# A CONSIDERATION OF WEED CONTROL THROUGH PHYSICAL PROPERTIES OF SEEDS

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By

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AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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in partial fulfillment of the requirements
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The problem of weeds in sugar beet fields is one of the major problems of the industry today. Even the best of present day methods of weed control requires at least one hoeing of the field by hand.

A possible solution of the problem would be killing the weeds in a narrow strip of soil by heating them with an alternating electric field. If there is enough difference in dielectric properties of soil and seeds, and between seed species themselves, selective heating may be possible.

To determine the feasibility of selective dielectric heating an investigation of the variation of dielectric constant and power factor of seed components with frequency and moisture content was initiated. For this preliminary work the components of wheat were used because they are available at a high degree of purity.

A significant variation of power absorbing ability between the components of wheat and variation of power absorbing ability with frequency is evidenced by the results of this work. This power absorbing ability or heating rate increases with frequency and moisture content for all of the components, but at different rates.

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# INTRODUCTION

In the past, the raising of sugar beets has always been closely associated with hand labor. All of the field operations, blocking, thinning, weeding, topping and loading, have been tedious manual operations. Within recent years, however, many advances have been made in the mechanization of the raising of sugar beets. Improved tillage methods, planting with segmented and decorticated seed, mechanical stand reduction and mechanical harvesting have all contributed to the reduction of hand labor. Although many of these developments are still in the experimental stage, it seems probable that most of the hand labor can soon be replaced by machine methods.

There is, as yet, one major stumbling block before the complete elimination of hand labor from beet fields--the problem of weeds. The complicated nature of dormancy, along with the very long life of weed seeds adds to the difficulty of weed control.

Present day methods of hand blocking and thinning require many hours of tedious work with hoes. Even with the newer methods of mechanical thinning and stand reduction, the operation must be followed by at least one hoeing. Results from the field indicated that if weeds could be controlled in a narrow strip on either side of the row, the major part of the problem would be solved. Weeds could be easily handled between the rows with present day cultivation methods.

One possible method of eliminating weeds from this narrow strip would be through heating. However, to heat the soil and accompanying seeds with flame or an electric current would require a great deal of energy and probably result in excessive drying of the soil. A possible solution might be selective instantaneous heating by an alternating electric field. If the physical properties of the soil and seed constituents are such that the power absorption of one material is higher than another at a given frequency, then selective heating may be possible.

For a fundamental approach to the feasibility of weed control through dielectric heating, the dielectric constant and power factor of seeds and seed components (germ, endosperm and hull) must first be evaluated, therefore, an investigation of the variation of the dielectric constant and power factor with frequency and moisture content of seed components has been attempted. For this initial investigation the germ, bran and endosperm of wheat have been used.

# REVIEW OF LITERATURE

## Weed Control Methods

Chemicals have assumed an important role in the control of weeds within recent years. The non-selective types (chlorates, arsenates, borates, etc.) have been used for several years in the control of heavy infestations of weeds in small areas (4, 41, 42, 43, 46).

The recent development of selective herbicides, however, has put a new emphasis on chemical farming. Probably the most widely known of these selective herbicides is 2, 4-D. A large amount of research work has been carried on with this chemical (4, 22, 24, 26, 27, 46), and its use is now quite generally accepted in the control of broad leaved plants.

Another group of chemicals, the trichloroacetates, has been found to control grasses, leaving broad leaved plants relatively untouched (30).

Recent work by Anderson and Lyerly (1) in Texas and by Talley (46) in Mississippi has indicated that control of many weeds and grasses by herbicidal oils is practical. Certain oils have been used as a selective spray in the cotton fields with good results. Pigweeds under three inches tall have been killed with one dosage.

Flame cultivation has also been used extensively in the cotton fields. Fairly good weed control was obtained, although Danielson and Crowe (15) stated that pigweeds and a few other weeds and grasses survived the flaming.

An investigation of the control of weeds by mechanical means by McBirney (29) showed that from 22.2 percent to 34.9 percent of the weeds could be removed by various implements. The spiked tooth harrow had the highest reduction in weeds.

Soil pasteurization has been practiced for a number of years in greenhouses. This sterilization of the soil not only kills weed seeds, but also parasites, nematodes, and insects. Newhall (32) found that the electrical energy required to raise the temperature of one cubic foot of soils from 15°C (59°F) to 65°C (149°F) for pasteurization was:

TABLE 1

ELECTRICAL ENERGY FOR HEATING SOIL

| Soil Type | KWH Per Ft$^3$ | Mean Watts °C |
|---|---|---|
| Sand | 1.15-1.68 | 27 |
| Loam | 1.16-1.62 | 28 |
| Muck | 1.54-2.05 | 35 |

Lachman (24) found that Stoddard Solvent could be used successfully as a pre-emergence spray for garden beets.

The use of ordinary sodium chloride sprays as a selective herbicide on sugar beets has been found to have some merit. Nichol (33) found that ragweed, wild mustard, pigweed, smartweed and small annual grasses could be controlled but no control was obtained over lambsquarter, sow thistle and quackgrass. Other workers (51) found that aromatic oil-pentachlorophenol sprays controlled the weeds with no damage to the sugar beets in an experimental plot.

## Dielectric Heating

Bitter (8) placed some barley seeds on the lower condenser plate of a short wave oscillator circuit. He tried various frequencies and exposure times but obtained no effect on the germination of the seed.

Bellinzaghi (6), however, found that inhibition of *Vicia faba* (English dwarf beans) results after a fifteen to twenty second exposure at a frequency of one hundred and seven megacycles.

Using a frequency of fifteen megacycles and exposures of two, three, four, and five minutes, Lambert, et al (25) treated wheat, oats, barley, perennial peppergrass, Canada thistle, field bindweed, wild mustard, wild oats, quackgrass and leafy spurge.

With a two minute exposure they reduced the germination of wild mustard from 22 percent to 3 percent and the germination of quackgrass from 88 percent to 9 percent.

## THEORETICAL INVESTIGATION OF DIELECTRIC HEATING

### Effect of Heat on Life

The exposure of seeds to a radio frequency field will, to some extent, alter the germination of the seeds. One of the possible effects of this alternating electric field is that of dielectric heating, with a corresponding increase in temperature.

This increase in temperature has a very definite effect on the life process of the seed.

Chemical reactions which have a measurable rate of reaction show an increase in rate of reaction with an increase in temperature. This increase in rate of reaction can be expressed theoretically by the van t'Hoff-Arrhenius law of physical chemistry.

$$\ln \frac{K_2}{K_1} = A\left(\frac{T_2 - T_1}{T_1 T_2}\right)$$

or,

$$\frac{K_2}{K_1} = e^{A\left(\frac{T_2 - T_1}{T_1 T_2}\right)}$$

where, $K_2$ is the equilibrium constant of the reaction at a temperature $T_2$,

$K_1$ is the equilibrium constant of the reaction at a temperature $T_1$, and,

A is the temperature characteristic.

This ratio $\frac{K_2}{K_1}$ is often expressed as a temperature coefficient "Q". For many life functions the value of Q for a temperature difference of 10°C ranges between two and three. This means that, with an increase of 10°C in temperature, the rate of reaction increases two or three fold.

According to Rahn (38) the value of Q for many proteins ranges between ten and one hundred for a 10° temperature rise. The heat coagulation of the protein Hemoglobin which takes place in twenty-six seconds at 80°, takes six minutes at 70°, ninety minutes at 60°, 20.6 hours at 50° and twelve days at 40°. If one of the vital proteins essential for the life process of the cell coagulates completely, the cell is dead. Also, most of the cell catalysts are similar to, or are linked to, native proteins. It has been found that the thermal death-point for a life process is fairly definite, being only a few degrees above the maximal temperature. The maximal temperature is that temperature at which the process proceeds at its maximum rate.

This indicates that it may be possible to kill the seed germ by an almost instantaneous application of heat if the proper temperature is attained. Since the nature of the proteins in the various seeds differs, and since the various proteins do not have the same coagulation temperature, it may be possible to obtain selective killing of different species by the proper temperature control.

## Heating Effect of a Radio Frequency Field

A dielectric, placed in an electrostatic field, is subjected to two forces: (1) the distortion of the molecules of the dielectric in which the orbits of the negatively charged electrons are displaced in the direction of the positive charge of the field and the positively charged nucleus is displaced, to a very small extent, in the direction of the negative charge of the field; and (2) the rotation of the molecules due to their dipole moment. If the electrostatic field is alternated very rapidly, the internal resistance to this distortion causes a heating of the dielectric.

