Application of electrophysical heating methods in food production processes

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Abstract. The electrophysical methods of heating (IR; IR- + Microwave, IR + convection, Microwave + IR + convection) using quartz infrared emitters, dark emitters, a magnetron for blowing hot air heater are widely used at the restaurant department. For business, a laboratory stand was developed, equipped with all instrumentation for fixing temperature, mass, humidity; changes in all parameters are reflected on a computer monitor with the appropriate software. Experimental studies were carried out on drying vegetable semi-finished products such as carrots, pumpkin. Experimental studies conducted in the laboratories of the department of restaurant business of the Plekhanov Russian University of Economics showed the influence of various methods of energy supply (convection, microwave energy, infrared energy, combined methods) on the drying processes of carrots and pumpkins. The optimal drying conditions for carrots and pumpkins have been developed, ensuring maximum preservation of the organoleptic characteristics (color and smell) of the dried product with minimal energy and duration of the process, as well as nutritional and biological value.

1. Introduction
In order to provide the population with quality products, the drying industry plays an important role, the task of which is to ensure maximum preservation of food and biological value in the process of dehydration of products, and for this it is necessary to select modern methods and methods of energy supply and develop design solutions for apparatus and equipment for the implementation of drying processes.

Over the past decades, the infrared method of processing food products has been widely used for the practical implementation and design of furnaces in industry. The depth of penetration into some typical food materials related to heating has been studied, including spectroscopic measurements of the chemical composition (analytical application) of food products. Table 1 shows the scope of infrared processing.

A number of Russian scientists introduced the theory and practice of studying electrophysical methods in various food technologies: Azarov, L.Ya. Auerman, V.Ya. Adamenko, I.Yu. Aleksanyan, V.S. Baranov, A.S. Bolshakov, A.A. Buynov, I.N. Owner, M.P. Volarovich, N.A. Voskresensky, A.N. Vyshelesky, A.S. Ginzburg, N.A. Golovkin, A.V. Gorbakov, V.S. Gruner, E.A. Guigo, A.I. Zharinov, Yu.S. Zayas, S.G. Ilyasov, E.I. Kaukhechshvili, V.V. Krasnikov, S.V. Nekrutman, Yu.M. Plaksin, I.A. Rogov, V.I. Khlebnikov et al.
Table 1. Scope and methods of IR processing [1]

