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METHOD OF PROMPT MEASUREMENT OF MOISTURE CONTENT IN FOOD

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Abstract: An original method and design of a sensor for electrical measurement of moisture content in comminuted food was presented. Equations were formulated presenting the dependence of electrical resistance of the tested sample on the resistivity (specific resistance) of food as well as the dependence of electrical capacitance of the investigated sample on the permittivity of food. Experiments were carried out on the measurements of moisture content in wheat flour and potato starch serving as examples. The results of these measurements were compared with the results obtained using the conventional gravimetric analysis. The time of moisture content measurement was 3 to 5 s, and the time it took to prepare the sample was not longer than 60 s. The advantage of the method is that the density of the investigated food sample does not affect the measurement results of moisture content.

Key words: moisture, electric specific resistance, electric capacitance, sensor

INTRODUCTION

Conventional methods of measuring moisture content in food products, including the gravimetric analysis [Adler 1971, Baryłko-Pikielna 1985, Pabis 1980] are still used in some analytical laboratories [Domagała and Janus 1991, Łapiński et al. 1978, Rüb 1984], in spite of the fact that they are time-consuming [Domagała 1983, Gildemeister and Raeuber 1986, Spicer 1974, Strumiłło 1985, Stuchły and Kraszewski 1976]. For example, the measurement of moisture content in dried potato food products with the gravimetric method takes 3 to 5 hours [Domagała 1985]. The duration time of the moisture content measurement may be shortened if specific electric methods, such as for example resistance or capacitance ones, are used [Domagała 1985, Gildemeister and Raeuber 1986, Łapiński et al. 1978, Spicer 1974, Stuchły and Kraszewski 1976].

Electric methods of measuring moisture content in various materials are comprehensively described in literature. However, there is little data pertaining to the measurements of moisture content in food products [Łapiński et al. 1978, Strumiłło 1985, Zander 1987]. It is probably due to the fact that electric sensors used to measure moisture content in food products are still not truly accurate or reliable [Domagała 1985, Gildemeister and Raeuber 1986], since electric properties of food have not been thoroughly investigated yet [Pabis 1980, Spicer 1974].

In the process of designing and constructing sensors measuring moisture content in specific food products it is necessary to know the electric properties of food. The sensor, the design of which is presented in this article, was based on the results of investigating the effect of moisture content in some food products on the changes in their resistance, capacitance and permittivity.

MATERIAL AND METHOD

The section of the sensor with integrated elements 1, 2, 4 and 6 is presented in Fig. 1. These elements are shown in Fig. 2 a as disassembled, Fig. 2 b as partly assembled, and Fig. 2 c as assembled. In the latter ones (b, c), samples of food are marked.

