Temperature Profiles in Dough Products during Microwave Heating with Susceptors

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Abstract

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The effect of food products on temperatures reached in the microwave heating with and without susceptors was followed in experiments with certain types of food samples. A household microwave oven (650 W), susceptors from commercial packages for microwave popcorn, samples of two commercial pizza products and two types of dough were used in the experiments together with Luxtron temperature measurement system. The temperatures reached at the end of heating on the bottom surface of samples varied between 103 and 115°C at the heating without susceptor, and between 110 and 155°C at the heating with susceptor. Not only the susceptor but also the parameters of the heated samples (the moisture content, height/weight, the initial temperature) influenced the increase of the temperature on the bottom surface of the samples. The highest temperatures were found at the end of the heating of samples from dough with a lower content of moisture. The linear correlation between the temperature at the bottom of the sample and the logarithm of the time of heating (ZUCKERMAN & MILTZ 1995) was proved only with the heating of samples from one type of dough. The application of susceptor in the microwave heating alters not only the product temperature in the places of contact with susceptor but also – to a certain extent – in other places of the product. The change in the shape of the vertical temperature profile in the heated sample was found in the experiments with susceptor heating. For the optimal results of the heating with susceptor, the optimization of certain product parameters (namely the moisture content and the dimensions) have to be made

Keywords: microwave heating; susceptor; temperature profile in food; browning effect; crisping effect

Microwave heating has become very popular in the food preparation. The microwave ovens are used for defrosting of food and reheating of pre-cooked food products both in households and catering. The popularity of microwave ovens leads the food producers to develop a new generation of products for microwave heating. Many of these products can be heated and served in their packages. To aid in achieving the optimum quality, special package systems for microwaveable food products have been developed.

One problem in the microwave heating of food is the inability to crisp and brown the food surface when required. Mainly those dough products which are expected to be crisp and brown on the surface after preparation become soggy with warm damp surface when heated in the microwave oven.

In order to achieve a significant browning and crisping reaction, the temperature of the food surface must be raised well above 100°C (TURPIN 1989). As follows from different measurements, the surface temperature of food product with a sufficient content of moisture does not exceed 110°C during the heating in a microwave oven without additional heating systems (IR or/and hot air heating).

The “susceptor packaging” technology was developed as one solution of how to overcome this problem.

Susceptor is generally a lightly metallized PET (polyethylenterephtalate) film which may be sandwiched within the package structure or laminated onto a rigid dimensionally stable substrate as paperboard. At the optimum metallization, the susceptor itself absorbs the microwave energy during the heating and converts it into heat. The amount of this heat is a function of the resistance properties of

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the susceptor which depend on the thickness of metallization (TURPIN 1989; MILTZ & ZUCKERMAN 1992, 1994; HOUŠOVÁ & HOKE 1998).

The heat is transferred from susceptor to the product by conduction in the susceptor/product contact area creating localized areas of high temperature on the product surface and causing there water evaporation and browning and crisping.

Susceptors have been used with some of microwaveable food products for more then 20 years. In spite of the experience with their application in the food production, there is still relatively little information on their performance and on their changes during the microwave heating.

The objective of this work was to follow the influence of the food product nature and parameters on the temperatures reached in the product during its heating in the microwave oven using susceptor.

The attention paid to the temperatures really reached in the microwave susceptor heating dates back to 90-ies years. The research had to give an answer to the question whether or not the susceptor package – as a very complex system – could affect the safety of the heated product.

Different experimental studies focused on the potential migration of certain volatile and non-volatile compounds of susceptor packaging system into the heated food began at that time and relevant results are available in the literature (RISCH 1993). The collaborative studies focused on the real values of the susceptor temperature during the heating preceded the migration studies (KASCHTOCK *et al*. 1990). Experiments were carried out in 10 laboratories in U.S. with heating of three types of commercial popcorn and frozen cheese pizza using different types of household microwave ovens (rated power about 700 W). The temperature at the susceptor/product interface was measured in all laboratories by Luxtron system. According to these studies, the temperatures reached at the end of heating were about 200°C (popcorn heating) and about 180°C (pizza heating). The results of these experiments also indicated that many factors such as the susceptor parameters, the oven type and load and the parameters of the product can affect the temperature reached by susceptor during the microwave heating.

The temperature on the susceptor/food product interface during the microwave heating was experimentally followed also in the work of ZUCKERMAN and MILTZ (1995). Specially prepared susceptors of certain parameters, samples of dough (without information on the chemical composition) of different weight and dimensions and household microwave oven (700 W) were used by the authors in the experiments together with Luxtron system for the temperature measurements. Susceptor/dough interface temperatures between 130 and 200°C were found at the end of the heating of the dough samples tested by the authors. The influence of the sample weight and dimensions on the temperature reached in the sample/susceptor contact area was confirmed. The linear rise of the susceptor/dough interface temperature with the logarithm of time was derived from the heating experiments. The slope of the line in this relationship depends on the weight and the diameter of the round sample of dough – the slope decreases with the increasing of weight. The parameters of the surface resistivity of susceptors, too, influence the rise of the susceptor/dough contact temperature as follows from other authors' experiments (ZUCKERMAN & MILTZ 1997) – the parabolic (inverted) change of the contact temperature with the surface resistivity of susceptor was deduced from experimental results.

In the following text, the results are given of our own experiments pursuing the temperature distribution in certain dough products or semi-products heated in the microwave oven with and without susceptor. A commercial household microwave oven (650 W rated power), food products of different nature, weight and dimension and susceptors from commercial susceptor packages were used in these experiments.

