Thawing meat blocks using microwaves under vacuum

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Introduction

There is an industrial requirement for a rapid thawing system for "standard" blocks of frozen boned out meat, which are increasingly used as raw material in many meat processing operations. The meat, ranging in size from large primal joints to small pieces and trimmings, is packed in 25kg lots within solid or corrugated fibre board cartons, usually containing a polyethylene inner liner. An average carton size is 61 by 40 by 15cm thick (Creed and James, 1981a). Cartoned meat blocks of this size require at least 22 hours to thaw to a centre temperature of 0°C in the fastest practical conduction based system which would use high velocity air at 30°C (Creed and James, 1981b). Even if the meat is removed from its carton, and thawed using condensing steam at 30°C under vacuum, the thawing time cannot be reduced below 13 hours (Creed and James, 1981b). Removing the carton and wrapping from the frozen meat is, in any case, a difficult, time consuming, double handling operation disliked by all industrial operators.

In the majority of thawing operations the thawing time is a function of the transfer of heat from the thawing medium to the surface of the meat, and the conduction of this heat into the centre of the frozen product. The poor conductivity of thawed meat, together with microbiological requirements which limit the maximum media temperature that can be used, restrict the rate of heat flow, and results in long thawing times. In theory, microwave systems should overcome these problems because heat is generated within the material, but their application is constrained by thermal instability. At its worst, parts of the meat may be cooked whilst the rest remains substantially frozen. This arises because the absorption by frozen food of electromagnetic radiation in the microwave region, 0.9 to 2.5 GHz, increases as the temperature rises, this dependence being especially large at about -5°C, increasing as the initial freezing point is approached. If for any reason during irradiation a region of the material is slightly hotter than its surroundings, proportionately more energy will be absorbed within that region and the original difference in enthalpy will be increased. As the enthalpy increases so the absorption increases and the unevenness of heating worsens at an ever increasing rate. Below the initial freezing point the temperature increase is held in check by thermal inertia since for a given energy input the temperature rise is inversely proportional to the thermal capacity. If irradiation is continued after the hot spot has reached its initial freezing point, the temperature may continue to rise to boiling point.

Such runaway heating can be reduced by lowering the power density (thereby increasing the processing time) to allow thermal conduction to even out the enthalpy distribution through the material. Order of magnitude calculations have been made of the times involved for thermal stability and showed that whereas below -5°C and above 0°C relatively uniform rapid heating is possible, at temperatures between -5°C and -1°C, where the major enthalpy change on thawing occur, conditions are unstable unless processing times of 8 hours or greater are employed (Jason, 1974., Ohlsson, 1983).

Since the main instability tends to occur at the surface, attempts have been made to cool the surface during thawing using air or liquid nitrogen (Bialod et al., 1975. Micro-ondes Industrielles, undated). Although experimentally successful the systems are not economically viable. In this paper investigations carried out into the feasibility of using a hybrid microwave/vacuum system to thaw cartoned blocks are described and the results discussed. The system reduces the likelihood of excessive surface temperatures by boiling off surface water at a low temperature, with consequent evaporative cooling.

Thawing System

The prototype thawing system shown in Figure 1 consisted of a cylindrical vacuum chamber approximately 1 metre in diameter and 1 metre long. This chamber could be evacuated to absolute pressures as low as 10 mbars by a water ring pump in series with a rotary pump. Microwaves at a frequency of 915 MHz were introduced into the chamber via two wave guides positioned near the top at the front and rear of the plant. The microwaves were produced from a 25 KW generator. In the trials the output from the generator was limited to 2.5 KW due to arcing problems within the chamber. A large circular twisted disc was rotated within the chamber during thawing to "stir" the microwaves and produce a more even distribution of field potential.

Experimental trials

Since no suitable equipment was available to monitor meat temperatures within a microwave field during thawing, two sets of trials were carried out. In the first trials the total amount of energy theoretically required to raise the average temperature of the meat to 0°C was calculated using the enthalpy data of Riedel (1957) and supplied within either a 0.5, 1 or 2 hour period to half or whole blocks. Since this resulted in significant under-thawing, with approximately 40 percent of the energy absorbed, the amount of energy supplied was increased by a factor of 2.5 in the second series of experimental runs.

The experimental procedure was the same in both cases. Chilled meat (85% visual lean) was obtained from a commercial abattoir and made up into either whole blocks 61 x 40 x 15cm, or half blocks 30 x 40 x 15cm. The blocks were then wrapped in polyethylene film and placed singly in solid fibre board cartons of nominal dimensions 61 x 40 x 15cm. All the cartons were blast frozen in air at -30°C, 3 m/s for 48 hours before being stored for a minimum of 4 days at -20°C. Single cartons weighed to 1g were placed on a rack in the centre of the vacuum chamber which was then evacuated to a pressure of 16 mbar before the microwaves were introduced. Cartons remained in the chamber for the times and under the conditions shown in Tables 1 and 2. During the thawing process the pressure in the chamber increased to between 20 and 28 mbar due to the inability of the pumps to maintain the high vacuum.