According to Terman (47), this heating effect may be expressed by:

$$H = \frac{(0.55 \times 10^{-12})\ (f)\ (E^2)\ (e)\ (p.f.)}{d^2} \text{ watts/cc.}$$

where, f is the frequency in cycles per second,

E is the difference in potential between the condenser plates,

p.f. is the power factor of the material,

e is the dielectric constant, and

d is the distance between the condenser plates in centimeters.

It can be seen from this equation that for a given voltage gradient and plate distance, the heating effect of a material in an electric field varies directly with frequency, dielectric constant and power factor.

## Variation of Dielectric Constant and Power Factor with Frequency

When a dielectric material is subjected to an alternating electric field the polarization of the dielectric will depend on the frequency and will be out of phase with the field. At low frequencies the ions and dipoles will contribute to their fullest extent to the dielectric constant without an appreciable time lag. At higher frequencies the motion of these ions and dipoles can not keep up with the change in field direction and will therefore contribute less to the dielectric constant. Therefore, the dielectric constant will decrease with increase in frequency.

The ions and dipoles get more and more out of phase as the frequency increases. This phase difference ($\theta$) is the loss angle and tan $\theta$ is the power factor. This phase lag gives rise to heat dissipation which is therefore proportional to the frequency and tan $\theta$.

Where the frequency corresponds to the relaxation time of the dipole, tan $\theta$ becomes a maximum.

The relationship between the dielectric constant and the power factor can be seen in Figure 1.

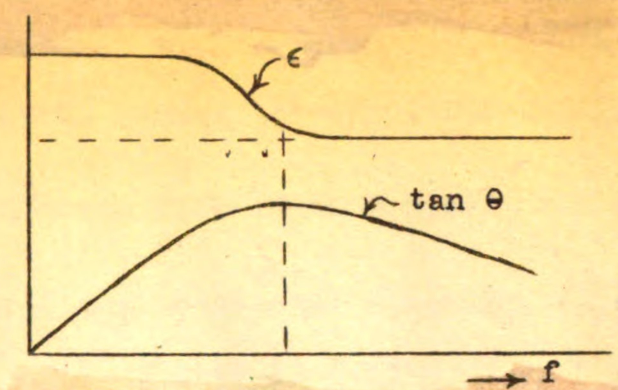


Figure 1. Variation of dielectric constant (ϵ) and power factor (tan θ) with frequency.

Variation of Dielectric Constant with Temperature

Morgan (31) has found that, in some dielectrics, there is evidence of a cooperative effect such that when one molecule starts to rotate it makes it easier for its neighbors to do so, and the effect spreads. These materials exhibit a sharp transition zone in which, with but a few degrees change in temperature, the dielectric constant increases three to eight times its original value.

Variation of Dielectric Constant with Moisture

Berliner and Ruter (7) obtained values of the dielectric constants of wheat and rye at various moisture contents. The values ranged from thirty at 10 percent to forty-three at 16 percent moisture and sixty at 19 percent moisture. These values indicate that water, dielectric constant 81, has a very large

influence on values of the dielectric constant of grain. The dielectric constant of starch and gluten (principal components of the endosperm) ranges between three and four.

Relation Between Dielectric Constant and Dipole Moment

From the Clausius-Mosotti equation of physical chemistry,

$$P = \frac{(e-1)}{(e+2)}\frac{(M)}{(d)}$$

where, P is the molar polarization of the substance,

e is the dielectric constant,

M is the molecular weight, and

d is the density,

one can obtain,

$$e = \frac{2P - \frac{M}{d}}{\frac{M}{d} - P}$$

which indicates, that, with an increase in molar polarization there is considerable increase in dielectric constant.

However, $P = P_D - P_\mu$

where $P_D$ is the induced or distortion polarization and

$P_\mu$ is the permanent polarization.

According to Debye,

$$P_D = \frac{4\pi N\alpha}{3} \quad \text{and} \quad P_\mu = \frac{4\pi N\mu^2}{9KT}$$

where N is Avogadro's constant ($6.02 \times 10^{23}$),

$\alpha$ is the polarizability of the dielectric,

$\mu$ is the dipole moment, and

K is the Boltzmann constant ($1.38 \times 10^{-16}$),

It can be seen that, for unsymmetrical molecules, the dielectric constant increases with the square of the dipole moment.

## Dielectric Constant of Soil

Ratcliffe and White (39) found a decrease in dielectric constant with an increase in frequency for soil. The values decreased from about forty at .25 megacycles to eleven or twelve at frequencies above three megacycles.

Banerjee and Joshi (3) found the dielectric constant of soil to be approximately three at six percent moisture at a frequency of seventy megacycles, increasing to 12.5 at fourteen percent moisture. They also found a decrease in dielectric constant with an increase in frequency.

## THEORY OF MEASUREMENT

Measurement of dielectric constant and power factor at frequencies ranging from 50 KC to 40 MC were accomplished with the aid of a Boonton 160A "Q" Meter.

By definition, Q is the ratio of the reactance to the resistance of the reactive element in question. This relationship may be expressed by:

$$Q = \frac{X_L}{R} = \frac{2\pi f L}{R}$$ for an inductance, and

$$Q = \frac{X_c}{R} = \frac{1}{2\pi f C R}$$ for a capacitance

where $X_L$ is the inductive reactance in ohms,

$X_c$ is the capacitive reactance in ohms,

R is the resistance in ohms,

f is the frequency in cycles per second,

L is the inductance in henries, and,

C is the capacitance in farads.

For a simple series circuit at resonance, $X_L = X_c$ and the current will be the same through all components.

Therefore

$$I = \frac{E}{R_e} = \frac{Ec}{Zc}$$

Then $$\frac{Ec}{E} = \frac{Zc}{R_e} = \frac{\sqrt{Rc^2 + Xc^2}}{R_e}$$

where E is the total voltage across the circuit,

$E_c$ is the voltage drop across the condenser,

$Z_c$ is the impedence of the condenser, and,

$R_e$ is the effective series resistance of the circuit.

Since the reactance is of considerably greater magnitude than the resistance of the condenser,

$\frac{E_c}{E} = \frac{X_c}{R_e} = Q_e = \frac{X_L}{R_e}$, where $Q_e$ is the effective Q of the circuit

In the "Q" meter $E_c$ is read by means of a voltmeter having negligible power consumption and E is held constant, therefore Q can be read directly from the voltmeter.

For inductances the true Q differs from Q. This difference is due to the distributed capacitance $C_d$ of the coil and can be expressed very closely by

$$Q = Q_e(1 + \frac{Cd}{C}).$$

Since the power factor is, by definition, the ratio of the resistance to impedence, therefore,

$$p.f. = \frac{R}{\sqrt{R^2 + X^2}} \cong \frac{1}{Q}$$

For impedences having Q greater than ten this is correct within one percent.

# EXPERIMENTAL INVESTIGATION

## Materials Used

An investigation was started to determine the effects of dielectric heating on seeds. Since the protein content of the seed germ is considerably higher than that of the endosperm or of the hull, it was felt that there might be enough difference in dielectric constant to allow for differential heating at radio frequencies.

Preliminary experiments were started to determine the difference in dielectric constant of the components of seeds. For this work wheat was chosen because the components of the seed are available in quantities and at a high degree of purity. Unbleached flour was obtained from the King Milling Company of Lowell, Michigan. Finely ground wheat bran was obtained from the National Biscuit Company of Cleveland, Ohio, and the wheat germ meal of over 90 percent purity was obtained from the Pillsbury Mills, Incorporated of Minneapolis, Minnesota.

The average percentage of protein and density of these components are:

TABLE 2

PERCENTAGE OF PROTEIN AND DENSITY OF MATERIALS

| | Protein Content Percentage | Density |
|---|---|---|
| Wheat flour | 8.55 | 0.58 g/cc. |
| Wheat bran | 13.51 | 0.39 g/cc. |
| Wheat germ | 33.46 | 0.62 g/cc. |

Determination of the composition of the materials used was made by the Agricultural Chemistry Department.

The density was determined in a packed condition as nearly similar to that in the condenser as was possible.

