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THE CORRELATION BETWEEN ELECTRICAL PERMEABILITY OF A MIXTURE AND QUANTITATIVE COMPOSITION OF GRANULATES

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Summary. BACKGROUND. The paper presents the methodology and measurement data of electrical permeability and particle size distribution on the example of milling grist obtained from wheat grain. The test stand has been presented in the present paper, too. The disc mill has been used in order to obtain proper fractions and dimension classes of dust originating from the prepared raw material. Common features of all such dust are their explosive properties that preclude the application of effective and efficient electrostatic filters operating at voltages of dozens of kV.
RESULTS. On the basis of the executed measurements the performance characteristics for the real and imaginary component of electrical permeability for the examined fractions of dust obtained from the milling of careopses of wheat ALMARI have been elaborated. In case of fractions resulting from grain milling process by means of laboratory mill the real component of electric permeability e' increases according to frequency voltage increase and achieves maksimum 7.5 for the frequency f = 300 kHz and gradually decreases thereafter. The electrical permeability measurements have been also carried out for the fractions produced in course of wheat careopses milling process in the mill. The results obtained from the measurements and calculations have been subjected to statistical processing.
CONCLUSION. The application of the methods based on the measurements of electric parameters for the determination of the granulation for the dust originating from milling of plant origin dielectrics and of its potential contaminations in form of foreign components seems to be an interesting issue. The data are to be used also in the design of a bifilar filter for application in the food processing industry for air cleaning of dusts of plant origin.

Key words: electrical permeability, grain milling, flour granulation, measurements methodology

INTRODUCTION

The purpose of the present paper is to find the correlation between the granulation of dust (flour) and electrical permeability. The creation of methodology and the measurement of electrical permeability of the flour produced in wheat careopses milling process vs. granulation is another subject of the study.

The scope of the tests encompassed the measurement of electrical permeability of the dust produced in wheat careopses milling process vs. granulation, determination of the correlation between the permeability of the mixture and quantitative composition of granulates as well as the statistical and graphical analyses of the tests results.

CHARACTERISTICS OF THE MEDIUM UNDER TEST

The corns are used mainly in food industry and agriculture as well as in other sectors of the economy [6, 7, 8].

The corn products are produced in course of grain milling process. A/m products are classified as follows in accordance with the kind and degree of processing:

– corn grain – the product not subjected to milling process,
– coarse and fine grain – subjected to preliminary milling processes,
– coarse and fine groats – subjected to milling or crushing process,
– grain dusts subjected to several milling phases,
– various types of flour – the final product of grain milling,
– bran and grain germs obtained as the by – product in the course of grain milling process.

WHEAT GRAIN MILLING PROCESS

The grain milling process consists of grinding of refined and conditioned grain followed by grinding of so called intermediate products produced in milling process until the final product i.e. the flour is obtained by sifting [6].

The simple or complex wheat grain milling process can be applied.

The simple process consists in single passage of grain through the grinding machine producing the flour made of whole grain called also the whole meal.

The complex milling process applied in order to produce white flours (and their various types), consists in multiple passage of grain and intermediate products through grinding machines followed by sifting machines in form of multiple milling passages.

The whole grain milling process can be subdivided into the following grinding and sifting phases:

– grinding,
– sorting and refining of grits,
– grinding of grits,
– final grinding of grits and dusts.

The special laboratory mills are used for grain milling in laboratory conditions. The milling results are affected by technical conditions of the milling process, the experience of its operator as well as by technological properties of grain. The volume of obtained flour is significantly influenced by the humidity of grain. The grinding of dry grain is facilitated. The grain to be milled should be carefully prepared prior to milling owing to significant influence of grain humidity on milling results [5, 6, 7, 8]. The selection of the mill type is frequently made on the basis of the grain sample size. Quadrumat-Junior mills are used for milling of very small sizes i.e. up to about 200 g.

The detailed methodology of grain milling in laboratory conditions is determined in the operating manuals supplied by the manufacturers of the laboratory mills or in the handbooks in the scope of grain processing technical analysis.