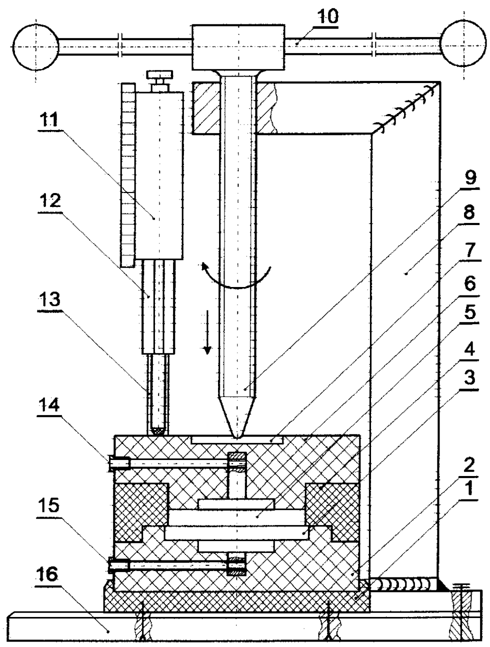

Fig. 1. Sensor for measuring moisture content in solid food products: 1 – stand, 2 – element with the lower electrode, 3 – metal electrode, 4 – container for the tested food sample, 5 – metal electrode, 6 – element with the upper electrode, 7 – metal disk, 8 – metal bracket, 9 – screw pressing the electrodes to the tested sample, 10 – screw arm, 11 – sensor of sample thickness, 12 – cantilever regulating the position of the dial indicator, 13 – rod to which the sensor of sample thickness is attached, 14 – input to the upper electrode, 15 – input to the lower electrode 16 – base of the sensor
Rys. 1. Czujnik do pomiaru wilgotności artykułów żywnościowych w stanie stałym: l – podstawka, 2 – element z dolną elektrodą, 3 – elektroda metalowa, 4 – pojemnik na badaną próbkę żywności, 5 – elektroda metalowa, 6 – element z górną elektrodą, 7 – krążek metalowy, 8 – wspornik metalowy, 9 – śruba dociskająca elektrody do badanej próbki, l0 – ramię śruby, 11 – czujnik grubości próbki, 12 – wspornik regulujący położenie czujnika zegarowego, 13 – pręt do zamocowania czujnika grubości próbki, 14 – wejście do górnej elektrody, 15 – wejście do dolnej elektrody, 16 – podstawa czujnika

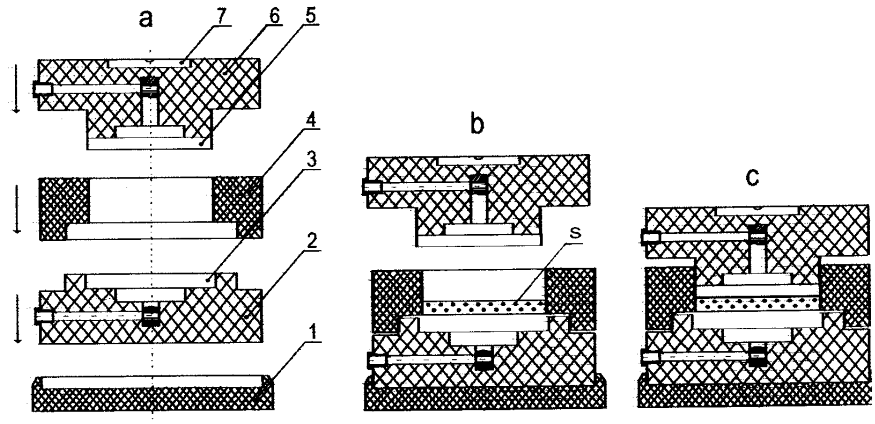

Fig. 2. Structural elements of the container for food samples: a) disassembled, b) partly assembled, c) assembled: 1 – stand, 2 – element with the lower electrode, 3 – metal electrode, 4 – container for the tested food sample, 5 – metal electrode, 6 – element with the upper electrode, 7 – metal disk, s – food sample
Rys. 2. Elementy składowe pojemnika na próbkę żywności w stanach: a) rozłożonym, b) półzłożonym, c) złożonym: 1 – podstawka, 2 – element z dolną elektrodą, 3 – elektroda metalowa, 4 – pojemnik na badaną próbkę żywności, 5 – elektroda metalowa, 6 – element z górną elektrodą, 7 – krążek metalowy, s – próbka żywności

Elements 1, 2, 4 and 6 are placed under screw 9 (Fig. 1) which is used to change the rotary motion of arm 10 into the straightline motion. By screwing the screw 9 in, the pressure on the tested sample of food is increased (this sample is not marked in Fig. 1). The sample may be compressed to a desired thickness. Sensor 11 indicates the thickness of the sample. Electrodes 3 and 5 (5 and 8 mm thick, and 40 mm in diameter) were selected empirically.

One of the advantages of the method presented above is the fact that measurements of moisture content of the examined food may be taken at the constant density of samples. Constant density may be obtained at equal weights and thickness of the investigated samples.

