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THE USE OF DIELECTRIC PROPERTIES OF STARCH IN MEASUREMENTS OF ITS HUMIDITY

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Key words: dielectric properties of starch, starch humidity, humidity of starch measurement.

The applicability of dielectric properties of starch in the range of low frequencies (316 Hz-10 kHz) and of electromagnetic wave attenuation in the range of very high frequencies (9.3 GHz) to measurements of starch humidity was studied. The effect of the starch's humidity on its permittivity and tangent of dielectric loss angle was analysed for various degrees of sample pressing and different frequencies of measurement voltage in constant temperature. The possibility of suitable modification and application to measurements of starch humidity of a serially produced microwave hygrometer WILMER type 63 was demostrated.

One of the indispensable elements in automatic control systems in food industry are converters of nonelectrical quantities into electric or pneumatic signals. To obtain such conversion the physical (electric) properties of the investigated substances are determined and the nonelectrical parameters derived indirectly therefrom. The most frequently used to this end are measurements of electric and magnetic parameters of bodies.

In measurements of humidity of loose materials the dielectric properties of the substances, namely permittivity ε and the coefficient of dielectric loss tan δ, are used fairly often [2, 4, 10, 12, 13]. The characteristics of various materials differ in the course of the function $\varepsilon = f(W)$ because of their various degrees of water binding. The course of this function is also affected by the frequency of measurement voltage — the gradient of the curve decreases with the increase of frequency [3, 5]. In measurements of humidity of dielectrical loose materials, sensors of two kinds are used: one in which the material is poured freely into the measurement condenser, and the other where controlled compression of the sample is employed. The dielectric hydrometers can measure the material's humidity in a wide range (0-60% H_2O) with an accuracy of 0.3-1.0% H_2O [1, 5, 6, 8, 14, 18].

Also positive results in the determination of humidity of products were obtained with the use of the phenomenon of microwave energy absorption by humid materials. The most characteristic feature of microwaves is that the dimensions of rotation elements are comparable with the wavelength.

The propagation of microwaves is possible only in dielectrics and in some semiconductors; in conductors they are severely dampened and after travelling a very short way the field intensity diminishes practically to zero [7, 15-17, 19]. Mladek and Komarek [11] have elaborated a method of continuous measurement of starch humidity, using the bridge method to measure damping and phase shift of the electromagnetic wave travelling through the studied substance. The Microwave Apparatus Plant WILMER designed a microwave hygrometer Wilmer type 6310 [9]. In our research employing this hygrometer we have studied a number of granular and powdered materials of humidity range 0-20% H_2O achieving an accuracy of the order from ±0.015% H_2O to ±0.5% H_2O. It was also found that dependence between the damping of an electromagnetic wave of frequency 9.4 GHz and humidity of the studied materials is of linear character. The application of microwave methods in measurements of humidity of loose materials guarantees small measurement errors (0.1-0.5% H_2O) in a wide range of the substance's humidity (0-50% H_2O).

However, such results are obtained only when the density of the studied material remains constant in the measurement space. To satisfy this condition it is necessary to introduce a strictly determined mass of the sample into the unchanging measurement space that is available. In other words, one has to weigh each sample separately and place it in the measurement vessel and this makes the measurement difficult and complicated as well as time-consuming.

In order to eliminate these inconveniences we have modified the well-known WILMER apparatus, ensuring constant density of the studied starch sample.

EXPERIMENTAL

The aim of the presented study is the determination of dependences between the basic physico-chemical properties of potato starch and its electric parameters that could serve as a basis for constructing an apparatus for determining the water content in starch through measurements of electrical parameters such as permittivity (ε), dielectric loss coefficient tan δ and microwave damping.

The studies concerned the applicability of dielectric properties of starch in the range of low frequencies (316 Hz-10 kHz) and of attenuation of electromagnetic waves at very high frequency (9.3 GHz) to measurement of humidity.