EQUIVALENT ELECTRICAL PERMEABILITY OF THE MIXTURE

The mixture consisting of grains characterized by diversified size and electrical permeability creates a uniform isotropic medium encompassing a significant area in comparison with the dimensions of individual grains. It is possible to determine the averaged value of dielectric constant ε_m for grains mixture by testing of electrical properties of such medium.

Assuming the spherical symmetry of the particles and insignificant differences between their dielectric constants, the following relation between the electrical permeability of the mixture εm and the values of the electrical permeability of both the components of mixture was obtained [1, 4]:

$$\varepsilon_m = \varepsilon_1 + C\frac{3(\varepsilon_2 - \varepsilon_1)\varepsilon_1}{\varepsilon_2 + 2\varepsilon_1}, \tag{1}$$

where:
ε_1 - electrical permeability of the first substance,
ε_2 - electrical permeability of the second substance,
ε_m - electrical permeability of the mixture of the both substances,
C - relative volumetric ratio of the both substances in the mixture.

$$C = \frac{V_1}{V_2}, \ (\text{or } C = \frac{m_1}{m_2}), \tag{2}$$

where:
V_1 – volume of the first substance,
V_2 – volume of the second substance,
m_1 - mass of the first substance,
m_2 - mass of the second substance.
For the measured value of ε_m and for the known two from among three parameters of the mixture (C, ε_1, ε_2) it is possible to determine the third one, e.g. $C = f(\varepsilon_1, \varepsilon_2)$, $\varepsilon_1 = f(C, \varepsilon_2)$, $\varepsilon_2 = f(C, \varepsilon_1)$ or $\varepsilon_m = f(\varepsilon_1, \varepsilon_2, C)$.
The examples of the calculations have been presented below and illustrated with the corresponding diagrams.

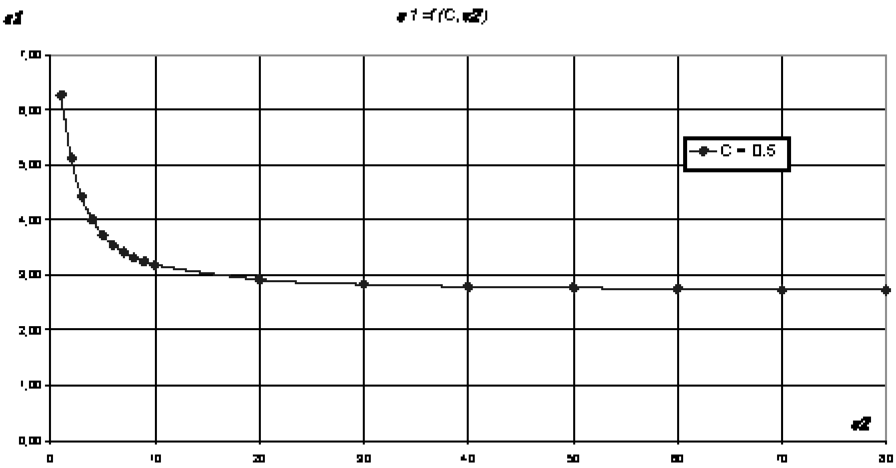

Fig. 1. Diagram for $\varepsilon_1 = f(C, \varepsilon_2)$ and $\varepsilon_m = 4$

