THE INTERACTION OF ELECTRODE DESIGN AND MOISTURE GRADIENTS IN DIELECTRIC MEASUREMENTS ON WOOD[1]

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ABSTRACT

Measurement of dielectric properties (capacitance and equivalent parallel conductance) of specimens with various moisture gradients, using twenty different electrode designs, showed that no electrode design eliminated the effect of moisture gradients on the measured average dielectric properties. A parallel-plate electrode, with poles on opposite faces of the specimen, was influenced least by moisture gradients, but as applied to dielectric moisture meters, the improvement did not appear to warrant the inconvenience of making contact with both sides of the specimen. There was a weakly defined indication that a dielectric moisture meter using the capacitance principle and operating at about 10 kHz would be least affected by moisture gradients.

Keywords: Dielectric properties, electrode design, moisture gradients.

INTRODUCTION

The variation of dielectric properties of wood with moisture content (MC) provides a convenient method of estimating wood MC through dielectric measurements. However, measurements made using typical surface-contact electrodes are strongly influenced by moisture gradients in the specimen. The purpose of this study was to determine to what degree the effect of moisture gradients on dielectric measurements can be minimized by specific electrode design, and thereby ease a major problem with dielectric moisture meters.

The variety of electrode forms studied gave data that demonstrated that the effect of moisture gradients was indeed dependent on electrode design, but also showed that the effect of gradients was very tenacious. Even electrodes that generate a nearly uniform, parallel electric field (at least with no specimen present) gave data strongly dependent on moisture gradients.

BACKGROUND

Dielectric moisture meters are attractive because the surface-contact electrodes they use are quick and easy to apply to the specimen, and they are completely nondestructive. By contrast, conductance-type moisture meters use pin electrodes that must be driven into the specimen.

It has long been recognized that the readings of dielectric-type meters predominantly reflect the surface or near surface MC of the specimen, but a study by Mackay (1976) first showed how severe this bias actually was. His data indicated

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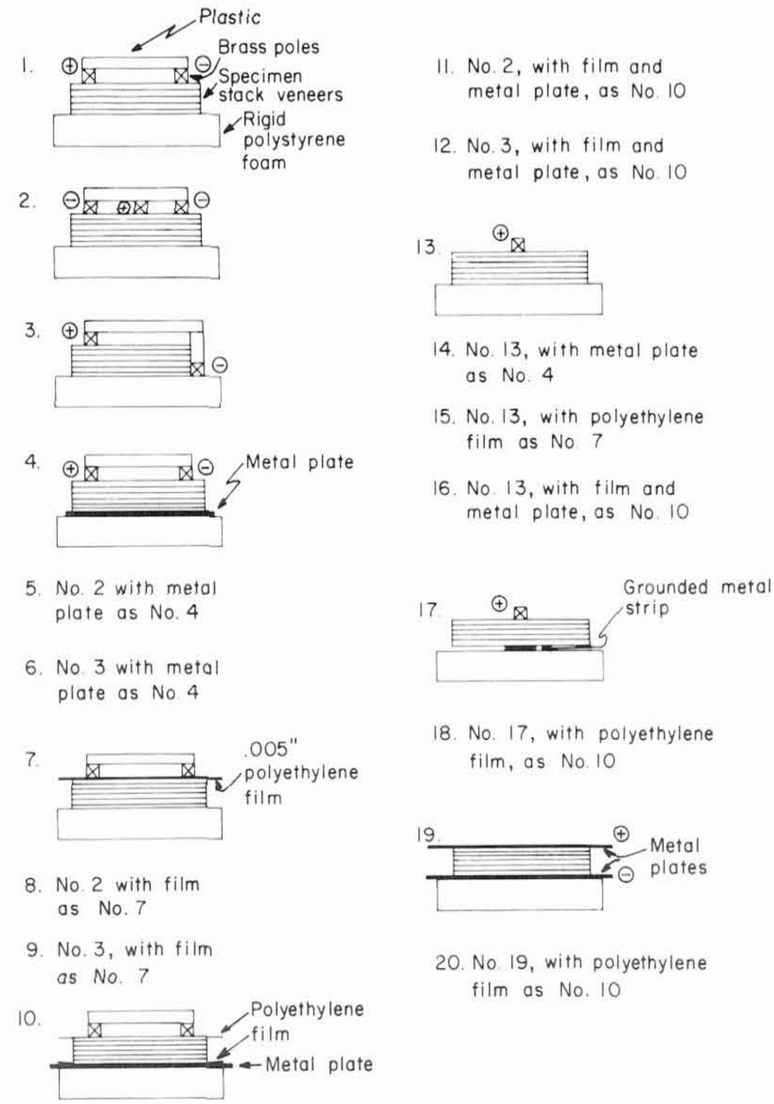