## Apparatus and Methods

The method used in the determination of the dielectric constant and power factor was the insertion of the test condenser in parallel with the calibrated condenser of the "Q" meter and resonating this capacitance with the various inductances.

The schematic diagram of this circuit is shown in Figure 2.

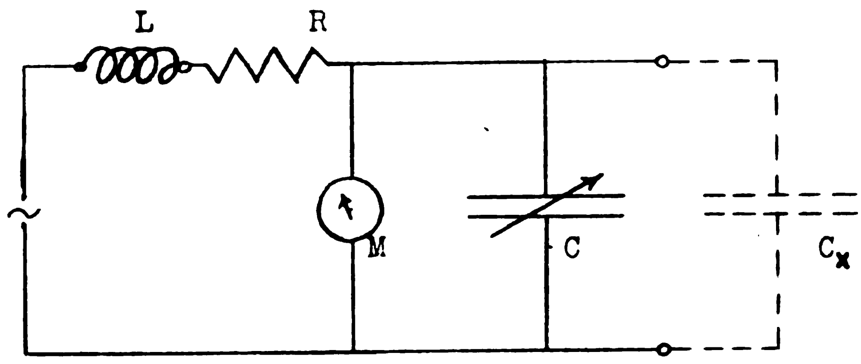


Figure 2. Schematic diagram of test circuit at low frequencies.

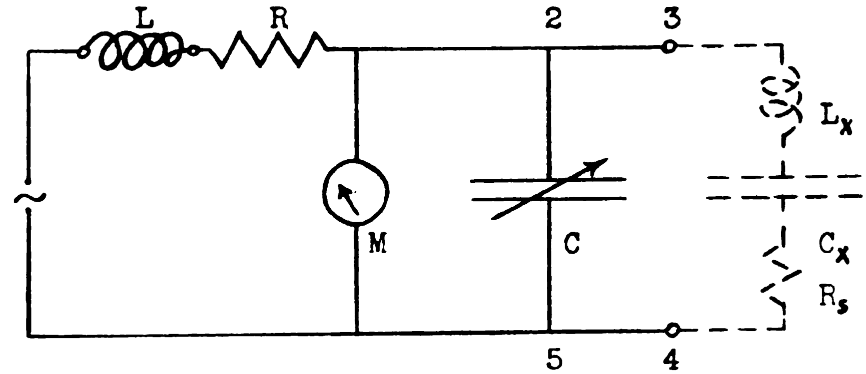


Figure 3. Schematic diagram of equivalent test circuit at high frequencies.

Meaning of Symbols

L is the external inductance used to resonate the circuit.

R is the series resistance of the circuit.

M is the voltmeter from which Q is read.

C is the calibrated variable capacitance.

$C_x$ is the external test condenser.

$L_x$ is the lead inductance of the test condenser, and

$R_s$ is the series resistance of the test condenser.

Readings of frequency, $Q_1$ and $C_1$ were taken. The test condenser was removed, the circuit re-resonated at the same frequency, and readings $Q_2$ and $C_2$ taken.

With these readings the dielectric constant and power factor can be calculated as follows:

Since $C_2 - C_1 = C_c$ = the capacitance of the test condenser, then

$$e = \frac{4.45 . C_c \cdot d}{A}$$

where $d$ is the distance between the condenser plates in inches, and, A is the active area of the condenser plates in square inches.

Also $Q = \frac{C_c Q_1 Q_2}{C_2 (Q_2 - Q_1)}$, therefore $p.f. = \frac{C_2 (Q_2 - Q_1)}{C_c Q_1 Q_2}$.

Figure 4. The Boonton 160A "Q" Meter with empty test condenser and inductance connected.

At high frequencies there was an apparent increase in the capacitance of the condenser due to the inductance of the condenser leads and plates. The value of this lead inductance was determined by clamping the condenser plates together, thereby shorting them out, and testing the condenser as an inductance. On the theory that there may have been some capacitance in the system due to oxide coating or poor contact of the plates, the distributed capacitance was determined but was found to be only one percent of the total capacitance of the circuit, and therefore neglibible.

The inductance of the condenser leads was found to be 0.26 $\mu$H, which was insignificant at low frequencies but very important at high frequencies where the inductance of the resonating coil may be as low as 0.08$\mu$H.

The resulting circuit at high frequencies was no longer a simple series circuit, but changed to a combination series-parallel circuit as shown in Figure 3. The Q of this circuit can not be used to calculate the Q of the condenser and $C_2 - C_1$ does not give the actual capacitance of the test condenser.

Calculations of capacitance and power factor were made as follows:

In the case of the series circuit, the total impedance of the circuit is equal to the sum of the impedance of the inductance and the impedance of the capacitance, or $Z_t = Z_L + Z_c = \sqrt{R_s^2 + (X_c - X_L)^2}$. At resonance the inductive reactance equals the capacitive reactance ($X_c = X_L$) therefore $Z_t$ is simply the series d.c. resistance of the circuit.

However, referring to Figure 3 for the combination series-parallel circuit,

$$Z_t = Z_{12} + \frac{Z_{25}\,Z_{34}}{Z_{25} + Z_{34}}$$

Since $Z_{12}$ is primarily inductive, the distributed capacitance and resistance of the coil can be neglected and $Z_{12}$ can be represented by $X_L$. Neglecting inductive reactance and resistance of the variable capacitance, $Z_{25}$ can be represented by $X_c$. The total impedance then becomes,

$$Z_t = X_L + \frac{X_c\,Z_{34}}{X_c + Z_{34}}$$

For the system to resonate, some equivalent capacitive series reactance must equal the inductive reactance of $X_L$. The value of this reactance was determined by resonating the circuit at the same frequency used for testing, but without the test condenser connected. The reading of the calibrated condenser then gave the value of the capacitance for computing the equivalent capacitive reactance $X_c'$. Another method of calculating this reactance would be the determination of $X_L$ itself but it was felt the capacitive reading would be less subject to errors brought in by the flux linkage and distributed capacitance of an external coil.

The capacitive reactance of the test condenser was determined by solving the following equation for $X_c''$,

$$X_c' = \frac{X_c Z_{34}}{X_c + Z_{34}} = \frac{X_c \sqrt{R_s^2 + (X_c'' - X_L')^2}}{X_c + \sqrt{R_s^2 + (X_c'' - X_L')^2}}$$

where $X_c'$ is the equivalent capacitive reactance,

$X_c$ is the reactance of the variable condenser,

$X_c''$ is the capacitive reactance of the test condenser,

$X_L'$ is the inductive reactance of the test condenser, and

$R_s$ is the effective series resistance of the test condenser.

Therefore, $X_c'' = X_L' \pm \sqrt{\left(\frac{X_c' X_c}{X_c - X_c'}\right)^2 - R_s^2}$

from which the positive root was used.

The capacitance of the test condenser can then be determined from $C = \frac{1}{2\pi f X_c''}$

The power factor was determined from the ratio, p.f. $= \frac{R}{Z_c}$ where $Z_c = \sqrt{R_s^2 + X_c''^2}$. The capacitance of the leads of the condenser was determined by testing the capacitance of similar leads without plates attached. This value was added to the value of $C_2$. The increase in the distance between the plates of the test condenser due to the material being tested was determined with a micrometer and the value added to d in the determination of the dielectric constant.

Three condensers were constructed and used. The 43 μμf condenser (Figure 5) was constructed of wood with four inch square sheet steel plates. The ends of the condenser were removable for filling and cleaning. This condenser had too much inherent inductance and was discarded.

Figure 5. The 43 $\mu\mu F$ Condenser.

This condenser is constructed of wood with four inch square sheet iron condenser plates. The ends of the condenser are removable for ease in filling and emptying.

The 38 uuF condenser (Figures 6 and 7) was constructed of Plexiglass with three inch square aluminum plates. Connecting leads were of stiff silver wire and all bolts were of brass. This condenser was designed so that one side of the condenser was removable, making filling and cleaning easier. The 54 $\mu\mu F$ condenser was similar to the 38 $\mu\mu F$ condenser but the distance between condenser plates was reduced from 0.056 to 0.040 inches.