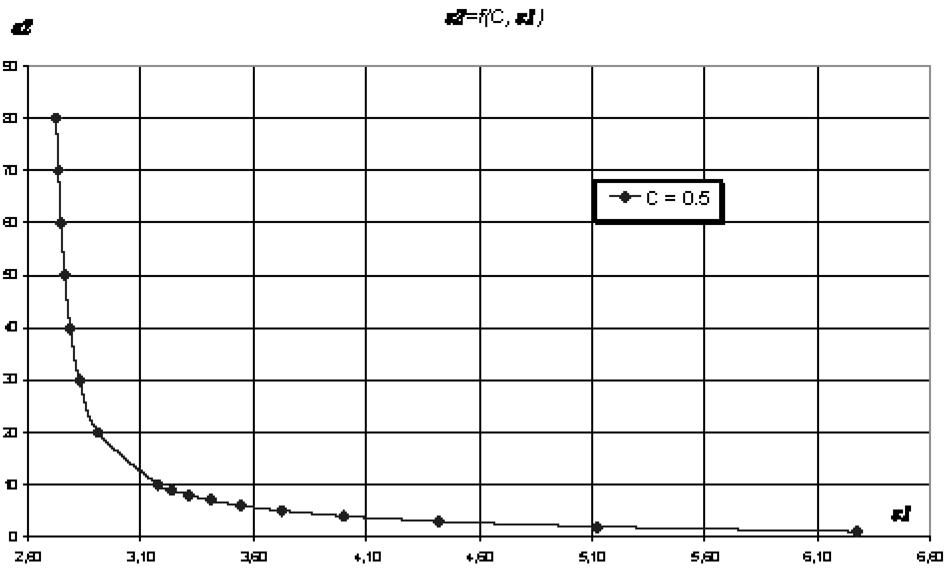

Fig. 2. Diagram for $\varepsilon_2 = f(C, \varepsilon_1)$ and $\varepsilon_N = 4$

TESTING METHODOLOGY

The measurements were carried out at the laboratory stand presented in Figure 3.

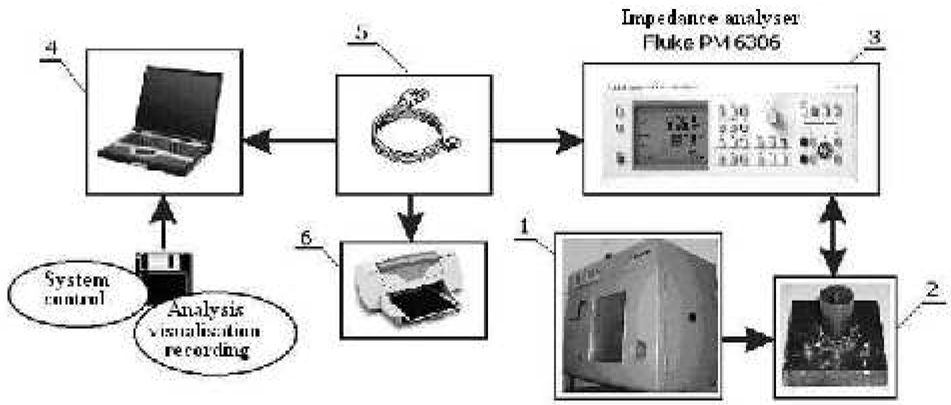

Fig. 3. Testing stand: 1 – climatic chamber, 2 – measuring capacitor filled with wheat fractions under test, 3 – impedance analyser, 4 – computer, 5 – connecting cable RS – 232, 6 – printer

The measurements were performed in accordance with the following methodology:

PREPARATION OF MATERIAL UNDER TEST FOR THE MEASUREMENTS

The milling fractions under test were obtained from technological wheat grain milling process carried out in the mill. Prior to the measurement, the fractions were held for 72 hours in the climatic chamber in order to determine appropriate humidity. After their removal from the climatic chamber, a sample has been weighed for measurement. The mass of the sample (m=32 g) was determined by the volume of the capacitor used for the measurements. A/m volume was determined by means of experiments in the course of preliminary tests.

THE DESCRIPTION OF LABORATORY STAND

The testing stand consists of Fluke PM 6306 impedance analyser, computer with printer, measuring capacitor, the climatic chamber and connecting elements (cables and terminals).

ELECTRIC PERMEABILITY MEASUREMENT PROCEDURE FOR GRANULATES FRACTION

– After 72 hours, the sample of fraction under test was drawn and placed in the measuring capacitor. The same conditions and the method of capacitor filling with the (dielectric) material under test were maintained each time.
– PM 6306 impedance analyser (see Fig.1) was used for its capacity measurement.
– The following measurement procedure was initiated for the impedance analyser.
  - The calibration of impedance analyser was performed.
  - The program enabling automatic measurements by means of impedance analyser was installed and configured.
  - SW63W Component View program used for measurement data acquisition and visualization was run.
  - The kind of link between the computer and meter was selected through RS-232.
  - After the selection of measurement option (Scanning Mode), the frequency range used for continuous measurement of capacitor capacity was determined.
  - The measurements were carried out in the form of five (5) measuring sequences for each fraction. Such number of measuring sequences was introduced in order to use them for t-Student distribution statistical analysis.
– The following procedure was followed:
  - The volume of the empty measuring capacitor C_o was determined.
  - The dust sample was placed in the measuring capacitor.
  - The volume of the measuring capacitor filled with dust Cr was determined.
  - The value of electrical permeability of dust was calculated by means of the following formula:

$$\varepsilon' = \frac{C_r}{C_o}, \tag{3}$$

where:
C_r – the volume of the measuring capacitor filled with dust, F,
C_o – the volume of the empty measuring capacitor, F.

