Electric resistance baking as a method for production of toast bread

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Abstract. Electric resistance baking (ER baking) was featured as an object of a large number of studies devoted to dough and bread. This paper provides a brief overview of the known and most prominent studies of this process. Almost all studies consider this method of baking only as a convenient scientific tool. However, there are almost no papers in which the electric resistance baking method would be used in the production of a particular type of bread. In this paper we examine the theory of the use of the ER baking for the production of toast bread. The best indicators belong to the samples, which were baked in the following conditions: use of the formula and technology of American toast bread; use of a specific way of bread dough shaping, characteristic of toast bread; division of the dough pieces by weight based on 225 g of dough per liter of mould volume; use of an electric resistance design of the oven, equipped with a clamp cap; greasing of the lower edges of the clamp cap; baking dough at 220 V, 50 Hz until the dough reaches a temperature of 98 ... 100 °C.

1. Introduction

Electric resistance (ER) baking is the process of baking bread, which is based on heating dough while passing an electric current through it. The physical meaning of electrical resistance baking is explained by the Joule-Lenz law. When a current is passed through a conductor, heat is generated inside the conductor; the amount of heat can be determined by the next equation:

\[ Q = I^2 \cdot R \cdot \tau, \]

where I is the current, A; R is the resistance, Ohm; \( \tau \) is the current passage time, s.

Electric resistance baking of dough was used as a research tool in a number of works. In the most studies, the use of the ER heating was due to the need for accurate, uniform dough heating in order to study how various components of the formulation and / or changes in breadmaking technology affect quality characteristics of dough or bread. Instead of the electric resistance baking convective baking is characterized by significant temperature gradients in volume of dough, difficulty of regulating temperature of dough, and inevitable formation of crust. It is possible to reproduce almost any temperature profile while heating dough by varying voltage during the ER baking.

Use of the ER baking as a research tool was carried out with the following objectives:

• to study the properties of dough at precisely specified temperatures [1, 2];
• to study the effect of shortenings and surfactants on the volume of bread and the gas retention ability of dough in conditions of controlled heating [3, 4];
• to use the ER baking to simulate the stages of convective baking of bread samples with and without replacing part of the flour with brewers spent grains [5];
• to perform accurate and adjustable heating of dough in order to study influence of different lipids and flour fractions on expansion rate and volume of bread [6];
• to study the rheological properties of cake batter at different temperatures; the value and accuracy of temperature maintenance were achieved by using of electric resistance heating [7];
• to determine the gas retention ability and carbon dioxide losses from the dough mixed with various types of flour under conditions of fermentation, proofing and baking. The electric resistance oven equipped with a carbon dioxide capture system was used for baking [8];
• to compare bread obtained by convection baking and electric resistance baking. The control of voltage in the ER oven was implemented so that the temperature profile during the ER baking was similar to the profile obtained with convective baking [9];
• to investigate the mechanism of moisture transfer and the processes of staling of pound cakes. Use of the ER baking allowed obtaining cakes without crust, which made it possible to make a study without the influence of a moisture gradient between crust and crumb, which is takes place when cakes are obtained by convective baking. The control of cake heating during the ER baking was implemented so that a temperature profile was close to the profile of convective baking [10].

More detailed review on the use of the ER baking in various scientific studies is given in paper [11].

A common feature of all studies devoted to the ER baking is that this method of supplying thermal energy was used by the authors as a convenient research tool. The practical application of this baking method to produce any kind of bread has never been considered, despite a number of advantages of this baking method: baking process speed, low energy consumption, absence of crust, a larger specific volume of bread in comparison with the convection method.

Toast bread is very popular in Europe, in the USA and in Japan. The homeland of this bakery product is the United Kingdom. Classical English toast bread has a thin elastic crust, a snow-white finely porous thin-walled crumb with uniform porosity without voids and, of course, a delicate, “melting” texture when biting and chewing, or “short bite”. Thanks to these characteristics, toast bread is an ideal base for sandwiches.

Toast bread is most often baked in special moulds, in the form of a “pencil case” with a lid, which makes it possible to achieve a certain form of finished products, a parallelepiped.

Currently, a trend for cutting crusts in toast bread is being developed in order to reduce the effort when biting sandwiches, so bread with the crusts cut off is often found in supermarkets in European cities. This operation significantly reduces the yield of the finished product, because crusts can make up to 30% of the product mass.

According to the abovementioned factors, it can be assumed that the use of the electric resistance baking for toast bread production is justified and may have the following advantages:
1. absence of crust on the toast bread and reduction of losses of finished products;
2. simple geometric shape of the bread is favorable for the ER baking process;
3. fine and uniform porosity is favorable for ER baking, as it increases the homogeneity of the bread dough;
4. high baking velocity and low energy consumption.

It should also be noted that the correct technology and the absence of crust on the toast bread obtained by the ER baking will presumably allow one to obtain good organoleptic characteristics of finished products, which, subsequently, favorably affects the possibility of commercialization of this solution [12].