The effect of the starch's humidity on its permittivity and coefficient of dielectric loss was studied for different pressures and for various frequencies of measurement voltage in a constant temperature using an apparatus depicted by the block diagram given in Fig. 1. The measurement vessel with an electrode was placed on a bow dynamometer (type PRL-T1) of a measurement range up to 3000 N. The top of the vessel was closed with a movable piston in a screw press exerting pressure on the studied starch sample (Fig. 2). The measurement electrode consisted of 16 con-

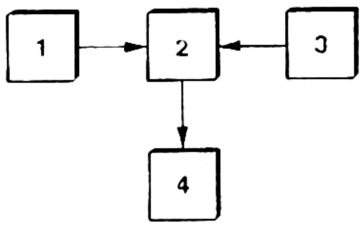

Fig. 1. Block diagram of measurement apparatus; 1 — measurement vessel with electrode placed in a screw press, 2 — measurement bridge, 3 — generator G, 4 — equilibrium indicator WR

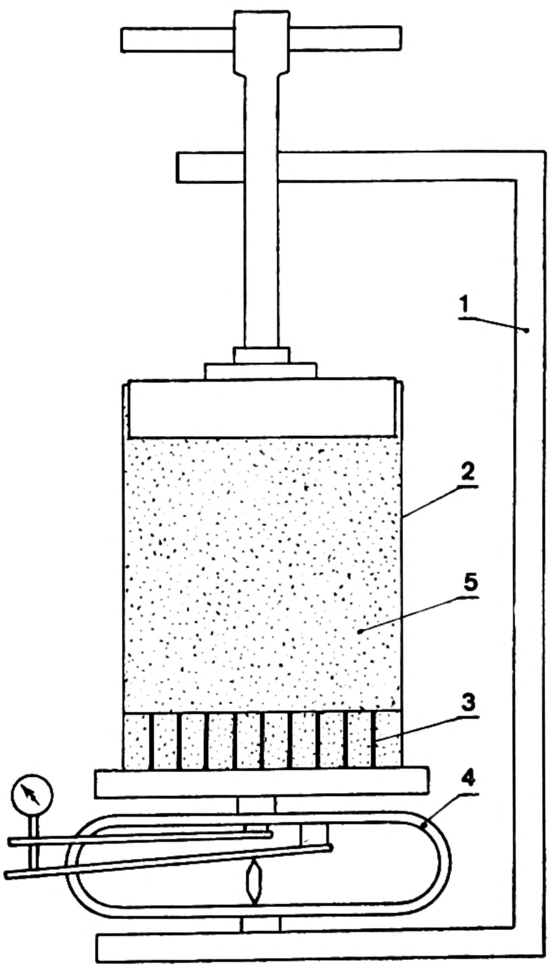

Fig. 2. Apparatus for compressing starch samples; 1 — screw press, 2 — measurement vessel, 3 — measurement electrode, 4 — bow dynamometer, 5 — starch sample

nected copper plates of total surface $2.1 \cdot 10^{-2}$ m^2. The plates of this measurement condenser were covered by a thin insulating layer so as to eliminate the effect of starch conductivity (especially at greater humidities) due to electrolytes content on the capacitance measurement. The electrode was coupled with a system measuring permittivity and the dielectric loss coefficient. The low-voltage Schering bridge was used in the system. The prepared starch samples of determined humidity were poured freely into the measurement vessel. The screw press was then used to increase the pressure of the piston on the starch layer and the capacitance of the condenser was measured. An attempt was also made to modify the serially produced microwave hygrometer WILMER type 63 so as to enable its practical application in measurements of starch humidity. The determination of the dependence between wave damping and humidity of starch was found experimentally with the apparatus shown in Fig. 3. The measure-