| Processing method                                                                                     | Materials to be processed                                                                 |
|-------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Thermo-radiation drying and polymerization of coatings. warming up culinary products                  | enamels, films, culinary products in polymer packaging [7]                                 |
| Infrared drying combined microwave + infrared radiation-convection drying in food, light, ceramic,   | cereals, seeds, vegetables, fruits, bread, refined sugar, tea, tobacco, marmalade products,  |
| food concentrate, etc.; in the production of vegetable oils                                            | pine nuts, waste pinecones, peppermint cotton seeds [4]; dry fruit and vegetable breakfasts  |
|                                                                                                       | from potatoes and carrots for baby food and preventive purposes [8]; fabrics, fibers,       |
|                                                                                                       | thermal insulation and ceramic products, raw plaster, foundry molds, food additives:       |
|                                                                                                       | powders of vegetable, animal and marine origin; food concentrates, dry mashed potatoes,   |
|                                                                                                       | sunflower seeds, malt, stone seed oil, cottonseed oil, tomato paste [2]                     |
| Baking with infrared rays and combined baking in a high frequency electric field and infrared rays    | biscuits, muffins, cakes, bread, national types of bread: flat cakes, Armenian pita bread;  |
|                                                                                                       | flour culinary products of Russian cuisine and cuisine of the Central Asian region [12]    |
| Roasting, smoking, baking, cooking                                                                   | meat, fish, sausages, hot smoked fish, soybeans, catering products, boiled beef, fried     |
|                                                                                                       | beef, boiled pork, fried pork, boiled potatoes, boiled chicken, cod, pollock, sea bass,     |
|                                                                                                       | hake, mackerel,pike perch, pike, fried horse mackerel, Far Eastern boiled flounder, boiled  |
|                                                                                                       | mackerel                                                                                   |
| Heat treatment (irradiation):                                                                         |                                                                                                                                               |
| In order to improve quality                                                                          | flour, cotton myatkakakha friable rice, millet porridge friable corn                      |
| Pest control                                                                                          | grain                                                                                     |
| Thermal conditioning                                                                                  | grain (before grinding) [1]                                                                |
| For peeling (during canning)                                                                           | apples, vegetables                                                                        |
| Pasteurization and many other processes                                                               | milk, cocoa, cream, beer, wine, compote, jelly, drink of rose hips, apricot puree, orange  |
|                                                                                                       | puree, banana puree, carrot puree, carrot cutlets, potato cutlets. tomato juice, beetroot  |
|                                                                                                       | juice, carrot juice, quince juice, grape juice pomegranate juice, apple juice, apricot     |
|                                                                                                       | compote                                                                                   |
| In the production of food additives - powders:                                                       | apple, beetroot, carrot, quince [10]; meat [11]; dried apples [1] and pears, dried melon, |
| fruit, vegetable; products of marine origin                                                           | dates, figs, raisins, candied fruits (papaya, banana chips, coconut)                       |
The intensive development of applied biotechnology, information technology, system analysis and mathematical methods created objective prerequisites for a new level of understanding of the physical nature, analytical description and numerical implementation of heat and mass transfer processes during the heat treatment of animal and vegetable raw materials. This allows you to scientifically substantiate the optimization of production processes when using non-traditional types of heat exposure, as well as the ability to control processes at all stages of food production [1,2,3].

For many years, the department of the restaurant business has been developing in the field of application of electrophysical heating methods for food processing in various drying processes, heat treatment.

2. The purpose of the study
Development of optimal food drying processes with maximum preservation of quality indicators.

3. The object of the study
Objects of the study are pumpkin and carrots.

4. Materials and methods
For the study we used a laboratory bench with combined microwave heating techniques such as heating elements, quartz infrared emitters, magnetron, convective heating method, injected air heater.

5. Discussion of the results
Studies were carried out to select the optimal drying regime for carrots, which should ensure the maximum preservation of carotene in carrots, from which vitamin A is synthesized in a living organism, which was ensured by the low temperature of drying air in the chamber (not more than 60-70 °C) [4].

Drying was carried out on samples without a peel cut into identical pieces weighing 0.710.5 g and sizes of 1-2 mm in the form of plates. The initial moisture of carrots is 86.1% extending to the final 10-14%. Qualitative indicators of dried samples were evaluated by appearance, color, smell, and consistency [5].

For experiments, a laboratory bench was used: an oven in which various methods of energy supply are implemented (convection, microwave drying, infrared drying, combined methods of energy supply [6,7].

The experiments resulted in graphical dependences of drying (Figure 2, 3).

![Carrot sample drying curves](Image)
Figure 2. Carrot sample drying curves

The drying time and energy consumption for the process under the considered modes are shown in table 2.

Table 2. Process parameters for different drying methods

| Drying method      | Drying time, s | Power consumption, kJ |
|--------------------|----------------|-----------------------|
| Convection         | 1260.00        | 2581.2                |
| Microwave          | 40.02          | 43.2                  |
| IR                 | 1140.00        | 1425.6                |
| Microwave + convection | 40.02  | 79.2                  |
| Microwave + infrared | 19.80         | 39.6                  |

Based on the experiments, the optimal mode was determined: pulsed drying mode with a phased alternation of energy supply methods, the results are presented in tables 2 and 3. The relative air humidity for 1.5 minutes of the experiment increases slightly due to evaporation of moisture from the sample, and then decreases due to temperature increase in the chamber [8].