The sensor works most efficiently with automatic bridges of electric resistance or capacitance, in which the bridge display indicates the value of moisture content for the examined food product. The duration time of moisture content measurement is 3 to 5 s, and the time it takes to prepare a sample for the measurement does not exceed 60 s.

The term "moisture content" used in this article denotes the percentage content of moisture in an examined food sample, referring to the moist sample. This definition is described by the following equation [Adler 1971]:

$$X = \frac{m_w}{m} \cdot 100 \quad [\%] \tag{1}$$

in which: X – moisture content, %, m_w – weight of water in the investigated sample, g, m – weight of the moist sample, g.

Resistance R for the investigated food sample is described by the following dependence:

$$R = \rho \cdot \frac{d}{S} \quad [\Omega] \tag{2}$$

in which: ρ – resistivity (specific resistance) of the investigated sample, Ω·m, d – thickness of the sample, m, S – surface of the sample, m^2.

In case of the designed sensor, d/S equals 31.8 m^{-1}. After substituting this value into equation (2), the following expression is obtained:

$$R = 31.8 \cdot \rho \quad [\Omega] \tag{3}$$

Capacitance C of the examined sample is described by the following equation:

$$C = \frac{\varepsilon \cdot S}{d} \quad [F] \tag{4}$$

in which: ε – permittivity of the tested food, F/m, S – surface of the sensor electrodes, m^2, d – thickness of the sample, m.

For the sensor in question, S/d equals $31.4 \cdot 10^{-3}$ m. After $S/d = 31.4 \cdot 10^{-3}$ m is substituted into the equation (4), the following expression is arrived at:

$$C = 0.0314 \cdot \varepsilon \quad [F] \tag{5}$$

Permittivity of the examined food is expressed in the form of the following dependence:

$$\varepsilon = \varepsilon_o \cdot \varepsilon_r \quad [F/m] \tag{6}$$

in which: $\varepsilon_o = 8.854 \cdot 10^{-12}$ – permittivity of vacuum, F/m, ε_r – specific inductive capacity of food.

After rearranging, the following formula for specific inductive capacity is obtained on the basis of equations (5) and (6):

$$\varepsilon_r = 3.6 \cdot 1012 \cdot C \tag{7}$$

On the basis of the dependence (7), it is possible to determine specific inductive capacity of the tested food product depending on its moisture content, since capacitance C is the function of moisture content X.

For this article only the results of studies on moisture content in wheat flour and potato starch were selected out of many other investigated food products.

Samples of food with varying moisture contents, which were prepared in the climatic chamber, were used in the experiments. The tests were repeated 6 times at the frequency of 1 MHz and the temperature of samples 18°C.

Moisture content of the prepared samples was measured using resistance and capacitance methods, and it was compared with the results obtained with the gravimetric analysis. The density of all the studied samples was constant and equaled 99.6 kg/m^3.

RESULTS AND DISCUSSION

Results of measurements of moisture content in the investigated food products using resistance and capacitance methods are presented on Figures 3 and 4. Figure 3 – wheat flour, Figure 4 – potato starch.