- The imaginary component of electrical permeability was determined by means of the following formula (4):

$$\varepsilon'' = \varepsilon' tg\delta \,, \tag{4}$$

where:
δ - dielectric loss angle,
tgδ = 1/Q - dielectric loss tangent,
Q - factor of the capacitor containing the dielectric dust, obtained from the measurements by means of impedance analyser.

MEASUREMENTS RESULTS ANALYSIS

The measurements results analysis has been carried out by means of t-Student test for the pairs matched with two samples for mean value. Therefore it is possible to ascertain whether the mean values for the tests are different. The equal values of variances are not assumed for both the populations in that kind of t-Student test. The test can be used for the matched pairs in case of natural matching of data pairs in the samples.
Furthermore, the corresponding values of standard deviation σ, mean errors $\Delta\varepsilon$[illegible] error of mean value and the correlation factors determining the electric permeability – frequency relation for one milling fraction with the consideration of the influence on another fraction (e.g. 118 μm – 360μm) were calculated.
The correlation factor (5) is a statistical function reflecting the relation between two comparable data sets in clear manner.
The standard deviation has been calculated by means of the following formula:

$$\delta_n = \sqrt{\frac{n\sum(\varepsilon_i)^2 - (\sum\varepsilon_i)^2}{n(n-1)}}, \tag{5}$$

where:
n – number of repetitions of the measurements for the determined frequency value,
T – Student distribution is used for the calculation of random errors in accordance with the following procedure:

- calculation of number of freedom degrees n_f = N –1,
- reading of the value of t – factor in t-Student distribution table for the specified confidence level and determined value of nf, [9, 10],
- calculation of random error for mean value by means of the formula for $\Delta\varepsilon$[illegible]:

$$\Delta\varepsilon_{[illegible]} = \pm\frac{t\delta}{\sqrt{N}}. \tag{6}$$

- The result of measurement ε refers to the mean value $\Delta\varepsilon$[illegible], assuming the limit values equal to:

$$\varepsilon = \varepsilon_{[illegible]} \pm t\frac{\delta}{\sqrt{N}}. \tag{7}$$

The correlation function [5] was used in order to determine the relation between the frequency and granulation as well as electric permeability of the milling fractions under test. Therefore it is possible to ascertain the existence of any relation between the variations of electric permeability resulting from the changes of measuring frequency for individual fractions with different granulation.

The correlation measures the relationship between two data sets scaled in the manner ensuring their independence of units of measurement. The calculation of the population correlation results in the covariance for two data sets, divided by the product of their standard deviations. The correlation tool can be used in order to determine if both data sets are moving together i.e. if the high values of one set are associated with the high values of another set (positive correlation), if the low values of one set are associated with the high values of another set (negative correlation) or if the values in both sets are not associated (correlation close to zero).

The following equation determines the correlation factor ρx,y [5]:

$$\rho_{x,y} = \frac{Cov(X,Y)}{\sigma_x \sigma_y}, \tag{8}$$

where:

$$-1 \le \rho_{x,y} \le 1, \tag{9}$$

and:

$$Cov(X,Y) = \frac{1}{n}\sum_{j=1}^{n}(x_j - \mu_x)(y_j - \mu_y), \tag{10}$$

where:

$Cov(X,Y)$ – covariance i.e. mean value from the products of deviations for each pair of data points. Therefore it is possible to determine the relation between two data sets,

x_j, y_j – jth element of data sets X and Y, compared correspondingly,

μ_x, μ_y – mean data of data sets X and Y, correspondingly.