FIG. 1. Electrode forms used in this study.

that material as little as 0.1 to 0.2 inch below the surface was not properly represented in the meter reading.

Other anomalies in the response of dielectric moisture meters were traced to electrode design (James 1981), which suggested that electrode design should interact with moisture gradients in the response of dielectric moisture meters. A goal of this study was, therefore, to exploit this interaction and find what electrode design, if any, would minimize the effect of moisture gradients on the readings of dielectric-type moisture meters.

Basic theoretical considerations dictate that the effect of moisture gradients would be minimized by an electrode that establishes a uniform, parallel electric field in the specimen. For example, considering the resistance-capacitance impedance of each layer in a specimen, the total impedance would be the vector sum of all such impedances assuming that the instantaneous charge transfer through each layer is the same. This condition would exist for uniform, parallel fields, and approximately so for diverging fields that penetrate the entire specimen. This condition would not be met by fringe fields or stray fields. For uniform parallel fields, the total impedance would not depend on the order in which the layers appear in the specimen, so drying or regain gradients resulting from different distributions of similar layers would give similar response.

On the other hand, specimens with similar average properties (primarily MC), but made up of layers with differing properties, would not be expected to give similar response. For example, specimens with the same average MC but one with a moderate gradient and one with a steep gradient would be expected to show different responses. The main reason for this is simply that for impedances in series, the sum cannot be less than single largest value, so the dryer layers in the specimen with the steeper gradient would usually result in a larger total impedance.

An additional goal of this study was to confirm these basic expectations, and to determine experimentally if an optimum electrode design could be developed for dielectric-type moisture meters.

THE EXPERIMENT

Specimen material

Specimens were made up of stacks of veneers. The veneers were prepared by sawing from blocks that had been conditioned to uniform MC in rooms maintained at 80 F and 30, 65, 80, and 90% relative humidity (RH), giving EMC's of about 6.5, 12.5, 17, and 20.5%. The finished veneers were 1/16 by 2½ by 4 inches along the grain. A special saw that produced smooth surfaces was used. After sawing, the veneers were returned to the conditioning rooms for storage until needed. Two species, Douglas-fir and a red oak, were used, but as species effects were small, only Douglas-fir data are presented here.

Specimens were stacks of nine veneers of one species, with various distributions of MC. The MC distributions were symmetric around the middle veneer. Veneer stacks at uniform MC gave dielectric data in good agreement with data from solid wood of the same species at the same uniform MC measured previously (James 1981).

Electrodes

Twenty different electrode forms were used (Fig. 1). These could be divided into three main classes:

a) both poles of the electrode in one plane and applied to one side of the specimen (electrodes 1 and 2),

b) poles on opposite sides of the specimen (electrodes 17 and 19), and

c) only one active pole used, so the other pole was the stray admittance to the specimen environment (electrode 13). Modifications to these classes included insulated poles (electrodes 7, 8, 9, 10, 11, 12, 15, 16, 18, and 20); conducting surfaces on the opposite face from the electrodes in class (a) (electrodes 4, 5, 6, 10, 11, and 12); an electrode with one pole on the specimen face and the other on the edge (electrode 3). The electrodes were chosen to provide (1) nearly parallel electric fields, (2) divergent fields, (3) fringe fields, as from a typical dielectric

