to assess the effect of the 7 fatness gradings for each combination of weight, air velocity and temperature, even if no replicates were made. Furthermore, it is almost impossible to obtain the extremes of fatness grading in the heaviest and lightest carcasses. Nevertheless, from the information obtained, it is evident that the cooling times to 10°C in the deep leg of the fattest and leanest carcasses can, respectively, be as much as 20% above or below the average value.

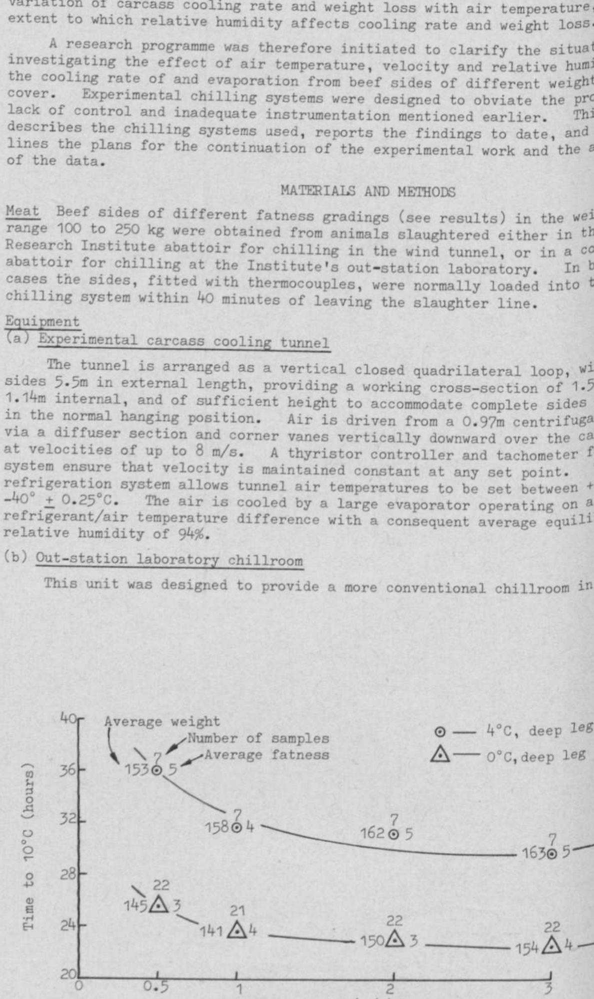

Figure 1. Effect of air velocity on the average cooling time to 10°C in the deep leg for sides in air at 4° and 0°C.

(ii) Effect of air temperature, velocity, carcass weight and fatness on evaporative weight loss

The effect of air velocity on the average evaporative weight loss in cooling to 10°C in the deep leg, for the same balance of samples described in Figure 1, is shown in Figure 4. It is evident that increasing the air velocity above 1 m/s has little effect in further reducing the percentage weight loss at either chilling temperature, but carcasses chilled at 0°C lost less weight at a given velocity than carcasses chilled at +4°C.

There is no clear effect of carcass weight on the evaporative losses incurred in chilling the deep leg to 10°C. The results are confounded by the interaction of not only fatness grading but also the increased cooling time required by the heavier carcasses. However, the effect of fatness on weight loss can be demonstrated for a given carcass weight range (Figure 5). It is clear that % weight loss decreases with increasing fatness at both 0.5 and 3 m/s.

(iii) Effect of radiation losses

The effect of radiation on the cooling time to 10°C in the deep leg was measured in the out-station chill room using 25 carcasses, with side weights in the range 98 to 194 kg, chilled in air at 0°C and 1 m/s.

A comparison of results for paired sides hung singly or between two further sides shows highly significant differences, both in time to reach 10°C, and in percentage weight loss. Those cooled with other carcasses surrounding them took, on average, 0.65 hours longer to reach 10°C (in the deep leg) than

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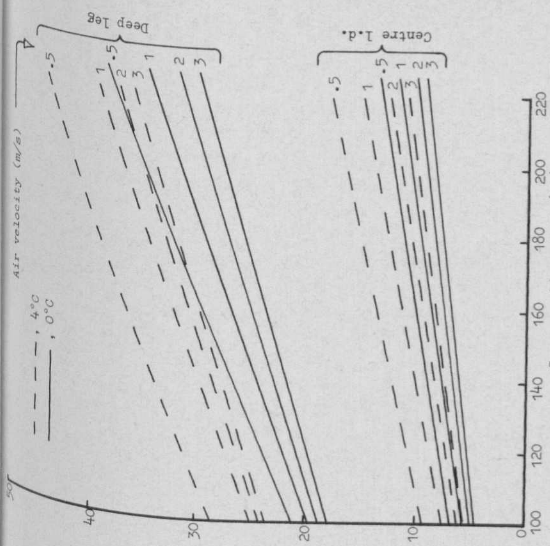