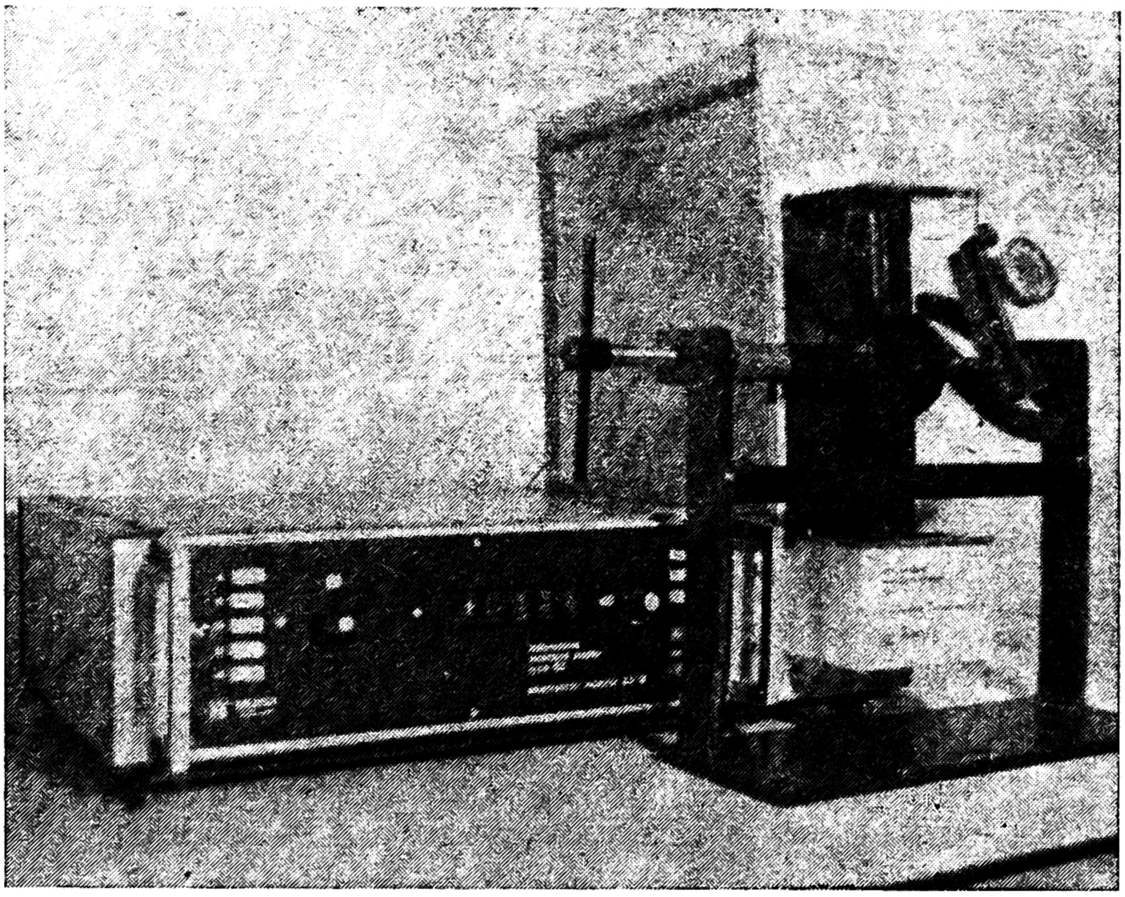

Fig. 3. Microwave hygrometer WILMER type 63 with measurement vessel and manual press

ment system consisted of the microwave hygrometer WILMER type 63, a measurement vessel of our design equipped with a screw press connected with a bow dynamometer (type PRL-T1) of a measurement range of up to 5000 N. The measurement vessel constructed by us ensures a constant and controlled pressing of samples (density of the material) of the investigated starch in a wide range of humidities. The starch samples were compressed with the manual press, its thrust being controlled by the dynamometer and oriented perpendicularly to the electromagnetic wave flux. The application of a revolving measurement chamber enabled the rotation of the compressed starch samples through and angle of 90° thus making it possible to introduce them into the microwave conduit. Measurements were performed for three different pressures exerted on the samples. Prior to performing measurements of dielectric properties of the starch and of electromagnetic wave damping, samples of a known humidity were prepared. Depending on the initial humidity, determined by the drier-gravimetric method, the starch was either dried or humidified