Table 3. Drying modes of the prototype

| № stage | Drying mode | Measurement time, τ min | The mass of the sample after τ min, g | Loss of mass, g | The humidity of the sample w,% | Air temperature in the chamber, t, °C | Humidity in the chamber φ, % |
|---------|-------------|------------------------|--------------------------------------|----------------|-------------------------------|-------------------------------------|-----------------|
| 1       | Microwave   | 0.000                  | 0.71                                 | 0.00           | 86.10                         | 26.1                                | 17.0             |
| 2       | Microwave   | 0.166                  | 0.67                                 | 0.03           | 80.28                         | 26.6                                | 17.5             |
| 3       | IR          | 1.166                  | 0.63                                 | 0.08           | 74.65                         | 28.8                                | 17.6             |
| 4       | Microwave   | 1.332                  | 0.59                                 | 0.12           | 69.01                         | 30.8                                | 17.5             |
| 5       | IR          | 2.332                  | 0.55                                 | 0.16           | 63.38                         | 34.2                                | 17.3             |
| 6       | Microwave   | 2.498                  | 0.52                                 | 0.19           | 59.15                         | 37.2                                | 17.3             |
| 7       | IR          | 3.498                  | 0.49                                 | 0.22           | 54.93                         | 40.3                                | 16.9             |
| 8       | Microwave   | 3.664                  | 0.45                                 | 0.26           | 49.30                         | 43.6                                | 16.7             |
| 9       | IR          | 4.664                  | 0.41                                 | 0.30           | 43.66                         | 45.6                                | 16.2             |
| 10      | Microwave   | 4.830                  | 0.38                                 | 0.33           | 39.44                         | 48.7                                | 16.1             |
| 11      | IR          | 5.830                  | 0.33                                 | 0.38           | 32.39                         | 50.0                                | 16.1             |
| 12      | Microwave   | 5.996                  | 0.30                                 | 0.41           | 28.17                         | 53.2                                | 16.0             |
| 13      | IR          | 6.996                  | 0.26                                 | 0.45           | 22.54                         | 53.7                                | 15.9             |
| 14      | Microwave   | 7.162                  | 0.23                                 | 0.48           | 18.31                         | 56.5                                | 15.8             |
| 15      | IR          | 8.162                  | 0.20                                 | 0.51           | 14.08                         | 56.5                                | 15.9             |
| 16      | Microwave   | 8.328                  | 0.19                                 | 0.52           | 12.68                         | 58.7                                | 15.8             |
| 17      | IR          | 9.328                  | 0.18                                 | 0.53           | 11.27                         | 58.9                                | 16.0             |
Figure 3. a) Drying curve $W = f(\tau)$; b) curve of the drying rate $\Delta W / \Delta \tau = f(W)$ under optimal conditions

Pumpkin is one of the best-selling vegetables. The production of dried pumpkin and the determination of the optimal drying regime with maximum preservation of quality indicators with minimal energy intensity and duration of the process are an urgent task [9].

The experiments were carried out using different methods of supplying energy to a dried sample, the moisture content of which is 90%, as average for different pumpkin varieties, cut into pieces with a mass of $M = 0.054 \pm 0.5$ g and side sizes of $3 \times 10 \times 15 \pm 1-2$ mm in the form of a plate. Samples were dried to a moisture content of 8-12% with three measurements. The finished, semi-finished product was evaluated by organoleptic methods [10].

With convective drying, the temperature in the working chamber reached 136 °C, which is unacceptable, since at temperatures above 70 °C, the destruction of nutrients and vitamins occurs in vegetables [11]. The heating period of the sample was 6 minutes, and then there was a slow decrease in the humidity of the sample, which reached the desired value (12.2%) after only 19 minutes. In this case, the energy consumption was 2337 kJ.

