Session 6.2 Meat technology and processing Unit operation and storage Technical equipment and robotics

L 1 NEW EQUUIPMENT FOR MEAT MANUFACTURING AND MINIMAL PROCESSING - EXISTING AND POTENTIAL USES

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Introduction

In order to keep up with global market demands, the meat industry continuously has to improve safety, quality and shelf life (SQS) of its products. In combination with the increasing size of the production facilities, the importance of new equipment is becoming acute: equipment suitable for fulfilling not only the SQS requirements but also the need for shorter manufacturing times and batch-to-batch uniformity. Furthermore, these new types of equipment and technologies must not adversely influence operational costs.

At the Danish Meat Research Institute (DMRI) a continuous surveillance is carried out on types of new equipment and technologies relevant to the above-mentioned requirements. This surveillance covers commercial equipment and technologies, equipment not yet in use on an industrial scale and new technologies that might prove beneficial for tomorrow's production. In addition to the theoretical surveillance, some of the more promising technologies have been tested in practice either in the laboratory or on pilot plant scale.

Main new technologies

In meat manufacturing the typical unit operations would be one or more of the following:

- Raw material preparation including thawing, cutting and pre-blending.
- Curing including brine injection, tumbling, draining etc.
- Drying/ageing including dehydration and flavour, colour and texture development.
- Preservation including heating or drying.
- Packaging including slicing, portioning and packaging in either vacuum or modified atmosphere.
- Decontamination including antimicrobial operations related to the retail packages.

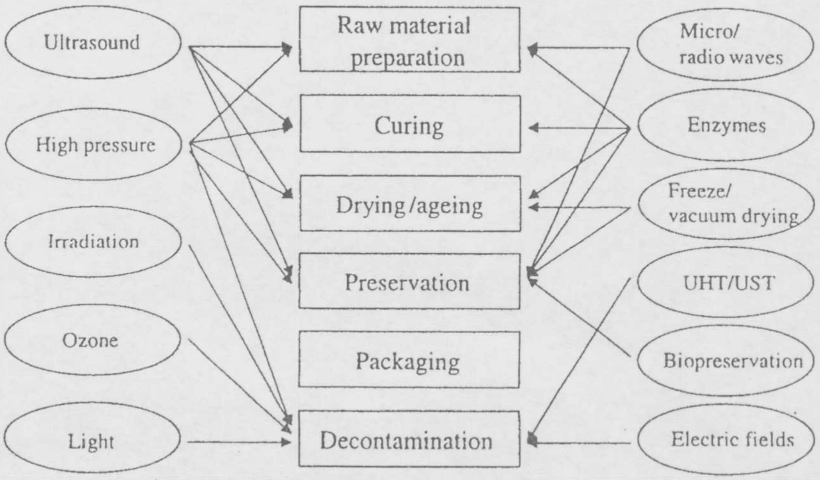

Figure 1 New technologies and equipment for meat manufacturing and processing. The technologies point towards the unit operations where they are typically applied or where they are the actual unit operation.

During these manufacturing steps a wide range of new technologies and equipment can be applied (*Figure 1*). Some, such as ultrasound and ultra high pressure (UHP) are multifunctional, and can be used in different unit operations for different purposes. Other types of equipment are focused on a specific task such as irradiation. In this presentation, the following technologies and the corresponding equipment will be dealt with: *Ultrasound, Ultra high pressure* (UHP), *Microwaves, Radio waves, Electric fields* (ohmic heating, oscillating magnetic fields and pulsed electric fields), *Freeze drying* and *vacuum drying, UHT/UST* (ultra high temperature, ultra short time), *Ozone, Irradiation, Light* (high intensive white light, UV and laser application), *Enzymes* and *Biopreservation.*

Some of the technologies are more promising than others with respect to fulfilment of the SQS requirements, process acceleration and batch uniformity in the meat industry. Focus will rather be on the equipment than on the theoretical mechanisms behind the technologies.