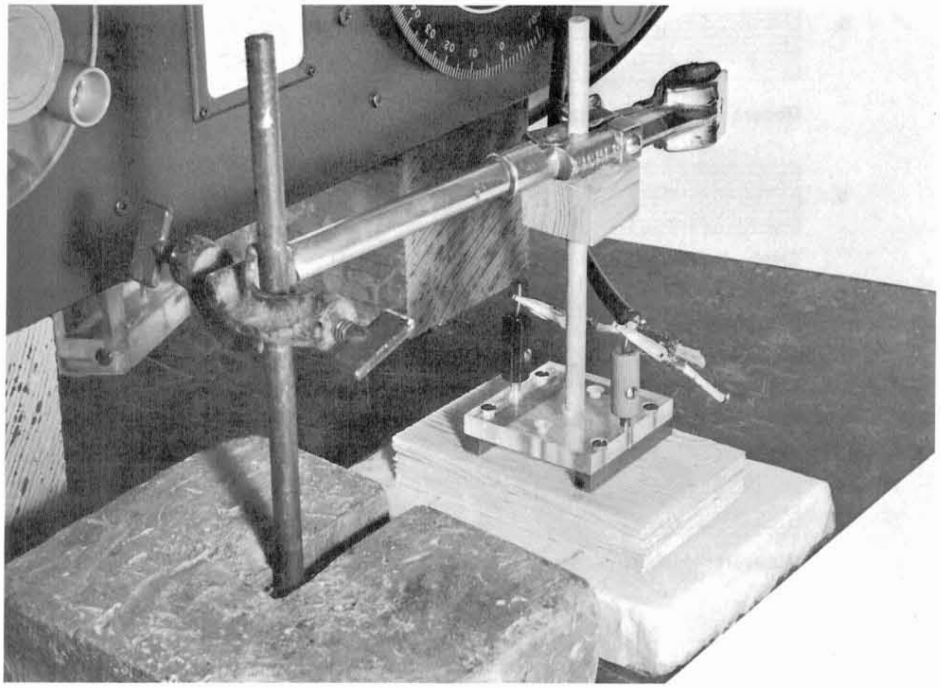

FIG. 2. Typical arrangement of electrode and specimen stack of nine veneers.

moisture meter, and (4) stray fields, typical of some dry kiln monitors that use only one active pole.

Specimens were supported on a 1-inch-thick slab of rigid polystyrene foam and the electrode pressed against the specimen stack of veneers with a force of about 3.0 N applied through a ¼-inch dowel (Fig. 2).

Specimen stacks were assembled in small plastic bags along with the appropriate electrode. The stacks were not kept assembled for more than about 10 minutes, to minimize moisture migration between veneers.

Other variables

The capacitance and equivalent parallel conductance of each specimen-electrode combination were measured at 80 F and at frequencies of 0.02, 0.1, 1, 10, and 100 kHz.

Moisture distributions studied were:

a) uniform (all veneers same MC),

b) a moderate drying gradient,

c) a steep drying gradient, and

d) a regain gradient (Fig. 3). The average MC of the specimens with moisture gradients was arranged to be close to the MC of material conditioned either at 65 or 80% RH.

Reliability of data

The data obtained in this study frequently appear somewhat illogical, and the question arises as to the errors that may be expected. Extensive and careful

