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Determination of consistency of concentrated dispersed systems by the method of gravitational penetration

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Abstract

Introduction. Analytical and experimental studies consistency dispersion systems of the new method – gravitational penetration.

Materials and methods. Dispersion systems – pate meat products from mechanically separated poultry are being investigated. The consistency was determined by gravity penetration. Penetration indices are determined on the basis of mathematical modeling of indenter motion in the product layer based on second order differential equations of motion.

Results and discussion. The proposed method for determining consistency is easy to use. The presented calculus dependencies and mathematical models are based on physical constants, which makes the method of gravitational penetration versatile for wide practical application in estimating the quality of food by the express method. The presented mathematical model obtained based on the second-order differential equations, suitable for different research and use me different designs gravitational penetrometer.

To perform a comparative analysis of the consistency of food products obtained from different technological modes or formulations, it is proposed to use a comparative characteristic in the form of a coefficient K. Its value is calculated as the ratio of the depth of immersion of the needle into the product layer when falling penetrometer from one height.

The highest rates were pate sample containing 40% of mechanically separated poultry meat and 8% of rice flour, and the smallest, pate sample, containing 30% mechanically separated poultry meat and 10% of rice flour.

Conclusion. Defining the method of gravitational penetration extends the possibility of obtaining accurate results in comparison with the use of existing methods and a priori formulas.

Introduction

The penetration method is widely used for researching the consistency of structured foods. The experience with the practical application has confirmed the difficulty of getting unambiguous indicators of the force or other selected characteristics of the consistency obtained while even penetrometers and research methods of the same design are used. This is due to the measurement features embedded in their design and using the variety of mathematical calculation models [1, 2].

The modern penetrometers measure the magnitude of the force and the immersion depth of the indenter to determine the consistency of solid-like foods. Measurement is usually automatic. In this case, they use complex and, accordingly, cost-integrated electronic mechanical systems [3, 4].

To simplify the design of the penetrometer, which significantly reduces its value and obtain an accurate measurement result, adapted for different research conditions and properties of the studied materials, a simple gravitational method for determining the consistency of food-structured whole-piece dispersed systems is proposed. The new method is based on the fundamental laws of mechanics, which describe the motion of a solid material system (indenter) by gravity through a layer of material [5, 6].

For the universality of the research method, it is possible to use interchangeable indenters of various designs, and as a characteristic of consistency to determine penetration force, for example, using a needle working member, and penetration energy while using any other form of indenter [7, 8].

The purpose of the article is to promote and familiarize professionals with an innovative method of determining the consistency of concentrated food dispersed systems.

Materials and methods

Experimental device

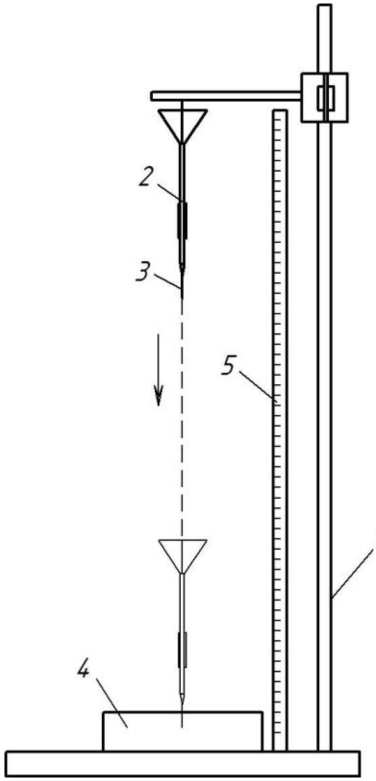
During determining the consistency by the gravitational penetration method, it is measured the mass of the penetrometer, the height of its falling and the immersion depth of the indenter. These measurements are very simple and do not require any special equipment. The measurement sequence of the consistency of concentrated dispersed systems is shown in Figure 1.

Measurement order

Penetrometer in the form of a dart with a needle (indenter), tripod or other device for fixing the penetrometer at height, ruler for measuring the depth of the indenter, sample product.

The measurement sequence is as follows:

- the penetrometer is fixed with a tripod at a height H;
- a sample of product is placed on the bottom of the tripod on a porous substrate;
- release the mechanism of attachment of the penetrometer, which allows it to fall under the action of gravity on the surface of the sample;
- measure the depth of needle immersion;
- in the selected mathematical model for calculating the characteristics of consistency substitute the measurement data: m – penetrometer mass; H – drop height; y – immersion depth of the indenter into the product sample;
- calculate the consistency characteristics.



a

b

Figure 1. Experimental device:
a – experimental device; b – penetrometer;
1 – tripod; 2 – dart; 3 – needle; 4 – products; 5 – straightedge.

