

AN INVESTIGATION OF THE INFLUENCE OF HUMIDITY AND WATER CONTENT ON THE ELECTRICAL PROPERTIES OF COTTONSEED CAKE

A. K. BHUIYA AND MAZHAR M. QURASHI

Physical Research Division, Central Laboratories, Pakistan Council of Scientific and Industrial Research, Karachi

(Received October 5, 1960)

In the course of investigations on the development of a rapid non-destructive electrical method for the estimation of oil content of a single cottonseed, the dielectric constant of cottonseed cake was found to rise about 50-fold when the dry cake absorbed water up to its saturation value 12-16%. The present communication deals with a detailed investigation of the nature of this variation of the dielectric constant and also the specific conductance of variously formed discs of cottonseed cake, using several different relative humidities.

The measured values of both the dielectric constant K and the specific conductance γ under various humid conditions are found to increase exponentially with the percentage water constant W of the cake and can be represented by the following equations $K = 4 \exp(26 \times w/100)$, $\gamma = 0.2 \exp(56 \times w/100)$. Further work is in hand for the elucidation of this type of variation, particularly with reference to other hydrated solids.

In the course of earlier investigations^{1,2} relating to the development of a rapid non-destructive electrical method for estimation of the oil content of a single cottonseed, it was found that the dielectric constant 'K' of a typical cottonseed cake rises about fifty-fold from nearly 3 to about 140 as the dry cake takes up water up to its saturation value of 12-16%. Figure 1 shows the observed

variation of $1/K$ plotted against the relative humidity and the percentage water content, and it was considered of interest to follow up this finding with a somewhat fuller investigation of the nature of the variation of both specific conductance and dielectric constant in humidified cottonseed cakes, which may be looked upon as a simple protein-water system.

1. Experimental Procedure

For this work, two types of samples were prepared in the shape of 6 cm. diameter discs with a thickness of 5 to 7 mm. Firstly, the sample used in the previous experiments, which was made from commercially available cottonseed cake after washing with petrol, and sieving to free it from bits of the hulls. The clean cake had then been compacted in a die at 100°C. under light pressure in a laboratory hydraulic press. The disc of cake obtained was found to have a density of 0.90 g./ml. The second sample disc was prepared from dehulled kernels of the M 4 variety of cottonseed after Soxhlet extraction of the oil. This method yielded a more compact disc, of density about 1.1 g./ml. For the dielectric constant and conductance measurements, these discs were placed between the two plates (2.5 cm. square) of the parallel-plate condenser used in the previous investigations, and connected by short stiff copper leads to the measuring terminals of the Marconi universal bridge. The plates of the condenser were adjusted to just touch the two faces of the sample disc, the criterion being that the disc should stay in place without external support but be capable of being withdrawn by a light touch.

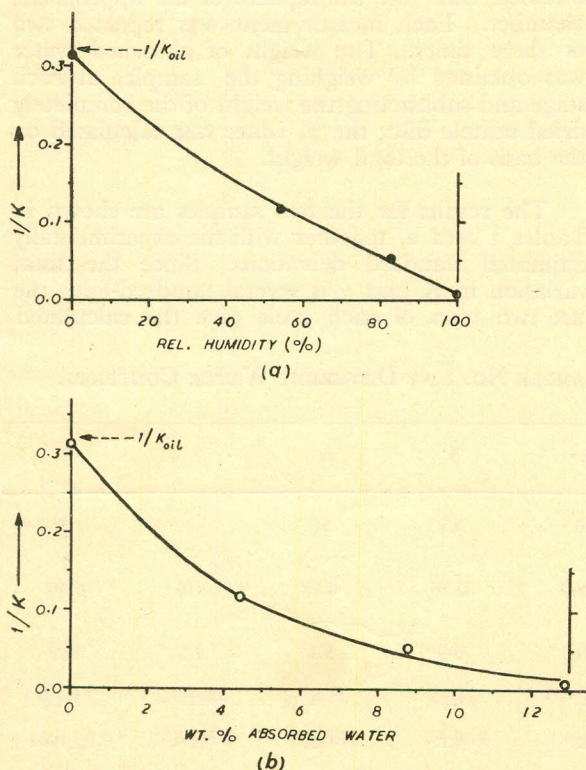


Fig. 1.—Previously noted variation of $1/K$, the reciprocal of the dielectric constant of cottonseed cake, against (a) relative humidity of the atmosphere, and (b) percent water absorbed by the cake.

