Engineering problems in cooling and storage of meat

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The engineering facilities recently established at the Meat Research Institute, Langford, permit the U.K. for the first time to carry out a planned programme of technological research on meat. In a new Institute with staff inexperienced in meat research, the published literature on meat cooling and storage is first of all being scanned in relation to the technical problems presented by the U.K. meat industry. Efforts are also being made by field observations to assess the current performance of the meat industry in controlling the physical factors, chiefly temperature and relative humidity (RH), that determine the quality of its products. This paper is based on the consideration being given to these new interests and activities.

1. Existing standards for physical parameters

There exist various national and international recommendations and regulations regarding the refrigeration of meat.

1.1 The Codex Alimentarius Draft Standard (CADS) proposals, submitted by Australia (1), are summarised in Table 1.

Table 1 Proposed Codex Draft Standard provisions for chilled meat (1969)

	MEAT	AIR	
CHILLING	Commence < 1 h after dressing Reduce interior to:		
Beef and Veal	≤15°C in < 20 h		
Pork	≤10°C in < 15 h		
Mutton and Lamb	≤ 7°C in < 12 h		
BONING AND CUTTING	≤ 7°C	10°C	
TRANSPORT	≤ 1°C in < 48 h	-1°C to 1°C	
STORAGE	-	0°C to 1°C	85-96% RH (87-91% preferred)

Question 1:- What is the justification for the cooling rate specified for beef? Vickery in 1951 (2) suggested cooling to <15°C in 24 h as necessary to control "bone-taint". But 20 h is more difficult to achieve in a large carcass, requiring exceptional refrigeration facilities (see later Section 3). Although the Australians must consider that they can attain this rate of cooling, some recent observers question whether it is generally attained there.

Question 2:- Is there any evidence that such rapid cooling can cause cold-shortening toughness in surface muscles, e.g. *longissimus dorsi*? Particularly in smaller carcasses, such as veal, considering Bendall's (3) advice not to cool to below 10°C in <14 h post mortem. For lamb, the minimum cooling rate prescribed in Table 1 incurs risk of cold-shortening toughness. This has been detected in commercial lambs ultra-rapidly cooled immediately after death (4), reaching a centre temperature of 10°C in about 4 h and 7°C in 5 h. New Zealand lambs for subsequent freezing do not now fall below 10°-15°C in 24 h (5).

Question 3:- For chilled (i.e. not frozen) lambs should the Codex Draft recommended minimum rate of cooling to 7°C in 12 h be replaced by a maximum rate to 10°C in 14 h; if so, what should be the minimum rate?

This admirable Australian attempt to codify good temperature practice in the handling of meat has recently all been set aside by the Codex Committee and replaced by the words:- "Temperature and degree of relative humidity should be maintained at a level suitable for the preservation of meat" (6).

Question 4:- Is this not meaningless unless related to a comprehensive specification such as CADS, perhaps modified in detail?

1.2 The European Economic Community (EEC) has already legislated as in Table 1 for boning and cutting of meat, but accepts 7°C as maximum temperature for storage (7). Also pH is supposed to be between 5.6 and 6.1 at the time of cutting.

Question 5:- Are temperature and pH systematically checked?

1.3 The International Institute of Refrigeration (IIR) has indicated (see Table 2) the storage life expected for various meats kept at temperature and RH recommended in 1.1 (8).

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Table 2 IIR recommendations for storage of chilled meat

	Temperature (°C)	Relative Humidity (%)	Expected Storage Life
Beef	-1.5 to 0	90	up to 3 weeks (4-5 weeks with strict hygiene)
Veal	-1 to 0	90	1-3 weeks
Lamb	-1 to 0	90-95	10-15 days
Pork	-1.5 to 0	90-95	1-2 weeks
Edible offals	-1 to 0	85-90	7 days
Bacon	-3 to -1	80-90	4 weeks
Rabbits	-1 to 0	90-95	5 days (maximum)

Question 6:- Can the slight differences in recommended temperature and RH for different species be justified?

Question 7:- How accurately can RH be measured at 0°C?

1.4 The U.K. Food Hygiene Regulations (9) require all cooked or partly cooked food, including meat products, to be kept either $< 10^{\circ}C$ or $> 63^{\circ}C$, except when exposed for sale. Following a typhoid outbreak from meat in a food shop, it has been recommended that cooked meat in shops should be kept $< 4.5^{\circ}C$ (10).

