MATHEMATICAL MODELLING OF THE INPRO-METHOD OF FRYING MEAT PATTIES

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A promising microwave application presently in use in the Swedish food industry is the finish cooking of pre-browned meat patties. A computer program was constructed to study the influence of different variables on the heating performance. In the calculations the influence of pre-browning temperature, microwave power density and sample thickness have been investigated as well as the influence of one-sided and double-sided microwave heating, all at 2450 MHz. The simulations show that meat patties of 12 mm thickness can be finish cooked in about 1½ minute at 0,3 W/cm² with a maximum temperature difference between surface and centre of 1°C. This is in good agreement with experience from practical industrial processing. Other examples of the influence of pre-browning and microwave heating variables will also be given.

The computer programs developed appear to be useful tools for studies of the influence of different heating parameters and for optimization of continuous microwave heating processes.

REPRÉSENTATION MATHÉMATIQUE DE LA MÉTHODE I N P R O POUR LA CUISSON DE STEAKS HACHÉS

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Une application à l'aide des micro-ondes, qui semble avoir de bonnes perspectives et qui, actuellement, est utilisée dans l'industrie alimentaire de la Suède, c'est la cuisson finale de steaks hachés pré-brunis. Un programme d'ordinateur a été établi dans le but d'étudier l'influence de différentes variables sur le procédé du réchauffage. L'influence de la température de "pré-brunir", de la densité de puissance des micro-ondes et de l'épaisseur des échantillons a été examinée dans les évaluations, ainsi que l'influence de la radiation à l'aide des micro-ondes d'un côté ou de deux côtés, tout à la fréquence de 2450 MHz. Les simulations montrent que les steaks hachés d'une épaisseur de 12 mm sont susceptibles d'être réchauffés en, environ, 1½ minutes à 0,3 W/cm², avec la différence de température de 1°C, au maximum, entre la surface et le centre. Cela est en bonne conformité avec l'expérience des procédés pratiques de l'industrie. D'autres exemples de l'influence des variables de "pré-brunir" et de réchauffage à l'aide de micro-ondes seront également présentés.

Les programmes d'ordinateur, qui ont été développés, semblent utiles dans l'étude sur l'influence de différents paramètres du réchauffage, ainsi que pour l'optimisation de procédés continus du réchauffage des micro-ondes.

MATEMATISCHE MODELLIERUNG DER INPRO METHODE ZUM BRATEN VON HAMBURGERN

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Eine vielversprechende Anwendung von Mikrowellen, die jetzt in der schwedischen Lebensmittelindustrie verwendet wird, ist das Fertigbraten von vorgebräunten Hamburgern. Ein Computerprogram wurde konstruiert, um den Einfluss von verschiedenen Variabeln auf den Wärmungsverlauf zu studieren. Der Einfluss der Temperatur bei der Vorbräunung, der Mikrowellenstärke, der Dicke der Probe sowie der einseitigen und zweiseitigen Mikrowellenwärmung wurde bei 2450 MHz untersucht. Die Simulationen zeigen, dass 12 mm dicke Hamburger in ungefähr $1\frac{1}{2}$ Minute bei 0,3 W/cm^2 mit einer maximalen Temperaturdifferenz zwischen Oberfläche und Zentrum von 1^{o}C zubereitet werden können. Dies stimmt mit der praktische Erfahrung aus der industrielle Herstellung gut überein. Weitere Beispiele für den Einfluss von Vorbräunung und Mikrowellenwärmung werden gegeben.

Computer-programme scheinen sich den Ergebnissen zufolge für Studien über den Einfluss von verschiedenen Wärmungsparametern und für die Optimierung von kontinuierlichen Wärmungsprozessen mit Mikrowellen gut zu eignen.

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ МЕТОДА INPRO ПО ОБЖАРИВАНИЮ МЯСНЫХ "ПАТТИ"

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Многообещающей областью применения микроволн, нашедших на современном этапе использование в шведской пищевой промышленности, является окончательная тепловая обработка предварительно обжареных мясных "патти". Для изучения влияния различных переменных на процесс тепловой обработки была разработана программа для вычислительной машины. При изучении было исследовано влияние температуры предварительного обжаривания, плотности энерговыделения микроволн и толщины образцов, а также влияние одно- и двухстороненного подогрева микроволнами, все при частоте 2450 МГц. Опыты, проведенные с модулированием, показывают, что мясные "патти" толщиной 12 мм могут быть подвергнуты окончательной тепловой обработке в течение, приблизительно, полутора минут при 0,3 Вт/см^3 с максимальным перепадом температур между поверхностью и центром в пределах 1^{o}C, что хорошо согласовывается с практическими данными, полученными при промышленном процессе. Будут приведены и другие примеры, показывающие влияние переменных предварительного обжаривания и микроволнового подогрева.

