RECENT DEVELOPMENTS IN HEAT TREATMENT AND HEAT STERILIZATION OF MEATS

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INTRODUCTION

The objective of this paper on developments in heat treatment and sterilization of meats is not to attempt a comprehensive review of all recent developments in this very wide field. Instead, I intend to select a number of interesting developments with which I am personally reasonably familiar, and where I may be able to contribute something also from recent work of our own at the SIK institute.

In any form of heat processing of meats heat transfer and temperature development with time is of essential interest, since it will determine not only the necessary processing time, but also temperature distribution and the accumulated outcome of all time-temperature dependant physical and chemical changes that occur. Closely related to heat transfer is mass transfer. To carry studies in this area over into the quantitative, data on the physical properties of meats are required as a function of composition, temperature etc., as well as mapping of the various temperature dependant reactions. Such information will form the basis for process calculation, mathematical modelling and process optimization. This is an area of meat technology where considerable progress is being made, applicable to heat processing of meats in general.

In conventional heat processing, heat transfer to the food interior is limited by its thermal conductivity. Over the last decade, direct in-depth heating with microwaves has, however, found applications in the meat industry for tempering of frozen meat and more recently for cooking and coagulation. For the cooking and reheating of foods in catering and in the home, microwave ovens are becoming standard equipment in several countries. In infrared heating (IR) a resurge of interest seems to be kindled by the further development of short wave tubes with high penetration, and also in electrical resistance heating new activity is noted.

In the industrialized countries living habits are changing quite rapidly, and there is a growing trend that food preparation is being transferred from the home and institutional kitchen to the food industry. At the same time as the market for industrially produced convenience foods is developping, a growing number of people's meals are being eaten outside of the home. In this situation it becomes increasingly apparent that we know too little of what actually happens in the food during cooking, frying etc. and about the influence of different processing variables on heat and mass transfer and related quality changes, of how final quality on the consumer's plate is influenced by raw material, processing, storage and reconstitution. Also, there is a need for more efficient industrial processing methods that can be optimized with regard to yield, quality and cost. In consequence, considerable research and development activity has been initiated, already resulting in new and interesting results and developments.

Frozen convenience foods have shown the most rapid growth and dominate over their canned counterparts in several countries like the United States and Sweden. However, much effort is now being devoted to research in the heat sterilization field on means of reducing processing time and increasing quality retention by improving heat transfer, reducing product thickness and applying HTST (high temperature - short time) type of processing. Research work on the fundamental aspects of heat processing with regard to spore destruction, enzyme inactivation and sensory quality change with time and temperature up in the HTST region will be of great importance to the continued technical development.

These are the areas of meat research and development on which I have chosen to concentrate my review of recent developments. Important areas being left out are for example research related to heat processing of luncheon meats and sausages, and more basic meat research work related to temperature effects which I trust will be dealt with in other sessions of the Congress.

TIME-TEMPERATURE DEVELOPMENT IN RELATION TO QUALITY CHANGE

The common procedure in heat process studies on meats has been to heat the sample by one or several standard procedures (grilling, broiling, roasting etc.), to measure temperature development at the sample centre up to the desired doneness and then to determine resulting yield, nutrient retention and sensory acceptability. Conclusions are drawn as to how the different heating methods, oven temperatures etc. compare with regard to yield and quality. Of more recent work on these lines the following may be mentioned, all related to effects on yield and tenderness from cooking processes.

In simulated oven grilling of beef at two different oven temperatures and to two different final temperatures Penfield and Meyer (1975) found that tenderness and the dissolution of hydroxyproline containing material at the central region of the sample increased with decreasing heating rate and with increasing final temperature. Locker and Daines (1974) found that slow cooking of beef to a given central temperature resulted in a higher cooking loss than more rapid heating, but in lower shear force values.

McRae and Paul (1974) studied the effect of rate of heating on the solubilization of collagen in beef, using four different heating "rates", represented by microwave heating, broiling, braising and roasting. The two fastest rates (microwave and broiling) gave the softest meat, and microwaves were found more efficient in solubilizing collagen.

Batcher and Deary (1975) compared roasting and broiling of beef steaks and found higher yield, juiciness and general quality for roasting, which was by far the slowest method.

A general impression from these investigations is that slow heating and temperature rise should give a certain advantage in tenderness, but it is very difficult to draw any more specific conclusions, because the geometry of samples and environmental conditions are not specified very well, and because temperature and quality changes are referred only to the sample centre. The results are of limited value as a basis for process and equipment optimization, since they are really valid only for the particular sample of meat and piece of equipment and equipment setting being used. Still, this has for long been the only approach available to the meat research worker. However, over the last few years researchers have started to pay more attention to the fundamental aspects of heat and mass transfer during heating, and to how these relate with raw material and processing variables and the resulting changes in composition and quality. With the growing importance of industrial and institutional food preparation, such more fundamental knowledge will be required for the development of optimal cooking procedures and equipment. Some examples of recent research to this end will briefly be presented.