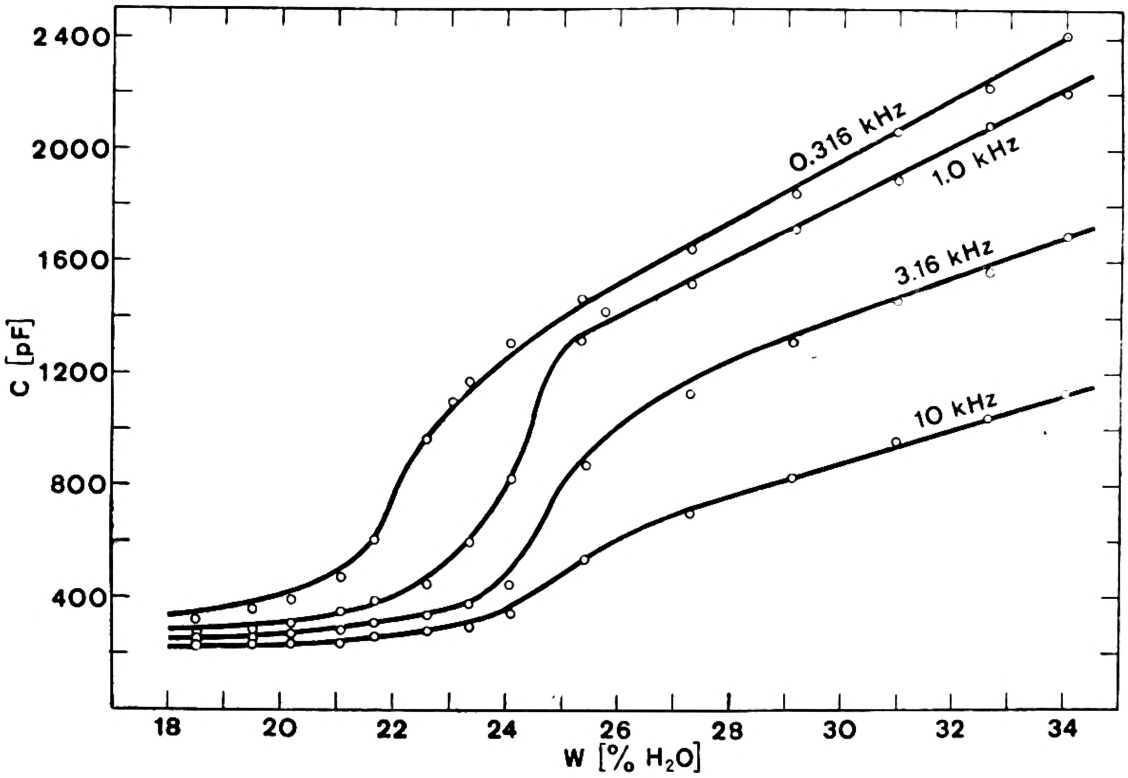

Fig. 4. Dependence of capacitance of starch on its humidity

and then sifted through a sieve to grind humid lumps and unify the entire mass. Samples thus prepared were kept in tightly sealed containers for several days which caused the equalization of humidity in the starch mass, this being indicated by the repeatability of humidity in different places in the sample. Next, the starch humidity was again dertermined and the sample poured into the measurement vessel. The obtained results are presented in Figs. 4-6. The dependence of the dielectric loss coefficient tan δ of the starch on its humidity is presented in Fig. 5. Extreme values of tan δ for various frequencies were obtained in the humidity range 24-26% H_2O; in this same range of humidity there occurs an inflexion of the function C = f(W).