The capacity 'C' of the condenser was measured on the bridge at 1,000 cycles per second, both with and without the sample disc, and the dielectric constant could be calculated from the ratio of

these two values. The values of the phase angle δ were also measured with the bridge, and from these the conductance of the sample could be calculated by means of the formula.

$$w C \tan \delta = 1/R \quad (1)$$

where $1/R =$ the conductance and $w = 2\pi f$, f being the frequency, in this case 1000 cycles per second.

A simple but significant correction is required for the stray capacity due to the leads and strips making connection with the actual condenser plates. This stray capacity, Δ , is to be subtracted from all the above values read on the bridge, and was determined experimentally by measuring the capacity of the (air) condenser for several values of the distance 'd' between the

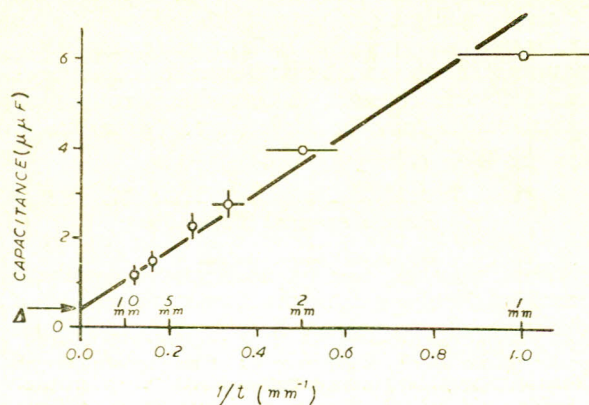


Fig. 2.—Graph for capacitance of measuring condenser against $1/t$, extrapolated to yield a measure of the stray capacitance, Δ . The short vertical and horizontal lines through the points represent the observational errors.

plates. If the area of the plates is 'A', then the measured value C_{air} will be

$$C_{\text{air}} = \frac{A}{4\pi d} + \Delta \quad (2)$$

So that the graph for C_{air} against $1/d$ should be a straight line extrapolating to the value Δ for $1/d = 0$. Such a graph is shown in Fig. 2 and yields the figure of $0.4\mu\text{F}$ for Δ , which is to be compared with an estimate of 0.3, calculated from the configurations of the leads, etc. (cf. also the measured capacity of about $2\mu\text{F}$ for the condenser when $d = 0.5$ cm., *i.e.* 5 mm.)

2. Results

Starting with the sample discs at atmospheric humidity (80%) the capacitance and conductance were measured as described above, and the dielectric constant K and specific conductance γ calculated. Each sample was then put through a complete hydration-dehydration cycle by placing it in various constant humidity chambers, and the electrical constants were measured after 20 to 30 hours when equilibrium had been very nearly attained with the atmosphere of the appropriate chamber. Each measurement was repeated two or three times. The weight of absorbed water was obtained by weighing the samples at each stage and subtracting the weight of the completely dried sample disc; the % water was calculated on the basis of the total weight.

The results for the two samples are shown in Tables 1 and 2, together with the experimentally estimated standard deviations. Since the total variation in K and γ is several hundred-fold, the last two rows of each table give the calculated

TABLE 1.—MEASURED ELECTRICAL CONSTANTS OF SAMPLE NO. 1 AT DIFFERENT WATER CONTENTS.