MATERIALS AND METHODS

Microwave oven

Moulinex, type FM 1515E, rated power output 650 W, power output according to IEC705 (1 l cold water) 660 W, cavity dimensions 190 × 175 × 290 mm, cavity usable volume 14.7 l, removable glass plate on the cavity bottom.

Food samples

Samples prepared from the following types of dough products or dough were used in the experiments: frozen pizza cake "Bon Giorno", frozen cheese pizza "Bon Giorno", "linecké těsto" – dough, type 1, dough for salty cracker – type 2 (own preparation – recipe see Table 1). The basic chemical compositions of the individual food products are given in Table 2 (POTÍŠKOVÁ 2001).

Round samples (diameter of 90 mm) were cut out from both pizza products. The dough was first rolled out to the predetermined thickness (5.5; 7, and 10.5 mm – dough type 1, and 9 mm – dough type 2) and subsequently round samples (90 mm diameter) were cut out.

Table 1. Recipe of dough for salty cracker

Ingredient	Quantity (g)
Wheat flour	333
Vegetable fat "Hera"	185
Water	70
Salt – alternative	3, 6 and 12

Table 2. Basic chemical composition (in %) of individual food products (Potíšková 2001)

Food product		Water	Drymatter	Fat	Proteins	Saccharides	Ash	NaCl
Pizza cake		33.01	66.99	7.28	8.48	47.79	3.44	0.83
Dough type 1		14.53	85.47	25.09	6.25	53.60	0.53	0.03
Cheese pizza	cake	38.48	61.52	5.58	7.79	45.72	2.43	0.75
	topping	58.57	41.43	9.28	13.93	14.57	3.65	1.18
Dough type 2		12	88	30	–	–	–	–

Before heating, the samples were kept in a refrigerator (dough samples and defrosted pizza cake) or a freezer (samples from pizza and pizza cake).

Susceptors

Round samples of susceptors (diameter of 90 mm) were cut out from the active part of commercial packages for microwave popcorn. The average value of susceptors optical density (O.D.) was 0.220 ± 0.002 (separate measurements with 10 samples of susceptors – Potíšková 2001), the average value of the microwave power absorbed in susceptor was 42.55 ± 1.23% of the incidental power (separate measurement with 10 samples, Česnek 2001 – personal commun.).

Insulating pads

In several measurements, the following types of thermal insulation were tested to prevent the loss of heat from susceptor by transition to the glass plate in the microwave oven: plate from PTFE, 100 × 100 mm, thickness of 5 mm, and corrugated paperboard, 120 × 120 mm, thickness of 4 mm.

Temperature measurement

Luxtron model 755 with four fluoroptic probes MIW-2 was used for the measurement of the food sample temperature during the heating. The temperature data were collected at intervals of 2 s by the four-channel acquisition system and transferred to the computer via RS 232 serial port.

The temperature of samples was measured in four predetermined positions (Fig. 1) in several horizontal levels – in the distance of 0.5 mm from the susceptor or glass plate (the temperature of samples near their bottom surface) and other two or three levels (according to the height of samples). To fix the locations of probes, a special holder from PTFE was used.

Experimental procedure

The sample of susceptor together with a food sample of certain dimensions, weight and initial temperature was placed in the middle of the oven glass plate. Luxtron probes were installed into the sample. An additional load (two glasses each with 100 ml of cold water) was installed

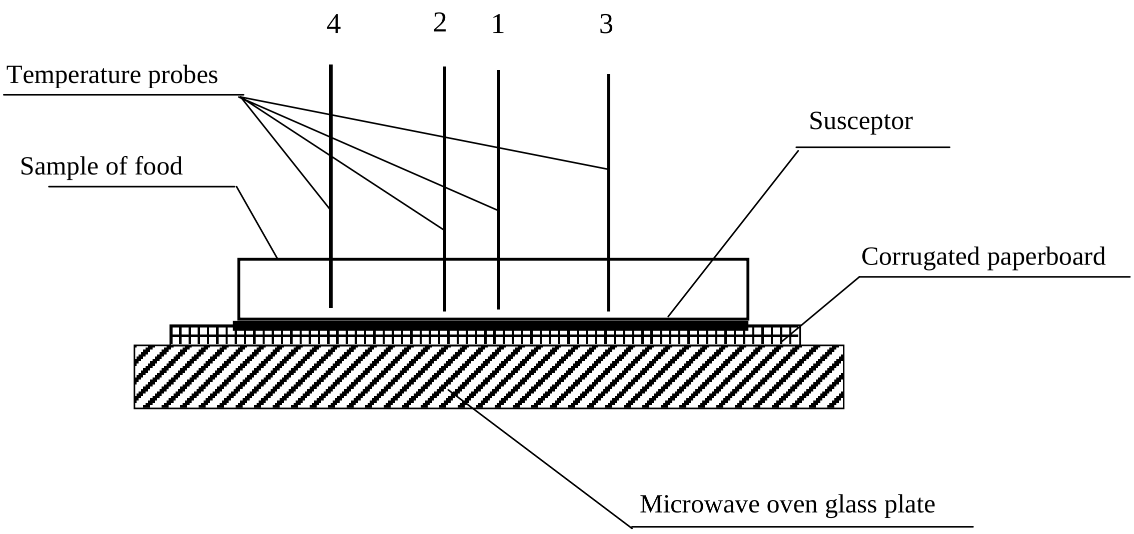

Fig. 1. The position of temperature measuring probes in food sample during the heating in the microwave oven with susceptor and an insulation pad from corrugated paperboard

on the glass plate in order to lower the increase of the temperature of small food samples during the heating. The food samples were heated for predetermined time (2 to 5 min) at 100% power output setting on the microwave oven. After the heating, the weight and the dimensions of samples were controlled and the sample appearance (namely of the bottom surface) was visually judged.