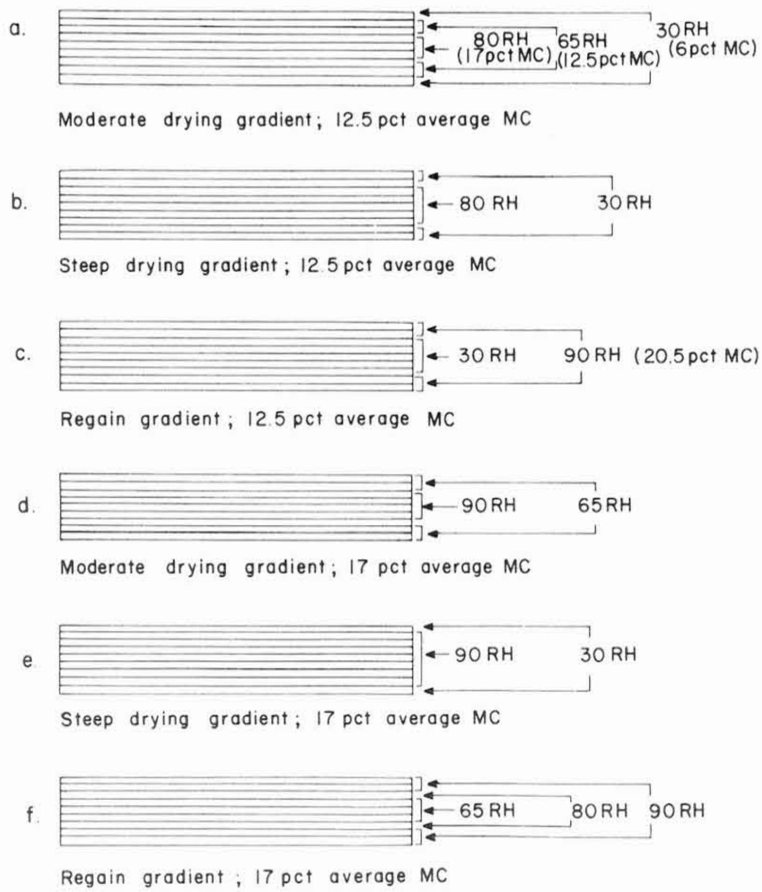

FIG. 3. Makeup of the specimen stacks for the various gradients and average MC values.

repeating of many measurements demonstrated that the reliability of the actual measurements was very high, but that considerable variability in the dielectric behavior of the specimen stacks was introduced by variability in the dielectric properties of individual veneers. There is little doubt, however, that the overall character of the responses plotted in the data figures is essentially correct, especially since the apparatus used is capable of measurements that are accurate and repeatable to 0.1 pf in capacitance and to 0.0005 in dissipation factor.

RESULTS AND DISCUSSION

Description of results

Representative data from 6 of the 20 electrodes are presented graphically in Figs. 4–9. The capacitance and equivalent parallel conductance of each electrode-specimen combination are given. Data from the other electrodes differ in detail but not greatly in overall character from those shown; they are not included purely for space considerations.

Figures 4a–9a show the capacitance of each electrode with specimens of uniform MC, plotted against MC. Figures 4d–9d are the same except for conductance