During the research to obtain reliable comparative indicators of consistency characteristics, it is necessary to use one-mass penetrometers with the indenters of the same shape and needle diameter and perform calculations according to one of the selected mathematical models, neglecting insignificant influencing factors on movement of the indenter in the product layer.

Investigated products

Changes in the structural and mechanical properties of a product that contains a different amount of mechanically separated poultry meat (MMV) are studied for recipes:

№2 – 30 %,
№3 – 35 %,
№4 – 40 %,
№5 – 45 %
and with rice flour addition:
№2 – 10 %,
№3 – 9 %,
№4 – 8 %,
№5 – 7 %

Results and discussion

Mathematical model of gravitational penetration

If in terms of product consistency characteristics, the vibration of the intension Fp movement resistance will be chosen, its magnitude could be found by using the motion differential equation of material system.

$$F_H + F_P = F_T , \qquad (1)$$

F_H – inertia force, H; F_P – movement resistance force of the indenter, H; F_T – gravity, H.

In Figure 2 it is shown a diagram of penetrometer immersion in the product and power layer that are acting during this process.

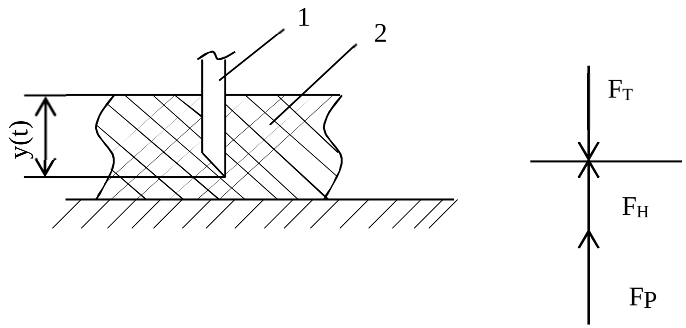


Figure 2. Scheme of penetrometer indenter immersion into the product layer and the forces acting on its motion:
1 – indenter needle; 2 – product.

Equation (1) is rewritten by revealing the magnitudes of forces.

$$m\frac{d^2 y(t)}{dt^2} + F_p = mg \qquad (2)$$

Consider the initial conditions: t = 0, $y(0)$ = 0; $V(0) = \sqrt{2gH}$,

H –height, from which the penetrometer falls.

The equation solution (2) is written as follows:

$$y(t) = \frac{\left(mg - F_p\right)\cdot t^2}{2m} + V_0 t \qquad (3)$$

From the equation (3) we find the resistance force of the indenter motion:

$$F_P = \frac{\left(t^2 g + 2V_0 t + 2y(t)\right)\cdot m}{t^2} \qquad (4)$$

The analysis of the equation (4) shows that in order to determine the magnitude of the force F_P it is necessary to know the quantities: the initial velocity V_0, which is calculated from the equation $V_0=\sqrt{2gH}$; m – by mass of the penetrometer, which we find by weighing it; g – acceleration of the free fall of the body, which is a known physical constant g=9,8 м/с^2; $y(t)$ the immersion depth of the indenter, which is found by measuring the length of the needlein the product layer after stopping the movement of the penetrometer; t – duration of the needle immersion in the product layer, it is found by calculation after below mentioned analytical research of the material system mathematical model.

From the equation (3), we find the speed of the indenter.

$$\frac{dy(t)}{dt}=\frac{(mg-F_P)\cdot t}{m}+V_0 \tag{5}$$

At the end of indenter immersion, we have zero motion velocity. $\frac{dy(t)}{dt}=0$.

From the equation (5) we find t:

$$t=\frac{V_0 m}{F_P-mg} \tag{6}$$

With the use of equations (4) and (6) we can find the characteristic of the product consistency F_P. The calculation of the indenter movement duration includes the use of averaging movement velocity method, considering the linear nature of change in its immersion depth.

Time calculation scheme t.

In Figure 3 shows a chart of the motion velocity of the indenter depending on the depth of its immersion.