1.5 For frozen meat maximum freezing times for carcasses and cartons and temperatures for transport and for storage given in Table 3 were also prescribed by Australia for CADS (1).

Table 3 Proposed Codex Draft Standard for freezing and storage of meat (1969)

	MEAT	AIR
FREEZING	Initially 15°C Reduce to -8°C in:-	
Beef	$<$ 80 h	Initially -10°C
Pork	$<$ 60 h	Reduce to:-
Mutton and Lamb	$<$ 48 h	-15°C in $<$ 15 h
Meat in cartons	$<$ 48 h	
STORAGE		
Beef and Veal) Mutton and Lamb)		-14°C for $<$ 9 mths.
Pork		-18°C for $<$ 6 mths.
TRANSPORT		-10°C

The storage temperatures specified, presumably current in Australia, are at the upper end of the ranged recommended by IIR as in Table 4 (11) - 1971 proposals in ( ).

Table 4 IIR recommendations for storage life of frozen meat

	-12°C	-15°C	-18°C	-23°C (-25°C)	-29°C (-30°C)
Beef	5-8	6-9	8-12 (8)	18 (12)	- (> 12)
Lamb	3-6		6 (6-8)	10 (10-12)	
Pork	2		4-6	8-10 (10-12)	12-14 (14)
Offals (packaged)			3-4		
Bacon (unsmoked)			4 (3-4)	- (3-6)	- (4-12)
Rabbits				up to 6	

Question 8:- What practical tests for adherence to temperature specifications are anywhere in operation?

2. Comparison between accepted norms and industrial practice

Every country has its own systems for control of standards for handling of foodstuffs, including meat, relevant to its economic framework. In the U.K., the Meat Research Institute is not strictly an integral part of the meat industry although it gives advice to industry and Government departments. The U.K. meat and refrigeration industries embrace numerous undertakings varying widely in size and scientific/

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technical competence. Also, competition between firms generates reticence and secrecy about their methods. In this situation, field observations are being made on a sample of the meat industry. About 100 premises throughout the country have been visited during the past 1½ years (12). This survey has revealed that actual performance at times departs considerably from the above standards. Nevertheless, it may be suspected, unless contradicted by comparable data, that other countries face similar discrepancies between precept and practice.

Question 9:- To what extent can meat research workers in other countries claim to be fully conversant with the entire range of practice in their industry, or the portion they are specially interested in?

In any case, although the main lines of good practice are clear, not everything that is known and practised has also been published; and there are still some gaps in knowledge.

3. Carcass cooling

3.1 Rate of cooling

Cooling curves of carcasses in a number of commercial abattoirs have been obtained by an M.R.I. field officer under a range of practical circumstances, with and without refrigeration, by means of miniature, battery-operated, continuous electronic temperature recorders. Experience has demonstrated that only data gathered under the discipline of the Institute can be relied on. The results from November 1969 to March 1971, related to CADS proposals, are presented in Table 5.

Table 5 Cooling times (h) in thickest part of commercial carcasses

	BEEF to 15°C Unrefrig. first 24 h	BEEF to 15°C Refrig.	PORK to 10°C Refrig.
Average	35*	23	12½
Minimum	29	17	9
Maximum	48	39	16
Codex Draft Standard	20		15
No. of values	5*	29	7
Weight range (kg)	122-142	80-183	42-67

*Excl. 3 totally unrefrigerated sides (117-126 kg) that reached only 18°, 17°, and 16°C in 30, 25 and 46 h, respectively.

Air temperature recorded in 43 abattoir chill rooms over a total period of > 12000 h was > 5°C for ~ ½ the time, > 7°C for > ¼ and > 13°C for 3%. Many installations are under-powered or overloaded or not operated effectively. Even in such a case, calves of 24-30 kg were cooled to 10°C in 8-12 h (i.e. within the limit for risk of cold-shortening toughness).

U.K. refrigeration engineers do not possess the information needed about meat for design of plant to extract heat at a specified rate. In a typical case refrigeration equipment is supplied capable of extracting the calculated heat load in a certain time "providing the meat will give up its heat in this time". The linear air speed over the carcass to effect the required rate of cooling is often either ignored or underestimated. This parameter is usually expressed in the bizarre terms of "air changes per hour".