For double sided contact frying of meat patties, Dagerskog (1974) studied the relationships among crust color formation, yield, heating time and pan temperature for different recipes. Very reproducible results were obtained which could be presented in the form of nomograms, such as shown in Fig. 1. Rate of heat transfer was found to be almost independant of pan temperature above 140°C, and color formation followed a first order reaction. Sörenfors (1974) determined temperature distribution in deep fat fried meat balls by IR heat photography for comparison with computer simulation, to study the mechanism of heat penetration. Unexpectedly high values found for the apparent thermal conductivity could be explained in terms of inward steam transport.

As shown in Fig. 2, Bengtsson et al.(1976) determined temperature profiles for oven roasting of beef for different oven temperatures and initial meat temperatures (frozen and thawed), and corresponding moisture and fat profiles were also determined. Using available data for juice release (drip) as a function of time and temperature, this type of results can be used to calculate the resulting changes at any position inside the meat sample, provided it is of rectangular shape.

In oven roasting of meats the relative humidity will play an important part, often neglected in the past. This is illustrated in Fig. 3, showing temperature rise at the meat surface and centre, as well as the dry bulb and wet bulb temperatures in the oven. For a moist meat surface both surface temperature, thermal driving force and rate of evaporation will be controlled by the wet bulb temperature.

PROCESS CALCULATION AND SIMULATION

For process calculations on food materials it is necessary to have accurate thermal data available. At the Meat Research Institute in Bristol good compilations of thermal data for meats have been published, which are gradually being supplemented by new data from a number of research institutions the world over. Sweat (1975) recently presented new equations for predicting thermal conductivity of meats as a function of temperature and composition, and Higgs and Swift (1975) measured the influence of temperature experimentally up to 80°C. Rogov and coworkers at the Central Meat Research Institute of Moscow have also determined the electrical conductivity of meats in connection with electrical resistance heating (1973). Dielectric properties of meats over a wide range of frequency and temperature have been reported by at least two research groups (Ohlsson et al. 1974, and To et al. 1974).

With the necessary thermal and other physical data at hand, and with the help of systematic experimental studies of time-temperature changes and related quality change, mathematical models for frying and cooking processes can be developped. The combined effects of a number of processing variables, such as thickness, starting temperature, distribution, oven temperature and humidity, can then be studied by computer simulation with regard to temperature distribution during heating and related time-temperature dependant quality changes. Fig. 4 illustrates computer simulations of temperature profiles, in comparison with experimental heating results for cooking in a microwave oven (Ohlsson 1976, unpublished).

More elaborate models are being developped and have already been put to practical use in process development work.

NEW PROCESS DEVELOPMENTS IN FRYING AND COOKING

Possibly the most important and difficult operation in industrial or institutional food preparation is the frying operation. The process should give an attractive and tasty surface crust, combined with rapid in-depth heating to the desired degree of doneness, and with as small losses in yield, nutritional value and sensory quality as possible.

Until fairly recently, deep fat frying was the only frying method suitable for large scale industrial processing. Inherent problems are lack in flexibility between different products, large working volumes of fat and risks for fat degradation and fat exchange between bath and sample. For this reason deep fat frying is much criticized and people are looking for other alternatives.

Beer (1975) studied the effect of reduced pressure (45 Torr) during deep fat frying and found less oil absorbtion and improved sensory quality compared to ambient pressure.

Nilsson (1975) reports on the development of the recently introduced industrial frying method, called the Inpro method, in which double sided contact frying between Teflon belts for surface browning is combined with finish cooking by microwave heating in a continous process, which is discussed in more detail in one of the papers of this session. Important advantages in comparison with deep fat frying are claimed both in process control and economy, and in sensory and nutritional quality, as supported by independant investigations by Asp et al. (1975) of nutritional values. Combinations of surface browning and microwave heating have previously been reported by Bengtsson and Jakobsson (1974), showing reduction in heating times, weightloss and fat content compared to conventional frying methods.

Infrared (IR) heating has been applied sparingly in the food industry using long wave radiators and fairly crude process control, and little research of much importance has been reported with the exception of the pioneering work in the USSR by Ginzburg and coworkers. These have reported important fundamental process studies and applications work also with shortwave radiators with higher penetration into foods and superior upstart and process control characteristics. Determination of the spectral and optical properties of meat products (Ostrovskii et al. 1974) showed substantial transmission in the short wave IR region, meaning that wavelengths about 1.2 µm should be more efficient for in-depth heating of meats. They also derived analytical calculation procedures for treatment time etc.