Figure 3. Relationship between carcass side weight and cooling time to 10°C in the deep leg and centre l.d. for air velocities of 0.5, 1, 2 and 3 m/s and temperatures of 0° and 4°C.

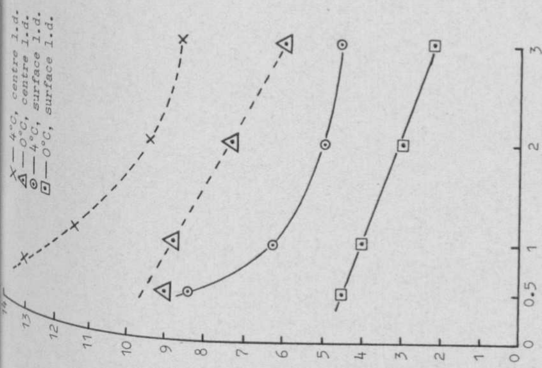

Figure 2. Effect of air velocity on the average cooling time to 10°C at the surface and centre of the l.d. for sides in air at 4°C and 0°C.

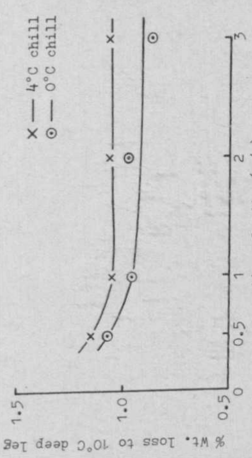

Figure 4. Effect of air velocity on the average % weight loss to 10°C in the deep leg for sides in air at 4° and 0°C.

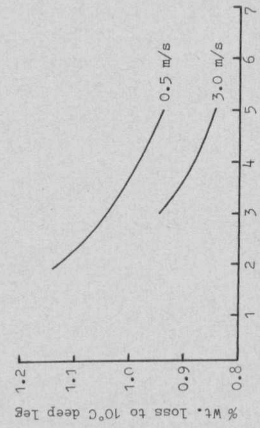

Figure 5. Variation of % weight loss with fatness grade for 130 to 150 kg sides in air at 0°C and velocities of 0.5 and 3.0 m/s.

those cooled singly. They lost 0.11 per cent more weight, on average.

The variation of these differences with carcass weight could not be established significantly from the current results, although the slopes of the regression lines of cooling time on initial side weight for the two chilling locations did, as expected, tend to converge at the upper end of the weight scale. Further experiments will be necessary to establish quantitatively the differences at each carcass weight.

DISCUSSION AND CONCLUSIONS

The principal reason for chilling meat is to reduce the bacteriological activity and so extend the storage life of the material. The more rapid the chilling rate the greater this effect will be. Rapid chilling, particularly in the early stages of cooling also benefits the meat by reducing drip loss (Taylor, 1972), and minimises evaporative losses by lowering the surface temperature and consequently the vapour pressure available for mass transfer. The factors which limit the rate of chilling to be applied are economics, as related to the capital and overall running costs of the system, and meat quality, which deteriorates as a result of the toughening that occurs if the temperature of the meat falls below 10°C before the pH has reached 6.2. This latter effect, known as cold shortening, has been expressed in practical terms by Bendall (1972) who states that "for optimal tenderness beef carcasses should not be chilled below 10°C for at least 10 hours after slaughter".

In the following analysis, the results of the effects of the environmental and carcass variables on cooling rate and evaporative losses are examined, in the first instance, to determine optimal practical conditions for beef chilling which can be compared with other findings in the literature. A subsequent examination considers the further limitations imposed in order to offset cold shortening. It should be stressed that this is only an initial analysis produced whilst a current in-depth statistical examination of the results by computer is in progress.