Ultrasound

The current knowledge about the effect of ultrasound on meat is mainly limited to bacterial lethality and tenderness improvement of fresh meat. However, some recent publications report interesting applications of ultrasound in meat processing. Investigations have been made into the use of ultrasound as a supplement to tumbling for accelerated protein extraction and sodium chloride diffusion, into accelerated drying using air-borne ultrasound and into accelerated thawing using high frequency ultrasound.

The pressure variations in the food caused by the sound waves allegedly contributes to an acceleration of the water transport and thus transport of water solutes. In the case of drying by ultrasound, the sound waves remove water from the outermost layer of the meat very fast thereby accelerating water transport from the core to the surface. In accelerated thawing, transformation of sound energy to heat (the so-called damping phenomenon) is utilized. Damping is greatest in the frozen phase increasing with increasing sub-zero temperatures and reaching a maximum near the freezing point. In contrast to microwaves, ultrasound thus heats up the ice at a greater rate than the thawed water. Overheated spots can thus be avoided.

Equipment for treatment of meat by high-powered ultrasound has not yet passed laboratory or pilot scale. At the DMRI, investigations have been made with equipment designed by the *FORCE Institute*, Denmark. This equipment can apply both low and high frequency ultrasound independently and at different energy levels. The prospects of using ultrasound for accelerated curing and thawing of meat were investigated.

Of the two applications, accelerated thawing looked most promising. It appeared that high frequency ultrasound at 0.5 kW could accelerate thawing of pork loins compared to traditional thawing in lukewarm water. As expected, no overheated spots were observed. An actual acceleration factor could not be established from these preliminary tests. The results have to be re-affirmed before an evaluation of the economics in an up-scaling and the future prospects can be accomplished.

Our tests using different combinations of low and high frequency ultrasound for accelerated curing were less promising. Despite a range of tests with varying frequencies and effects, the nitrite-salt did not diffuse faster into the meat from the curing brine than without the use of ultrasound. Contrary to the information in the patents, we have not found ultrasound waves able to "carry" water solutes. Basic research on mass transport and ultrasound is needed before further application testing is performed.

Two of the more promising uses of ultrasound close to application or already on a commercial scale are thermo-sonication and continuous cleaning of process equipment.

As mentioned earlier, heat is one of the effects of applying ultrasound to meat and meat products. Investigations have shown that it is possible to reduce traditional heat treatment by 50% when applying high-energy ultrasound. At the same time the meat is tenderized, mainly as a result of increased myofibrillar denaturation compared to traditional heat treatment. From these tests it was concluded that an increased kill-effect on microorganisms could be achieved in various food test systems by using a combination of ultrasound and mild heating, the so-called thermo-sonication.

Another study showed that the continuous cleaning system, *Stericlean*, UK, by use of ultrasound was significantly better for cleaning process equipment than conventional systems. On a poultry line, it markedly reduced cross contamination resulting in longer shelf life of the products. Reliability was high, and the operational life of the ultrasound transducers was more than 6000 hours.

The ultrasound technology is likely to be used increasingly for manufacturing and processing in the food industry. Preliminary calculations indicate that capital and running costs are low enough to justify the use of ultrasound in food manufacturing. However, apart from the use for continuous cleaning, it is expected that industrial application of ultrasound for meat manufacturing will take some years, as additional research is still required.

Ultra high pressure (UHP)

Equipment for UHP is, similar to ultrasound, multifunctional. Prospective applications are: acceleration of freezing, thawing, curing and ageing, preservation or decontamination and the use for new minimally processed meat products. The technology is still under development and receives increasing attention from the food industry. As of today, the only application in the meat industry is decontamination of retail packed meat products improving SQS properties.

The Spanish meat processor, *Espuña*, is using UHP equipment from *ACB Pressure Systems*, France, for decontamination of cured, cooked ham. They are able to prolong the shelf life to 60 days in an undisturbed cooling chain. They claim the same level of freshness throughout the 60 days as for the freshly sliced ham. Pressurizing at 4000 atmospheres and 12°C, they treat 600 kg pr. hour equal to 6000 100g packs. The ham product has been on the Spanish market for two years. The UHP process is highlighted on the label stating: "Ultra high pressure pasteurised product. To preserve freshness until consumption".

