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Application of ultrasonic method for investigation of porous plates

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Abstract

Application of ultrasonic method for evaluating porous plates is presented in this article, The ultrasonic echolocation measurement method to evaluate porous structures is presented. The mathematical model is considered for uniform and non-uniform volume structure of the product. The pores on the surface are smaller then in the depth of a flat surface. The indirect ultrasonic measurement method is proposed for investigation of porous plates. The porosity of a product is evaluated by absorbed liquid volume versus time using this method. The volume of the absorbed liquid is calculated according to the liquid level in the cylindrical measurement vessel versus time. The level of liquid is measured by acoustical echolocation method through air. The measurement vessel construction was improved for planar objects. The obtained uncertainty in distance measurements till the liquid surface is five micrometers in the forty millimeters measurement interval. The focusing electroacoustical transducers were used for investigations.

The experimentally tested technique allows to apply acoustic method for various porous plates structures investigations when others methods give results with great uncertainties. This article can be beneficial for researchers, who specialize in evaluation of porous structures.

Keywords: physical-mechanical properties of porous food products, evaluation of porous products, structure of porous products, acoustic echolocation method, ultrasonic measurement method, focusing electroacoustical transducer.

Introduction

The porosity and its distribution with in depth of plates is considered in this paper**.** Porosity is one of the most important quality properties of grain products [1]. Porosity parameters were estimated using various methods [2-6]. We compared results of porosity evaluation of wafer plates obtained by measurement of mechanical deformations and by a complex (using ultrasound) method. The measurements using mechanical deformations are based on force registering when the product is bent [1].

The complex ultrasonic method at the same time is analyzed [6-10]. In this method we measured the quantity of absorbed liquid without taking the sample out of the measurement vessel. Also we determined the quantity of liquid penetrating the sample in real time. We measured the change of liquid's level in the measurement vessel. For this purpose, a highly accurate level meter for liquids and a special measurement vessel were used.

After the sample is submersed, the level of liquid begins to change in the measurement vessel. The velocity of this change depends on the material's porosity. Among other methods, the ultrasonic echolocation method can be used to measure the change of liquid's level. The obtained results, when using this method to measure porosity of various materials, were described by us in [7].

Object

The objects of investigations were plates of wafer which were baked from the mixture, the receipt of which is presented in Table 1. Different components of the receipt are given in percents of weight (g):

Quantity of corn flour in separate samples are change with secant case: samples 11 – 2,76 g, samples 8 – 4,26 g, samples 4 – 4,76 g, samples 6 – 7,76 g, samples 7 - 8,26g.

Table 1. **Receipt of baking mixture**

Wheat flour 550C	95,95
Corn flour	Sample N4,6,7,8,11
Sugar powder	40,29
Raps oil	2,88
Lecithin	0,95
Soy(a)bean flour	2,39
Salt	0,50
Water	125,92

The samples of the same volume were taken for investigations in different ways.

Models of the objects

The peculiarity of flat porous products is that they are produced often by pressing the raw material between flat surfaces. The volume of the product cannot change considerably during the formation process. Because of these specific features the structure of layers near to the surface can differ noticeably from the structure of deep layers. The layers on the surface are pressed, are denser and more influenced by higher temperatures during production. The density of formed pores in this part of product is smaller and they are of smaller volume by considering them separately.

In the case of a flat product we can consider a model of an infinite flat surface semi - space into which the liquid is penetrating (Fig. 1). Such a model is valid for products of limited thickness till liquid penetrating from two sides of the product reaches internal central plane that is at equal distances from two sides of the product.

In investigations of liquid penetration into deep layers of such surface we should have in mind arising resistance to the liquid flow by flowing through filled layers. This resistance increases with a depth linearly in the first approach in which volume is considered being uniform. If the structure changes with a depth (Fig.1) it influences the velocity of liquid penetration non-linearly.