	1	2	3	4	5	6	7	8
Relative humidity (%)	80	100	30	0	85	85	—	0
Weight of water (g)	1.21	2.73	0.32	0.00	0.76	0.78	0.19	0.06
% of water = w	7.7	15.8	2.2	0.0	5.0	5.1	1.3	0.4
K	19 ± 2	125 ± 10	4.3 ± 0.2	3.4 ± 0.0	24 ± 2	28.5 ± 2	3.5 ± 0.2	2.8 ± 0.1
γ ($m\mu$ Mho/cm.)	10.5 ± 1	1050 ± 100	0.8 ± 0.1	0.2 ± 0.1	14.2 ± 1	17.0 ± 1	0.5 ± 0.1	0.3 ± 0.04
$\ln K$	2.94 ± 0.1	4.83 ± 0.1	1.45 ± 0.05	1.22 ± 0.06	3.18 ± 0.08	3.35 ± 0.07	1.25 ± 0.06	1.03 ± 0.04
$\ln \gamma$	2.35	6.97	1.78	2.39	2.65	2.83	1.22	2.30

values of the Napierian logarithms of the dielectric constant 'K' and the conductance γ .

Firstly, it is seen that the large change in K is accompanied by an equally large change in the conductance. The changes in the electrical quantities are similar for the two samples and are on the whole reversible when the samples are taken through a complete hydration-dehydration cycle. This is clearly brought out by the graphs of Fig. 3, in which the logarithms of K and γ are plotted against weight % absorbed water, the triangles and circles corresponding to the two specimens of Tables 1 and 2, respectively, while the subscript numbers correspond to the column nos. in these tables. It is seen that, with rising or falling water-content, there is no definite bias for the plotted points to lie on any one side of the mean graph, and therefore no indication of irreversible changes.

3. Discussion

Taking into account the tabulated standard deviations of $\ln K$ and $\ln \gamma$, which are indicated by the short vertical lines in Fig. 3, the straight lines shown can be drawn and the following equations derived to fit the experimental data:—

$$\ln K = 1.18 + 26 \times w/100$$

$$i.e. \quad K = 4 \exp. \left(26 \times \frac{w}{100} \right) \quad (3)$$

$$\text{and} \quad \ln \gamma = -1.8 + 56 \times w/100$$

$$i.e. \quad \gamma = 0.2 \exp. \left(56 \times \frac{w}{100} \right) \quad (4)$$

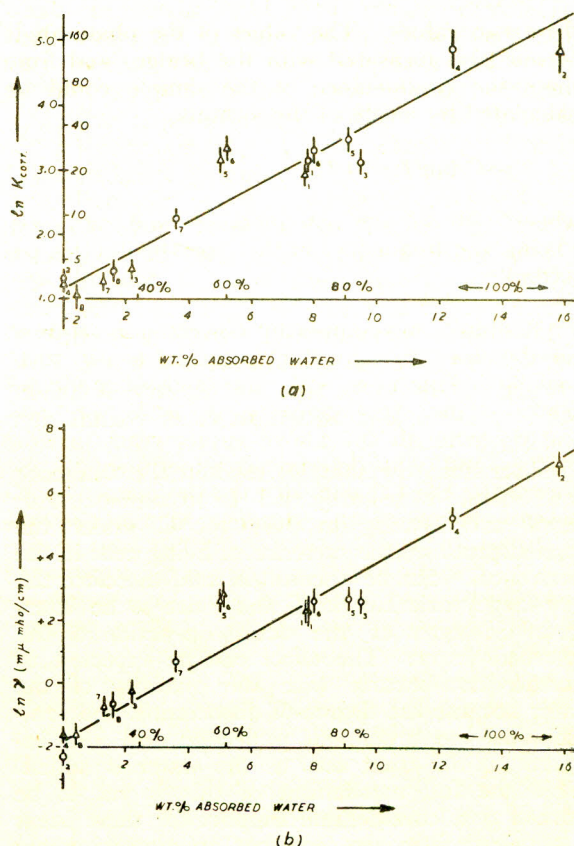


Fig. 3.—Semi-logarithmic plots of (a) the dielectric constant, K, and (b) the specific conductance, γ , of the two samples of cottonseed cake, carried through about one and a half hydration-dehydration cycle. The triangles are for the sample of Table 1, and the circles for the sample of Table 2; the short vertical lines through the plotted points indicate the estimated standard deviations, while the subscripts to them correspond to the numbers heading the columns in Tables 1 and 2.