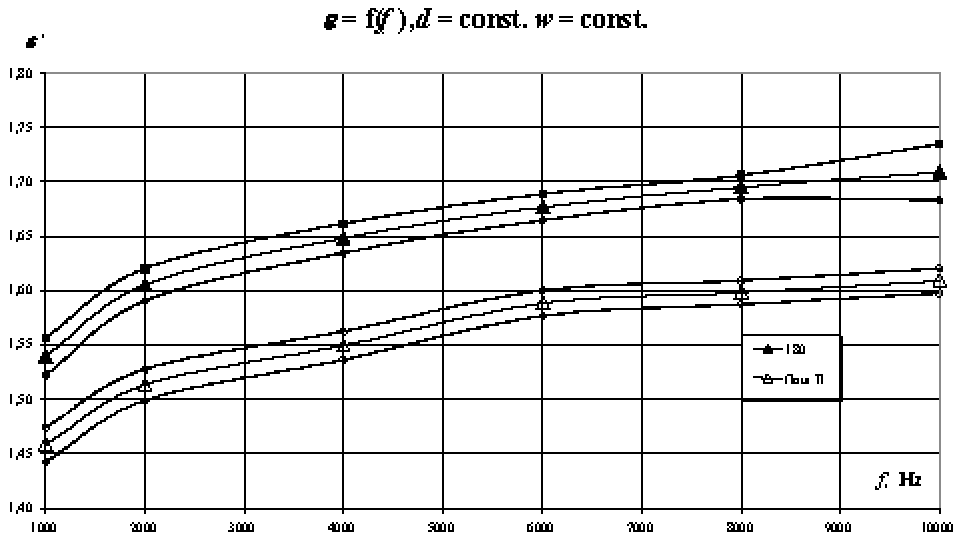

Fig. 4. Frequency curves of real component of electric permeability for dielectric dust with granulation d = 180 μm and flour II, humidity w = 11 %

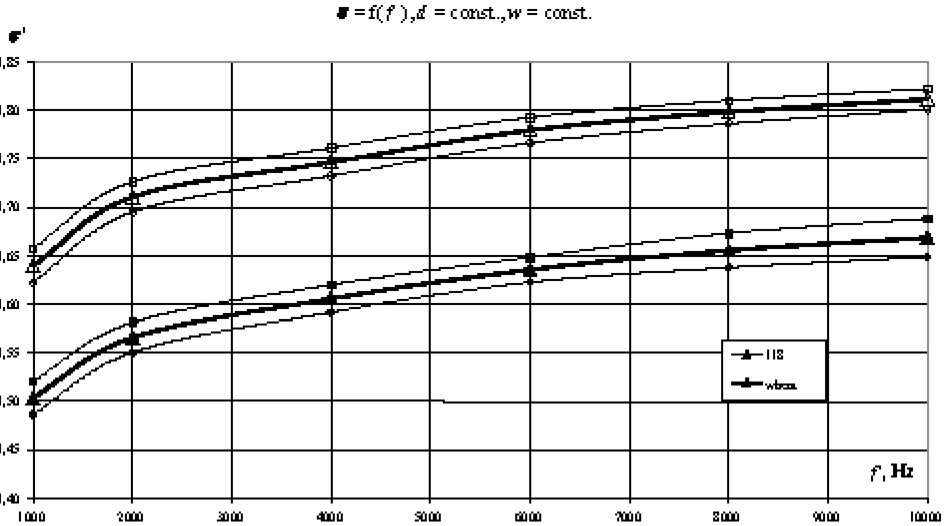

Fig. 5. Frequency curves of real component of electric permeability for dielectric dust with granulation d = 118μm and wheat grain with humidity w = 11 %.

The presented relationship $\varepsilon = f(f)$ reflects the relation between electric permeability and humidity.