In the USA, *Hormel Foods* announced in February 2001 that they had installed UHP equipment from *Flow International* (formerly *ABB Pressure Systems)*. In the short term the equipment will be used for R&D, but it will soon be used on a commercial scale. Apart from a use for general decontamination as at *Espuña*, the equipment will be used mainly for elimination of *Listeria monocytogenes*. In the USA, the authorities maintain a zero tolerance for *L. monocytogenes*. It has been documented that this can be achieved with UHP. As of now there are no details regarding products, launching time or treatment details.

The most important producers of industrial UHP equipment are *ACB Pressure Systems* and *Flow International*. The main difference between the equipment from the two manufacturers is, that *Flow International* is using a vertical chamber with loading and unloading from the top and *ACB Pressure Systems* a horizontal chamber with loading at one end and unloading at the other end. In addition there are differences in capacities, cycle times, achievable pressures, capital cost etc. In general, during the last couple of years the cost of treatment pr. kg UHP product has improved. The capacities have increased due to design improvements and optimised loading and unloading systems. The cost of treatment pr. kg product is now 0.03 – 0.08 Euros depending on capacity. This goes up to 5,000 kg pr. hour.

Like other R&D centres, the DMRI has investigated alternative uses of UHP. Decontamination is apparently the application that has made the technology known and accepted in the food industry. UHP equipment has potential for other applications. We have looked into these alternative uses or will do so in the future.

The use of UHP for accelerated thawing is one seldom mentioned area of application. At the DMRI, UHP has been tested on frozen pork loins. The basic concept in UHP assisted thawing is that high pressure imposes phase changes, lowering the melting point of ice. In other words, UHP can "convert" ice to water without having to increase the temperature. Our tests showed that with an initial water temperature in the pressure chamber of 25°C and a pressure of 2000 atmospheres, the unthawed core made up 8% of the loin after 40 minutes in contrast to 75% in a thermo regulated water bath at 25°C and 1 atmosphere pressure. At pressures above 2000 atmospheres, the loins began to denature, leaving them pale and unacceptable. From a technical point of view, the prospects for UHP assisted thawing are obvious, although requiring considerable research. It is also necessary that the capital cost is reduced.

Only limited research has been carried out on UHP assisted curing and ageing. Nestlé has patented a method of improving water holding capacity of ham muscles, which are UHP treated prior to multi-needle injection. A couple of years ago a raw ham product, which was matured considerably faster than traditionally by using UHP, was marketed by the *Fujichiku Company*, Japan. At the DMRI it was tried to accelerate brine diffusion by UHP, but with limited success only. No correlation was found between diffusion, pressure and pressure holding times. Our theory is that it is the pressure gradients over time that drives the diffusion. The pressure building and release is too slow to create sufficient gradients in a traditional UHP chamber. It has to be almost instantaneous.

The application of UHP, which has been studied most intensively, is microbial intervention, primarily against pathogens. It is profoundly documented, that UHP is very effective against vegetative microorganisms, but less effective against spores. Very high pressures (7000 – 9000 atmospheres), a combination of mild heat and UHP or several cycles of pressure and pressure release all seem to be lethal to spores. At the DMRI tests have been made on the killing of verotoxic *E. coli* in smoked loins and drycured sausages by UHP with convincing results. At 6000 - 8000 atmospheres a 5 log reduction was achieved without affecting the sensory quality of the fermented sausages but with a somewhat cooked appearance in the smoked loins.

Microwaves and radio waves
Microwaves and radio waves belong to the volumetric heating technologies. They are termed volumetric because the heat is first generated inside the meat. Radio waves have lower frequencies (13.56 or 27.12 MHz) but higher wavelengths (30 or 10 m) than microwaves (915 or 2450 MHz, wavelengths 30 or 10 cm). Radio waves penetrate deeper into the product than microwaves, but carry less energy.