For comparison, the heating of samples of each type of food without susceptors was also performed.

The heating procedure was repeated three times for each process, food parameter, and vertical placement of temperature probes in food samples. The oven was allowed to cool between the runs (30 min breaks).

The temperatures reported in the following text and graphs are average values of the temperatures measured in two places in the central parts of samples (probes 1 and 2) in three repeated runs.

RESULTS AND DISCUSSION

Temperature of food sample near its bottom surface during the microwave heating with and without susceptor

The increase of the sample temperature near its bottom surface (0.5 mm from the susceptor or glass plate) during the microwave heating with and without susceptor is shown in the two following figures. Fig. 2 presents the results obtained in the heating of defrosted pizza cake samples and Fig. 3 refers to the heating of the samples from dough type 1.

As follows from the graphs, during the microwave heating without susceptor the food surface temperature did not exceed very much the water boiling temperature, namely if the food had enough moisture. During the heating of samples from pizza cake and cheese pizza, the bottom surface temperature of samples remained at 100°C for most of the heating time; only at the end of the heating it increased to 105 (cheese pizza) or 110°C (pizza cake). A little higher temperature was reached in the heating of samples prepared from both types of dough with lower moisture contents, where the maintenance of temperature at 100°C was shorter.

The use of susceptor in the heating influenced positively – but not to the same extent – the increase of the bottom surface temperature in all types of samples. It is evident from the graphs that the effect of the additional heat from susceptor began to show after some time of heating. In the initial period of heating, the bottom surface temperature of the samples was lower in the heating with susceptor compared to the heating without susceptor. During the heating of pizza type samples, a signified shortening of the temperature delay at 100°C was found if susceptor was used. The temperatures reached at the end of heating with susceptor were higher compared to the heating without susceptor in all food samples tested. An average temperature of about 130°C was found at 180 s of susceptor heating of frozen and defrosted pizza cake samples, and of about 155°C at the end of the heating of samples from dough, type 1.

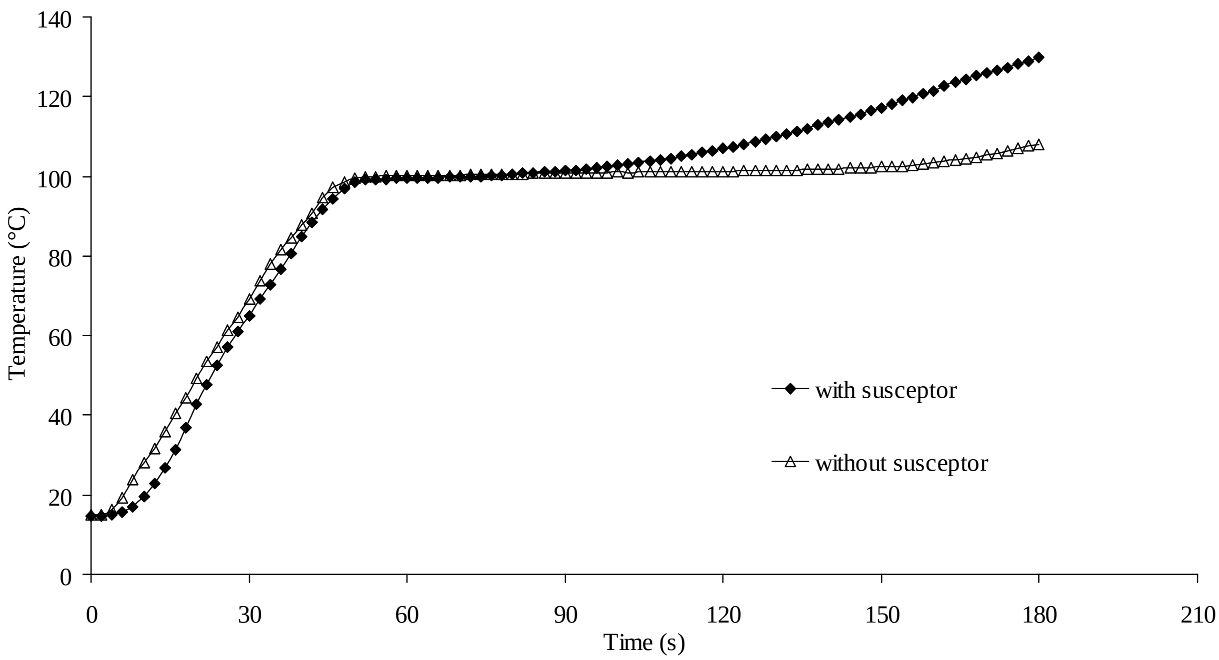

Fig. 2. Microwave heating of defrosted pizza cake samples with or without susceptor. The increase of temperature on the bottom surface of the samples during the heating