Question 10:- Are refrigeration engineers in other countries (i) better informed than those in the U.K. or (ii) better served with design data by their respective research institutes or other advisory bodies? Or (iii) is the required information often inaccessible or (iv) non-existent?

3.2 Thermal properties of hot carcasses

A work of reference commonly used by English-speaking refrigeration engineers (13) quote values for the specific heat (S.H.) above freezing of meats varying between 0.50 and 0.68 based on the crude empirical equation:- S.H. = 0.2 + 0.008W, where W = % water, derived in 1892 (14), the corresponding formula for frozen meat being even more inaccurate.

Values of about 0.90 are now accepted for the effective specific heat of pig carcasses in chilling from 37° to 4°C, taking into account the latent heat released in solidification of the fat (15). This agrees better with data on muscle (16).

Question 11:- Are such uncertainties critical for engineers specifying refrigeration

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equipment for the meat industry?

3.3 Initial carcass temperature

It is well known that centre temperatures rise immediately post-mortem and values as high as 41°-42°C are frequently registered in carcasses up to 4 or 5 h after death. However, such measurements provide only a rough guide to the heat evolved.

Bendall (17) has calculated that post-mortem biochemical changes can release up to 1.8 cals/g within 10 mins of death and that the total heat produced during rigor can be as much as 3.3 cals/g. This could result in a 4°C rise in temperature, requiring about a 10% increase in the total heat extraction calculated between 37° and 4°C. This calculation requires confirmation by temperature measurements.

3.4 Evaporation during cooling

In the U.K., beef is still often allowed to cool without assistance in air at ambient temperature, and it is common practice to place it in a refrigerated room only after 24 h post mortem. Pork is usually refrigerated, but lamb often is not. The results of a recent sample survey of evaporative losses during industrial cooling are summarised in Table 6.

Table 6 Evaporative losses in U.K. carcass cooling

	No.	Weight (kg) Range (average)	% loss Range (average)
Beef - refrig.	50	70-177 (125)	0.7-3.8 (1.8)
- unrefrig.	43	109-174 (145)	1.9-3.8 (2.7)
Pork - refrig.	26	31-52 (44)	1.9-2.8 (2.4)
Lamb - unrefrig.	25	16-25 (18)	3.7-7.1 (4.9)

Table 6 appears to confirm that evaporative losses in cooling are less with refrigeration (although statistical validity is not claimed).

"Institutional" factors invalidate much U.K. commercial data on carcass weight "shrinkage". The "official" dressed carcass weight includes a standard allowance for subsequent evaporation loss, depending on the period between slaughter and weighing. Differentials of more than a kg can occur, and along with accuracy of balances and variability of meat hooks can obscure judgement on technological factors.

3.5 Rapid chilling

It is now widely accepted that evaporative weight loss during chilling of hot carcasses is minimised by a rapid chilling schedule that quickly reduces surface temperature to near freezing point. This is usually effected by means of a relatively brief initial treatment with very cold air, which may be as low as -15° or -20°C combined with a fairly high velocity. A careful two-phase or multi-phase cycle of temperatures and velocities then maintains low surface temperature, without freezing, until the carcass temperature equalises at the value required. This technique is best established for pigs where weight loss can thereby be lowered from 2.5 to 3.5% for natural cooling and 2.10% for ordinary chilling to little more than 1.0% (18). Similarly for beef, the weight loss of 80-100 kg sides, for example, has been reduced in U.S.S.R. from between 1.66 and 2.0% to 1.0% (19).

However, in spite of 40 years' work and publications there are still some uncertainties and conflicting opinions. Also, potential users cannot always believe advocates of new equipment. Obviously the greater the air velocity at a given air temperature, the faster is the rate of evaporation, but the quicker the cooling. Thus, one recent study on beef cooling, based on field observarions, concludes that "in order to minimise the weight losses, the air velocity should be low", and expresses a preference for 0.75 m/s (compared with 1.5 and 3.0 m/s) as the minimum required to reduce the bone temperature of a side of beef of 100 kg to 10°C within 16 h in air at 0°C (20). 1-2 m/s has also been recommended (19) (21). Conclusions regarding RH are also contradictory.