Equipment for both technologies is used on an industrial scale for continuous heating; either for accelerated pasteurising or for tempering/thawing of frozen products, often in combination with traditional heating equipment. A radio frequency cooking equipment for extremely rapid heat treatment of meat products was developed in the nineties by *APV*, Denmark. Unfortunately the equipment never left the R&D stage to be implemented on industrial scale. At the DMRI, radio waves have been tested for their ability to achieve accelerated thawing of frozen meat raw materials. The tests were performed with commercial radio frequency equipment manufactured by the French company, *SAIREM*. This equipment is capable of thawing 750 - 900 kg pr. hour from –18°C to –2°C – 0°C. The tests demonstrated that a uniform temperature rise in the products depended on product homogeneity, both with respect to volume and to meat/fat/air distribution. Time required for reaching –2°C - 0°C was 75-90 minutes. For use in the manufacture of emulsified products, this temperature is acceptable. For use in cured, tumbled products, the minimum temperature of raw materials has to be above 0°C. This is hard to achieve even with radio frequency thawing, without local overheated spots. Temperature equalisation after radio frequency treatment is thus necessary. However, thawing by radio frequency probably has its greatest potential where there is a daily need for thawed or tempered frozen meat in blocks with a homogeneous composition.

One of the major problems in implementing these new heating technologies in the meat industry might be a lack of documentation on temperature profiles inside the products. Fortunately, new temperature imaging techniques allow for this. Several scientific groups have published promising results covering data tomography. This might clear the way for an industrial breakthrough of microwave and radio wave heating in the meat industry.

Electric fields
Three recent preservation technologies in food processing emanate from the science of electric fields: ohmic heating, high electric field pulses/pulsed electric fields (HELP/PEF) and oscillating magnetic fields.

Ohmic heating is an "old" new technology. It was used commercially more than twenty years ago for heat treatment of skinless frankfurter sausages in the Tender-Frank Method developed by *Swift & Co* in the USA. Today, ohmic heating is mainly used commercially for continuous heating of liquids or particles suspended in an electrically conductive and pumpable liquid (e.g. meat pieces in gravy). For such pumpable products a considerable reduction in cooking time can be achieved combined with a more even temperature distribution compared to traditional heat treatment. *Unilever* has recently patented a method for ohmic heating of whole muscle products.

Advances in HELP/PEF technology are one step behind UHP preservation, but catching up, primarily due to the process being continuous contrary to UHP and the capital and running costs allegedly being lower. Until recently HELP/PEF was suitable only as a minimal preservation technique for liquid foods. A new patent from 2000 claims that the patented equipment can be used on pumpable foods such as meat pieces in gravy, hamburger batters etc. This might bring renewed interest to the technology from meat processors.

Oscillating magnetic fields are applied to foods sealed in plastic bags. Frequencies between 5 and 500 kHz, 1-100 pulses for a total duration of 25-100 milliseconds are typically used. Unfortunately, the effects of magnetic fields on microorganisms have produced contradictory results. Until more consistent and convincing results are produced, the prospects for this technology are poor.

Freeze drying and vacuum drying

Both freeze drying and vacuum drying are capable of accelerating manufacturing times considerably. The technologies have been thoroughly researched and developed over the last 30 years. A lot of patents and scientific papers are available. However, a major industrial breakthrough in the meat industry has not yet occurred. This might be due to some obvious factors. One is the high capital cost of the equipment. Another that it is not multi-functional. A third and perhaps most important factor is that when the drying time is accelerated compared to traditional air dried meat products, the organoleptic ageing parameters are sacrificed.

In order to achieve both accelerated drying and ageing one must search for the optimum combination of vacuum drying and use of enzymes and starter-cultures. Due to the prospects for such combinations, intensive research is carried out in this area.