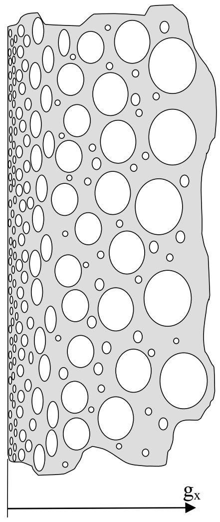

Fig. 1. **Model of flat surface having changing internal structure; g_x is the coordinate of depth into the sample**

In the case of the same diameter of pores, e.g. uniform distribution, the velocity of moistening depends on a thickness of the layer already moistened:

$$dV_g = -k_{ps} V_g \, dt, \quad (1)$$

where V_g is the velocity of liquid absorption in the unit area surface; k_{ps} is the coefficient of resistance to the flow; t is the time. In the case of the uniform density the k_{ps} is constant.

The velocity of liquid absorption after integration is [11]:

$$V_g = V_{g0} \, e^{-k_{ps} t}, \quad (2)$$

where V_{g0} is the initial velocity of absorption.

The volume of the absorbed liquid will be integral of the liquid absorption velocity:

$$V_s = \int V_g \, dt = V_{g0} \, (1 - e^{-k_{ps}}) / k_{ps} . \quad (3)$$

The integration constant is set under initial condition that no liquid was absorbed at the beginning.

If the structure of a sample changes with depth the flow resistance coefficient k_{ps} changes too. For example, if the density of material decreases (because of less pressing), the contribution into sum resistance of these deeper layers is smaller. Let us consider two cases:

1) the change is linear: $k_{pst1} = k_{ps0} - k_{pk1} \, t$; where k_{pk1} is the inclination coefficient;

2) it can change by the square law: $k_{pst2} = k_{ps0} - k_{pk2} \, t^2$.

Graphs of these cases are shown in the Fig.2.

We can see from the graphs in Fig.2 that in the case of the uniform distribution of pores inside of the volume the exponential growth of the absorbed liquid volume can be obtained. The graph 2 represents the linear decrease of the resistance coefficient with a depth. The last stages of liquid absorption are similar to the linear growth. In the case 3 decrease of the flow resistance coefficient is according to the square law. Variations of the polinoms coefficients produce a little bit different shapes of graphs.

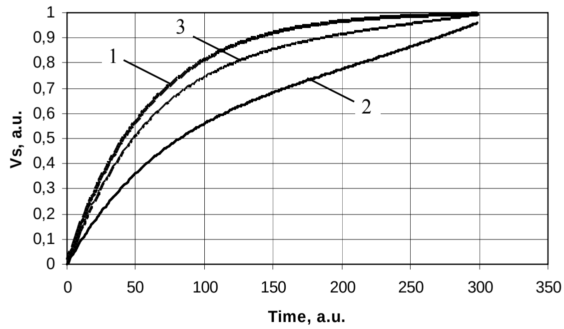

Fig. 2. **Graphs of the absorbed liquid volume versus time in different cases: 1 - porous volume is uniform; 2 – the flow resistance coefficient depends on the depth linearly; 3 – the flow resistance coefficient depends on the depth by the square law.**

Methods

The force of wafer deformation is accomplished with the analyzer of texture TA – XT2 [1]. The changes of the force (for the samples 4, 6, 7, 8, 11) are shown in Fig. 3.

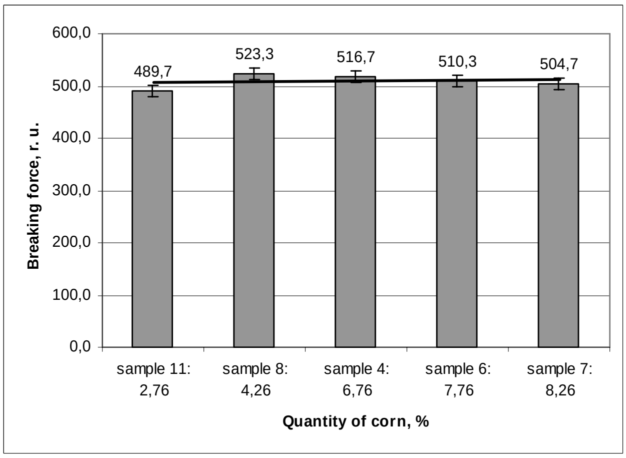

Fig.3. **Diagram of the mechanical measurement method for determining the porosity of plate food products (samples 4, 6, 7, 8, 11).**

The small diferencies of braking force for various receipts were obtained. It is difficult to distinguish mechanical properties of different products.