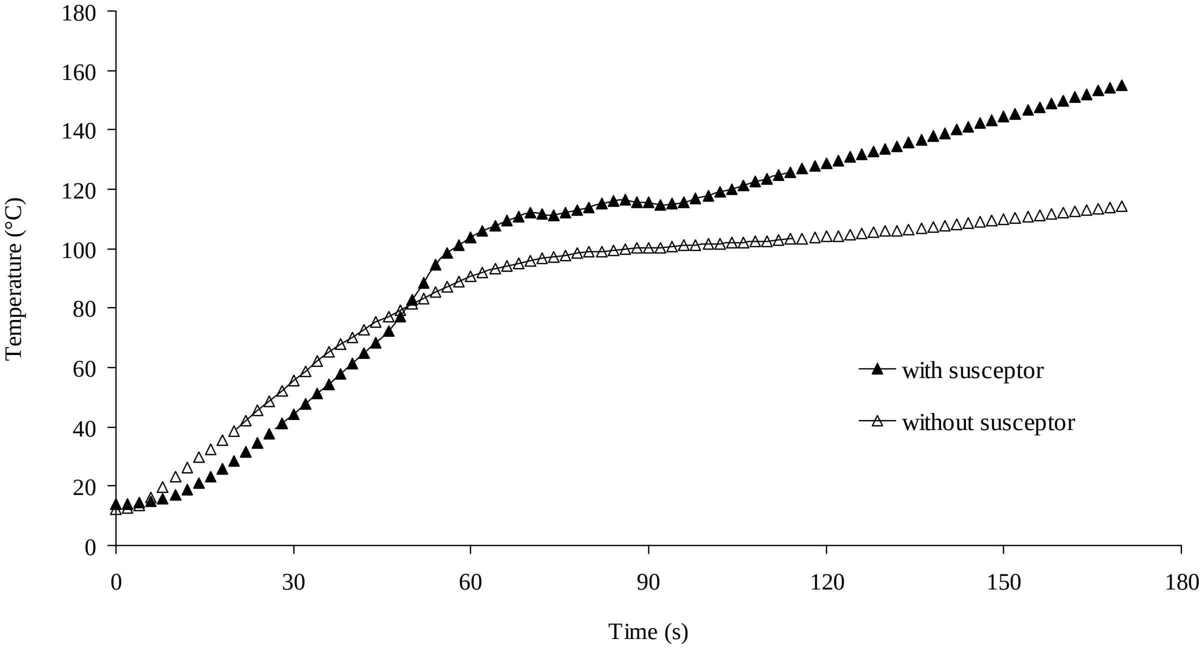

Fig. 3. Microwave heating of samples from dough type 1 (height 7 mm) with or without susceptor. The increase of temperature on the bottom surface of samples during the heating

The appearance of the bottom surface of the samples after the heating correlated well with the final temperatures in these parts of the samples: a pale, soggy, and damp surface of the pizza after the heating without susceptor and a brown and crispy one after the heating with susceptor was the result of the visual judgement of these samples after the heat treatment.

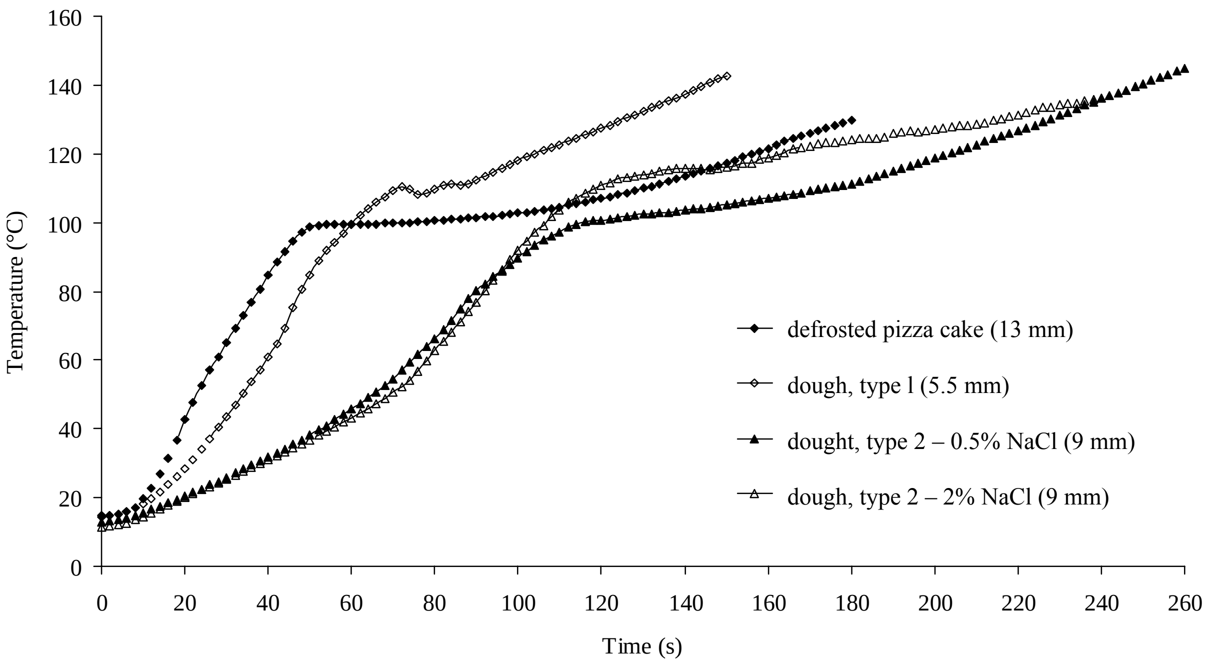

Fig. 4. Microwave heating of samples from defrosted pizza cake (height 13 mm), dough type 1 (height 5.5 mm), dough type 2 (height 9 mm) with the addition of 0.5 and 2% NaCl. The increase of temperature on the bottom surface of the samples during the heating with susceptor