UHT/UST

Decontamination of meat surfaces with steam is commonly used in abattoirs. Such application is outside the scope of this presentation. Pilot plant techniques have been developed to perform surface preservation of meat products using ultra high temperature, ultra short time (UHT/UST). One technique employs vacuum before and after the heat treatment, so called vacuum-steam-vacuum. Steam at 138°C is applied for a few milliseconds with a very short vacuum cycle before and after the steam treatment. USDA tested a prototype of this equipment in 1999 with promising results. With three consecutive treatment cycles, and a total time of 1.9 seconds a five log reduction in *Listeria innocua* was achieved on the surface of frankfurters. According to the authors, such treatment times are consistent with an industrial process flow.

The prospects for UHT/UST are primarily related to meat products that cannot tolerate heat denaturation such as pork loin, bacon and salami. When dealing with products, which are already cooked, a simple steam or hot water decontamination for instance prior to slicing is a much more obvious technique. According to the USDA, there might also be advantages in using vacuum-steam-vacuum equipment on retail-packed products.

Ozone

The use of ozone is a surface decontamination technology like UHT/UST and light (see below). It is by no means a new method. During more than 85 years it has been used for disinfection in drinking water treatment applications. Ozone (O_3) is a highly reactive gas, with high water solubility and a short half-life. Un-reacted ozone reverts to oxygen. It oxidises most organic material and is claimed to have a kill rate 3125 times faster than chlorine. On process equipment surfaces almost free from other organic material than microorganisms, it is allegedly effective.

Gaseous ozone as a disinfectant on the surface of pork loin inoculated with verotoxic *E. coli* has been tested at the DMRI. Even at a concentration of 5 ppm ozone, 50 times the permitted concentration for humans in a working environment, only a very low reduction in the *E. coli* count was achieved (< 0.4 log units).

It is likely that the best potential use for ozone is as an equipment sanitizer.

Irradiation

Since the approval by USDA of low dosage irradiation of fresh meat in the USA as of February 2000, many irradiated products have been launched. As of now (May 2001), irradiated meat products are sold in more than 2000 supermarkets throughout the USA. One of the leading manufactures of irradiation equipment, *SureBeam*, has signed contracts with the biggest meat processors: *Tyson/IBP Inc., Cargill, Huisken Meats, American Foodservice* and others to test the technology or use it commercially. A petition for approval of irradiation for ready to eat foods incl. meat products is presently awaiting final ruling by the FDA.

Even though consumer surveys show that the average American consumer tends to be more negative towards irradiation now than five years ago, sales of the irradiated products are increasing steadily. It probably has to do with educational efforts. If the consumers are taught about the risk of pathogens, and how irradiation can eliminate this risk, the majority will prefer irradiated meat. They would also be willing to pay a premium for it. According to these studies, only scientific facts are perceived positively.

In addition to *SureBeam*, a subsidiary of *Titan Corporation*, the other major manufacturers of equipment are *MDS Nordion* and *IBA*. *SureBeam* specialises in e-beam equipment, *MDS Nordion* in gamma equipment and *IBA* in both e-beam, gamma and x-ray equipment. Depending on throughput rate, dosage level and equipment type, the average treatment cost is 0.15 Euros pr. kg.

In addition to the last 40 years' research on the toxicological effects of irradiation, applicational studies including studies with meat products showing irradiation effects on the SQS properties are presently lacking. Particularly studies dealing with organoleptic properties and oxidative stability. Results from 2000 and 2001 published recently seem to document that the changes in these characteristics are small when irradiation doses between 0.5-5 kGy are used.

Another undocumented area relates to irradiation and packaging materials. Only little is known about the effects of irradiation on new polymer films, e.g. which radiolytic products are formed and do they migrate to the meat?

Most of the above mentioned are exclusively American issues. It is likely to take a long time before the European Union can reach consensus on approving irradiation for preservation of food products. It will probably depend on how the use of irradiation develops in the USA.