With the development of quartz tube IR radiators in the short and intermediate wavelength ranges for applications in other fields in Sweden, there has been a revival of interest also for heating foods. This can be illustrated by Fig. 5, showing a comparison of ours by computer simulation between shortwave IR frying and double sided contact frying of meat at the same specific energy input. Results from experimental pilot plant work look very promising, particularly with regard to frying of meats in the catering field, where commercial equipment is already in the introductory stages as a result of development work elsewhere in the country.

The common attire of institutional kitchens for food cooking, such as batchwise kettles and steam cooking cabinets, is used to a considerable extent by the food industry, while high pressure cookers are finding increasing use mainly in the catering field. However, continous methods for heating wrapped or unwrapped meats in water, steam or steam-air mixture are also in use. For pumpable foods such as stews, soups etc., tubular scraped surface heat exchangers are coming into use and can be operated both at ambient pressure and as pressure cookers with HTST characteristics.

For the cooking-extrusion of minced or emulsified meats a tubular microwave heater has been developped in Germany by Püschner (1973) and is reportedly in industrial use. Similar type equipment is advertised in Britain for the precoagulation of meat pie fillings. At the 1975 meeting of Meat Research Workers, Klebnikov and Gorbatov (1975) reported work on skinless frankfurter production by microwave extrusion with good results. Similar work is in progress in Sweden, using a novel type of tubular microwave applicator, in which the temperature profile through the tube diameter can be controlled, for example so that the rate of heating tapers off from the centre and outwards to prevent sticking to the tube walls (Risman and Ohlsson 1975).

Electrical resistance cooking is presumably in practical use in the USSR, judging from numerous reports over the years on its processing fundamentals, and a certain interest is emerging also in other countries, judging from the recent flow of patents. Possibly it may develop into a low cost alternative for microwave heating for some applications.

As is the case for frying, sufficient fundamental data are emerging to permit calculations of time-temperature progress during cooking and related quality changes, at least for solid foods of defined geometry.

CONVENIENCE FOODS

Tändler (1974) reviewed the various alternative methods of preservation and storage available today for large scale institutional service of precooked foods: frozen, refrigerated semipreserves (warm filling and heating after closure), 3/4-preserves (F-value 0.8 and storage at 12-15°C) and fully heat processed (F-value above 4). Of these, attention will be paid only to the frozen and fully heat sterilized alternatives in the following.

Frozen convenience foods

Of particular interest is to find out how convenience foods compare with foods cooked directly from fresh raw materials in the institutional kitchen and handled in a normal way up to the point of consumption, taking into account all quality changes that may take place in the industrially prepared food during the entire chain from the factory to the consumer. The accumulated influence on product quality in this chain is illustrated, in principle, in Fig. 6, where one "good" and one "poor" alternative is indicated for each variable. The accumulated effects of poor practises in several links of the chain may result in a final quality lower than that in a conventional catering system with several hours of warm holding, and continued research in this field is therefore very important.

The most comprehensive large scale study of convenience foods for institutional use to my knowledge is being carried out in Western Germany in collaboration between several of the leading research institutions, centered on school meals. A large study of frozen meals has been published already, comprising over 100 different dishes, which were investigated with regard to quality change in storage, reheating and warm holding. Most of the items retained acceptability for 5 - 6 months at -25°C. Heating above 70°C affected vegetables and starchy foods more than the meats. Meals could be held warm for 30 - 60 minutes without apparent quality loss. Prolonged storage, heating to high temperatures and keeping hot caused reduction of the B-group vitamins and particularly of ascorbic acid content (Stübler 1975).

Results from studies by Jakobsson and Bengtsson (1973, 1974) on the influence of pretreatment, freezing, storage and reheating of sliced beef are summarized in Table 1 to illustrate some important variables which must be taken into account in attempts to optimize the quality of meats as convenience foods. From a study of the literature it is apparent that results vary a good deal between investigators which is not surprising, since temperature distribution and development with time must vary with the wide variation in raw material, sample geometry and heating conditions.

Ang et al. (1975) studied the effects of heating method on vitamin retention, comparing six different frozen convenience foods with freshly prepared equivalents which were held warm, among them pot roast. For reheating both convection oven, IR, microwave heating and pressure steam cooking were compared. Reheating by IR and microwaves resulted in more thiamine retention than in freshly prepared which had been held warm for 1 hr. Reheating by pressure steam gave a quality retention about equivalent to 3 hrs of warm holding of the freshly prepared sample.

Jonsson and Karlström (1976) recently studied the influence of reheating and warm holding of meats on PER-value and on linoleic acid retention, observing some negative effect on linoleic acid from overheating, and on PER-value from the combination of overheating and warm holding.