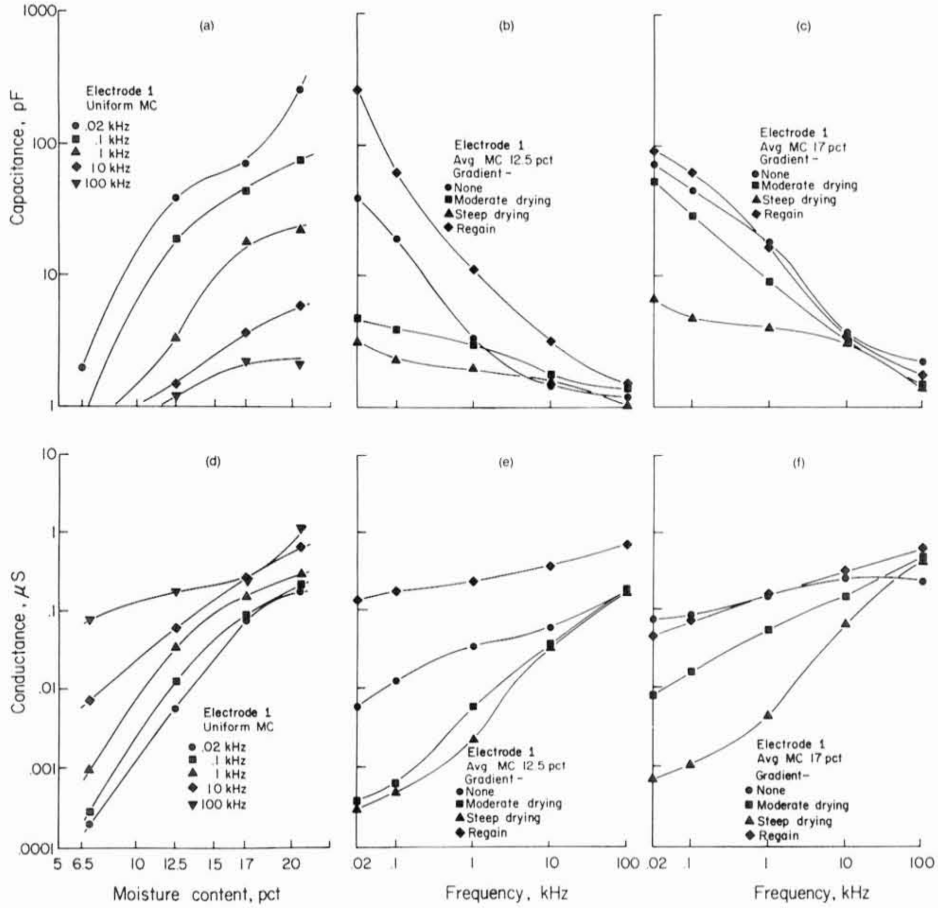

FIG. 4. Data obtained using electrode 1. a. Capacitance with specimens of various uniform levels of MC at various frequencies. b. Capacitance of specimens with various distributions of MC but all at about 12.5% average MC at various frequencies. c. As (b), except at about 17% average MC. d, e, and f. As (a), (b), and (c), respectively, except for equivalent parallel conductance instead of capacitance.

instead of capacitance. These plots serve to illustrate the response of the electrode to changes in MC, in order to judge the effect of other variables in comparison to MC.

The other graphs in each figure are plots of the electrodes' response to specimen stacks with various moisture distributions, but the same average MC for a given graph, plotted against the frequency of the applied electric field. Two average MC levels are shown—about 12.5% (equivalent to 65% RH) and 17% (equivalent to 80% RH). The moisture distributions covered are:

1) uniform,

2) a steep drying gradient (large change from surface to core),

3) a moderate drying gradient (lesser difference between surface and core), and

4) a regain gradient, typically the reverse of one of the drying gradients. It follows that the differences between the graphs in a given figure illustrate the effect of moisture gradients on the response of the associated electrode at various frequencies.