Light

Different wavelengths of light have potential as surface decontamination methods: ultraviolet light (UVA: 315 – 400 nm, UVB: 280 – 315 nm, UVC: 200-280 nm), high-energy focused laser beams (different wavelengths in the visible area) and pulsed white light (170-2600 nm). Industrial equipment for using UV and pulsed white light (*PurePulse*) is available, whereas laser equipment is still on laboratory scale. The principles of how bacteria are killed might differ between the methods, but a common denominator is, that the bacteria must be accessible to the light photons. Their penetration is almost zero, leaving bacteria hidden in micro crevices untouched. Therefore, the prospects for these technologies are either as surface decontaminators for equipment or for meat surfaces in conjunction with other intervention strategies.

At the DMRI blue (488 nm) and green (514 nm) laser light has been tested on agar plates and meat surfaces inoculated with Gram positive and Gram negative pathogens. The specific wavelengths of the laser was claimed to make the laser light able to penetrate the meat surface without being absorbed, thereby reaching even hidden microorganisms. However, no bacterial reduction was achieved.

Enzymes

As illustrated in *Figure 1*, enzymes have potential applications in a range of different meat manufacturing operations: Proteases in meat preparation for making hydrolysates with flavour, functional or antimicrobial properties, nitrate reductases in curing for colour formation, proteases for optimised protein extraction, transglutaminases for "gluing" meat pieces together during tumbling, lipases and substrate specific proteases for enhanced water holding or emulsifying properties, proteases and lipases during drying/ageing for texture improvement and enhanced substrate availability for starter cultures, lysozyme for antimicrobial properties and proteases for tenderisation before or during heat treatment. There are many possibilities. However, only a few applications have until now found industrial use: texture improvement with transglutaminase, hydrolysate formation from by-products and tenderisation.

At the DMRI the possibilities of using commercial and test enzymes have been investigated for accelerated manufacturing or improved SQS properties. From a large number of enzymes screened for various applications and process conditions only two showed promising results. One was the use of transglutaminases for accelerated drying. These enzymes reduce water holding capacity thus accelerating the drying. An 8% reduction in drying time was achieved without significant changes in texture or flavour. The other promising result was controllable tenderisation of traditionally tough muscles by substrate-specific proteases.

To exploit the potential of enzymes in meat manufacturing fully, a cooperative and focused investigation is needed involving the meat industry and enzyme producers. Enzymes tailored for specific applications are likely to be the next step.

Biopreservation

Biopreservation will be the last, but not the least significant new technology dealt with in this presentation. Like the other minimal processing technologies mentioned, it is well in line with the consumer trends predicted for the next decade: clean labels, no additives, natural products and high quality.

In biopreservation, a culture of harmless desirable bacteria, which can eliminate or inhibit the growth of unwanted, often pathogenic, microorganisms, is used. Biopreservation is mainly based on the use of starter-cultures producing special peptides - the so-called bacteriocins. Investigations have shown, that a large proportion of the bacteria already occurring naturally in meat products can inhibit growth of *Listeria monocytogenes* when present in a sufficiently high concentration.

The DMRI has used this to design a new patented method for applying bio-protective lactic acid bacteria to the surface of cooked meat products. The lactic acid bacteria were originally isolated from meat products. When sprayed in large numbers onto meat product surfaces during slicing and packaging, they prevent growth of *L. monocytogenes*. Being carefully selected, they do not affect sensory attributes of the meat products in any way.

Conclusions

As indicated, there is a number of new technologies and equipment with large or smaller potential for meat manufacturing. Some of these have already been implemented in the industry. Others, still on laboratory scale, seem to have little chance of a commercial industrial breakthrough at least within the next decade, either because further basic research is needed or because they are simply not suited for meat manufacturing. From an industry point of view, it is expected that the greatest potential exists for methods combining conventional and new technologies.