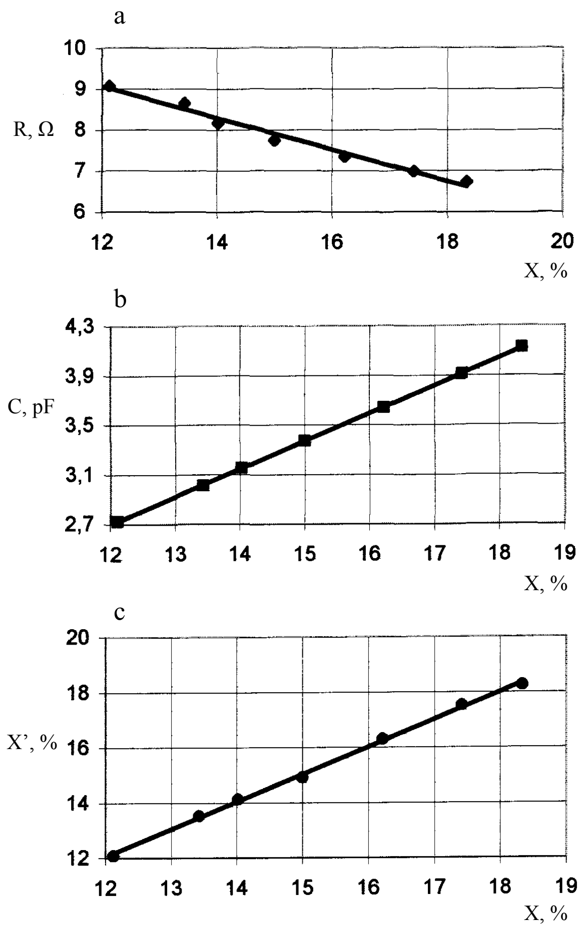

Fig. 3. Moisture content and the values of electric properties of wheat flour: R and C – electric resistance and capacitance measured with the RC electric bridge, X – sample moisture content measured using the RC electric bridge, X' – sample moisture content determined with the gravimetric analysis, a) R = f(X), b) C = g(X), c) X' = h(X)

Rys. 3. Wilgotność i wartości wielkości elektrycznych mąki pszennej: R i C – rezystancja i pojemność elektryczna mierzone za pomocą mostka RLC, X – wilgotność mierzona za pomocą mostka elektrycznego RLC, X' – wilgotność próbki oznaczana grawimetrycznie, a) R = f(X), b) C = g(X), c) X' = h(X)

The results indicate that resistance R changes in a linear way in the function of moisture content X in food (Fig. 3 a and Fig. 4 a) and electric capacitance C changes in a linear way in the function of moisture content X in food, too (Fig. 3 b and 4 b). For this reason, this approach may be used to measure moisture content X in food without reservations in a wide range of values.

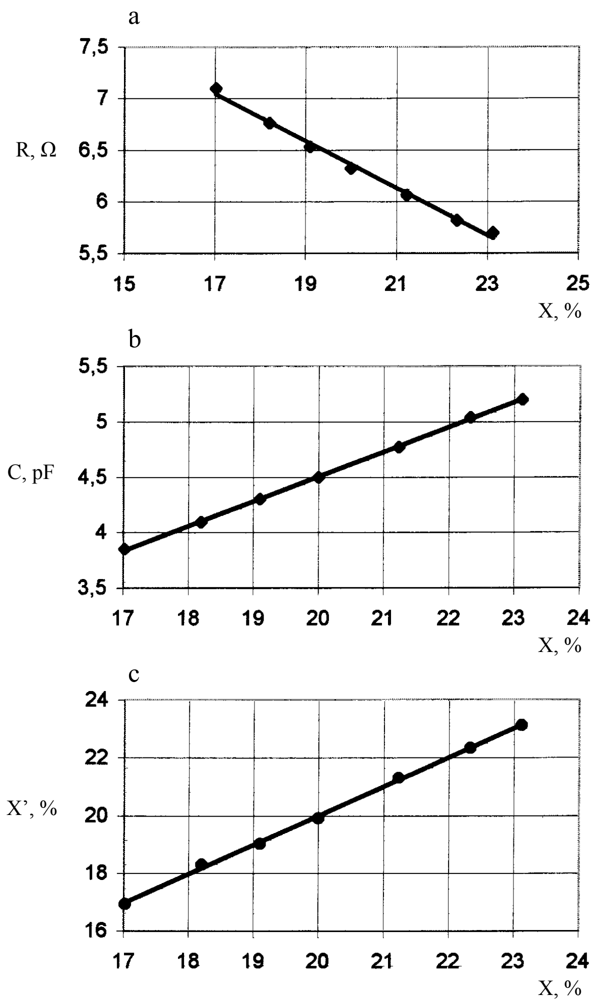

Fig. 4. Moisture content and the values of electric properties of potato starch: R and C – electric resistance and capacitance measured with the RC electric bridge, X – sample moisture content measured using the RC electric bridge, X' – sample moisture content determined with the gravimetric analysis, a) R = f(X), b) C = g(X), c) X' = h(X)