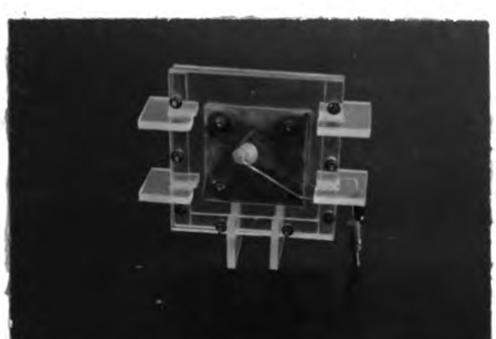

Figure 6. The 38 $\mu\mu F$ Condenser.

This condenser is constructed of Plexiglass with three inch square aluminum condenser plates and silver wire leads.

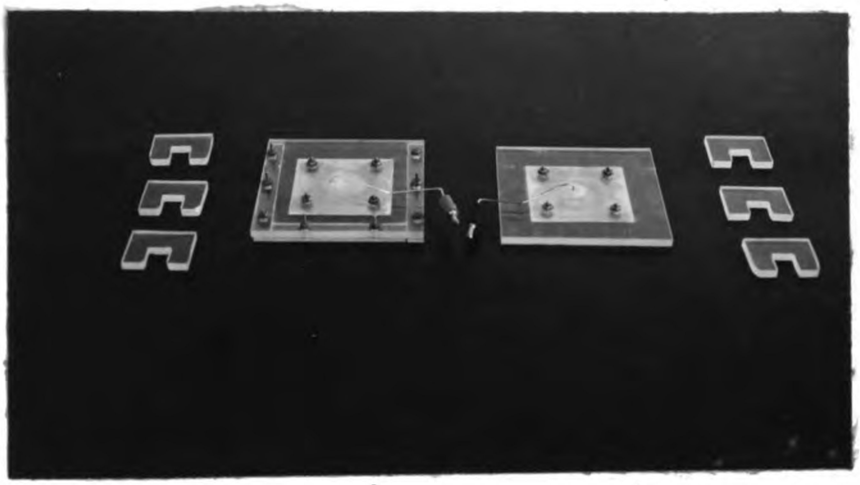

Figure 7. Disassembled 38 μμF Condenser.

This improved design with one side removable allowed for easier filling and emptying.

Corrections for fringing were made using the formula:

$$C_i = 0.0716\, L \left[ \frac{\pi b + d}{d} + \ln\left( \frac{\pi b + d}{d} + \ln \frac{\pi b + d}{d} \right) \right],$$

where $C_i$ is the capacitance of the condenser with fringing,

L is the length in inches,

b is the width in inches, and

d is the distance between plates in inches.

A variable inductance (Figure 8) of from zero to sixty turns was constructed from an antenna tuning coil but it was found to be unsatisfactory at high frequencies. Separate inductances (Figure 8) were connected in series with the condensers for resonance at the various frequencies.

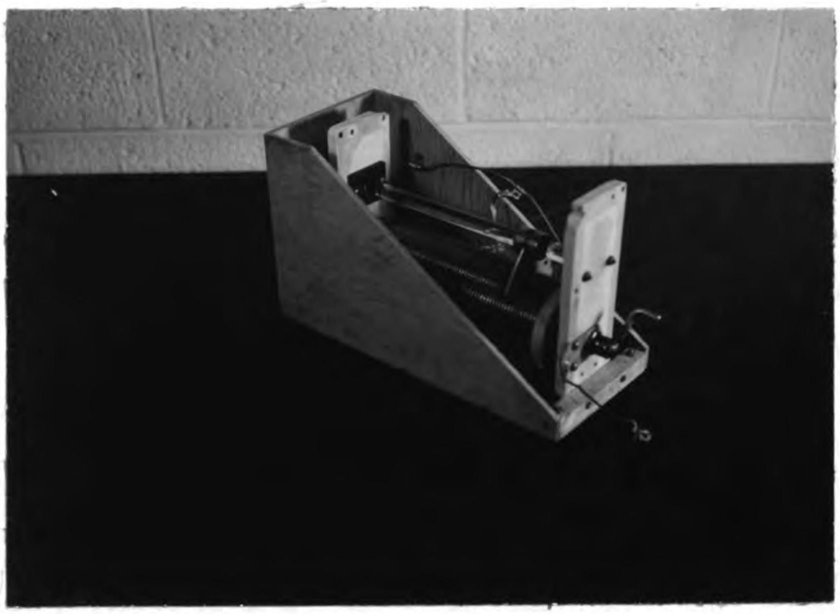

Figure 8. This variable inductance was constructed from an antenna tuning coil. It proved unsatisfactory at high frequencies because of harmonics.

Figure 9. Inductance coils which were connected in series with the condenser for resonance at various frequencies.

The water content of the material was regulated by constant humidity jars (Figure 10) containing solutions of sulfuric acid and distilled water. The material was suspended in containers above the solution and the partial pressure of the water vapor, as regulated by the strength of the acid solution, controlled the moisture content.

Figure 10. Humidity Control Chamber.

The moisture content of the material is regulated by suspending the material above a given solution of sulfuric acid and water.

The percentage of moisture was determined by heating a weighed sample of the material in a constant temperature air oven at 130°C for one hour and reweighing after cooling in a dessicator. The percentage of moisture was determined on a wet basis. This method, though not the most exact, was found by Burton (10) to be fairly consistent with results obtained by the standard method of slow heating in a vacuum oven at

98-100$^{o}$ C for forty-eight hours, and with the Brown-Duval method. For the purpose of these preliminary tests this approximate method was considered sufficient.

## Experimental Results

The variation of the dielectric constant of wheat endosperm with frequency and moisture content can be seen in Figure 11. There is evidence of the Debye resonance at frequencies above nine or ten megacycles. The upper limit of this resonance, where the molecules are rotating in the same period as the frequency of the field, was not determined. The relatively slow decrease in dielectric constant indicates that there is a range in the size of molecules and, as the frequency increases, less and less of the molecules are able to rotate with the changing field, thereby adding less to the dielectric constant.

There is some indication that there may be another Debye resonance at frequencies below fifty kilocycles, which was the lower limit of the Q meter. The value of the dielectric constant decreased approximately thirty percent in the range of frequencies from fifty kilocycles to nineteen megacycles.

An increase in moisture content adds considerably to the dielectric constant but without an appreciable alternation of the basic frequqncy curve.