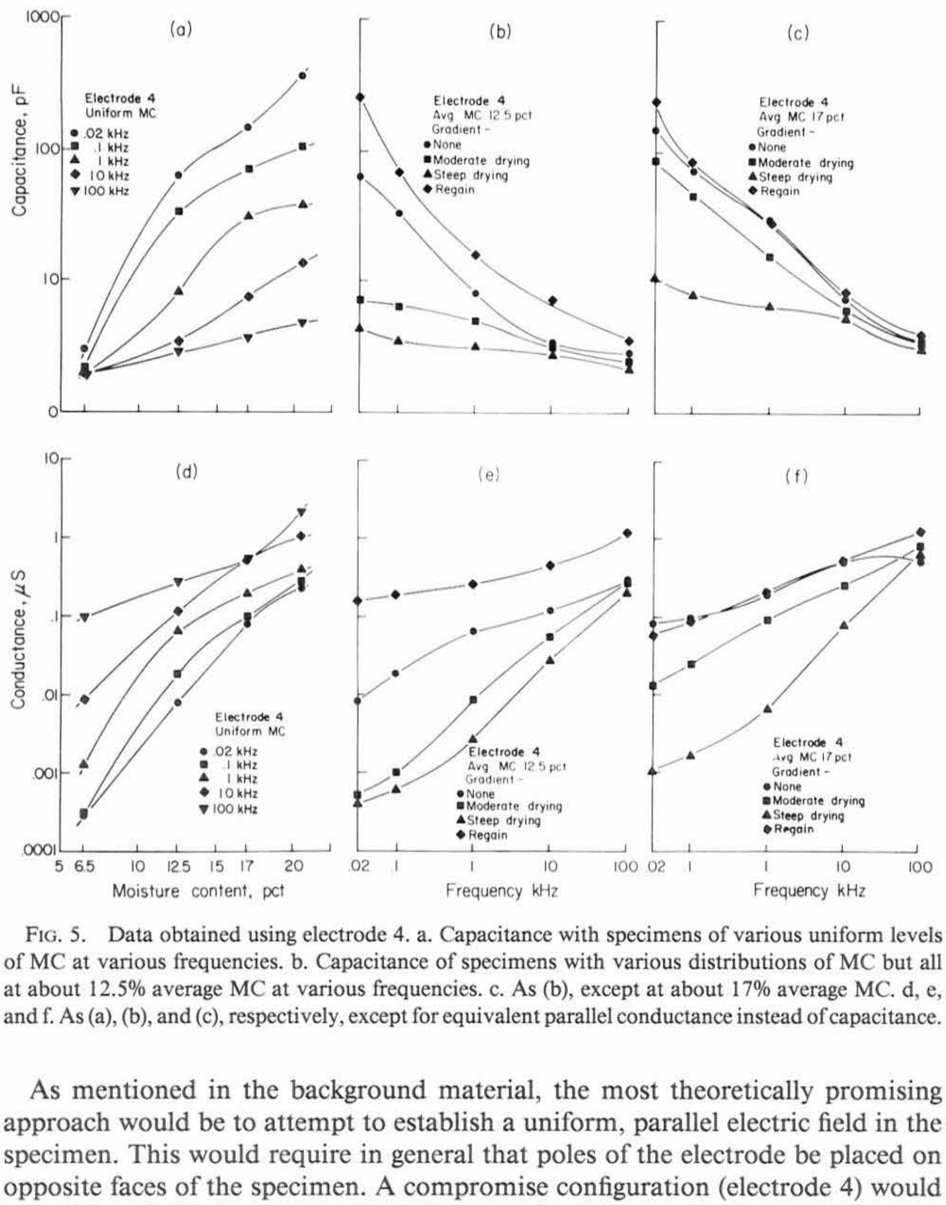

FIG. 5. Data obtained using electrode 4. a. Capacitance with specimens of various uniform levels of MC at various frequencies. b. Capacitance of specimens with various distributions of MC but all at about 12.5% average MC at various frequencies. c. As (b), except at about 17% average MC. d, e, and f. As (a), (b), and (c), respectively, except for equivalent parallel conductance instead of capacitance.

As mentioned in the background material, the most theoretically promising approach would be to attempt to establish a uniform, parallel electric field in the specimen. This would require in general that poles of the electrode be placed on opposite faces of the specimen. A compromise configuration (electrode 4) would use a fringe field electrode, such as electrode 1, with a conducting surface on the opposite face to distort the field towards the opposite face. Comparing data from electrodes 1 and 4 (Figs. 4, 5) demonstrates that the conducting plate does not have significant effect on the response of the electrode to different moisture gradients. This was a consistent observation with the other pertinent electrode forms also, for which the results are not shown here.