Rys. 4. Wilgotność i wartości wielkości elektrycznych skrobi ziemniaczanej: R i C – rezystancja i pojemność elektryczna mierzone za pomocą mostka RLC, X – wilgotność mierzona za pomocą mostka elektrycznego RLC, X' – wilgotność próbki oznaczana grawimetrycznie, a) R = f(X), b) C = g(X), c) X' = h(X)

Moisture contents X, measured with the use of electric methods, were compared with the values of moisture contents X', determined with the use of gravimetric analysis (Fig. 3 c and 4 c). The differences fall within the ± 0.1% range.

The regression equations for wheat flour (Fig. 3):

– electric resistance $R = -0.3843X + 13.663$, $r^2 = 0.9818$, $S_{y \cdot x} = 0.12808$ (Fig. 3 a),

– electric capacitance $C = 0.225X - 0.007$, $r^2 = 1$, $S_{y \cdot x} = 0.002908$ (Fig. 3 b),

– moisture determined with the gravimetric analysis $X' = 0.9943X + 0.1059$, $r^2 = 0.9983$, $S_{y \cdot x} = 0.098895$ (Fig. 3 c).

The regression equations for potato starch (Fig. 4):

– electric resistance $R = -0.2285X + 10.929$, $r^2 = 0.9937$, $S_{y \cdot x} = 0.044056$ (Fig. 4 a),

– electric capacitance $C = 0.2238X + 0.028$, $r^2 = 0.9996$, $S_{y \cdot x} = 0.011104$ (Fig. 4 b),

– moisture determined with the gravimetric analysis $X' = 1.0098X - 0.2133$, $r^2 = 0.998$, $S_{y \cdot x} = 0.080915$ (Fig. 4 c).

CONCLUSIONS

1. One of the advantages of the method presented above is the fact that measurements of moisture content of the examined food may be taken at the constant density of samples.
2. Measurements of moisture content with the method presented here have to be performed at constant temperature and constant density of the tested food sample. A system of temperature compensation needs to be used for samples with different temperatures.
3. In the presented method, a constant density of the investigated sample is obtained using at all times identical mass and thickness of the sample.
4. Each newly developed sensor based on the electrical method of moisture content measurement needs to be tested, since the measurement results are affected by e.g. the size of sensor electrodes, and the density and thickness of the investigated food sample.

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METODA SZYBKIEGO POMIARU WILGOTNOŚCI W ŻYWNOŚCI

Streszczenie: Zaprezentowano oryginalną metodę i konstrukcję czujnika do elektrycznego pomiaru wilgotności w żywności w stanie rozdrobnionym. Opracowano równania przedstawiające zależność rezystancji elektrycznej badanej próbki od rezystywności (oporu właściwego) żywności oraz zależność pojemności elektrycznej badanej próbki od przenikalności elektrycznej żywności. Badania przeprowadzono na przykładzie pomiaru wilgotności mąki pszennej i skrobi ziemniaczanej. Wyniki tych pomiarów porównano z wynikami otrzymanymi za pomocą konwencjonalnej metody grawimetrycznej. Czas pomiaru wilgotności stanowił 3 do 5 s, a czas przygotowania próbki do pomiaru nie przekraczał 60 s. Zaletą metody jest to, że gęstość badanej próbki żywności nie ma wpływu na wynik pomiaru wilgotności.

Słowa kluczowe: wilgotność, elektryczny opór właściwy, pojemność elektryczna, czujnik

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