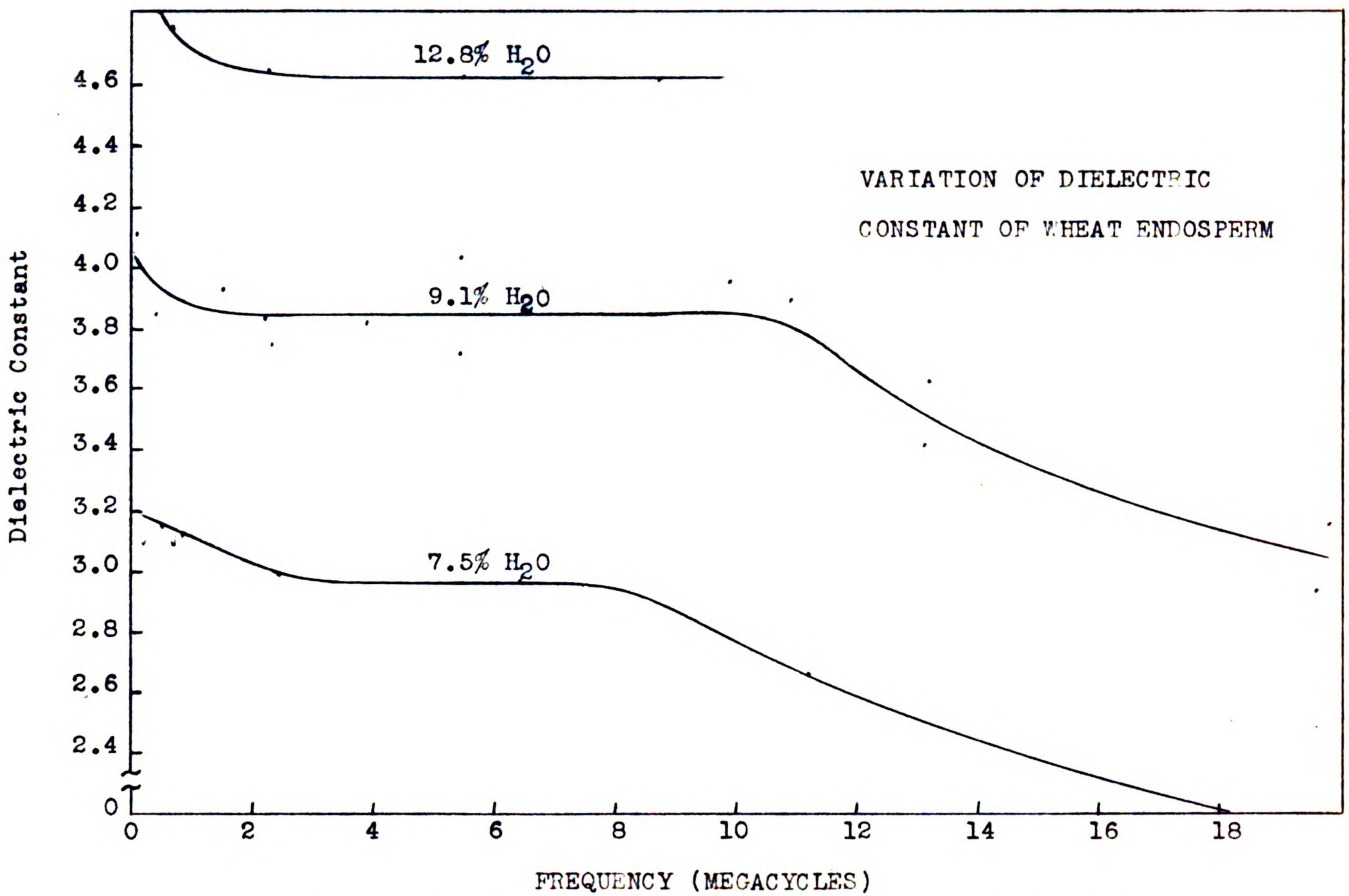


Figure 11. The variation of dielectric constant of wheat endosperm with frequency and moisture content.

The variation of the power factor of wheat endosperm with frequency and moisture content is shown in Figure 12. There appears to be a levelling off of the power factor at frequencies above twelve megacycles, but a further increase is noted at around nineteen megacycles for the endosperm at 9.1 percent moisture. This increase indicates that there might be a levelling off of the dielectric constant, above nineteen megacycles, possibly in the approach to another Debye resonance at some higher frequency.

In the frequency range used (0.05 to twenty megacycles) therewas an approximate 100 percent increase in power factor for the endosperm at 7.5 percent moisture and 140 percent increase at 9.1 percent moisture.

There is an apparent increase in power factor with an increase in moisture content although the power factor for 9.1 percent moisture and for 12.8 percent moisture were practically the same.

The variation of dielectric constant of bran with frequency and moisture content is shown in Figure 13. A Debye resonance is found, beginning at frequencies above twelve megacycles. The decrease in dielectric constant is gradual, indicating a considerable variation in molecule size. The dielectric constant of the bran at 6.6 percent moisture approaches a value of one, which is the value of the dielectric constant of air. An increase in moisture content served only to increase the dielectric constant without significantly altering the shape of the curve.

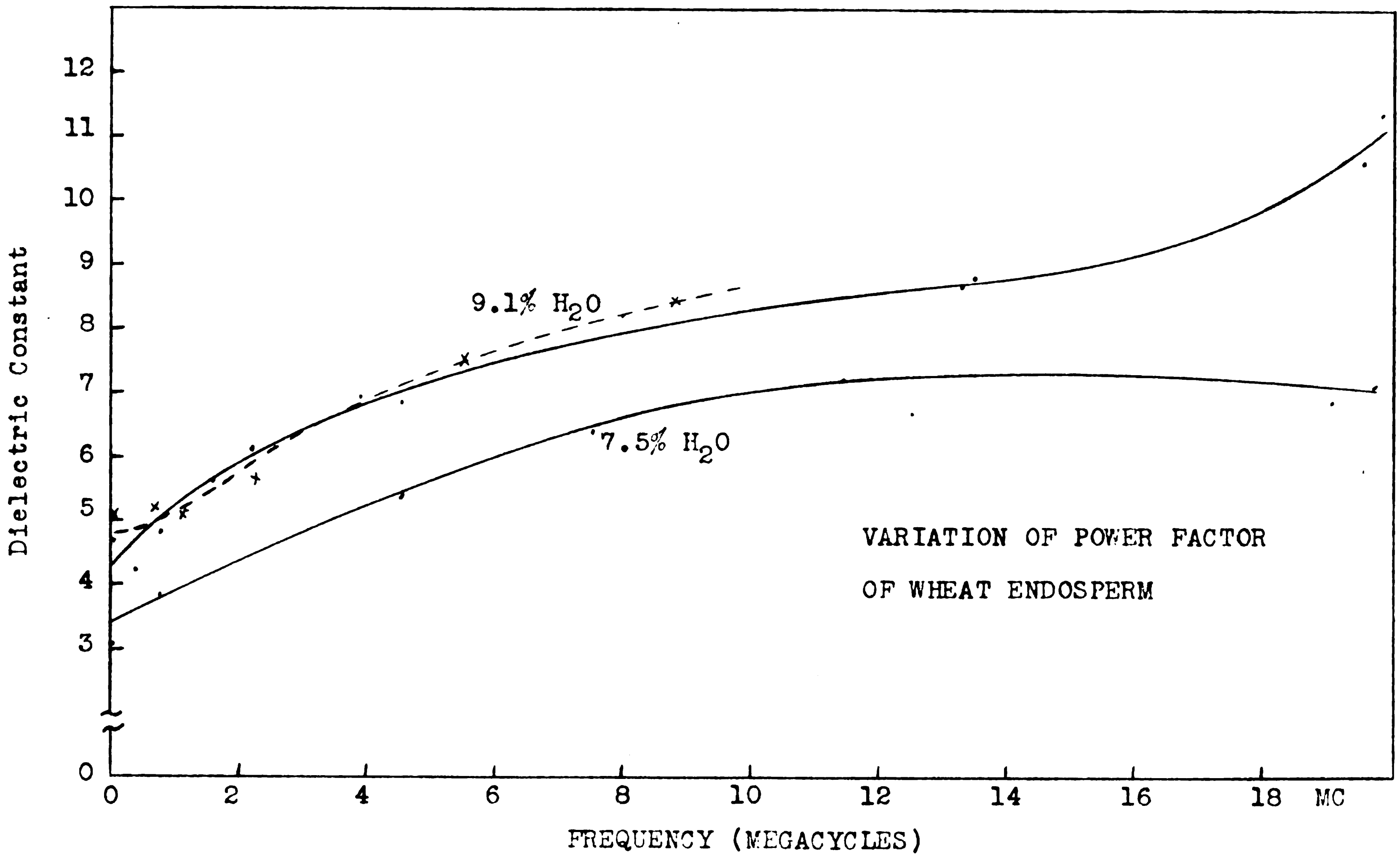


Figure 12. The variation of power factor of wheat endosperm with frequency and moisture content.