During microwave drying, the sample decreased in size and acquired a uniformly solid golden crust along the edges, however, a burning area appeared in the central part. The drying curve (Figure 4) shows a section of rapid heating of the pumpkin sample, which is characterized by a sharp increase in the drying rate, which is explained by the extremely efficient absorption of microwave energy by the product, which results in the conversion of this energy to heat in the entire volume of the sample, resulting in an extremely intense rise in temperature. Further, a gradual decrease in humidity to 22% is observed, but it is not possible to achieve the desired value of 8-12% due to the strong overheating of the sample, which leads to its burning.

During infrared drying, the sample is quickly warmed up under the influence of IR radiation, and in 14 minutes it is possible to achieve its moisture content of 11.5%, a uniform crust over the entire area of the product. There were no signs of the slightest burning, and the smell and color were characteristic of the heat-treated pumpkin.

The infrared drying mode allows you to get a product with high organoleptic characteristics, the drying time is 15 minutes.

In the combined method of drying microwave + convection, the sample was quickly dehydrated, but when the humidity reached 40% in the central region, signs of a burnt product were observed [12].

In the combined method of drying the microwave + infrared, the initial dimensions of the sample changed, the plate was deformed due to burning in the middle part. Burning is noticeable in the central region with a characteristic dark brown color and crumbling fibers. Microwave drying allows you to quickly and throughout the volume warm up the product, which is reflected in the greatly
increased drying speed in the first 10 seconds (Fig. 2). Parallel IR drying contributed to the heating of the pumpkin due to the absorption of IR energy by water molecules. Upon reaching the evaporation temperature, moisture is removed slowly, since its movement is prevented by a crust on the surface of the sample [13]. In this drying mode, the sample burned very quickly, while the final humidity was only brought up to 61.7%.

![Figure 4. Drying curve W = f (τ) of a pumpkin sample at various energy supplies](image1)

![Figure 5. Curve of the drying rate ∆W / ∆t = f (W) of a pumpkin sample at various energy supplies](image2)

To select the optimal drying mode for a pumpkin sample, in the same way as for carrots, experimental studies of various modes were carried out with a phased alternation of methods for supplying energy with different durations for each stage [14]. As a result, the following mode was selected: the first stage - microwave drying - 20 seconds; the second stage is IR drying - 300 seconds. Drying curves and drying rates are shown in Fig. 6,7. In this mode, the sample humidity reached 12% in 640 seconds, which is less than with IR drying or convection [15].

As can be seen from the drying curves (Fig. 3) and drying speed (Fig. 4), moisture is intensively removed at the stages of microwave energy supply, where the drying speed is high, and then more slowly - at the infrared stages, where the drying speed decreases sharply [16]. This is explained by the influence of the microwave field, which contributes to extremely fast volumetric heating of the entire pumpkin sample [17, 18]. The air temperature in the chamber in this mode is only 63 ° C. Such a low
temperature helps to maintain up to 80-90% of nutritional value and vitamins in the dried product [19]. The organoleptic assessment was positive, the energy consumption was 790 kJ, which is much less than with other modes.

![Drying curve W = f (τ) of a pumpkin sample under optimal conditions](image1)

**Figure 6.** Drying curve $W = f (\tau)$ of a pumpkin sample under optimal conditions

![Drying curve $\Delta W / \Delta t = f (W)$ of a pumpkin sample under optimal conditions](image2)

**Figure 7.** Drying curve $\Delta W / \Delta t = f (W)$ of a pumpkin sample under optimal conditions

6. **Conclusion**
Experimental studies conducted in the laboratories of the department of restaurant business of Plekhanov Russian University of Economics showed the influence of various methods of energy supply (convection, microwave energy, infrared energy, combined methods) on the drying processes of carrots and pumpkins. The optimal drying regimes of carrots and pumpkins have been developed, providing maximum preservation of the organoleptic characteristics (color and smell) of the dried product with minimal energy and duration of the process [20], as well as nutritional and biological value.

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