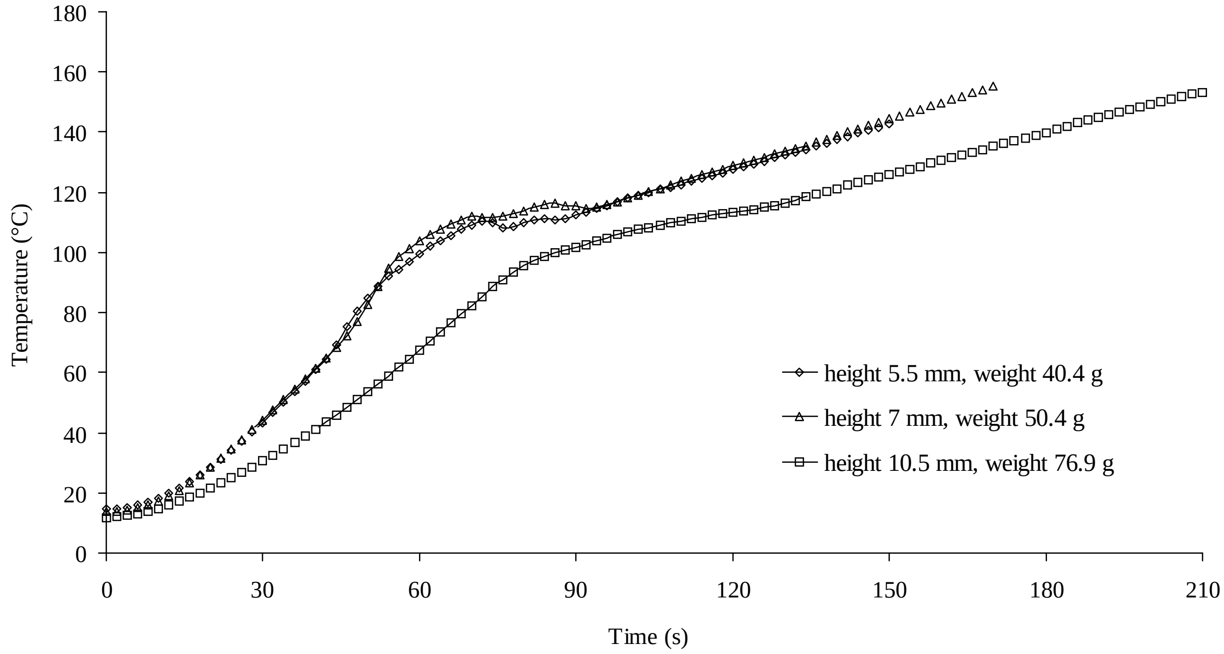

Fig. 5. Microwave heating of samples from dough type 1 of different heights. The influence of the height (weight) of the samples on the increase of temperature on the bottom surface of the samples during the heating with susceptor

As the results of the experiments confirmed, it was not only susceptor that influenced the product temperature reached in the contact area at the end of the microwave heating. Fig. 4 illustrates the influence of the nature and physical parameters of the heated product on the increase of temperature at its bottom surface during the heating. The time–temperature relations for the heating of defrosted pizza cake, dough type 1 (5.5 mm height), and dough type 2 with the addition of 0.5 and 2% NaCl (height 9 mm) are compared in this figure.

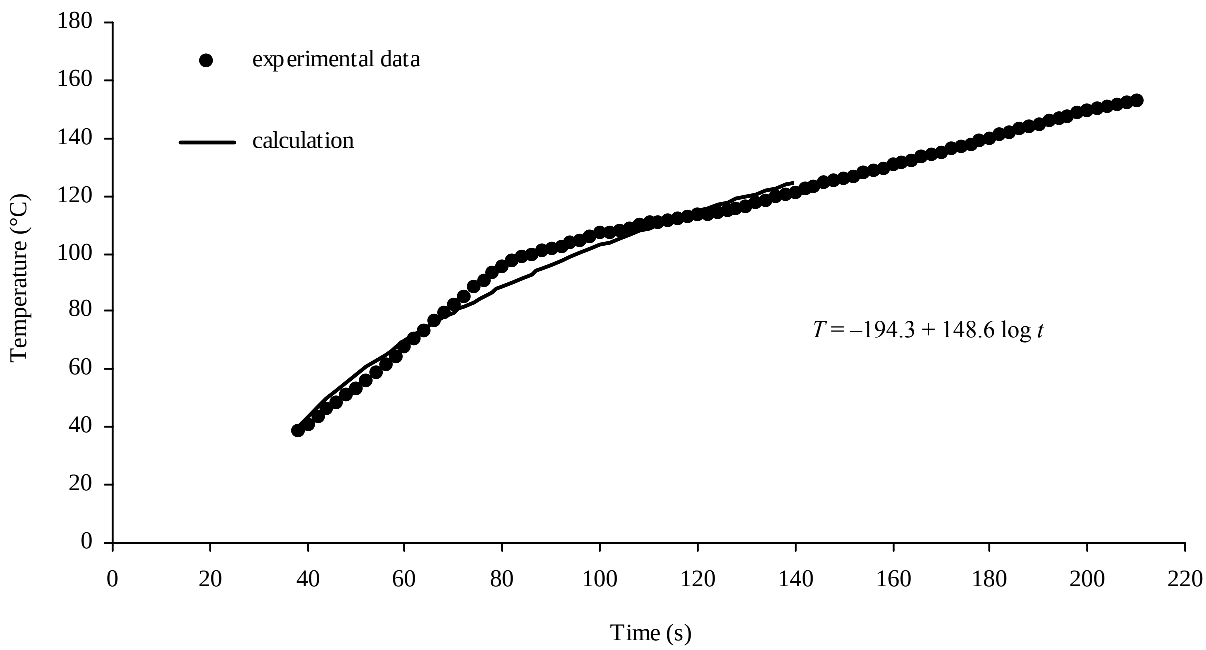

Fig. 6. The increase of the temperature on the bottom of samples (dough type 1, 0.5 mm thickness) during the heating with susceptor. The comparison of the experimental values and the values predicted by the use of the relationships by ZUCKERMAN and MILTZ (1995)