The measuring diagram for plate porous materials by using acoustic echolocation method is shown in Fig. 4. The measurement vessel construction was improved for planar objects. The obtained uncertainty of the distance measurements till the liquid surface is 5 micrometers in the forty millimeters measurement interval h_m. The focusing electroacoustical transducers (FUT) were used for investigations. From the moment of the sample's submersion, the reducing water level is being constantly recorded until it reaches h_m (Fig. 4). The water level is falling, because it is penetrating into the pores of the sample, replacing air is the process. The penetration rate of the water is directly proportional to the porosity of the sample [7].

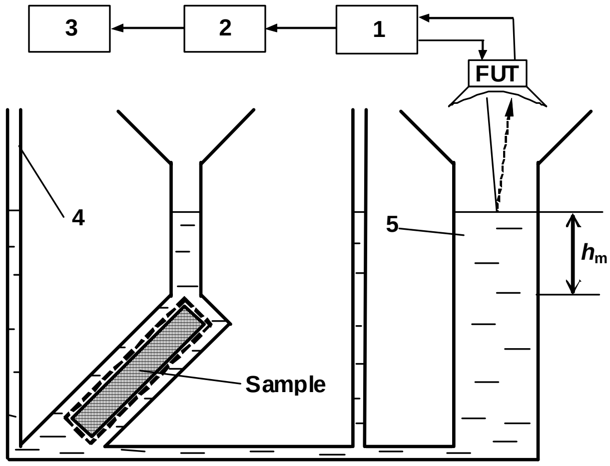

Fig.4. **Stages of the porosity evaluation process using the acoustic echolocation method: 1 - the acoustic liquid level meter, 2 – interface, 3 – personal computer, 4 - the reticular case for the sample, 5 - the liquid level measurement part**.

The changes of the water level are shown in Fig.5.

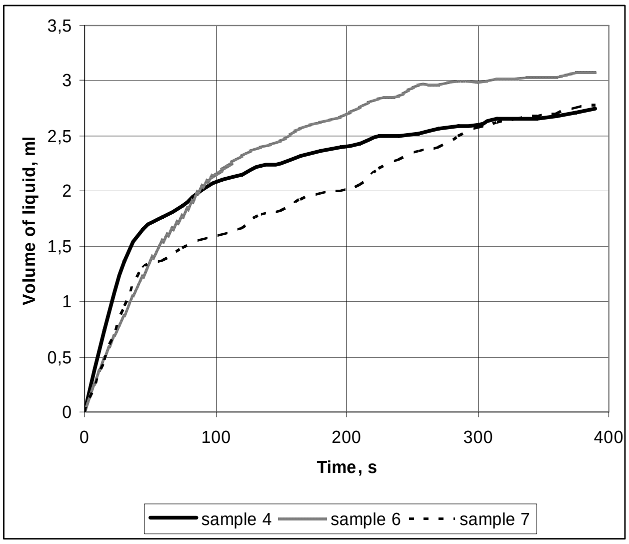

Fig.5. **The dependencies of the volume of the absorbed water of plate food products (samples 4, 6, 7)**.