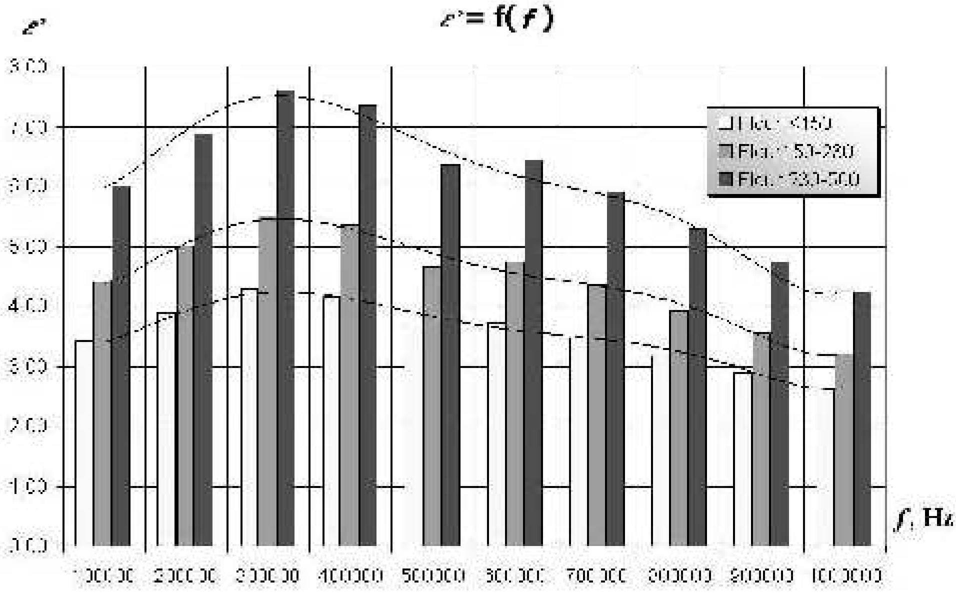

Fig. 6. Frequency curves of real component of electric permeability for flour fraction in frequency range of 100 –1000kHz.

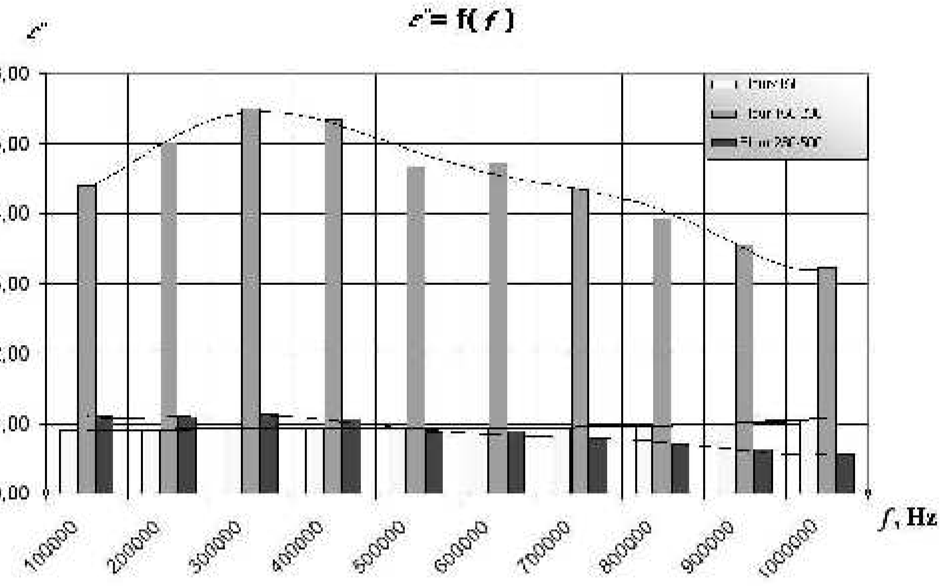

Fig. 7. Frequency curves of imaginary component of electric permeability for flour fraction in frequency range of 100 – 1000kHz