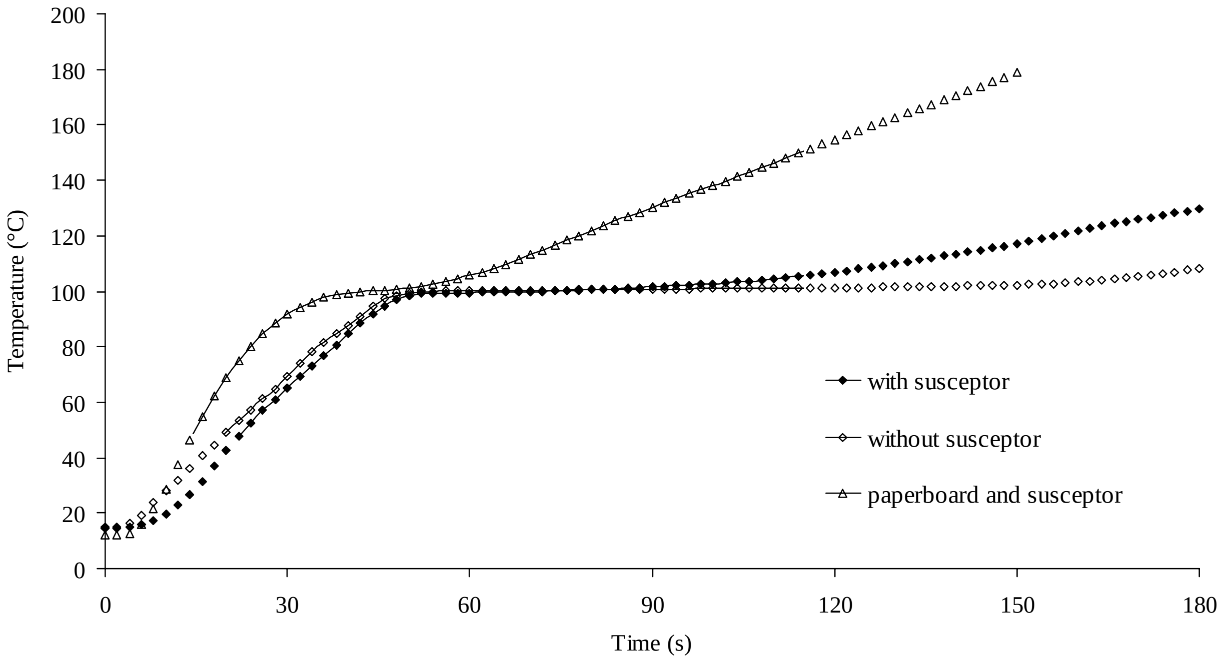

Fig. 7. The influence of the insulation pad (corrugated paperboard) placed under susceptor on the bottom surface temperature of samples during the heating (defrosted pizza cake)

Fig. 5 illustrates the influence of the height (or weight) of a food sample (dough type 1) on the rate of the increase of the bottom surface temperature. The decrease of the sample surface temperature in the place of contact with susceptor with the increase of the sample weight corresponds well with the experiments of ZUCKERMAN and MILTZ (1995).

The data obtained in the heating experiments with susceptor were correlated using the linear dependence of the bottom surface temperature of the sample (T) on the logarithm of the heating time (t) as proposed by ZUCKERMAN and MILTZ (1995): $T = A + B \times \log t$, where A and B are coefficients affected by the product.

Fig. 6 illustrates the results of this correlation for the heating of the samples from dough type 1 with the height of samples of 10.5 mm. As seen from the figure, the proposed relationships is relatively satisfactory for this type of food product. With the decrease of the sample height (weight), the slope of the lines increases. The respective values of both coefficients were: A coefficient –194.3 (10.5 mm), –147.4 (7 mm) and –145.0 (5.5 mm) and B coefficient 148.6 (10.5 mm), 134.6 (7 mm) and 132.4 (5.5 mm). For the salt dough with 2% of NaCl, the value of A coefficient was –221.1 and that of B coefficient 153.2, respectively, but the agreement between the experimental and calculated values of temperature was not so satisfactory in this case.

The application of the proposed relationships was tested also for the other two types of food samples used in our experiments. However, great differences between the experimental and the predicted values of temperature were found. It seems that the correlation proposed by Zuckerman and Miltz will be available only for food products of certain compositions.

The bottom surface temperature of the samples heated in the microwave oven with susceptors can be positively influenced using certain insulation under the susceptor. Good results were obtained mainly in the tests with corrugated paperboard – see Fig. 7 (the heating of samples from defrosted pizza cakes).

Vertical temperature profiles in food samples in the microwave heating with and without susceptors

Susceptor used at the microwave heating of food samples influences mainly the temperature in the susceptor/sample contact area but a certain influence on the temperatures in other regions of samples was also found in our experiments.

In the following two figures, the development is compared of temperatures monitored gradually in different heights in food samples during their heating with and without susceptor.

In Fig. 8, the results are shown of the heating of cheese pizza samples and in Fig. 9, those of the tests with samples from dough the type 1 (7 mm).