One rapid chilling tunnel for lambs in the U.K. is no longer used, reportedly because of excessive weight loss.

It is disputed whether differences in moisture losses of bacon pigs due to evaporation during cooling are equalised in curing. A recent publication (22) confirms that rapid chilling does not increase yield. In a similar investigation with paired sides in 1958 (23), although rapid chilling reduced loss in summer (to 1.28% compared with 1.81% for cooling in ambient air) but not in winter (1.25% and 1.26%), there was a slight advantage in slow cooling in winter, but not in summer. However, Danes are

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convinced that there is a slight but statistically significant gain from rapid chilling.
Question 12:- Are there further data to help bacon-curers to decide whether to equip for rapid chilling?

Australian workers conclude that:- "there is a great deal of information on chilling yet to be gained. 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 effect on weight loss of air velocity, or the extent to which relative humidity affects cooling rate and weight loss" (24).
Question 13:- Is this statement generally agreed?

The Meat Research Institute hopes to clarify this situation by a controlled experimental attack on the problem and thus provide some much-needed advice to the U.K.

3.6 Effect on quality

Question 14:- Do consumers get any benefit from the attention paid to weight control by the meat industries of all countries, of whichever economic system? Although accountancy is presumably facilitated by minimising weight loss, this primarily affects producers and "middle-men".

Rapid cooling of PSE-prone pigs reduces the incidence, although it is doubted whether even liquid nitrogen cooling could confer complete immunity.

"Drip" exuding after packaging (which is unsightly as well as uneconomic) is also markedly reduced by cooling carcasses immediately after slaughter (25). This happens to some extent even with PSE pork. Joints from pig sides delayed 1-6 h before chilling in still air at 0°C lost 110% more drip than when quickly cooled. Similarly l. d. samples at 9 th-10 th rib from beef sides held 7-24 h at 15°C before chilling lost 120-190% more drip than from sides cooled at 0°C, depending on air movement.

Although excessive dehydration is detrimental, this does not occur in ordinary slow chilling. Furthermore, the surface microbial flora is inhibited by dehydration. In fact, about 2% surface evaporative loss was the basis of the U.K. import of beef from South America. However, it is often claimed that rapid cooling improves keeping quality.
Question 15:- Are there decisive data on the effect on keeping quality of differences in loss of weight incurred in various chilling procedures?

4. Conditions of storage

4.1 Temperature

Classic U.K. data show that bacterial multiplication on the surface of meat (at nearly 100% RH) at 5°C is nearly 4 x, and at 2°C 2 x that at 0°C (26). $0^{\circ} \pm 1^{\circ}$C is therefore recommended (as in Tables 1 and 2) for maximum storage life. However, EEC is satisfied with meat at an internal temperature not exceeding 7°C (or 3°C for offals). Danish pigs are equilibrated to 4°C presumably to facilitate cutting. Meat stores and retail display cabinets are often held at 3°-4°C. And in summer, store temperature is quite often deliberately raised to 7°C, apparently to minimise condensation (see 4.3). It is unusual in the U.K. to refrigerate boning rooms to below 10°C but fresh meat nevertheless is mostly kept below 7°C during distribution except when it is displayed or prepared without refrigeration.

4.2 Relative humidity

The classic data at nearly 100% RH (26) limit storage life at 0°C of meat with a typical bacterial load to 1-2 weeks, whereas meat can be kept for much longer than this if 2-3% superficial drying occurs to reduce the water activity in the surface layer. Again, it might be said that "Nowhere in the literature are there reported conclusive experimental results of the variation of carcass" spoilage rate with air temperature and relative humidity under conditions where the evaporative loss has been quantitatively studied.