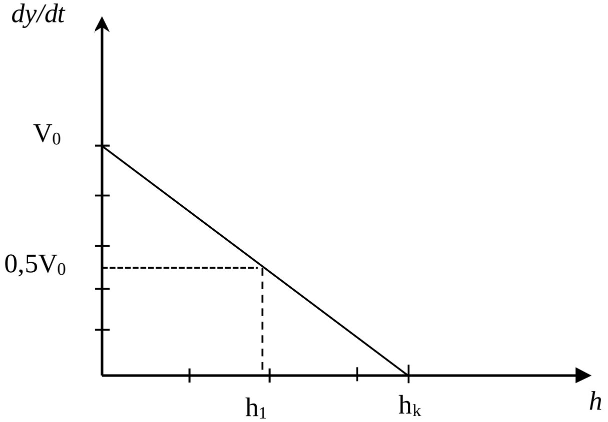


Figure 3. Chart of the motion velocity change *dy/dt* of the indenter depending on the depth

***h* of its immersion**

The indenter movement duration when it is immersed in the product at a depth of h_1, we find from the equation:

$$0{,}5V_0 = \frac{h_1}{t} \Rightarrow t = 2\frac{h_1}{V_0}$$

The method of proportions determines the duration of its motion to a stop when the immersion depth is h_k, so $t_k = h_k t_1 / h_1$.

The proposed method of determining the consistency of the product restricts the possibility of using penetrometers of different designs. A more accurate result can be obtained by refining the mathematical model – the differential equation of motion of the indenter, taking into account the dependence of the area of contact of its surface with the material [9, 10].

In this case, we can rewrite the differential equation as follow:

$$m\frac{d^2y(t)}{dt^2} + \pi D\mu_1 \frac{dy(t)}{dt} - mg = 0 \qquad (7)$$

here D – the penetrometer needle diameter, m; μ_1 – the consistency characteristic, kg/m ×s.

Bear in mind that the consistency characteristics μ_1 and F_P have different units of measurement and different physical natures correspondingly.

Perform an equation analysis (7).

Equation solution (7) under initial conditions $t = 0$, $y(0) = 0$, $V(0) = V_0$ we have:

$$y(t) = \frac{m}{\mu}\left[(gt + V_0) + \frac{mg - V_0\mu}{\mu} e^{-\frac{\mu \cdot t}{m}} - \frac{mg}{\mu}\right], \qquad (8)$$

here $\mu = \pi D\mu_1$

Equation (8) has the same characteristics m, g, t, V_0 as equation (5). The difference is that in equation (5) the characteristic of the product consistency is the penetration force F_P, which has the unit of measurement N (Newton), whereas μ in equation (8) has the unit of measurement kg / s or N x s / m (Newton multiplied by a Second and divided by a Meter).

In food technology, there is a need for comparative analysis of the consistency of different foods. It occurs mainly when a product is adopted as standard and needs to be defined as a new product or obtained from different technological modes or formulations, differing in their consistencies [11, 12].

In this case, it is quite enough to measure the immersion depth of indenter in the product. The use of penetrometers with the same design and mass, and falling them from the same height are prerequisites for such studies.

The ratio of different values of the needle indenter immersions in the product is a comparative characteristic of the consistency of the product.

It is the index $K = \frac{H_S}{H_{pr}}$, here H_S – the immersion depth of the penetrometer needle into the product which is adopted as standard; H_{pr} – the immersion depth of the penetrometer needle into the test product.

When $K > 1$, we have a product of a harder consistency. And on the contrary, if $K < 1$, we have a product of a softer consistency.

Determination of structural and mechanical properties of meat products

Changes in the structural and mechanical properties of a product that contains a different amount of mechanically separated poultry meat (MMV) are studied (recipes №2 – 30 %, №3 – 35 %, №4 – 40 %, №5 – 45 % correspondingly) with rice flour (recipes №2 – 10 %, №3 – 9 %, №4 – 8 %, №5 – 7 % correspondingly).

The data of experimental studies of the indenter immersion depth into the pate are shown in Figure 4.