In both figures it can be seen that the susceptor application in the heating affects not only the bottom surface temperature of the sample but – to a certain extent – it

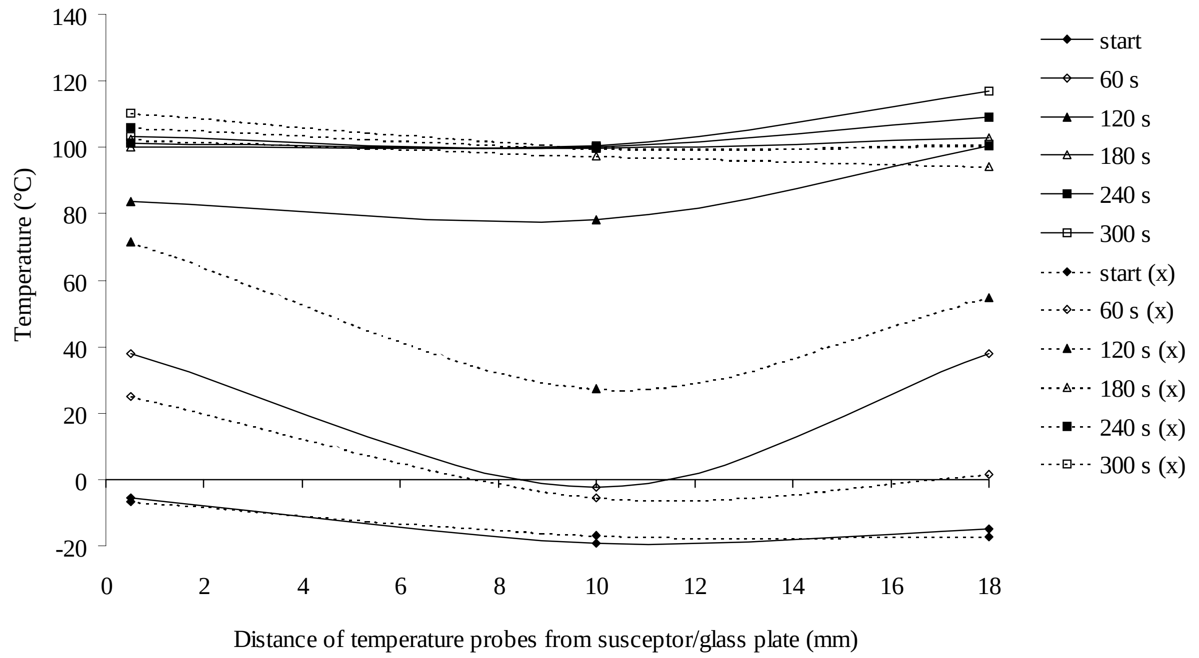

Fig. 8. Vertical temperature profiles in samples of cheese pizza (24 mm) during the microwave heating without and with susceptor (×)

changes also the shape of the vertical temperature profile. The influence of the food product type is also evident from the comparison of the figures.

In the initial period of heating, the application of susceptor resulted in a slow-down of the increase of temperature in the whole of the sample (in all points in which the temperature was measured). After the rise of temperature to 100°C approx., a marked increase of it was observed on the bottom surface in the case of the heating with susceptor but only a slow increase of temperature in other layers

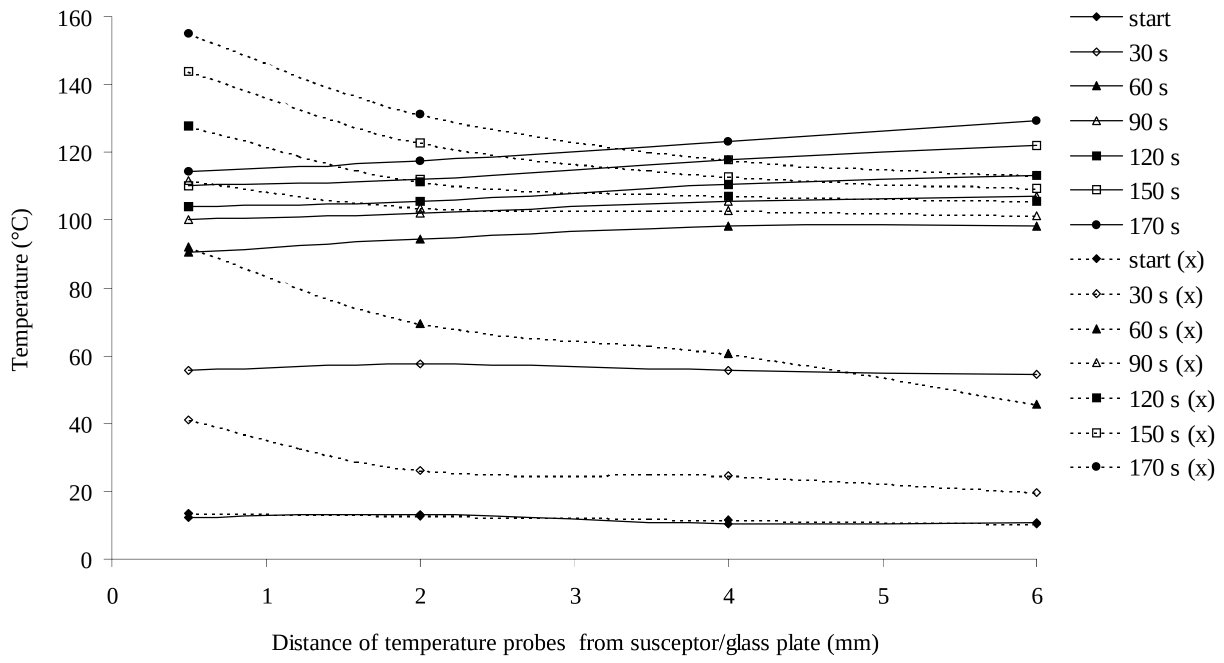

Fig. 9. Vertical temperature profiles in samples from dough type 1 (7 mm) during the microwave heating without and with susceptor (×)

of the samples. At the end of the heating with susceptor, the highest temperatures were found on the bottom surface of the samples, contrarily to the heating without susceptor in which the highest temperatures were found on the upper surface of the samples.