Разработанные программы для вычислительной машины представляются полезным инструментом при изучении влияния различных параметров подогрева,и в деле оптимизации процесса непрерывного микроволнового подогрева.

MATHEMATICAL MODELLING OF THE INPRO METHOD OF FRYING MEAT PATTIES

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INTRODUCTION

Owing to the ability of microwaves to penetrate into foods and directly heat the interior, microwave heating offers prospects for rapid and mild heating of foods. Today microwave heating has institutional and domestic applications for reheating and cooking of foods in microwave ovens. A great number of applications of microwave heating in the food industry have been investigated in the laboratory and pilot plant scale. An account of these different applications have been made by Bengtsson and Ohlsson (1974). They present more in detail some of the applications of greatest industrial use, among others the cooking of meat products.

An industrial plant for frying and cooking of ground meat products has been presented by Nilsson (1975). In this method (the so called Inpro-method) the process is divided into two steps; 1) pre-browning and formation of frying crust in a two-sided belt grill and 2) finish cooking in a microwave tunnel oven. Experiments have shown that the time for formation of a frying crust is independent of product thickness, while the time for raising the core temperature using contact frying is highly dependent of the thickness. In the Inpro-method the microwave power input is instead adjusted so that sufficient direct heating of the core is achieved. Besides the advantages in increased rate and capacity, Nilsson states that better process economy and product quality is reached. The improvements in product quality compared to deep fat frying have been investigated by Asp et al. (1975). Using the same ground meat recipe they found that the Inpro-processed meat patties had a slightly lower fat content and a higher degree of unsaturated fatty acids than the deep fat fried patties. Also the protein efficiency ratio (PER) values were better for the Inpro-processed meat patties.

Comparisons between experimental and calculated temperature profiles for microwave heating have earlier been reported by Ohlsson and Bengtsson (1971) and Kirk (1975). In these two investigations the same calculation methods were used (the numerical finite difference method). Good agreement was reached between experimental and computer simulated temperature profiles on microwave heating at 2 450 MHz of slabs of salted ham, beef and a phantom food material. (Ohlsson and Bengtsson, 1971). Also Kirk (1975) reached good agreement between experimental and calculated temperatures in experiments using agar gels. In addition Kirk (1975) studied the influence of a number of different parameters on the developed temperature profiles. Calculations and studies of the temperature development in biological tissues on diathermy treatment have also been presented (Cook, 1952 and Chan et al., 1973).

In this paper computer simulations are presented on the time-temperature distribution in industrial frying and cooking of ground meat patties and the influence of varying thickness, power density and of one- or two-sided microwave heating. The same time for pre-browning has been used throughout irrespective of the thickness of the products. Comparison is also made between calculations and experimental results from an industrial plant.

METHODS

A numerical calculation method was chosen, based on finite difference approximations of the temperature derivates. This choice also enabled the use of temperature dependent dielectric and thermal data. The theoretical background and the employed equations have earlier been presented by Ohlsson and Bengtsson (1971). In the calculation program the temperatures at different depth are calculated at each time step in the central portion of a slab. In the simulations the conveyor speed through a microwave oven of given dimensions was adjusted so that a predetermined final temperature in the core of the meat patties was reached. For all the different thicknesses the processing was started by the calculation of a 70 second two-sided contact frying of the patties. Prior to the microwave oven an equalisation tunnel was placed. The microwave heating tunnel had an active heating length of 3.6 meters. The microwave power was in the simulation applied both from two sides and from one side only.

In the calculations thermal and dielectric data for a commercial ground meat mixture was used. Density, specific heat and thermal conductivity were determined according to methods presented by Dagerskog and Sörenfors (1976). The dielectric properties of the pre-fried meat patties were determined using measurements according to Risman and Bengtsson (1971) and Bengtsson and Risman (1971). The ventilation air temperature in the tunnels varied according to experimental measurements. The heat transfer coefficient was chosen to have a constant value of 10 $W/cm^2, {}^oC$ throughout the tunnels, owing to the difficulties to determine true values, i.e. for evaporation at high surface temperatures.