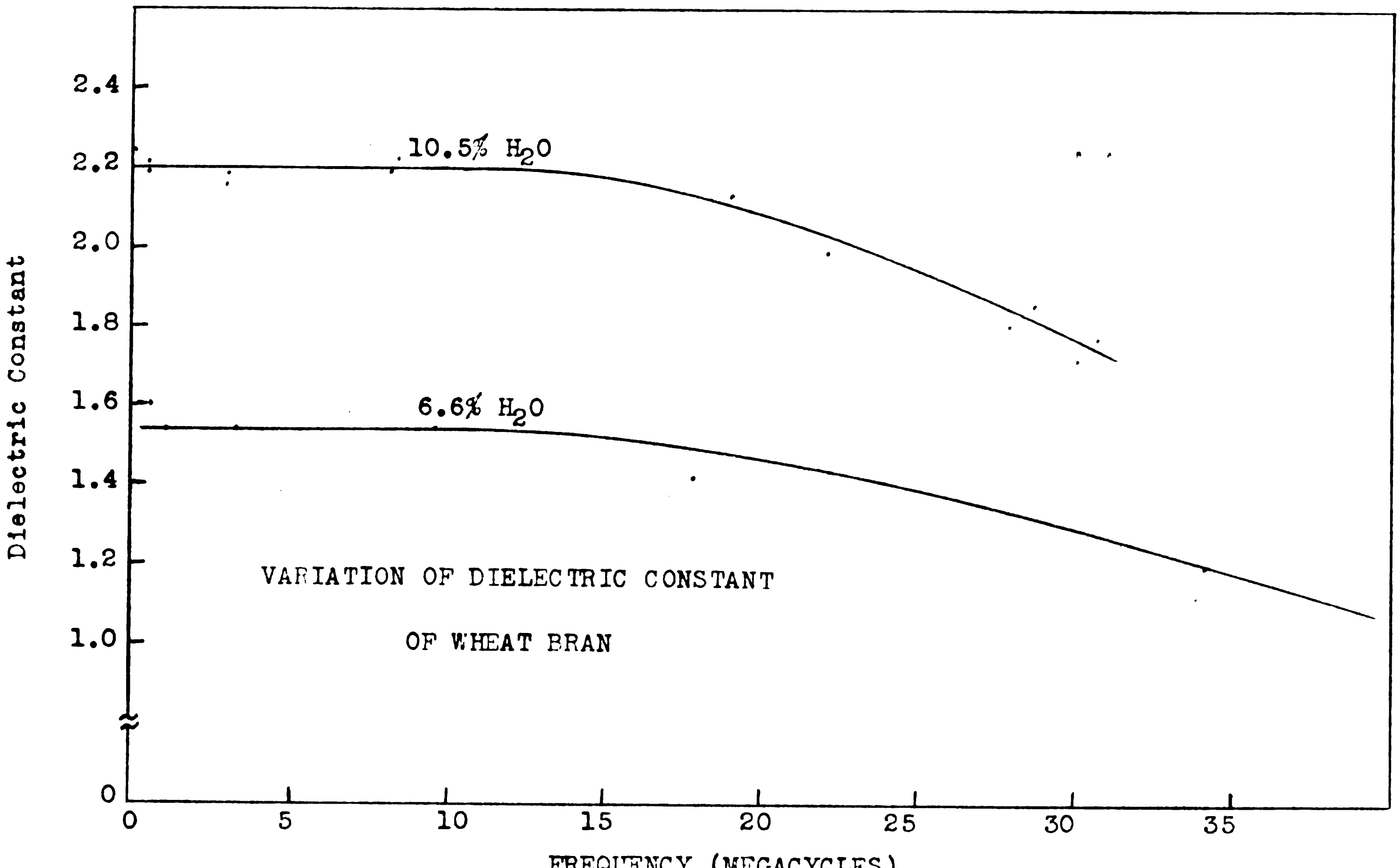


Figure 13. The variation of dielectric constant of wheat bran with frequency and moisture content.

The power factor of the bran (Figure 14) levelled off at about ten megacycles and gradually declined with an increase in frequency. The values for the dielectric constant and power factor of bran are considerably less than those for the endosperm.

The variation of dielectric constant and power factor of wheat germ are shown in Figure 15. There is apparently a Debye resonance between ten and eighteen megacycles, evidenced by a decrease in dielectric constant and maximum power factor. The power factor and dielectric constant vary abruptly indicating a fairly uniform molecule size at this point of resonance.

There is another drop in dielectric constant and power factor at frequencies between twenty-four and twenty-eight megacycles. The exact nature of this drop was not determined but the abruptness of the drop would indicate another resonance point of molecules fairly uniform in size.

A comparison of the three components shows that the beginning of at least one Debye resonance occurs for all of the materials at a frequency of about ten megacycles. For the endosperm the decrease in dielectric constant continued up to twenty megacycles but the power factor curve indicates that there may be a levelling out of dielectric constant and another Debye resonance at some higher frequency. This would be similar in behavior to the germ. There is also an indication that another resonance may be found for frequencies below fifty

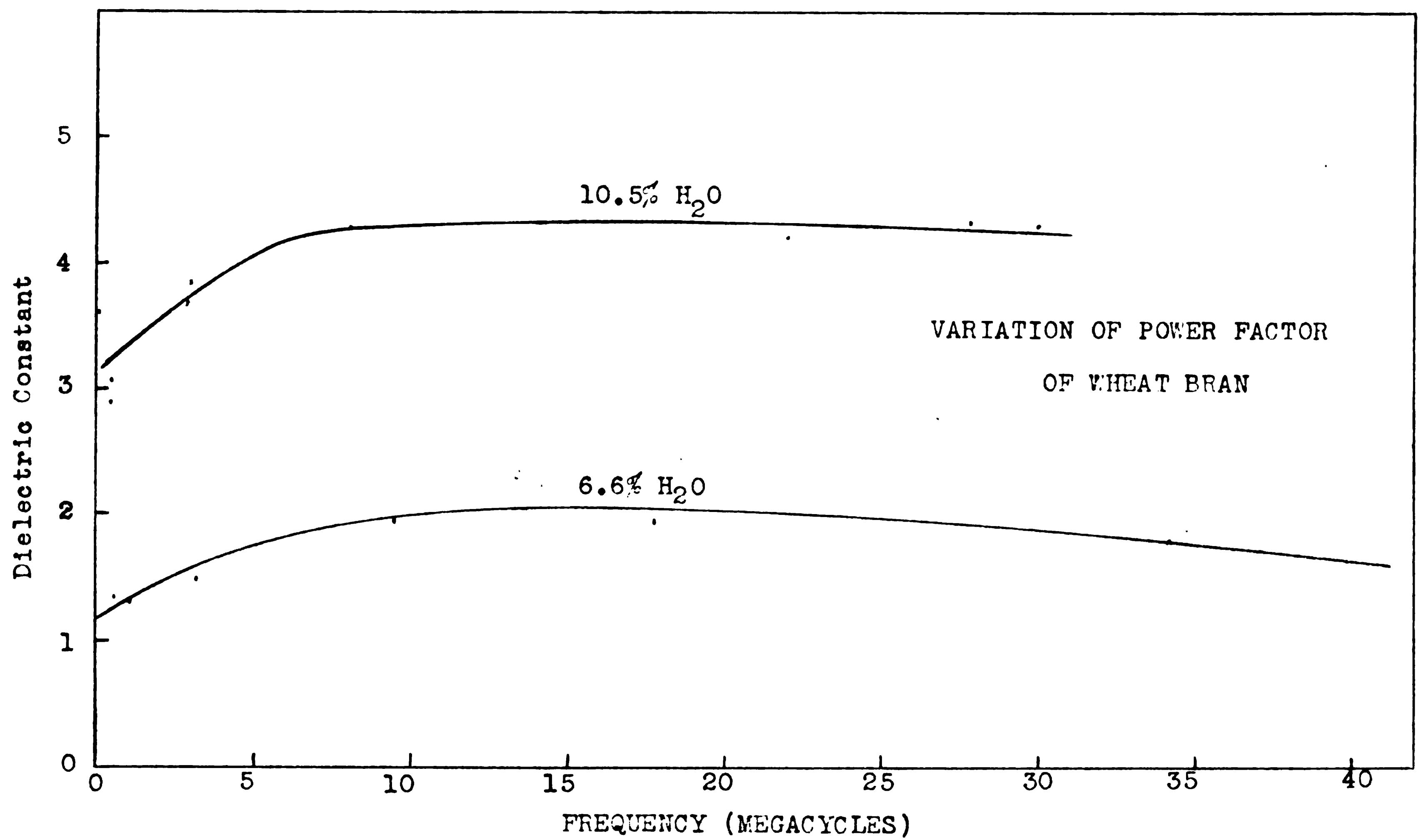


Figure 14. The variation of the power factor of wheat bran with frequency and moisture content.