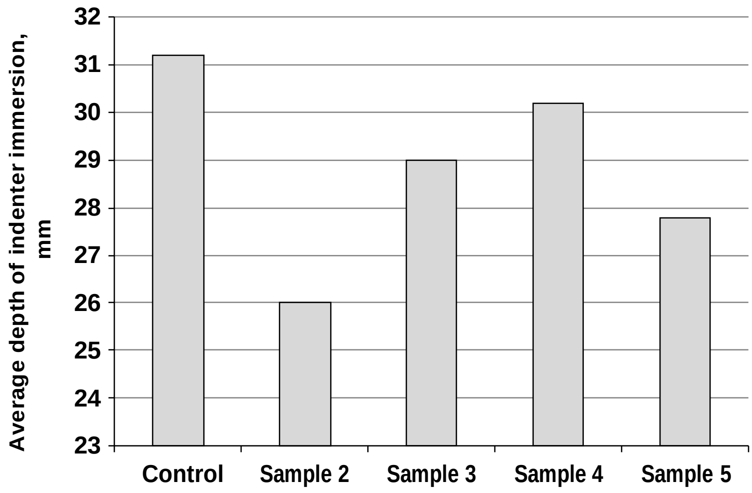


Figure 4. Indenter immersion depth into pate with MMB and rice flour

As a result of the research of the immersion depth of the indenter in the meat pate samples, the following data was revealed: in the control sample, the immersion depth of the indenter was – 31,2 mm, whereas the indices for samples containing MMV and rice flour were: №2 – 26,0; №3 – 29,0 mm; №4 – 30,2 mm; №5 – 27,8 mm. The lowest immersion depths of the indenter were ones for sample №2 containing 30 % MMB and 10% rice flour. So we can say that that the index of its consistency has K> 1, it is equal to K = 1,2.

The analyisis of the obtained data indicates that the including MMV and rice flour in the paste mass contributes to a slight change in the consistency of the product.

The results of the theoretical investigation of the movement of a material object in the form of indenter through the product layer are presented. There is a certain sequence of the consistency of the product, its mathematical model in the form of a second order equation. The solution has been found on initial terms which take place when using the gravitational characteristics of falling penetrometer from a predetermined height.

The sequence of execution of researches is given and the features of use of the needle indenter are shown.

For a comparative analysis of the consistency of similar products we have the possibility to determine its level of change by calculation the ratio of the indenter penetration depth. In the case when the ratio of penetration depth of certain product, adopted as a standard with its consistency, to the penetration depth of the tested one (it can be produced by new technology) is less than one it means the consistency is considered too hard. And on the contrary, if the ratio exceeds one it means that its consistency is too soft [13, 14].

The proposed method for determine the consistency of food is an alternative to widespread method with the use of electronic mechanical devices with wide range of indenters of different constructions (conical, needle or spherical).

Conclusion

Conducted research and received mathematical data let think that this proposed research method of structuring food consistency by gravitational penetration with the use of the needle indenter is competitive comparing with the best worldwide analogs of express measurement.

Its distinctive feature is simplicity of constructive content and at the same time it has scientific point that relies on the classical laws of material systems [16].

Comparing to existing methods of measurement of consistency and defining some efforts of penetration the mathematical models of movement of material systems with applying second order differential equations were used. This fact expands significantly the ability of obtaining exact results comparing to the use of previous formulas, for example during conducting research on conical indentometers.

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Визначення консистенції концентрованих дисперсних систем методом гравітаційної пенетрації

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Вступ. Проведені аналітичні та експериментальні дослідження консистенції дисперсних систем новим методом – гравітаційної пенетрації.

Матеріали і методи. Досліджуються дисперсні системи – паштетні продукти з м'яса птиці, механічно відокремленого. Консистенція визначалась методом гравітаційної пенетрації. Показники пенетрації визначені на основі математичного моделювання руху індентору в шарі продукту на основі диференціальних рівнянь руху другого порядку.

Результати і обговорення. Запропонований метод визначення консистенції простий у використанні. Представлені рахункові залежності і математичні моделі базуються на фізичних константах, що робить метод гравітаційної пенетрації універсальним для широкого практичного застосування при оцінці якості харчових продуктів експрес-методом.

Для проведення порівняльного аналізу консистенції харчових продуктів, отриманих за різних технологічних режимів або рецептур, запропоновано використовувати порівняльну характеристику у вигляді коефіцієнта К. Його величину розраховують як відношення глибини занурення голки у шар продукту при падінні пенетрометра з однієї висоти.

Найбільші показники мав зразок № 4, який містить 40% м'яса птиці, механічно відокремленого, та 8% рисового борошна, а найменші – зразок № 2, який містить 30% м'яса птиці, механічно відокремленого, та 10% рисового борошна.

Висновок. Визначення методу гравітаційної пенетрації розширює можливості отримання точних результатів, якщо порівняти з використанням наявних методів і апріорних формул.

Ключові слова: *гравітаційний пенетрометр, пенетрація, консистенція.*