Heat sterilized foods

General

Heat sterilization implies that foods are heated to such high temperatures and for so long that they may be stored practically indefinitely at room temperature without health hazard. With regard to sensory quality shelf life will be more than a year for packaging materials with good barrier properties such as tin cans and aluminium foil-plastics laminates. As a rule, the heat treatment required for protection against survival of Clostridium botulinum spores is so strong, that even raw foods will become completely cooked and mostly overcooked, causing so called cooked or canned flavor. Over the last 5 - 10 years, thinner types of packages of novel materials have come into use, e.g. flexible, laminated pouches or semirigid trays. The reduced sample thickness has made possible reduced treatment times and higher sterilization temperatures, so called HTST treatment, with a certain improvement in quality with maintained hygienic safety. While the general principle of such treatment has long been known, process calculation data have been lacking in terms of time-temperature relationships for enzyme inactivation, spore destruction and sensory quality changes in real food materials and up in the high temperature region. For this reason, work has by necessity been rather empirical, even if sterilization values (F-values) are being calculated on a routine basis based on extrapolated data for Clostridium botulinum spores in standard media and at lower temperatures. However, in recent years several research projects have been undertaken in this field, and a better foundation for process calculation and optimization is beginning to emerge.

Since no pertinent data for meats have been available to me, the concept of HTST-sterilization is illustrated for peas in Fig. 7, where point 1 represents a conventional canning process and point 2 HTST-treatment, both equivalent in terms of F-value. The HTST-process gives only a fraction of the appearance deterioration of the conventional process, but is close to being insufficient for enzyme inactivation. So far, truly HTST treatment of solid foods can only be achieved for very thin samples, but intermediate processes may also result in quality improvement noticable to the consumer. For example, Persson and von Sydow (1974) found a marked positive effect on meat aroma from HTST-like processing of beef in 28 mm high cans or 15 mm thick flexible pouches, as determined both by sensory evaluation and gas chromatography.

In a recent review of the technical and technological status of meat preserves production Wirth (1975) concludes that an optimal temperature range exists for the processing of each product, and a listing of such ranges is given for a number of meat products. The position of the optimum will be decided by the nature and composition of the product, its heat transfer characteristics and by the shape and size of the container. If heat transfer conditions are favourable, HTST-like treatment will result in quality improvement, for example for Gulasch under rotation sterilization. Reichert (1974) reports on optimum sterilization temperatures for ready-to eat dishes with regard to F, E and C-values for the products. Recommended sterilization conditions are given for 24 different products.

In the development of preserves with better retention of sensory quality, flexible or semi-rigid packages play an important role. The interest in this area is illustrated in papers by Tändler (1973,1974). Among interesting aspects is the possible flavor contamination from packaging materials. In an overview of the retort pouch by Mermelstein (1976) the intensive development work in the United States is discussed and the promising market development in Japan and in Europe. Pouched foods are expected to make inroads into the frozen convenience food market.

Process calculation and simulation

Mulley, Stumbo et al.(1975) have reported a comprehensive study of thiamine degradation by heat as a basis for process calculations.

New spore inactivation data up into the high temperature region are being determined at several institutes in Germany and in Britain, such as the Institut für Lebensmittelverfahrenstechnik in Karlsruhe and the Food RA at Leatherhead, and similar work on enzyme inactivation and sensory quality change is in progress at the SIK institute in Sweden.

The validity of available data for heat destruction of Clostridium botulinum spores is in some doubt with regard to high temperatures and real food substrates. Perkins (1975) studied the accuracy of process calculation with regard to the z-value of Clostridium botulinum by innoculated packs and toxin testing, and found that the slopes of the thermal death rate curves were 20% lower than normally assumed, meaning a lower practical process efficiency than expected.

Teixeira et al. (1975) report on computer simulation of the effect of container geometry and retort temperature on thiamine retention, underlining the importance of geometry to take advantage of HTST processing. This is further spelled out by Bauder and Heiss (1975) who developed mathematical models for process calculation based on heating experiments with model food material, and verified experimentally for liver sausage. For a given container volume, specific surface and F_c-value, calculations show that a quality optimum will be found at a specific processing temperature. With increasing specific surface follows decreasing quality loss and a transition of the optimal process temperature upwards for quality factors which have a higher z-value in comparison with that for heat destruction of Clostridium botulinum spores.

This may be further illustrated from computer simulation work by Ohlsson, SIK, applying a program based on finite difference approximation for rectangular slabs. In Fig. 8 the cooking value (C-value) is shown as a function of can thickness and processing temperature for a high moisture solid food material with a z-value of 33 for flavor deterioration. The data refer to flat cans at a final centre F-value of 10.

It is apparent that HTST-sterilization of solid conduction heated meats with a resulting sensory quality approaching that of the deepfrozen counterpart, will be limited to small can or pouch thicknesses, presumably not exceeding 10 - 15 mm. For higher thicknesses microwave heating shows considerable promise, as will be discussed separately later on.