Conclusions

1. The use of susceptors in the microwave heating of the food samples tested affected positively their final appearance. The expected "baking effect" of susceptors was observed to a certain extent after the heating with all food samples tested. The appearance of the samples after heating correlated well with the temperatures measured at the end of the heating on the bottom surface of the samples. Higher values of temperature were found in these locations at the end of the heating with susceptor in all types of food samples as compared to the heating without susceptor.

2. The temperatures reached on the bottom surface of the samples at the end of the heating were influenced not only by the application of susceptor but also by the product itself confirmed in the experiments. Higher surface temperatures were found at the end of the heating with susceptor on the bottom of samples from dough type 1 and type 2 with a lower moisture content in comparison to the samples from pizza (cake, cheese) with a higher moisture content.

3. Except the moisture content, the dimensions and the weight of samples also affected the temperature reached on their surface at the end of the heating. An increase of the height (and the weight) of samples resulted in a slowdown of the increase of the sample bottom temperature.

4. The initial temperature of the food product is also important for the result of the microwave heating. The susceptor application influenced very positively the result of the microwave heating of the frozen samples.

5. The relationships proposed by Zuckerman and Miltz for the description of the time-temperature dependence for the food product/susceptor interface seems not to be available commonly but only for food products of certain chemical compositions.

6. The application of susceptor in the microwave heating which exerts an influence mainly on the temperature of the heated product in the contact area, alters to a certain extent also the local temperatures in other parts of the product. A certain change in the shape of the vertical temperature profile was derived in all types of samples from the comparison of the results of the heating with and without susceptor.

7. For the optimal result of the microwave heating with susceptor, a certain optimization of the food product parameters (moisture, dimensions) seems to be needed.

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Souhrn

HOUŠOVÁ J., HOKE K. (2002): **Teplotní profily ve výrobcích z těsta během mikrovlnného ohřevu s použitím susceptorů**. Czech J. Food Sci., **20**: 151–160.

Průběh teplot při mikrovlnném ohřevu několika typů potravin za použití susceptorů byl monitorován za použití mikrovlnné trouby pro domácnosti (650 W – štítkový výkon). Byly zjištěny konkrétní hodnoty teplot dosažené při mikrovlnném ohřevu vzorků několika různých potravin bez susceptoru a s ním. Účinek susceptoru byl sledován při mikrovlnném ohřevu vzorků plochého tvaru, připravených ze dvou druhů těst (linecké a křehké s přídavkem NaCl) a ze dvou komerčních výrobků (sýrová pizza a korpus pro pizzu). Všechny vzorky měly kruhový tvar s průměrem 90 mm. Výška vzorků závisela na typu potraviny a pohybovala se od 5,5 mm (nejnižší vzorky z lineckého těsta) do 24 mm (zmrazená sýrová pizza). Vzorky susceptorů byly vystřiženy z komerčních obalů pro popcorn určený k přípravě v mikrovlnné troubě. Teploty vzorků potravin byly postupně monitorovány pomocí termometrického systému Luxtron. Vedle teploty spodního povrchu vzorků (0,5 mm od susceptoru) byly zjišťovány teploty v dalších dvou nebo třech místech jejich výšky. Na konci ohřevu se susceptorem (2 až 5 min podle druhu vzorku) byly u spodního povrchu vzorků naměřeny průměrné teploty v rozmezí 110–155 °C (podle druhu vzorku), při ohřevu bez susceptoru jen 105–115 °C. Souběžně prováděné vizuální hodnocení vzhledu vzorků po ohřevu dobře korelovalo s naměřenými konečnými teplotami. Výsledky zkoušek potvrdily výrazný vliv samotného vzorku na průběh měřených teplot, zejména pak vliv obsahu vlhkosti a výšky, resp. hmotnosti vzorku. U vzorků s vyšším obsahem vlhkosti (pizza) byly naměřeny výrazně nižší konečné povrchové teploty než u vzorků z obou těst s nižší vlhkostí. Pomalejší vzrůst teploty spodního povrchu vzorků byl zaznamenán při zvyšování výšky (resp. hmotnosti) vzorků (zkoušky se vzorky lineckého těsta). Vzrůst teploty spodního povrchu jednotlivých typů vzorků při mikrovlnném ohřevu se susceptorem byl porovnáván s empirickým vztahem, který doporučili ZUCKERMAN a MILTZ (1995), tj. s lineární závislostí teploty potraviny v místě kontaktu se susceptorem na logaritmu času. Podle výsledků výpočtů není použitelnost tohoto vztahu obecná, je omezena pouze na některé typy výrobků. V daném případě byla zjištěna dobrá shoda naměřených teplot s údaji, vypočtenými podle empirického vztahu, pouze pro ohřev vzorků z lineckého těsta, příp. křehkého těsta. V článku jsou uvedeny hodnoty příslušných koeficientů empirické závislosti, závisející na parametrech vzorků (složení, výška, resp. hmotnost). Pomocí naměřených hodnot je dokumentován i příznivý vliv použití izolační podložky pod susceptor, který snižuje ztráty tepla odvodem do skleněné desky mikrovlnné trouby. Aplikace susceptoru při mikrovlnném ohřevu, ovlivňující vzrůst a konečnou výši teploty potraviny v místě jejího kontaktu se susceptorem, mění do určité míry i teplotu v ostatních vrstvách potraviny. Míra vlivu susceptoru na vertikální rozložení teplot ve vzorcích během ohřevu souvisí s typem potraviny. Výsledky experimentální studie potvrdily, že pro dosažení optimálního účinku aplikace susceptoru při mikrovlnném ohřevu je třeba určité optimalizace parametrů samotného výrobku (rozměry, obsah vlhkosti).

Klíčová slova: mikrovlnný ohřev; susceptor; teplotní profil potravin; hnědnutí potravin; křehkost potravin

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