At the end of the set time the vacuum was released, the top of the carton removed and the wrapping opened so that the maximum surface temperature could be determined using a Kane May radiation thermometer accurate to 2°C. A single point hypodermic probe was then used to find the minimum temperature within the meat. The carton was then re-weighed and a multipoint thermocouple probe (of the type described by James et al. 1977) placed vertically through the geometric centre of the meat block. The block was then placed inside an insulated box and the whole assembly stored in a chill room at 0°C for 2 hours. During this time the temperatures within the meat were monitored and recorded to 0.5°C using a Solartron data logging system. From this data the average temperature of the block was calculated.

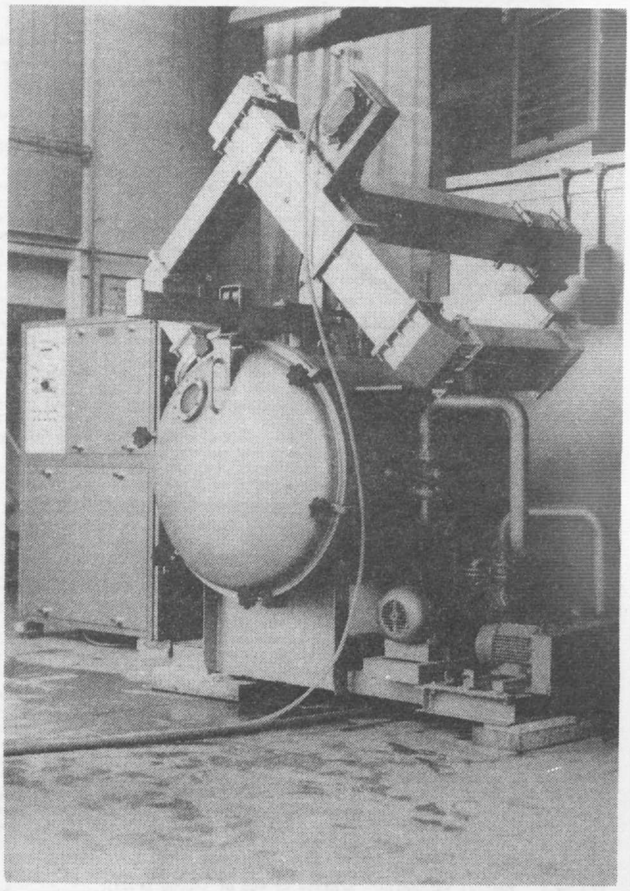

Figure 1 Microwave Vacuum Thawer

Results

The conditions and times used in the trials together with the minimum, maximum and average temperatures and the percentage weight loss after thawing are shown in Tables 1 and 2. Typical temperature profiles through a block at the end of its thawing cycle for the first and second set of trials are shown in Figures 2 and 3 respectively.

Run No.	Weight Initial (Kg)	Weight Loss (%)	Thawing Time (h)	Power (KW)	Temperature Minimum (°C)	Temperature Maximum (°C)	Temperature Average (°C)
1	26.0	1.5	2	0.91	-3.6	2.1	-2.8
2	25.0	0.8	2	0.88	-2.7	7.7	-2.5
3	26.1	1.9	1	1.83	-4.4	0.9	-3.5
4	26.0	1.2	1	1.82	-3.7	4.0	-3.2
5	14.5	2.1	0.5	2.03	-4.6	1.4	-3.5
6	16.6	1.8	0.5	2.32	-2.2	6.8	-2.0

Table 1. Initial weight and % weight loss from meat, thawing time and microwave power supplied during the first set of thawing trials, and the maximum, minimum and average meat temperatures after 'thawing'. All runs were carried out from an initial starting temperature of -20°C at a pressure rising from 16 to 28 mbar.

It is clear from Table 1 that insufficient energy was supplied to the blocks to raise their average temperatures above 0°C, however both surface temperatures (maximum 7.7°C) and percentage weight losses (average 1.6%) were low.

Run No.	Weight Initial (Kg)	Weight Loss (%)	Thawing Time (h)	Power (KW)	Temperature Minimum (°C)	Temperature Maximum (°C)	Temperature Average (°C)
1	25.6	9.0	2.0	2.5	3.0	24.3	8.0
2	25.5	7.9	2.0	2.5	2.6	24.0	8.1
3	25.6	7.3	2.0	2.5	-2.0	12.7	4.0
4	24.5	10.3	2.0	2.5	21.2	26.7	23.3
5	33.2	5.9	2.0	2.5	-2.0	22.0	4.8
6	27.9	7.1	2.0	2.5	-0.2	25.0	6.2
7	11.9	6.5	1.0	2.5	4.6	14.9	12.2
8	11.9	6.2	1.0	2.5	7.0	17.5	13.0
9	12.3	7.0	1.0	2.5	-4.2	3.2	-1.0
10	11.5	9.4	1.0	2.5	15.5	28.4	20.5
11	11.9	7.5	1.0	2.5	-2.4	15.2	4.3

Table 2. Initial weight and % weight loss from meat, thawing time and microwave power supplied during the second set of thawing trials, and the maximum, minimum and average meat temperatures after 'thawing'. All runs were carried out from an initial starting temperature of -20°C at a pressure rising from 16 to 28 mbar.