It is clear from the experiments conducted to date that there is considerable interaction between carcass weight and fatness, and that the latter has a marked effect on both cooling time and evaporative weight loss. However, in almost all publications on beef chilling in the literature, fatness has been completely ignored or at best given a cursory mention. This fact, coupled with a lack of detail on measurement systems, location of sensors, and control of environmental conditions, creates considerable doubts about the validity of some of the findings.

The results of this investigation have shown that although the cooling time to 10°C in the deep leg continues to fall with increasing air velocity there would appear to be little advantage in using values above 0.5 to 1 m/s because the small further time savings incurred would be unlikely to offset the considerable increases in the capital and operating costs of the plant. The energy consumption of the fans, for example, increases with the cube of the air speed and the heat equivalent of this energy has to be removed by the refrigerating plant. This agrees basically with the findings of Fruhwald (1956), and also those of Gac and Tupin (1964) who argue that systems become economically inefficient at air velocities greater than 0.25 m/s. Figure 4 shows that there is almost no change in evaporative weight loss with increasing air velocity above 0.5 to 1 m/s, and consequently no economic benefit in terms of increased yield at high velocities.

Air temperature has a more marked effect on both cooling time and evaporative weight loss (Figures 1, 2, 3, 4). The actual values of cooling time for average fatness grading agree reasonably well with those of Gac and Tupin (1964), although they in fact delayed commencement of chilling by up to 4 hours post slaughter. The chilling times given by Hodgson (1964) for the same environmental conditions appear to be considerably shorter than those measured in our experiments, particularly when it is noted that our results are somewhat faster than those anticipated in practice because of radiation effects. It is not possible to compare our results with those of many other workers whose figures are quoted over ranges of conditions and/or do not refer to the weight and fatness of the carcasses. Kuprianoff (1964), for example, claims that beef sides between 120 and 130 kg can be chilled to a deep leg temperature of 3°C in 18 to 20 hours in air at -1°C using cooling tunnels in which air velocity can be varied from 0.5 to 5 m/s. If an air velocity of 0.5 m/s is assumed then such chilling times cannot be achieved. In fact it is extremely doubtful that the schedules could be attained even at the higher velocity, which in any case would be impractical for the reasons mentioned earlier.

Measurement of the effect of radiation losses has established a significant difference in the average cooling times of and weight losses from carcasses in a radiating and a non-radiating situation. The variation of these differences with carcass weight has not yet been established. No carcass in a commercial environment will be completely free of radiation losses even if closely packed (e.g. radiation from rump to ceiling and neck end to floor), and consequently any correction factor applied will have to take account of carcass spacing and location in estimating the likely extent of radiation effects.

Swenson et al (1969) report more agreement in the literature on the effects of air temperature on both chilling rate and weight loss than any other variable, and note that all findings have been that the temperature should be held as low as possible at all times, the limiting factor being that the surface of the meat must not freeze. However, this is not so if the effects of cold shortening are to be taken into account. It is clear from Figure 3 that if the criterion to obviate cold shortening is ten hours to 10°C, then for average (140 to 150 kg) sides the centre of the longissimus dorsi was chilled more rapidly than this for all environmental conditions greater than 1.0 m/s and +4°C. In fact it is obvious that even at this rate the outer part of the l.d. (and of other parts of the carcass for that matter) must have incurred a degree of cold shortening. However, Figure 2 shows that at 0.5 m/s and 4°C, shortening should be virtually eliminated for average carcass weights and fatnesses as the surface of the l.d. is only marginally below 10°C in 10 hours. Such cooling conditions are representative of the performance of better than average UK chillrooms (Malton, 1972) and consequently explain why there are no reported problems of cold shortening in UK beef. The actual extent of toughening for smaller or leaner carcasses at 0.5 m/s and 4°C has not yet been determined, neither has the correct temperature required to completely prevent its occurrence. It is evident that some urgent work is required to establish these facts since chilling at these relatively high temperatures will be expensive both in terms of evaporative weight loss and extended cooling time. It will then be up to the individual operator to assess the overall commercial implications of either chilling to avoid cold shortening or chilling at a rate which will involve an accepted degree of toughening.

A detailed analysis of the results by computer is currently in progress. This will determine the extent of any of the interaction effects mentioned earlier and indicate what further experiments might be required in order to extend the findings reported to date. At the same time a comprehensive mathematical analysis is in progress from which, by the use of models or other techniques, it is hoped to produce equations and/or nomographs which will allow the prediction of cooling times and weight losses under environmental conditions other than those covered by the experimental investigation.

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