I have tried to sum up my opinion about the likely potential for meat manufacturing in the following table:

Availability at present	Potential for meat manufacturing		
	Small	Medium	Large
Industrial scale	White light UV Ozone	Microwaves Freeze/vacuum drying Ohmic heating	UHP Irradiation Biopreservation Radio waves
Laboratory scale	Magnetic fields Laser	HELP/PEF Vacuum-steam-vacuum Ultrasound	"Tailored enzymes"

Of course, even technologies shown in the upper right hand square have to be investigated further for their potential to be fully elucidated. For instance, the potential of UHP must be investigated for its ability to create new, minimally processed meat products, to accelerate thawing, to adapt to modified atmosphere packaging etc. For radio waves, the new tools of visualizing temperature profiles must be utilized to optimise heat distribution. For irradiation, the packaging migration issue needs further investigation. For tailored enzymes to be applicable, appropriate accelerated drying methods and starter-cultures must be found in combination with the right enzyme etc. etc.

The potential applications are numerous, but successful use of new technologies and equipment also depends on relevant and reliable research into the financial aspects, the competitive situation and not least the consumer attitudes and statutory restrictions.

Literature

Ahn, D.U., Nam, K.C., Du, M. & Jo, C. (2001). Effect of irradiation and packaging conditions after cooking on the formation of cholesterol and lipid oxidation products in meats during storage. *Meat Sci.*, **57**, 413-418.

Bows, J.R. (2000). A classification system for microwave heating of food. *Int. J. Food Sci. Tech.* **35**, 417-430.

Brody; A.L.; Antonevich; J.N., (1959). Ultrasonic defrosting of frozen foods. *J. Food Technol.* **13**, 109-112.

Gants, R. (2000). Post-processing pasteurization. *Meat & Poultry*, April, 32-37.

Graham, D. M. (1997). Use of Ozone for Food Processing. *Food Tech.*, 51, **6**, 72-75

Hoogland, H., Heij, W. & Schepdael, L. (2001). High Pressure Sterilisation: Novel Technology, New Products, New Opportunities. *New Food*, **1**, 21-26

Johnson, S.C., Sebranek, J.G., Olson, D.G. & Wiegand, B.R. (2000). Irradiation in Contrast to Thermal Processing of Pepperoni for Control of Pathogens: Effects on Quality Indicators. *J. Food Sci.*, **7**, 1260-1265.

Kalichevsky, M.T., Knorr, D. & Lillford, P.J. (1995). Potential food applications of high-pressure effects on ice-water transitions. *Trends in Food Sci. & Technol.*, **6**, 253-259.

Kozempel, M., Goldberg, N., Radewonuk, E.R., Scullen, O.J. & Craig, J.C. (2000). Rapid Hot Dog Surface Pasteurization Using Cycles of Vacuum and Steam To kill *L. innocua*. *J. Food Protec.*,63, **4**, 457-461.

Madsen, K.B., Jensen, J.S. & Søltoft-Jensen, J. (1999). Perspectives in new meat processing technologies. In Proceedings from 45th ICoMST, pp. 106-115, Yokohama, Japan.

Miles, C.A.; Morley, M.J.& Rendell, M. (1999). High power ultrasonic thawing of frozen foods. *J. Food Eng.* **39**, 151-159.

Nott, K.P. & Hall, L.D. (1999). Advances in temperature validation of foods. *Trends Food Sci. & Tech.*, **10**, 366-374.

Povey, M.J.W. & Mason, T.J. (1998). Ultrasound in Food Processing. Blackie Academic & Professional, UK.

Zhao, Y., Flores, R.A.& Olson, D.G. (1998). High hydrostatic pressure effects on rapid thawing of frozen beef. *J. Food Sci.*, **63** (2), 272-275.

Weber, D.E., Katz, F.R. & Mattson, C.L. (2000). Special Supplement: Kinetics of Microbial Inactivation for Alternative Food Processing Technologies. *J. Food Sci.*

www.meatingplace.com (2001). News on irradiation from 8 January, 1 March, 14 March, 30 April.

US Patent No. 4464 401. Acoustic thawing of frozen food. Kissam.

US Patent No. 6110 423. High strength electric field pumpable food product treatment in a serial electrode treatment cell. PurePulse Inc.

DK Patent Application No. 2001 00094. Fremgangsmåde og anlæg til fremstilling af skiveskårne fødevarer. Danish Meat Research Institute.