Warm holding of heated foods

At the present time, warm holding for some time before serving is unavoidable in most catering services, whether the food is prepared in the own kitchen or convenience foods from the industry are being used. That warm holding constitutes a real problem is becoming increasingly apparent, both from the before-mentioned German study and from other work in the literature or in progress.

In a study of handling practises in Sweden, Karlström and Konradsson (1974) encountered warm holding times from less than 20 minutes all the way up to 5 - 6 hours. Hansson et al. (1972) found very important quality loss both in sensory and nutritional quality in vegetables after 1 - 2 hours of warm holding, while changes in meats were less apparent. For breaded products very marked quality loss was seen both in appearance and texture.

In work presented in one of the papers of this session Dagerskog et al. observed that warm holding of fried sliced beef and hamburgers in closed containers for 2 hours at 75°C resulted in a loss of sensory quality by about two grades on a 9-point acceptability scale.

This is a very important field of research, and ways must be looked for both to reduce warm holding and quality loss during warm holding and to find alternative methods of handling and preparation with better quality retention. Own work in this field indicates that quality loss can be reduced considerably by proper control of environmental conditions such as temperature and relative humidity, so that even breaded products may be held warm for several hours without serious acceptability drop.

MICROWAVE HEATING

During this presentation microwave heating has been briefly referred to several times. The most interesting recent developments for industrial meat applications of microwaves appear to be for tempering or partial thawing, on-line cooking and heat sterilization. However, while industrial applications have been much publisized, their actual use is very limited, but growing. The main usage of microwaves for foods is still by far for microwave oven cooking and reheating of meals or meal components in catering and, in a few countries, in the private homes. Sales of home microwave ovens in Japan and the United States are approaching one million ovens a year, and a number of cookery books for microwave food preparation are in wide circulation, requiring a considerable amount of practically oriented research and development work as a basis for cooking instructions. Armbruster and Haefele (1975), for example, report results from cooking experiments with 37 different food items, using glass or ceramic containers with or without plastic film covers at microwave frequencies of 915 and 2450 MHz. Plastic covers were found to result in more uniform cooking, better sensory quality and shorter cooking times.

Most of the research work done has been entirely empirical. However, a better theoretical background common to household and industry applications is rapidly developping, resulting in a better understanding of the heating process and in improvements both in oven design, heating performance and resulting product quality.

Fundamental work on the dielectric properties of meats and their variation with composition, frequency and temperature has been reported by To and coworkers (1974) and by Ohlsson et al. (1974). Successful computer simulation work with very good agreement with experimental heating has been reported by Ohlsson and Bengtsson (1971), Kirk and Holmes (1975) and by Nykvist and Decareau (1976).

In very recent work on microwave roasting of cylindrically shaped beef roasts (1976) Nykvist and Decareau were able to derive important conclusions from computer work based on limited experimental data. Geometry of the roast was found to have marked influence on field and temperature distribution, particularly on the focusing effect of energy to the interior of the roast. Calculations demonstrated that a lower frequency and power input must be used than in previous experiments, to obtain optimal heating rate and temperature distribution. This was also confirmed experimentally. This kind of approach, combining theoretically based calculations and experimental heating results, is a much more powerful tool in process optimization than purely empirical experimentation.

It has already been mentioned that microwave heating may offer better possibilities for HTST sterilization of solid foods, permitting more rapid heating to the desired holding temperature. Experimental work by Ayoub et al. (1974) demonstrated the feasability of continuous microwave sterilization of 10 mm thick meat slices in flexible pouches to a central temperature of 121°C at F = 6. O'Meara et al. (1976) very recently reported on successful experiments with batch sterilization of precooked meats in plastic pouches by a combination of microwave heating at 2450 MHz and water heating, with a total processing time of 7 minutes. Superior color, texture and flavor was obtained compared to conventional processing to 121°C for 40 minutes.

Computer simulation work by Ohlsson and Bengtsson (1975) indicates a sizeable advantage to be gained for this type of continuous processing of beef of 20 mm thickness, with reduction in processing time by a factor of at least 4 and a very small resulting difference in temperature, F-value and cooking value between surface and product centre.

An advanced pilot plant microwave sterilizer for precooked foods has been developped by a Swedish equipment manufacturer (Holmberg 1976) in cooperation with microwave heating specialists. The equipment shown in Fig. 9 is used for HTST processing up to 130°C of foods in plastic pouches, and clear quality advantages are claimed compared to conventional heat processing of "pouched" foods both for the HTST-sterilization and pasteurization.

Other promising microwave developments such as for finish cooking of hamburgers and extrusion cooking of meat emulsions have already been discussed.

CLOSING WORDS

A review of recent developments must by necessity be somewhat subjective and colored by the interests of the reviewer. Whether the areas covered and the work cited are really those of greatest general interest I canno judge. I also apologize if I have left out important results that may have appe red over the last few years, by negligance or because the pertinent journals have not come to my attention. Nevertheless, I believe you will agree that most of the developments discussed are important or becoming important areas of meat research, development and application.