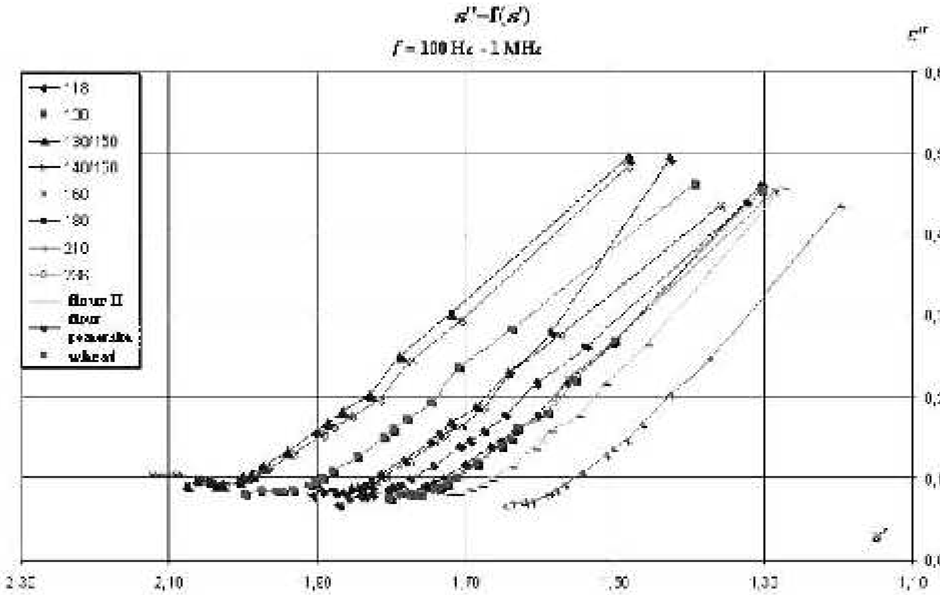

Fig. 8. Cole –Cole diagram for wheat milling fractions for f = 100 Hz ÷ 1000 kHz

CONCLUSIONS

The following conclusions were found in the course of the performed analysis:

– The electric permeability varies according to the voltage frequency

– The electric permeability of dielectric material fraction varies according to the humidity and voltage frequency (Figure. 4 ÷ 8.).

– The real component of electric permeability of the dust increases according to frequency voltage increase.

– The results of measurements suggest the possibility of using the electric properties for the evaluation of corn grain milling quality and for the detection of contaminations in the material subjected to the milling process in milling process products.

In case of fractions resulting from grain milling process by means of laboratory mill:

– The real component of electric permeability ε' increases according to frequency voltage increase and achieves maximum for the frequency f = 300 kHz and gradually decreases thereafter.

– component of electric permeability ε'' is an irregular function of frequency.

In case of fractions resulting from the wheat grain milling in the course of technological milling process in the mill:

– The real component of electric permeability ε' increases according to frequency voltage increase. Its curve after exceeding of the frequency f = 100 kHz is characterized by linear shape.

– component of electric permeability ε'' decreases according to frequency voltage increase. Its curve after exceeding of the frequency f = 200 kHz is characterized by linear shape.

The investigation of possibility to use the electric properties of dusts for the evaluation of corn grain milling quality and for the detection of contaminations in the material subjected to the milling process also seems to be an interesting issue to be investigated.

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KORELACJA MIĘDZY PRZENIKALNOŚCIĄ MIESZANINY A SKŁADEM ILOŚCIOWYM GRANULATÓW

Streszczenie. W artykule przedstawiono stanowisko badawcze oraz metodykę pomiaru przenikalności elektrycznej dla frakcji przemiałowych otrzymanych z ziarniaków zbóż. W oparciu o przeprowadzone pomiary opracowano charakterystyki częstotliwościowe składowej rzeczywistej i urojonej zespolonej przenikalności elektrycznej badanych frakcji pyłu uzyskanego z przemiału ziarniaków pszenicy odmiany Almari. Dla pozyskania odpowiednich frakcji i klas wymiarowych pyłu z przygotowanego surowca zastosowano młynek tarczowy. Przeprowadzono również pomiary przenikalności elektrycznej frakcji powstałych z technologicznego przemiału ziarniaków pszenicy we młynie. Na podstawie tych pomiarów zbadano korelację między zależnością przenikalności elektrycznej i rezystywności od częstotliwości dla jednej frakcji przemiałowej w powiązaniu z wpływem na inną frakcję pyłu otrzymanego z laboratoryjnego oraz technologicznego przemiału ziarna pszenicy. Wyniki pomiarów i obliczeń zostały poddane obróbce statystycznej. Interesującym zagadnieniem wydaje się być również zastosowanie metod opartych o pomiary właściwości elektrycznych do określenia granulacji pyłu powstałego z przemiału dielektryków pochodzenia roślinnego oraz ewentualnej obecności w nim zanieczyszczeń obcymi składnikami.

Słowa kluczowe: przenikalność elektryczna, przemiał ziarna, granulacja mąki, metodyka pomiarów

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