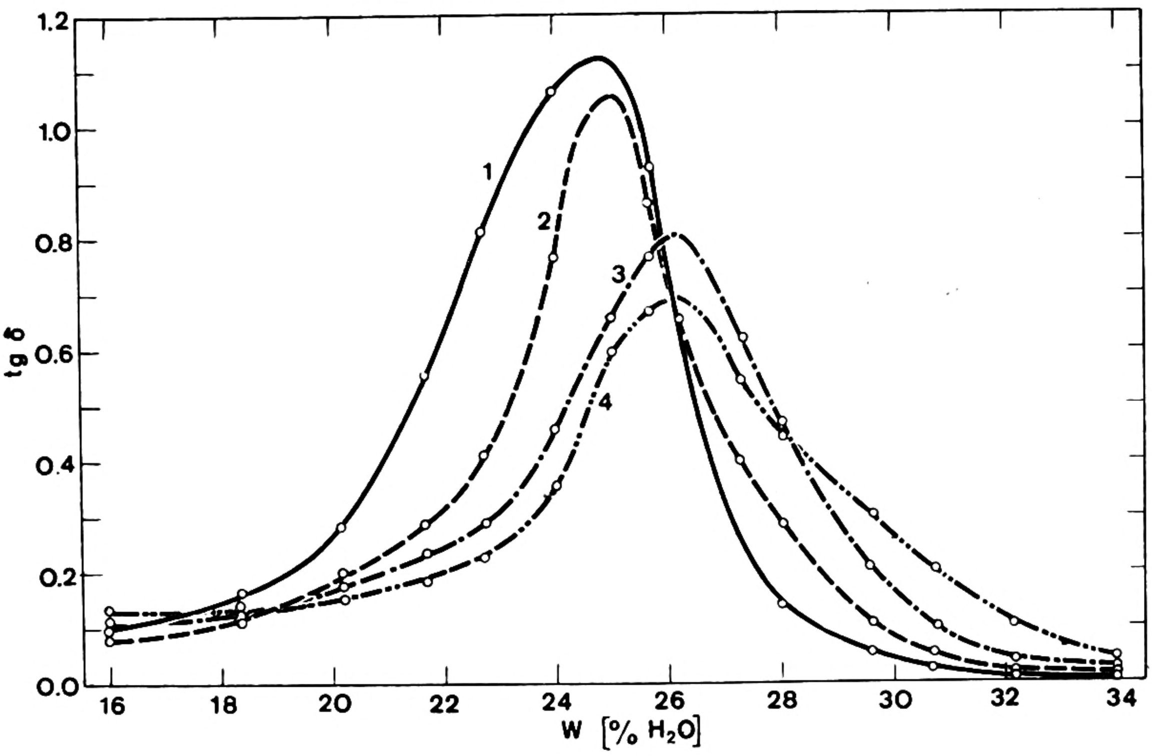

Fig. 5. Dependence of the dielectric loss coefficient tan δ of starch on its humidity; 1 — 0.316 kHz, 2 — 1.00 kHz, 3 — 3.16 kHz, 4 — 10.0 kHz