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Table 1.

AGING TIME	4 days 14 days	Aged meat more tender, less juicy, lower TBA, higher water binding
FREEZING RATE	13 cm/h 2 cm/h 0.04 cm/h	Lowest rate gave significantly lower yield
FROZEN STORAGE	1 month/-20°C 8 m/-30°C+ 1 m/-20°C	Long storage gave lower flavor, tenderness, yield and water binding
PACKAGING	air headspace N_2 or vacuum	Advantage N_2 or vacuum
STARTING TEMP. OF HEATING	-20°C + 5°C	Higher yield and juiciness when heating from frozen
INFLUENCE OF DIFFERENT PRETREATMENT VARIABLES ON THE QUALITY OF FROZEN SLICED MEAT AFTER PAN FRYING		

DEGREE OF PRECOOKING	rare medium well done	After reheating to well done-sign.adv. lowest degree precooking
FREEZING RATE	200 cm/h 20 cm/h 3 cm/h 0.01 cm/h	Higher total yield for the two highest rates
FROZEN STORAGE	2 m, -20°C 7 m, -20°C	Long storage more tender but lower water binding
REHEATING	pan frying microwave	Microwaves higher yield but lower flavor score
INITIAL TEMP.	frozen thawed	No sign. difference
WARM HOLDING	1-3 h	Slight, continuous loss of quality
INFLUENCE OF DIFFERENT POST TREATMENT VARIABLES FOR PAN FRIED SLICED BEEF.		

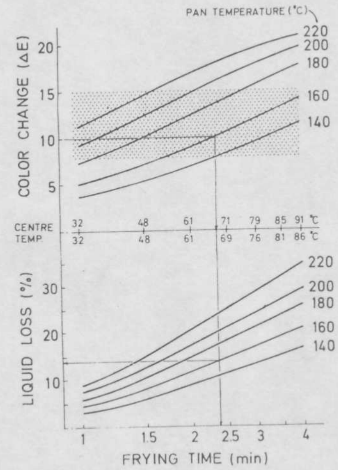

Fig. 1. Relationship between color formation, frying time, centre temperature and yield during double sided contact frying of hamburgers (Dagerskog).

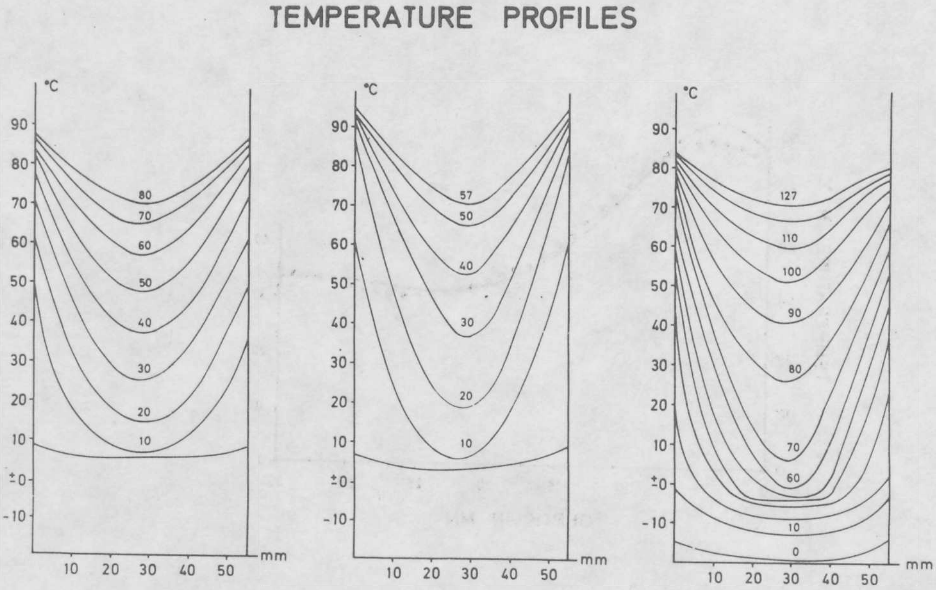

Fig. 2. Temperature profiles in beef during oven roasting for oven temperatures and initial product temperatures of 175°C (+5°C), 225°C (+5°C) and 175°C (-20°C) (Bengtsson et al.).