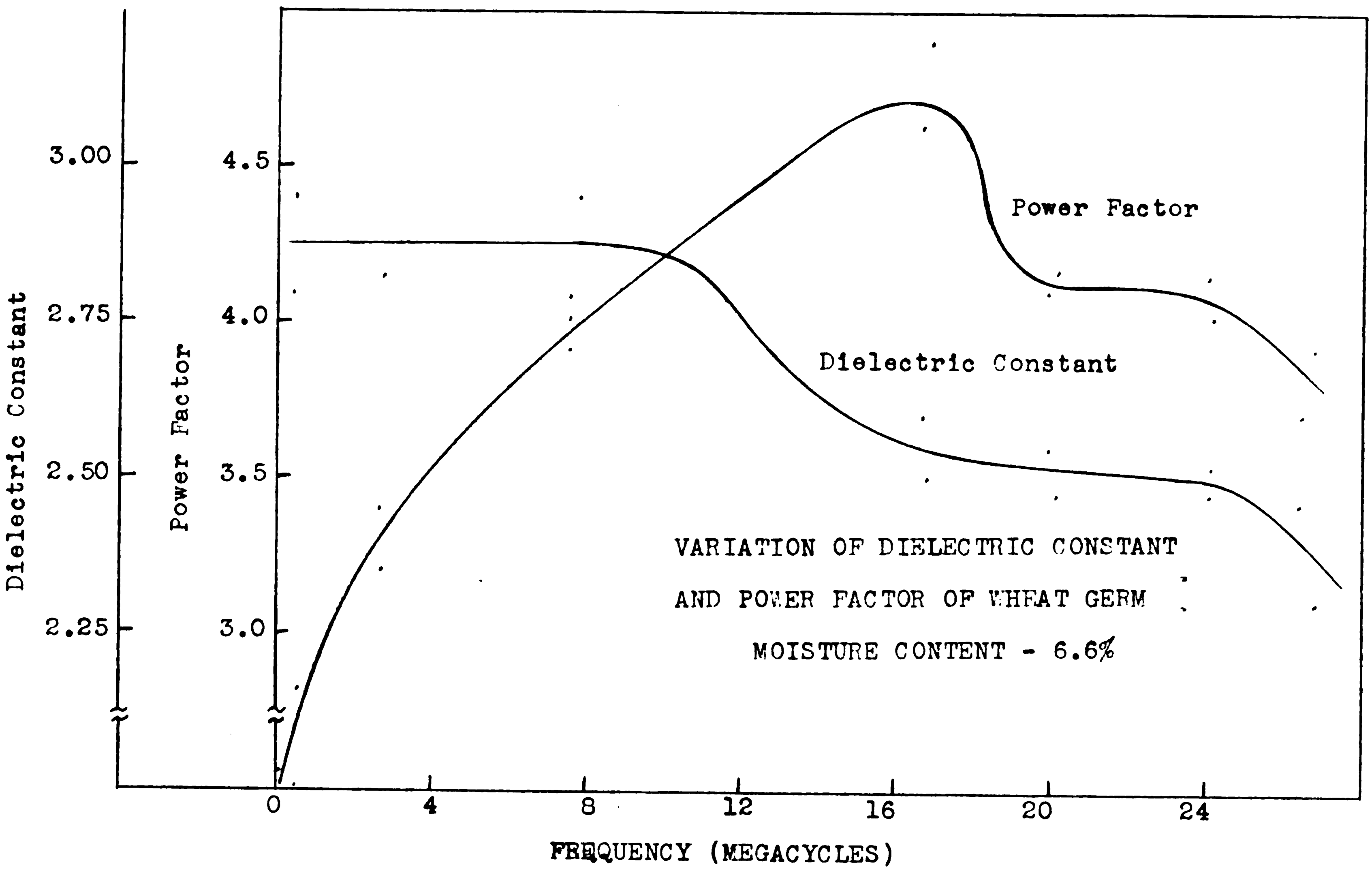


Figure 15. The variation of dielectric constant and power factor of wheat germ with frequency.

kilocycles. The bran exhibited a gradual decline in dielectric constant and power factor with no abrupt changes in value. The germ evidenced the most pronounced Debye effect of the three, two very definite points of resonance being noted.

The relative rate of heating of an alternating electric field for the three components is shown in Figure 16. This value was computed from the frequency, dielectric constant and power factor, and serves as a basis of comparison of the relative heating rates that could be expected using a given voltage and distance between condenser plates.

The power absorption of the endosperm and bran varies uniformly with the frequency but two pronounced plateaus are noticed for the germ.

The heating rate of the endosperm and germ increases very rapidly with an increase in frequency. With any given voltage, doubling the frequency very nearly doubles the heating rate or power absorption of the material. At the two plateaus in the curve for the germ, however, an increase in frequency does not increase the power absorption. The heating rate of bran varies slowly with frequency and reaches a maximum at around thirty-five megacycles.

The relative power absorption of the three components, expressed as percentage of the total power absorption is shown in Figure 17. Within the frequency range of 0.05 to twenty megacycles the power absorption of the bran remains almost constant between eight and ten percent. The power absorption

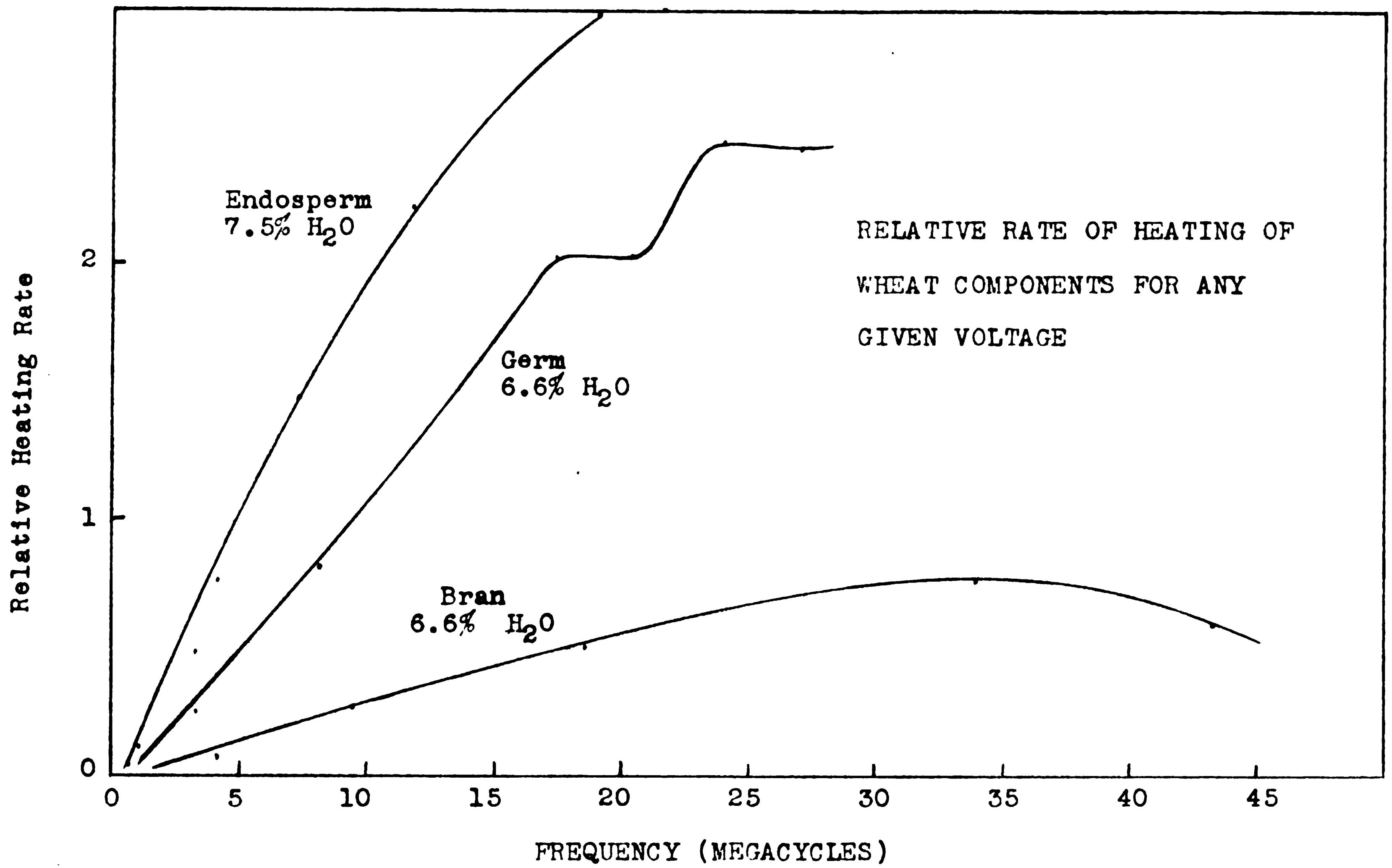


Figure 16. Variation of relative heating rate of grain components with frequency for any given voltage.