4.3 Condensation

Repeated complaints about the condensation of moisture on meat during handling reveal several different problems. The most obvious case is when (i) chilled meat is taken out of a chill room for transport or display and moisture condenses until the surface temperature rises to the dew-point. For example, an exposed lamb of 18 kg at 0°C placed in air with a dewpoint of 14°C increases in weight by 0.7% on account of moisture deposit. On frozen lambs at -10°C to -20°C the weight increase can amount to 1.5% (27). In both cases this is obviously detrimental to appearance and subsequent keeping quality. In addition, instances have been observed when (ii) in chilling hot meat, the water vapour released can condense either on cold surfaces of exposed metal and thence trickle over the meat and onto the floor; or onto previously chilled meat already in the room; or even possibly, onto the meat itself, whilst it is being chilled depending on the precise temperature and RH cycle in the chill room. Conditions favouring condensation were revealed during the survey of 43 abattoirs in which the RH was between 95% and 100% on average for 8%, and in some instances for 17% of the time (12).

Another type of condensation problem occurs (iii) in refrigerators for holding small quantities of meat in shops and catering establishments. Here 95-100% RH has been observed in some cases for 30% of the time. Automatic hot gas defrost systems cause RH to rise to 100% at regular intervals, so that moisture alternately deposits on the meat and then dries off again, causing disagreeable discolouration as well as conditions conducive to intermittent spoilage. In the case of salt cured products, such as bacon, which of course have a lower equilibrium RH than fresh meat, good air circulation is required, otherwise pockets of high RH in the pleural cavity can rapidly cause sliminess and spoilage (28).

Question 16:- Are these condensation problems unique to the U.K.?

5. Frozen meat

5.1 Rate of freezing

A study of the results reported in the literature over the past 50 years suggests that, in spite of contradictions, the rate of freezing within very wide limits in most circumstances has no significant effect on the quality of frozen meat.

Question 17:- Is this opinion widely accepted? Liquid nitrogen spray freezing of slices of meat seems to possess no advantage over rapid air blast freezing at about $\frac{1}{4}$ of the rate (29). IIR claims that freezing in $< 30'$ eliminates drip (11, 1971 revision)

5.2 Storage conditions

As storage life is so temperature-dependent (see Table 4), there is a general realisation that cold storage temperatures ought to be as low as possible. However, much U.K. bulk storage is still at -10° to $-12^{\circ}C$ and in the smaller stores sampled air temperature was above $-10^{\circ}C$ for half the time. The temperature of frozen meat when delivered is liable to be even higher. There still lingers in the U.K. meat industry a fear that dehydration is greater the lower the temperature, whereas all practical measurments and observations prove the contrary. However, exceptional cases are conceivable.

5.3 "Jacketed" cold stores

In the case of frozen meat, surface dehydration is highly detrimental to keeping quality, chiefly on account of oxidation. There therefore seems more technological, as contrasted with economic, incentive to reduce weight losses than in the case of chilled meat. Of the various means proposed for reducing evaporation loss in frozen food, the most promising at one time seemed to be the "jacketed" store, of which a pioneer example was the Moscow 12 store opened in 1954. However, apparently no more cold stores will be built in the U.S.S.R. on this pattern because, although rate of dehydration was reduced by 50-60%, cost of construction was 5-10% greater than for ordinary stores. Packaging and other methods of maintaining high RH are now used to reduce weight loss. Nevertheless "jacketed" stores are still well regarded in Canada and Norway, although in neither country have new stores of this type been built in recent years.

Question 18:- Are there any other views or experiences on this topic?

6. Temperature of meat in shops

Where packaged meat is displayed in a refrigerated cabinet, thermal radiation can raise its temperature by $5^{\circ}C$ above the surroundings (30). Meat pies on display in 16 shops sampled during 1970 were above $10^{\circ}C$ in almost every instance and during hot weather one consignment exceeded $30^{\circ}C$ (12).

Question 19:- Does temperature of meat on sale in shops cause concern in other countries?

7. Conclusions

From a U.K. point of view (i) meat scientists need to make greater efforts to study practically the existing processes and behaviour of the industry they are trying to serve; (ii) greater efforts seem to be required to ensure that recommended procedures are observed; (iii) there is an acute need for a co-ordinated technical information service to which the meat and refrigeration industries can refer for unprejudiced advice and information; (iv) there are still numerous problems for the refrigeration industry to overcome on the basis of existing published information; (v) more original technical information still has to be provided by research workers before the refrigeration industry can design equipment of optimum performance for the meat industry; (vi) in general, average

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industrial practice lags far behind scientific theory and experiment. Conversely, scientific theory may be too far ahead of average industrial practice.
Question 20:- Is this agreed?

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