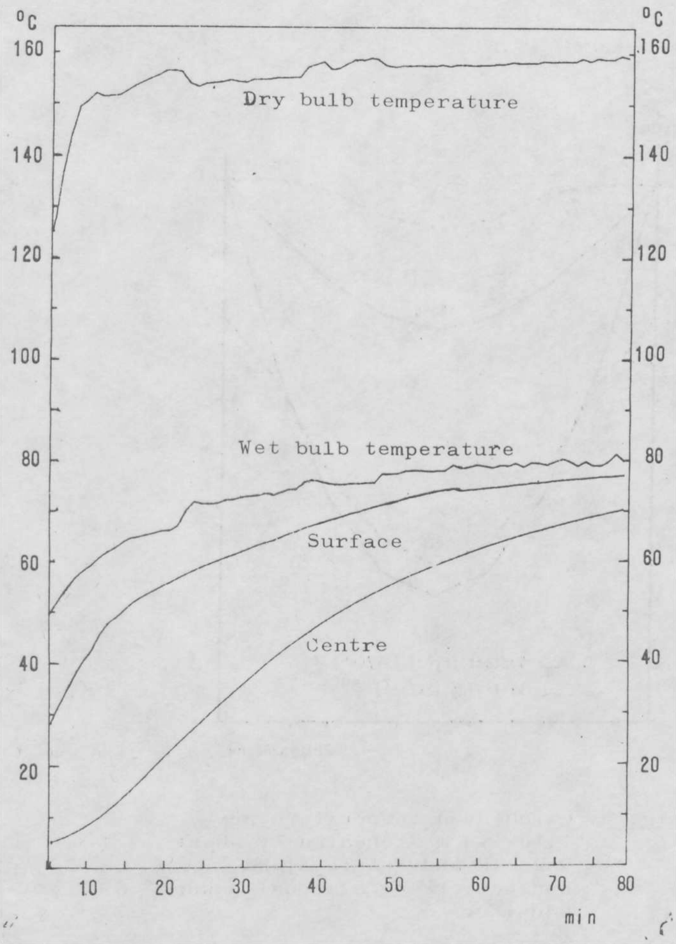

Fig. 3. Temperature development in beef and air during oven roasting (Bengtsson et al.).

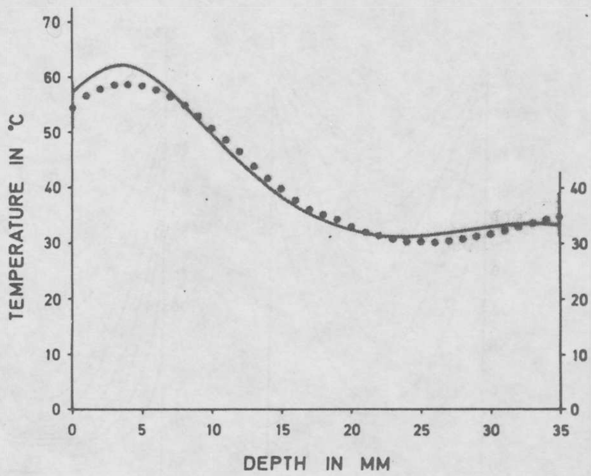

Fig. 4. Experimental (dotted line) and computer simulated temperature profiles for heating of a 35 mm meat slab in a microwave oven at 2450 MHz (Ohlsson).

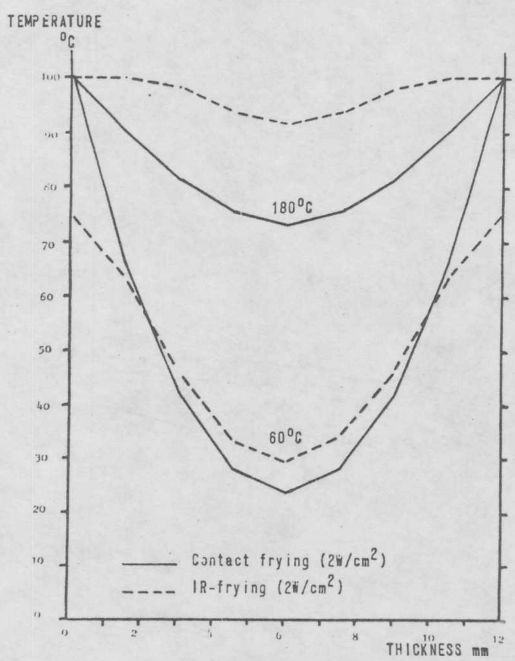

Fig. 5. Calculated temperature profiles in meat heated by short wave IR and double sided contact frying at equal power density.