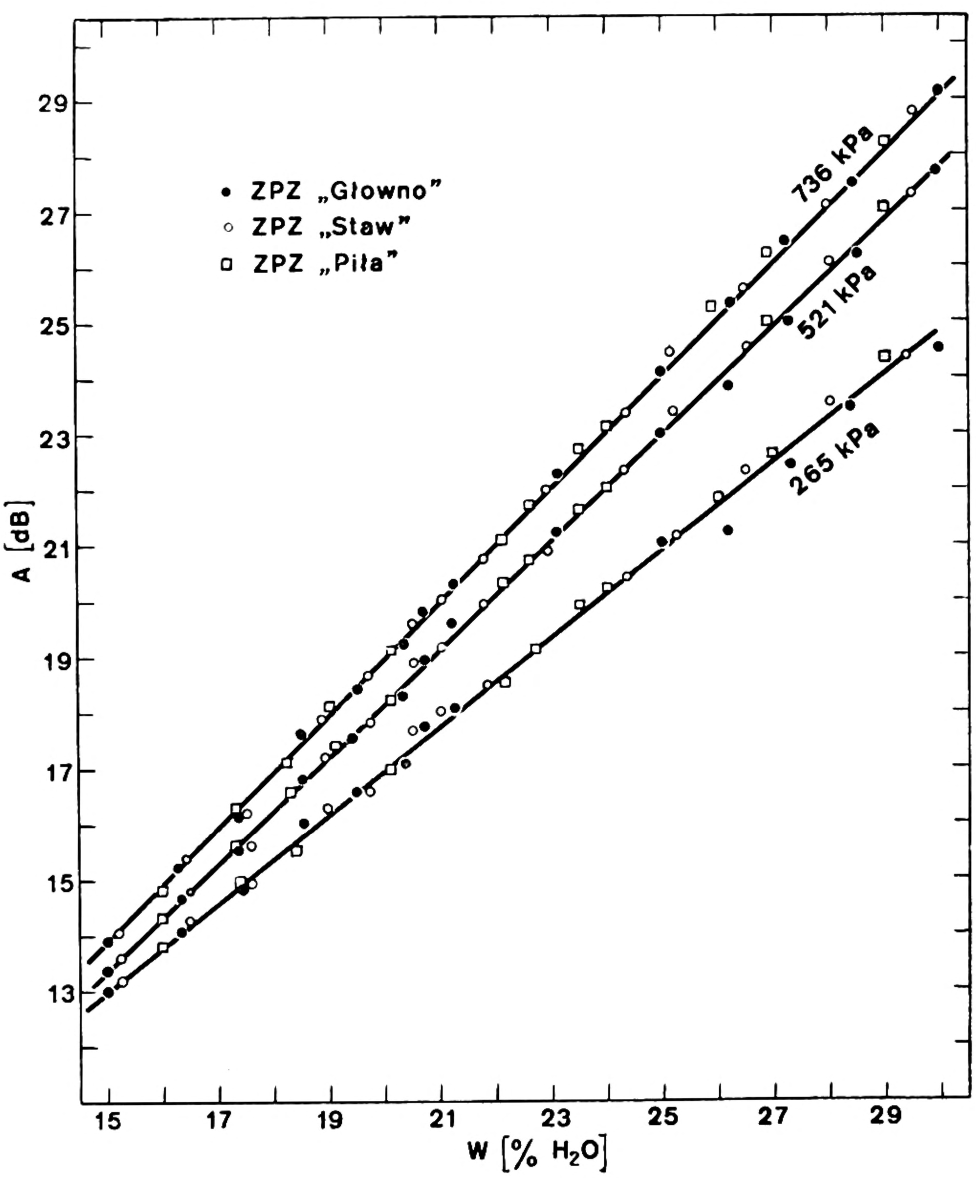

Fig. 6. Dependence of electromagnetic wave damping on starch humidity for different pressures exerted on the sample; Potato Industry Enterprises: "Głowno", "Staw", "Piła"

DISCUSSION OF RESULTS

The measurements performed with the use of the novel measurement vessel for the microwave hygrometer WILMER, ensuring a constant and controlled density of material in the measurement space, made it possible to determine the dependence between the studied starch and the damping of electromagnetic wave. The starch for the studies came from Potato Industry Enterprises in Staw, Głowno and Piła; the humidity of the

Table. Dependence of electromagnetic wave damping on temperature of starch at different humidities

Temperature (°C) Damping (dB)	14.0	17.0	20.0	23.0	26.0	29.0	32.0	35.0	38.0	40.0
Humidity (% H_2O)										
13.1	11.0	11.5	11.8	12.0	12.4	12.5	13.2	13.4	13.6	13.9
16.0	13.0	13.4	13.8	13.6	14.5	15.1	15.6	15.7	16.4	16.5
18.8	15.8	16.2	16.3	16.8	17.3	17.8	18.3	18.6	18.8	19.2
21.7	18.8	19.2	19.6	19.7	20.5	21.0	21.4	21.8	22.2	22.1
22.6	19.8	20.2	20.6	20.8	21.8	22.0	22.1	22.8	23.2	23.5
27.7	23.2	23.8	24.4	25.2	25.8	26.1	26.4	27.0	27.8	28.1
30.0	24.6	25.3	25.8	26.5	27.0	27.6	28.2	28.8	29.3	29.5
33.0	27.5	28.2	28.7	29.4	30.0	30.6	30.9	31.6	32.3	32.5
34.5	29.0	29.6	30.0	30.7	31.4	32.0	32.6	33.0	33.7	33.8
39.5	31.3	31.9	32.8	33.0	33.7	34.4	35.0	36.0	36.2	36.5

material ranged from 15 to 30% H_2O. Since the measurements were performed for three pressures exerted on the starch samples (265, 521 and 736 kPa), we obtained three straight lines of regression described by the following equations:

— for 265 kPa $A_1 = 0.7995\ W + 0.907$
— for 521 kPa $A_2 = 0.9564\ W - 0.976$
— for 736 kPa $A_3 = 1.0112\ W - 1.255$

where A_1, A_2 and A_3 — electromagnetic wave dampings, W — humidity of the investigated starch. Correlation coefficients R were calculated for the regression equations; they are, respectively, $R_1 = 0.972$, $R_2 = 0.9839$, $R_3 = 0.9972$. The values of R, close to unity, indicate the small scatter of results and the linear character of the dependence.

The effect of temperature (in the range 14-40°C) on the damping of electromagnetic waves at different humidities of the starch samples was also ivestigated (Fig. 7). The dependence was found to be linear (Fig. 7). The straight-line course of the dependence $A = f(t)$ for different humidities enables the elaboration of a simple system compensating the effect of temperature on the measurement.

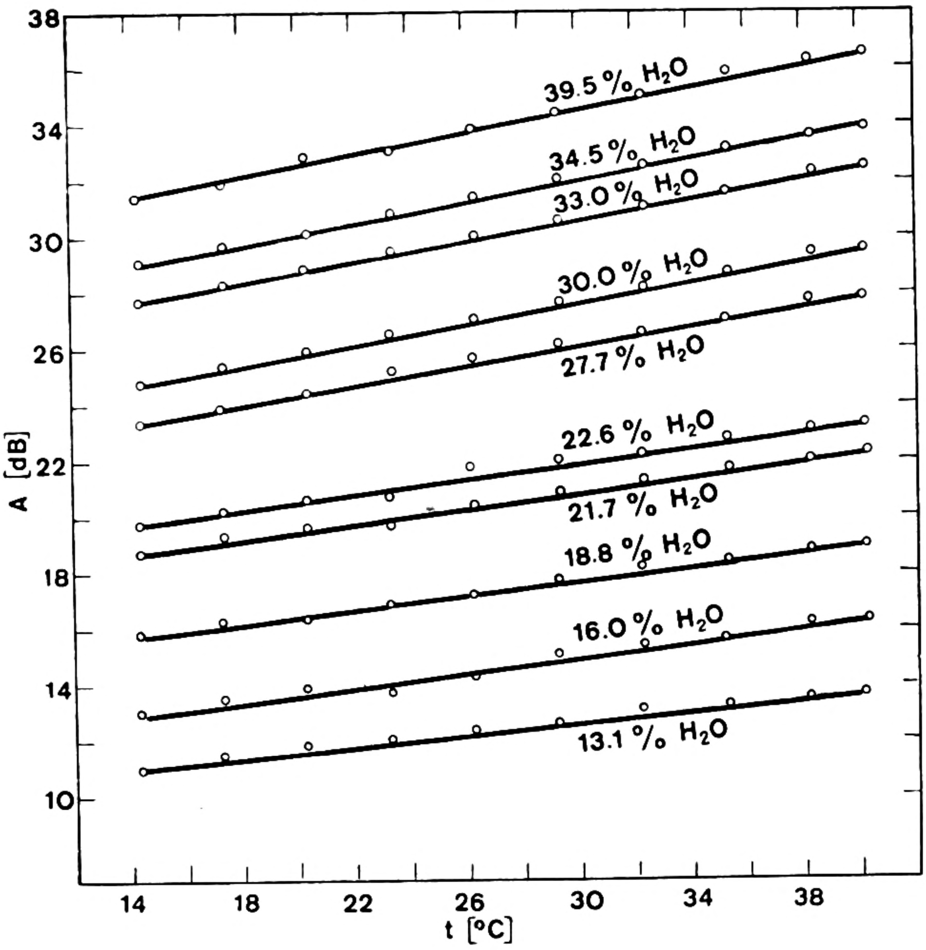

Fig. 7. Dependence of electromangetic wave damping on temperature of starch at different humidities