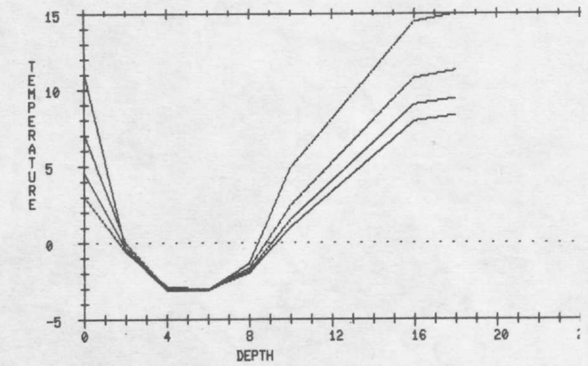

Figure 2 Typical temperature profile at end of first trial.

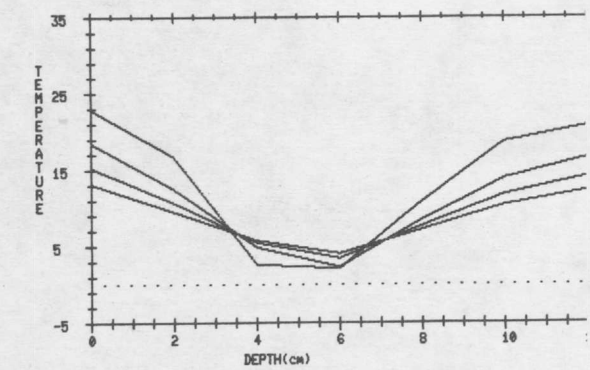

Figure 3 Typical temperature profile at end of second trial.

Four blocks in the second set of trials had minimum meat temperatures below 0°C, however only one had an average temperature below this value. Weight losses averaged 7.6 percent, and maximum surface temperatures ranged from 3.2 to 28.4°C.

From the enthalpy data of Riedel (1957), 335 KJ/Kg of energy are required to raise the temperature of lean meat (assuming a water content of 75%) from -20°C to 9.0°C (the average final meat temperature). The average energy required in the second set of trials, calculated from the data in Table 2 was 690 KJ/Kg, giving an efficiency of 49%. Assuming that the average weight loss of 7.6% consisted only of water boiled out of the surface layers, this would consume 187 KJ/Kg of meat thawed. The remainder 168 KJ/Kg was absorbed by the wave guides and thawing chamber.

Discussion and Conclusions

These experiments have demonstrated that it is possible, using a hybrid microwave/vacuum system, to thaw 15 cm thick blocks of meat inside solid fibre board cartons in either a one or two hour cycle. The average meat temperature after thawing was 9.4°C (ranging from -1.0°C to 23.3°C between cartons) and the maximum surface temperature measured on any block was 28.4°C. Surface temperatures of this magnitude would be unlikely to produce substantial increases in bacterial numbers because of the very short thawing times. However temperatures much higher than this could result in some protein denaturation.

Weight losses averaging 7.6% (ranging from 6.2 to 10.3%) appear large when considered against other reported thawing losses of 1 to 2% (Bailey et al., 1974., James et al., 1977., Creed et al., 1979), but the latter were obtained from carcasses or large joints with a low cut surface to volume ratio. Unpublished values from industrial thawing systems that handle similar types of blocks range from 3 to 10% (Malton, 1984).

The overall energy efficiency of 39% appears low, but no comparative figures have been located for other thawing systems. One third of the energy supplied was absorbed by the vacuum chamber. The prototype was constructed from mild steel and a vessel made of either stainless steel or aluminium would substantially reduce the absorption of microwave energy. However, even if no energy were absorbed in this way it would still require approximately 520 KW to thaw one kilogram of meat. This would create a substantial problem in scaling up the prototype to a commercial sized thawing plant. The largest microwave generators currently available have an output of 60 KW and would therefore only thaw approximately 0.5 metric tons per hour. Since they would need regular loading and unloading their maximum output per 8 hour working day would be no more than 4 metric tons of thawed meat. Many industrial plants require considerably higher throughputs than this, and would thus need multiple units. The capital cost of a unit is likely to be very high which would severely limit its commercial viability.

Furthermore commercial thawing systems are required to process a number of cartons in a single operation. These results show wide variation in final average temperatures between individual blocks ranging from -1° to 23°C. This is probably due to differences in fat/lean content and distribution of material within a carton, and uneven microwave field strength within the vacuum chamber. All the meat used in these experiments was obtained from a single source and was carefully packed; variations under commercial conditions due to these factors are likely to be even greater. Uniform irradiation of considerable numbers of cartons inside a large vacuum vessel would also present problems that would be expensive, if not impossible to solve.

It is clear that a hybrid microwave/vacuum system will thaw single meat blocks in a time that would be attractive in many commercial operations, but energy and other practical considerations could severely limit its industrial use.

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