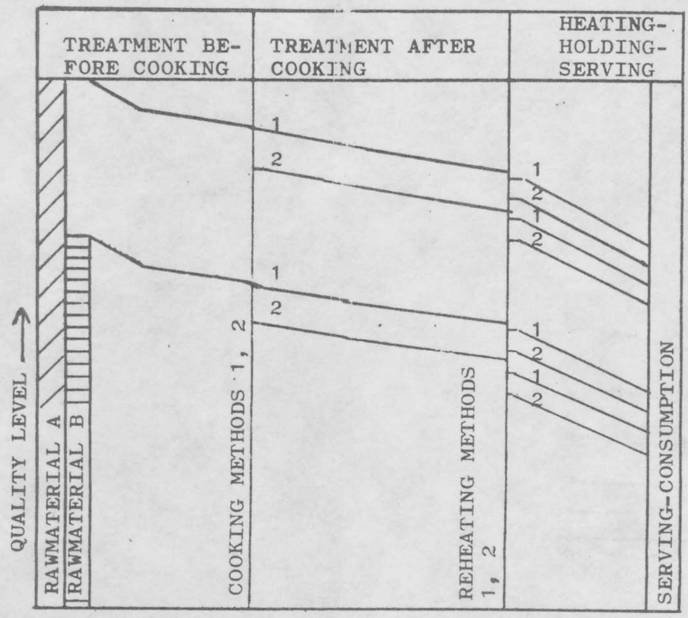

Fig. 6. Accumulated influence (in principle) on product quality in the chain from raw-material to consumer consumption of convenience foods. One "good" and one "poor" alternative for each variable.

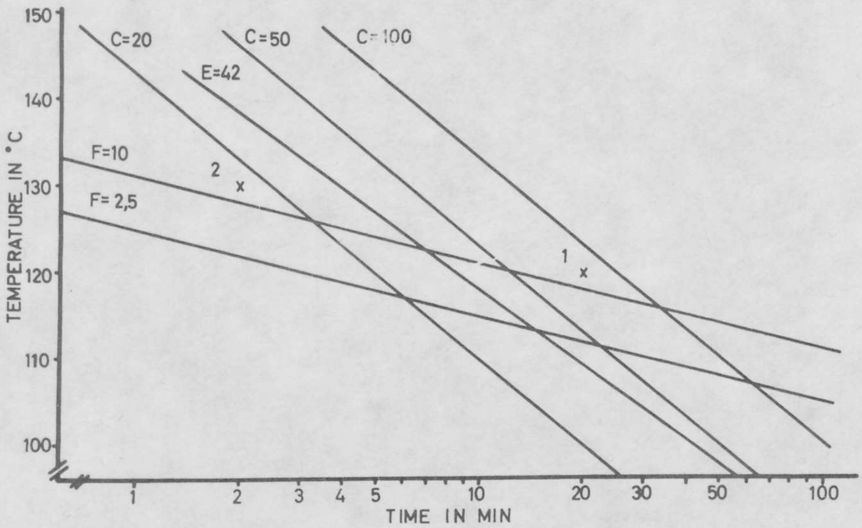

Fig. 7. Time-temperature relationships for spore destruction (F-value), enzyme inactivation (E-value) and appearance change (C-value) for peas. Point 1 corresponds to conventional processing and point 2 to a HTST-process (Ohlsson).

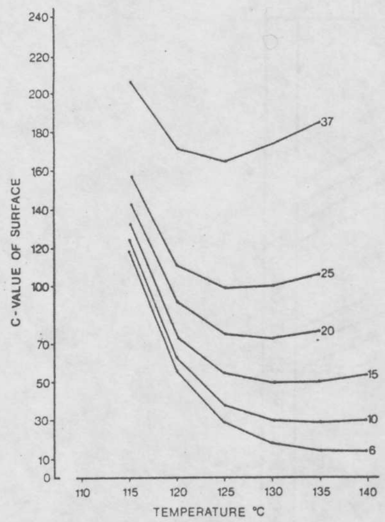

Fig. 8. Computer calculation of accumulated cooking value (C-value) at food surface against sterilization temperature for different thickness of flat cans (Ohlsson).

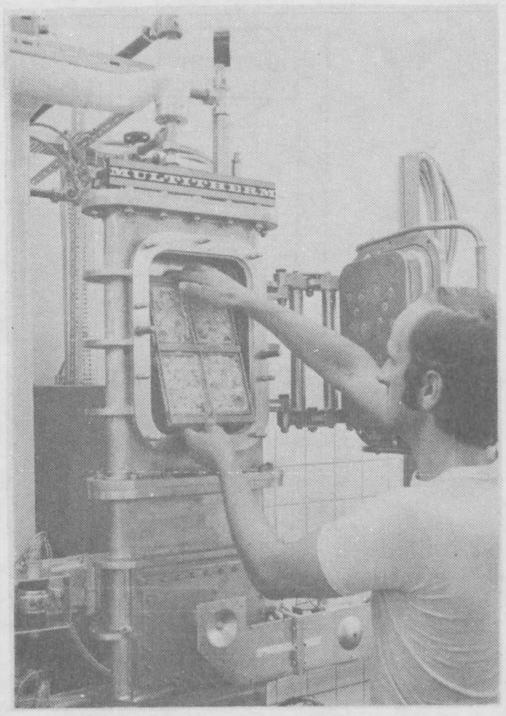

Fig. 9. Pilot plant for microwave HTST heat processing of foods in flexible pouches. (Courtesy Alfa-Laval, Sweden).