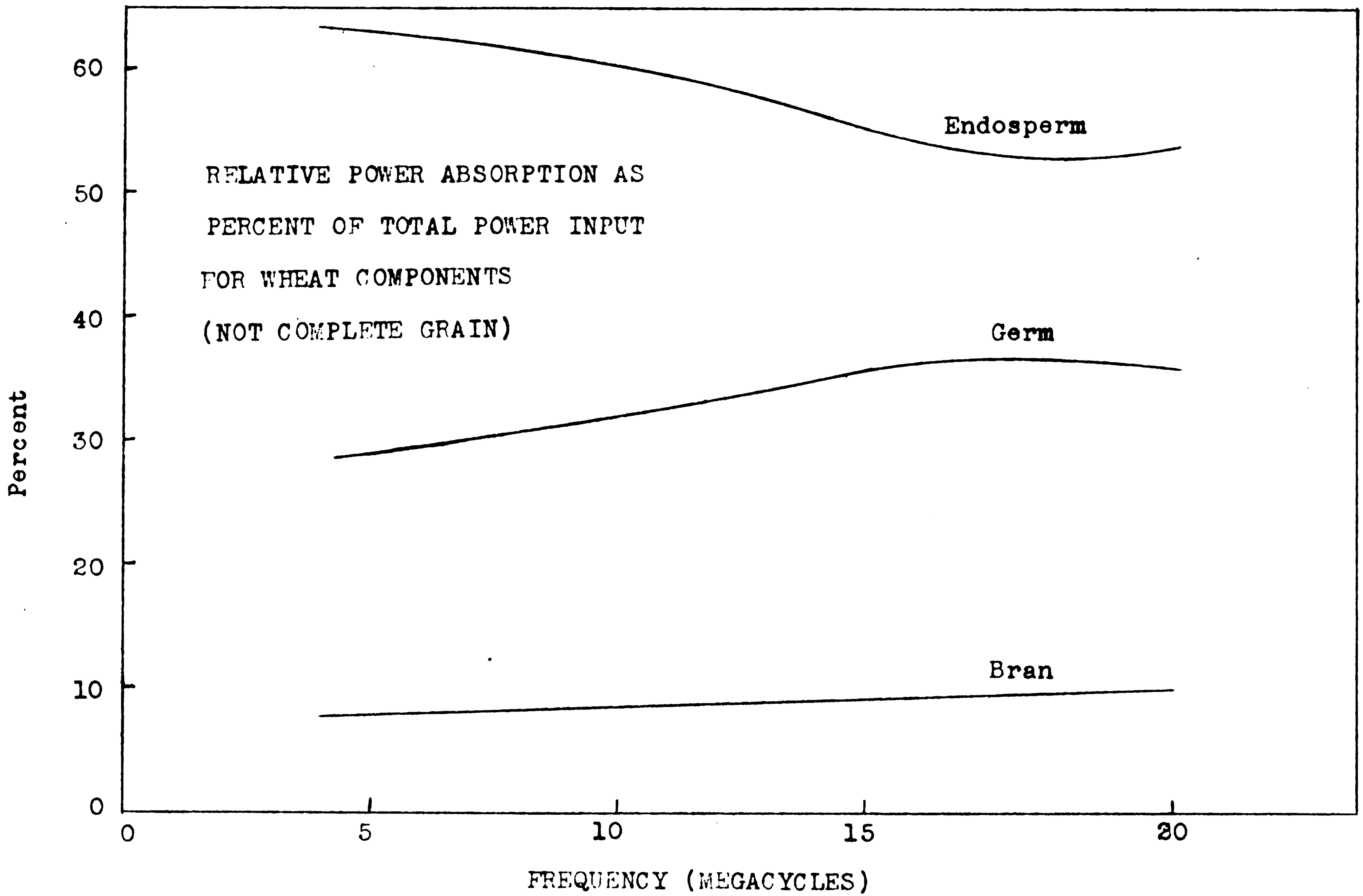


Figure 17. The relative power absorption or heating rate of wheat components as percent of total power input.

of the endosperm remained considerably higher than the other components although there was some decrease with increased frequency. The minimum value of absorption for the endosperm was fifty-three percent and the maximum absorption sixty-three percent. The power absorption of the germ reached a maximum value of thirty-seven percent at about 17.5 megacycles.

## Interpretation of Results

There is evidence of the Debye resonance in all three components of wheat at frequencies above ten megacycles. The decrease in dielectric constant and power factor for bran, as a result of this Debye resonance, is gradual over a frequency range of ten to forty megacycles. The dielectric constant for wheat endosperm and germ decreases at a much more rapid rate and there is evidence of a second Debye effect at twenty-four to twenty-six megacycles for germ.

The dielectric constant of endosperm ran very close to the dielectric constant of germ but about twice the value for bran. Representative values of dielectric constant, for example at five or six megacycles, would be 2.9 for endosperm at 7.5 percent moisture, 3.9 for endosperm at 9.1 percent moisture, 4.6 for endosperm at 12.8 percent moisture, 1.5 for bran at 6.6 percent moisture, 2.2 for bran at 10.5 percent moisture and 2.8 for germ at 6.6 percent moisture.

The power factor of endosperm and germ varied considerably with frequency but remained fairly constant for bran.

Since the heating rate, or ability to absorb power of a material depends on the dielectric constant and power factor there will be a considerable difference in heating rate for materials of different characteristics. This variation in power absorption with frequency for the materials has been shown in Figures 16 and 17. Therefore, if a grain of wheat is subjected to an alternating electric field, the greatest part of the power absorption (over one-half) will be in the endosperm, approximately one-third of the power will be absorbed in the germ and the remainder will be absorbed in the hull of the grain.

If the time of exposure is of a long duration the heat transfer by conduction from one medium to another will even out the internal temperature of the seed. If the time of exposure is almost instantaneous, differential heating of the components would be possible. There would be some evening out of the temperature after exposure, however.

The actual temperature attainable would depend on the specific heats of the components.

These results can not be applied directly to weed seeds. They do give a basis upon which further investigation could be based. Weed seeds, because of their hard seed coats and other characteristics, will undoubtedly yield different results. It is on the basis of the difference in physical characteristics that selective treatment of different seed species might be possible.

# DISCUSSION

There is a great distance to be covered before the results of this study can apply directly to the farm. The results of this investigation show a significant difference in heating rate or power absorbing ability between the components of wheat. It can be surmised then, that difference in power absorbing ability for the seed components will be found in weed seeds, as well as other crop seeds. The exact nature of this difference would have to be determined experimentally.

If significant differences in power absorbing ability of the various components of the seed are found, selective heating may be possible. Similarly if differences are found between seed species a further application of selective heating may be possible.

Further use of the dielectric characteristics of seed components and seed species could be made in the choice of frequency where optimum heating of the desired material is possible. For wheat, the optimum frequency for heating the germ within the frequency range studied would be at around 17.5 megacycles. It is here that the germ has the highest percentage of power absorption of the total power input. The endosperm will still absorb over one-half of the power at this point. To determine the actual temperatures which would be reached the specific heats of the materials must be known.

The value of dielectric constant and power factor, as determined in this investigation, are not the absolute values but are reasonably close approximations. The determination of the absolute values would require many refinements in equipment and procedure. These results are sufficient for the purpose of the tests and show decided trends in the field of frequencies covered.

If results of this investigation are to be applied to wheat or to wheat components, further investigation of the effect of frequency above and below those used in the investigation would be advisable.

The values of dielectric constant of the germ were considerably lower than expected. The physical nature of the protein molecules may prevent or, at best, allow for but limited rotation.

The effect of temperature on dielectric constant was not investigated. The determination of this effect may prove to be of very significant value. With many substances rotation of the molecule will not occur below a given temperature, but when this temperature is exceeded there is an abrupt increase in dielectric constant up to eight times. It could well be that the protein molecules of the germ require some temperature above room temperature for this rotation to occur.

An increase in moisture increases the dielectric constant and power factor of the material but does not alter the basic pattern of frequency variation. Since the dielectric constant and power factor are increased, an increase in moisture content will increase the power absorbing ability of the material.

In the final analysis, then, a significant variation of power absorbing ability of wheat germ, endosperm and bran in an alternating electric field is evidenced by the results of this work. Although the results can not be carried over directly to other species of seeds, they do indicate that a variation in power absorption between the components of these seeds and between species themselves is probable. Whether this variation is significant would depend on the time of exposure and the specific heats of the respective materials.

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