TABLE 2.—MEASURED ELECTRICAL CONSTANTS OF SAMPLE NO. 2 AT DIFFERENT WATER CONTENTS.

	1	2	3	4	5	6	7	8
Relative humidity (%)	80	0	85	100	85	85	—	0
Weight of water (g)	1.01	0.00	1.24	1.69	1.20	1.03	0.44	0.19
% of water = w	7.8	0.0	9.5	12.5	9.1	8.0	3.6	1.6
K	24 \pm 2	3.7 \pm 0.2	23 \pm 2	130 \pm 15	33 \pm 4	28 \pm 3	9.6 \pm 0.5	4.2 \pm 0.2
γ (m μ Mho/cm.)	10.1 \pm 1	0.1	14.0 \pm 1	198 \pm 15	15 \pm 1	13.7 \pm 1	2.0 \pm 0.02	0.5 \pm 0.1
$\ln K$	3.18 \pm 0.08	1.31 \pm 0.06	3.14 \pm 0.08	4.87 \pm 0.12	3.50 \pm 0.12	3.33 \pm 0.10	2.26 \pm 0.05	1.44 \pm 0.05
$\ln \gamma$	2.30	3.70	2.64	5.29	2.71	2.62	0.69	1.37

These equations show that both the conductivity and the dielectric constant vary exponentially with the percentage water content w of the cake, and further that the conductivity varies nearly as the square of the dielectric constant, because the coefficient of w in equation (4) is nearly twice that in equation (3). This latter point is further confirmed by the plot of Fig. 4 for $\ln \gamma$ against $\ln K$, whose slope is 2.02 ± 0.15 . A noteworthy feature of Fig. 4 is that the scatter of the experimental points about the straight line is considerably less than for Fig. 3, in which there is probably a component of error due to lack of complete equilibrium of the absorbed water. This is supported by Fig. 5, showing the data of Tables 1 and 2 plotted as $1/K$ against relative humidity.

Since both the samples used in the foregoing experiments were subjected to treatment with petrol and heating to over 100°C . under the applied pressure, the presence of living cells in the pressed cake can be discounted, and therefore the very large variations in K and γ are to be interpreted in terms of the electrolytic action of the absorbed water. The effect can be expected to increase non-linearly with the quantity of the water because the degree of dissociation and ionization of the proteinous molecules will also increase rapidly from zero as the water is added. While the full mechanism of this is yet to be worked out, considerable support for these ideas is obtained from the fact that an approximately exponential dependence of conductivity on percentage water is observed in the case of very highly concentrated aqueous solutions of salts at concentrations of 15 to 20 equivalent weights per litre

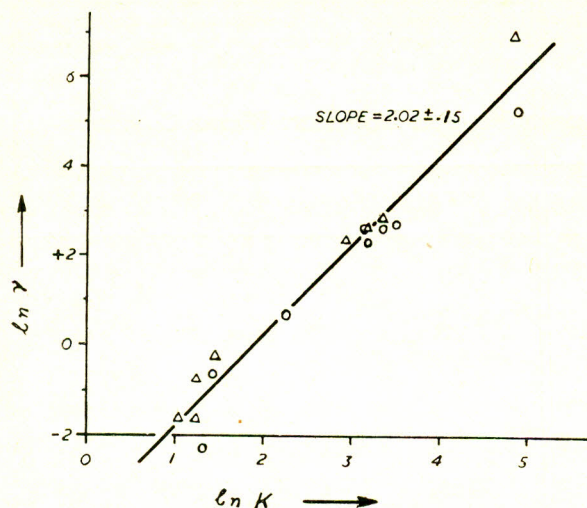


Fig. 4.—Plot showing the linear relationship between $\ln \gamma$ and $\ln K$, the slope being almost exactly 2; the circles and triangles correspond as before to the two samples.