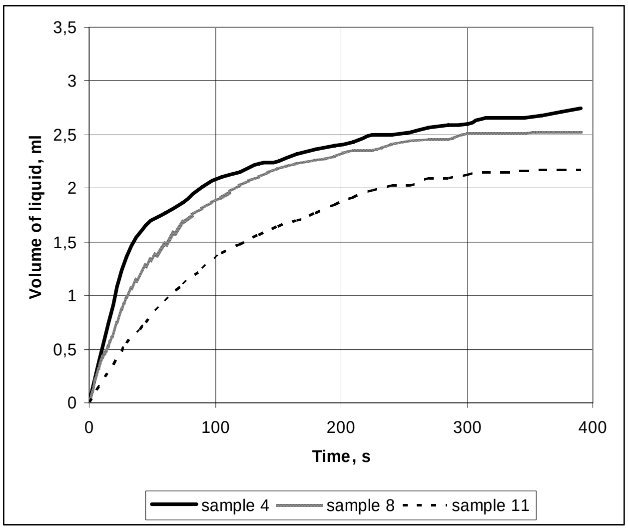

Fig.6. **The dependencies of the volume of the absorbed water of plate food products (samples 4, 8, 11).**

We can see from Fig. 5 and 6 that the samples with a smaller percentage of corn flour amount have a smaller surface porosity and with a greater amount of corn flour have a greater surface porosity. At the same time results of the investigation using the mechanical force measurement did not show any differencies (Fig.3).

Conclusions

We can see from the results of modeling and measurements that liquid level measurement during liquid absorption by a product can have advantages in comparison to the mechanical method. From dependencies of the absorbed liquid volume by plate food products they can make decision about not only porosity of the product, but also about law of changes of pores diameters with depth.

The acoustic echolocation method for determining porosity can be used in laboratory conditions, because they are faster when comparing them with mechanical measurement methods. When measuring the changes of liquid's level by using an acoustic level meter, the sample remains submersed during the whole measurement time. In this way, the dynamics of water absorption process can be recorded.

During the first instants after submersion, a porous materials with a defect-free surface layer absorb liquid very slowly and the absorbed quantity of water is low (up to 1 ml). Because of that, the liquid's level in a measurement vessel changes very slowly. To detect such low changes in the liquid's level (corresponding to the volume of 1 ml), a very precise ultrasonic acoustic level meter is required. The level meter must be able to measure distance interval from 1 till 40 mm. The absolute error of the unit should be less than 5 microns, when the temperature is 60˚C.

When using an indirect acoustic method for measuring porosity, an additional information about the defects of the product's surface is obtained versus the time, during which the product completely disintegrates.

When combining acoustic level meters for measurement of small distances with special technological measurement equipment, they can be used to determine porosity of materials. Therefore, such equipment can be used in research projects for the food industry.

Acoustic level meters for small distances can be used during designing measurement equipment to analyze and evaluate internal structure of plate-like food products.

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Ultragarsinis metodas poringų plokštelių struktūrai tirti

Reziumė

Nagrinėjamas poringų plokštelių struktūros matematinis modelis. Buvo tiriamos tokios plokštelės, kurių paviršiuje poros mažesnės negu plokštelės gilumoje. Poringoms plokštelėms tirti siūloma taikyti netiesioginį poringumo matavimo metodą, kai poringumas nustatomas pagal įgeriamo skysčio kiekį laikui bėgant. Įgerto skysčio kiekis cilindriniame matavimo inde nustatomas pagal skysčio lygio kitimą laike. O šis kitimas matuojamas aidolokaciniu akustiniu metodu. Matuojama per orą. Naudojant patobulintos konstrukcijos matavimo indą, gauta skysčio stulpelio aukščio matavimo inde neapibrėžtis - trys mikrometrai keturiasdešimties milimetrų matavimo intervale. Matavimams naudoti ir fokusuojamieji elektroakustiniai keitikliai.

Įgyvendinta plokščių gaminių poringumo nustatymo galimybė leidžia pritaikyti akustinį metodą įvairių poringų plokštelių (tarp jų ir duonos gaminių) struktūrai tirti, kai kitais metodais tyrimo rezultatai gaunami su didelėmis paklaidomis. Straipsnis skirtas tyrėjams, dirbantiems naujų poringų gaminių kūrimo srityje.

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