RESULTS

In Fig. 1 the temperature distribution for meat patties of 3 different thicknesses (12, 20 and 30 mm is shown, 1) directly after frying for 70 seconds, 2) before and 3) after the microwave finish cooking. The temperature differences between surface and center is illustrated in fig. 2 for different microwave power densities (energy levels)and thicknesses investigated in the simulations.

DISCUSSION

The computer calculated temperature distribution is made for an infinite slab. The results are thus mainly valid for the central part of a sample with significantly smaller thickness than other dimensions. In practise, edges and corners are heated more rapidly, both from a heat transfer point of view and because of reflections and concentrations of the microwave energy. It can thus be anticipated that the problems with too high temperatures in edges, corners and surfaces may be larger in practise than indicated by the simulations. However, the overall validity of the calculation program has earlier been demonstrated by the author in studies where good agreement was reached between experimental and calculated temperature profiles on microwave heating of meat, ham and phantom food material. (Ohlsson and Bengtsson, 1971, and Ohlsson, 1976).

In the comparison between calculated and the experimental results for Inpro-processed meat patties of 12 mm thickness, good agreement was reached for central and average temperatures. However, the experimental microwave power input was higher than the calculated, probably because of losses due to evaporation of drip resulting from protein coagulation and shrinkage in the temperature range of 60 to 70°C (Dagerskog and Bengtsson, 1976).

The simulations of microwave finish cooking of pre-fried meat patties of different thickness show that quite thick products can be microwave heated with small to moderate temperature differences between surface and center, if a sufficiently low power density is used. (See fig. 2). However, the heating times will then be long, making coordination between the conveyor speeds of the belt grill and of the microwave tunnel difficult. Higher power density means faster cooking, but also larger tendensies for surface overheating. The choice of power density for different sizes and thicknesses must therefore be governed by the temperature differences that can be accepted in practise.

The simulations clearly show that two-sided heating is to be preferred over one-sided heating, even for low power densities and thin samples. This can be explained by the fact that the dielectric penetration depth in the pre-fried meat patties is only about 7 mms at 60°C according to the measured dielectric values.
The comparison between the heating times for the combined method using belt grills and microwave heating and the time for finish cooking using a belt grill only, show that the differences in processing times are small. The advantages using the combined method are found in the much more even temperature profile reached during and after the processing, giving lower processing losses and a superior final product quality for the Inpro-processed meat patties (Nilsson, 1975). The calculations also show that for thicknesses of 10 mms and lower the microwave heating tunnel does not give any noteworthy advantage over the belt grill alone except to increase the speed of temperature equilibration, and thus reduce the conveyor length of the processing line. However, if a subzero initial product temperature is used, for which there is a trend in meat processing today, microwave finish cooking might be truly benificial even for thinner meat patties.

In conclusion the presented results demonstrate that simulations of the time-temperature distribution in microwave heated foods can be useful tools in studies of the influence of the different process parameters, extending experimental results, although the calculated temperatures only refer to the central part of the samples.

Litterature

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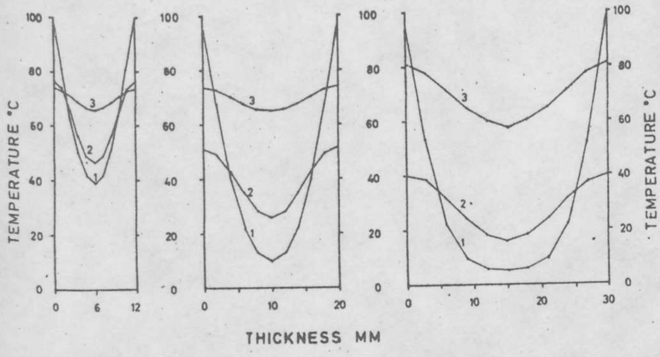

Fig. 1. Temperature profiles in crossections of meat patties of 3 thicknesses; 1) after browning for 70 seconds, 2) before and 3) after microwave finish cooking

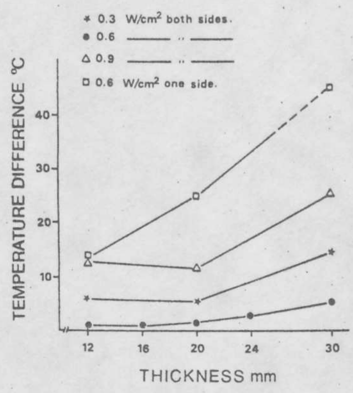

Fig. 2. Maximal temperature differences after equilibration in microwave heated meat patties for different microwave power densities and thicknesses