of solution.³ Figure 6 depicts this data³ for zinc chloride on a semi-logarithmic graph, and the tendency of the graphs for specific conduc-

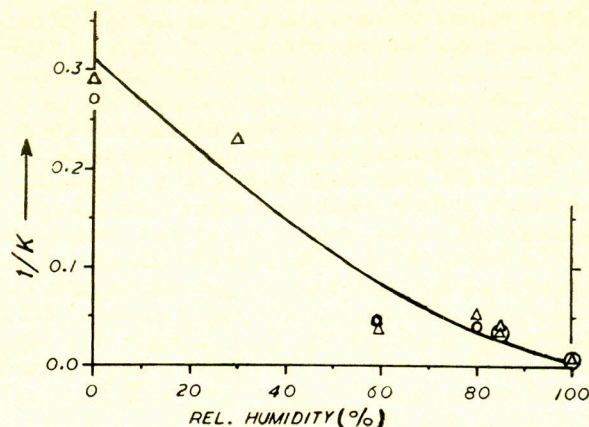


Fig. 5.—Plot of $1/K$ against percent relative humidity, based on the present data. Except for the scatter of the points, the graph is in good agreement with that of Fig. 1 (a).

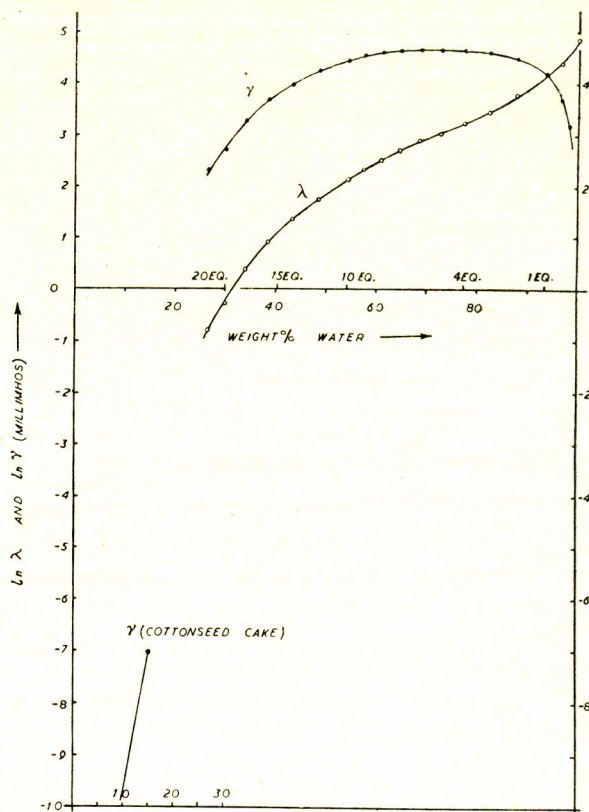


Fig. 6.—Standard data on conductance of concentrated solutions of zinc chloride, plotted semi-logarithmically for comparison with the results obtained with cottonseed cake in the present paper (bottom of figure). The possibility of a general connection between the two is strongly suggested by the graphs.

tance γ as well as equivalent conductance λ towards inclined straight lines at water contents of less than 35% is clearly marked. Moreover, the slopes estimated at 15% water content are of the same order of magnitude as in the case of the graph of Fig. 3 for cottonseed cake.

These results indicate the desirability of a thorough investigation of the influence of small percentages of water on the electrical properties of various solid compounds before a full interpretation of the electrical conduction mechanism is put forward.

References

1. Hilal Ahmad and M. M. Qurashi, Pakistan J. Sci. Ind. Research, **2**, 223 (1959).
2. A. K. Bhuiya, S. H. Ahmad and M. M. Qurashi, Pakistan J. Sci. Ind. Research, **3**, 143 (1960).
3. *International Critical Tables* (McGraw Hill Book Co. Inc., New York & London, 1929), VI, pp. 231-41.