The aim of this study is to determine the optimal technology of dough preparing and the parameters of the ER baking process in order to obtain crustless toast bread.
2. Materials and methods

2.1 Experiment plan
In this study we determined the influence of the following factors:
• Factor 1: baking bread with and without a clamp cap.
• Factor 2: stopping the baking process when the minimum current force is reached (stopping by current) after reaching the temperature of 100 °C, and when the temperature reaches 98 °C (stopping by temperature).
• Factor 3: baking with and without the spray «Spray King» for baking moulds, while the spray was applied on the electrodes of the ER-oven.

2.2 Dough preparation technology
The dough formula is shown in table 1. This recipe was used in all three series of experiments.

Table 1. The dough formula

| Ingredients                      | Dough, g | %   |
|----------------------------------|----------|-----|
| Premium wheat flour              | 1000,0   | 100 |
| Water / Ice                      | 560      | 56,0|
| Salt                             | 15       | 1,5 |
| Red yeast "Record"               | 50       | 5,0 |
| Margarine                        | 50       | 5,0 |
| Granulated sugar                 | 80       | 8,0 |
| Taste improver RS 190 star        | 1,0      | 0,1 |
| Milk powder                      | 20       | 2,0 |
| Dough total                       | 1776,0   | 177,6|

The technology of bread-making was carried out in the following order:
1. Knead the dough following the formula from Table 1, on a dough mixer (Diosna) during 5 minutes on slow mode and 9 minutes on fast mode in order to achieve the perfect development of the gluten frame. The temperature of the used mixture of ice and water is of 1±0,5 °C, the dough temperature after kneading is of 27,5±0,5 °C.
2. Let the dough rest at 22±1 °C during 15 minutes.
3. Divide the dough into pieces for moulding.
4. Roll the dough on a rolling machine (Bongard), divide the rolls into 3 or 4 parts, put them in moulds orienting them perpendicularly to the electrodes or the longitudinal sides of the baking moulds.
5. Proof the dough at 40 °C, 75% rh in a proofing cabinet (DEBAG) up to the height of 80 mm in an electric resistance oven or until the height of 1 ... 2 cm from the top of the baking mould cap is reached.
6. Bake with the ER-method at 220 V, 50 Hz or in a baking oven (SVEBA DAHLEN) at 240 °C for the first 10 minutes of baking, then lower the temperature to 190 °C for the next 25 minutes until the end of the baking.

In each series of experiments, two dough samples were baked simultaneously following the electric resistance method.
The weight of dough samples in a series of experiments is shown in Table 2.
The baking loss was measured by weighing on a laboratory balance immediately after baking.
### Table 2. The weight of dough samples in the series of experiments

| Factor 1                  | With a clamp cap | Without a clamp cap |
|--------------------------|------------------|---------------------|
| Weight of a dough sample, g | 450              | 500                 |

| Factor 2                  | Stopping by current | Stopping by temperature |
|--------------------------|---------------------|-------------------------|
| Weight of a dough sample, g | 450              | 500                     |

| Factor 3                  | With the use of spray | Without the use of spray |
|--------------------------|-----------------------|--------------------------|
| Weight of a dough sample, g | 500                  | 500                      |

#### 2.3 Electric resistance oven design

In order to study the process of electric resistance baking, an experimental installation was developed; the corresponding drawings are given in Figure 1.

An electric resistance oven consists of a body made of non-conductive material. Electrodes are installed in the body grooves; the electric current is supplied to the dough through the electrodes. The electrodes are made of 3 mm AISI 304 stainless steel. The body is equipped with a folding bottom. Grooves are made to allow the electrodes position and to set different parameters of distance between them. The folding bottom allows extracting the finished bread without deformation, which is important, because the bread baked using the electric resistance method, holds its shape worse and is more easily deformed due to the absence of crust. The installation shows the system of clamp caps that are attached to the common bar. The bar is fixed on two guides, and allows the clamp caps to easily move up and down. Caps can be easily removed from the bar, which allows one to easily place the dough inside. Each clamp cap is perforated with round holes of Ø5 mm in 10x10 mm distance for the access of moist air in the proofer. The cap itself, as well as the common bar and the caps edges are made of monolithic 8 mm polycarbonate sheet. During the experiment, 6 thermocouples were fixed in the clamp cap of one sample; the layout is shown in Figure 2.

![Figure 1. Drawings of an installation for electric resistance baking](image1)

![Figure 2. The layout of thermocouples in the clamp cap](image2)
2.4 Parameters measured during baking

During baking, we measured the current going through the dough samples, as well as the dough temperature. The current was measured with an IEK 266 C digital multimeter. The temperature was measured with K-type thermocouples with a shrink tube sheath. Thermocouples were connected to the OWEN MB-110 analog input module connected to a personal computer via the RS485-USB interface. Temperature changes were monitored in MasterScada software [13].