The performed studies revealed the dependence between the humidity of the starch and the capacitance of the measurement condenser filled with it, and the dielectric loss coefficient tan δ. The humidity of the starch used ranged from 16 to 34% H_2O. The measurement bridge was supplied with voltage of four different frequencies (0.316, 1.00, 3.16 and 10.00 kHz). During measurements the starch sample was compressed with the pressure 124 kPa. Fig. 4 shows the effect of the humidity of the starch on its capacitance. An increase of measurement voltage frequency causes a decrease of the curve gradient. The curves may be divided into three parts:

I — from 16 to 20% H_2O the gradient of the curve is low which means that the water particles are strongly bounded to the starch affecting the change of capacitance to a low degree.

II — in the range 20-26% H_2O there occurs a sharp increase of the sample's dielectric constant (causing an equivalent growth of capacitance) due to the increasing content of water particles and their increasingly weaker bounding to starch.

III — from 26 to 34% H_2O the water particles occur in an unbounded state which is manifested by a greater effect on permittivity; in this range of humidity the increase of capacitance of starch is directly proportional to the increase of its humidity.

CONCLUSIONS

1. At controlled pressing of starch samples there occurs a dependence between the humidity of the starch and its capacitance which may be used to determine starch humidity.

2. The gradient of the curve depicting the dependence of capacitance of the starch on its humidity depends both on the humidity and on the frequency of measurement voltage.

3. The dependence of the dielectric loss coefficient tan δ of starch on its humidity is maximum at humidity corresponding to the point of inflexion of the function $C = f(W)$. The maxima are different for different frequencies of the measurement voltage.

4. The results of microwave measurement of humidity of starch supplied by three different producers are arranged along one straight line (at equal compressions of samples).

5. An increase of the pressure exerted on the sample reduces the scatter of results and increases the precision of measurement.

6. The linear dependence between electromagnetic wave damping and temperature enables the construction of a simple compensatory system.

7. Increasing humidity causes a greater effect of temperature on the measurement of electromagnetic wave damping.

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WYKORZYSTANIE DIELEKTRYCZNYCH WŁAŚCIWOŚCI SKROBI DO POMIARU JEJ WILGOTNOŚCI

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S t r e s z c z e n i e

Prowadzono badania nad zastosowaniem do pomiaru wilgotności skrobi jej właściwości dielektrycznych w zakresie niskich częstotliwości (316 Hz-10 kHz) oraz tłumienności fali elektromagnetycznej w zakresie bardzo wysokiej częstotliwości (9.3 GHz). Badano wpływ wilgotności skrobi na jej przenikalność elektryczną i tangens kąta strat dielektrycznych przy różnym sprasowaniu próbki oraz przy różnej częstotliwości napięcia pomiarowego w stałej temperaturze. W naczyniu pomiarowym znajdował się kondensator pomiarowy włączony w układ mostka Scheringa. Otrzymane zależności świadczą o możliwości oznaczania wilgotności skrobi wskutek pomiaru przenikalności elektrycznej i współczynnika strat dielektrycznych.

Przeprowadzono również badania w celu modyfikacji i zastosowania seryjnie produkowanego mikrofalowego miernika wilgotności WILMER typ 63 do pomiarów wilgotności skrobi. Skonstruowano nowe naczynie pomiarowe wraz z oprzyrządowaniem zapewniającym mierzenie stopnia sprasowania próbki skrobi. Uzyskane wyniki pozwoliły na wyznaczenie zależności funkcyjnej typu $y = ax+b$ między wilgotnością badanej skrobi a tłumiennością fali elektromagnetycznej.