3. Results and discussion

3.1 Experiment 1. Baking without a clamp cap, stopping by current, absence of greasing.

The graph of changes of the current and temperature measurements is shown in Figure 3. The layout of thermocouples and of digital multimeters is shown in Figure 4.

![Figure 3. The graph of changes in current force in experiment 1.](image)

The analysis of the graph shows that the baking time was of 9 minutes, the maximum dough temperature at three points was of 100 .. 103 °C, and the maximum value of the current going through one dough sample was of 2.43 A. The difference between the current measurements can be explained by some difference in the proofing degree, in the contact area of the dough with the electrodes of the two samples, as well as by the measurement inaccuracy. During baking, the maximum height of the dough samples, which were not limited from above, increased by more than 20% and was of more than 100 mm, while the initial height before baking was of 80 mm.

![Figure 4. The layout of thermocouples and of digital multimeters in experiment 1](image)
The weight of bread after the electric resistance method baking was of 461 and of 464 g respectively, while the weight of the control sample made with convective baking was of 429 g. Thus, we can conclude that the baking loss after the ER-method baking is less, which positively affects the yield of the finished bread.

The finished products obtained after EC-baking showed the following defects:
1. The lateral surfaces of the bread in contact with the electrodes were wet and sticky after baking; the surfaces dried up after cooling for 1 h at a temperature of 22 ± 1 °C.
2. During the cutting of bread after cooling, it was found that the structure of the crumb is not homogeneous; in the lower right quarter of the cross section of the bread there is a region of low humidity, which is characterized by higher obduracy and hardness of the crumb.

The photos of finished products are shown in Figure 5.

3.2 Experiment 2. Baking with a clamp cap, stopping by temperature, absence of greasing

A graph of changes in current and temperature measurements is shown in Figure 6. The layout of thermocouples and of digital multimeters is shown in Figure 7.

Figure 5. The photos of finished products of experiment 1

Figure 6. The graph of changes in current force in experiment 2
The analysis of the current and temperature measurements shows that in experiment 2, the baking time was of 5 minutes, and the current measurements are similar to those of the experiment 1. The maximum process temperature was of 99 °C, and the maximum current going through one dough sample was of 2.53 A. The measurements of the current of the two samples are very close; it is likely that the clamp caps reduce the differences in the contact areas of the two samples. The clamp caps were set so that the weight of the caps did not impact the dough until it reached the height of 80 mm. We considered the moment when the dough touched the clamp caps as the end of the proofing. At the same time, during baking, the dough raised the caps to the height of 95 mm, completely filled the space under the claps and formed a flat surface.

The weights of dough samples obtained by the ER baking were measured immediately after baking and were of 428 and 425 g respectively. The weight of the control dough sample after baking was of 394 g. As in the previous experiment, the baking loss after the ER baking was lower than during the convective baking method.

The photos of finished products are shown in Figure 8.

The products obtained during experiment 2, showed the following features:

1. The defect of the wet side surfaces in contact with the electrodes completely disappeared; this was, probably, due to a shorter baking time. At the maturation of the dough sample after reaching a temperature of 100 °C, the moisture evaporation may continue. A visual analysis showed that
moisture evaporates the most intensively from the contact area of the dough and electrodes, and a high evaporation rate can provoke a defect on the wet side surfaces of the bread.

2. There is no defect in the area with low humidity; the entire section of the obtained bread is uniformly baked and not overdried.

3. The finished bread is characterized by tenderness and elasticity of the crumb, uniform porosity with a small pore size, and a high quality of organoleptic characteristics.

According to the results of experiment 2, experiment 3 was performed in which the surface of the electrodes and the lower edges of the clamp caps were sprayed with a mould grease.

3.3 Experiment 3. Baking with a clamp cap, stopping by temperature, greasing of electrodes and of clamp caps.

The experiment 3 is almost completely identical to experiment 2. There were no significant differences between the bread samples obtained in experiments 2 and 3. Thus, we can assume that the dough absorbs the greasing spray during proofing, leveling the difference between experiments. However, the use of a spray is justified for the treatment of clamp caps, as in the absence of any greasing; the caps stick to the dough during proofing.

4. Conclusions
In the course of the experimental work, it was revealed that the technology of electric resistance baking allows getting a crustless toast bread with high quality organoleptic characteristics. The use of this method of heating the dough shortens baking time and reduces to zero the loss associated with cutting the crusts.

High quality organoleptic characteristics of finished products can be achieved under the following conditions:
1. use of the formula and technology of American toast bread;
2. special method of dough shaping, which includes rolling the dough and cutting the rolls into 3 or 4 parts, followed by putting them in moulds and orienting them perpendicularly to the electrodes;
3. division of the dough samples into pieces based on 225 g of dough per liter of the mould volume for ER baking;
4. use of the electric resistance oven design, equipped with a clamp cap that can move up and down;
5. greasing of the lower edges of the clamp caps;
6. baking the dough at 220 V, 50 Hz until it reaches a temperature of 98 .. 100 °C.

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