Electrode 13 consisted of one ungrounded pole, with no ground reference used; this electrode simulated the configuration used in some capacitive-admittance type kiln monitors. Then electrode 17 added a grounded conductor on the opposite face of the specimen. Comparing data from electrodes 13 and 17 (Fig. 6, 7) shows that adding the ground reference has a large influence on general electrode re-

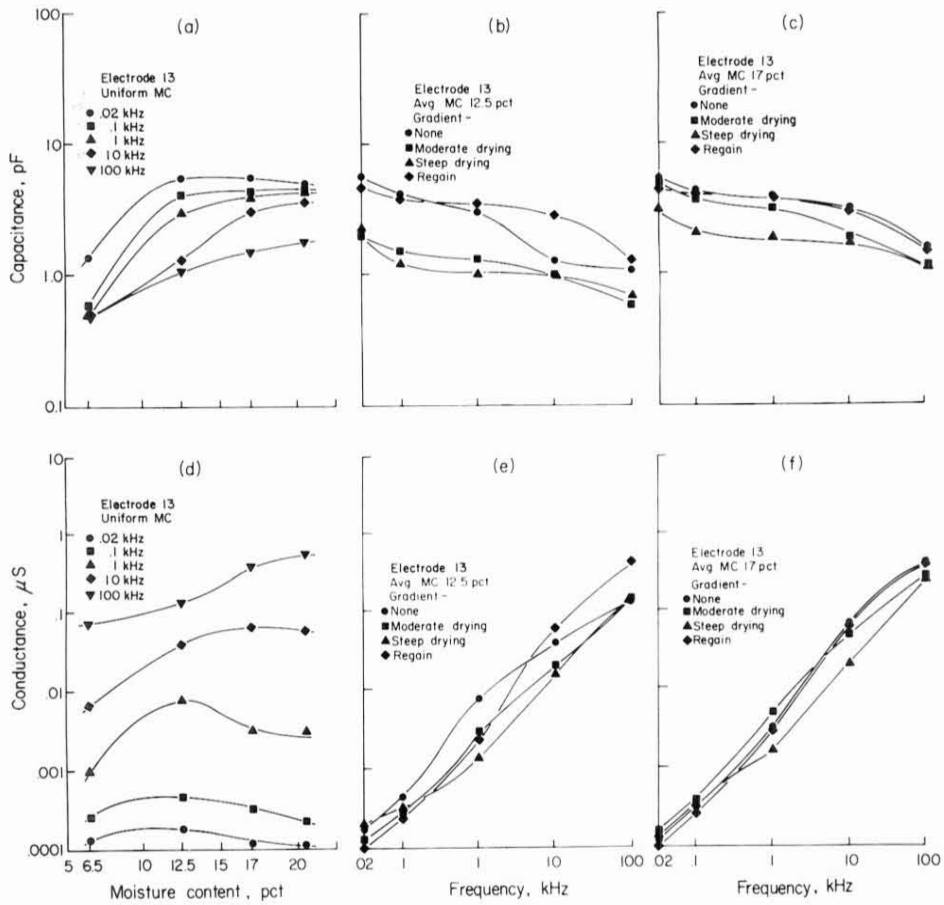

FIG. 6. Data obtained using electrode 13. a. Capacitance with specimens of various uniform levels of MC at various frequencies. b. Capacitance of specimens with various distributions of MC but all at about 12.5% average MC at various frequencies. c. As (b), except at about 17% average MC. d, e, and f. As (a), (b), and (c), respectively, except for equivalent parallel conductance instead of capacitance.

sponse, but gives no improvement in the response to gradients. Figures 6e and 6f seem to indicate a relatively small influence of moisture gradients on conductance when using electrode 13; but when these plots are compared with Fig. 6d, it is clear that this small effect of gradients has little meaning because the overall response is not well correlated with average MC. With electrode 17, the response to average MC is well defined, but the effect of gradients is also correspondingly greater.

Electrode 19 was a parallel-plate electrode, with conducting surfaces large in comparison to the specimen thickness. This electrode will produce a nearly uniform, parallel electric field in the space between the plates, as long as the material between the plates is homogeneous. Considering only primary effects, this electrode theoretically should be the form least influenced by moisture gradients. The data taken with this electrode (Fig. 8) show, however, that the influence of gradients is still substantial.

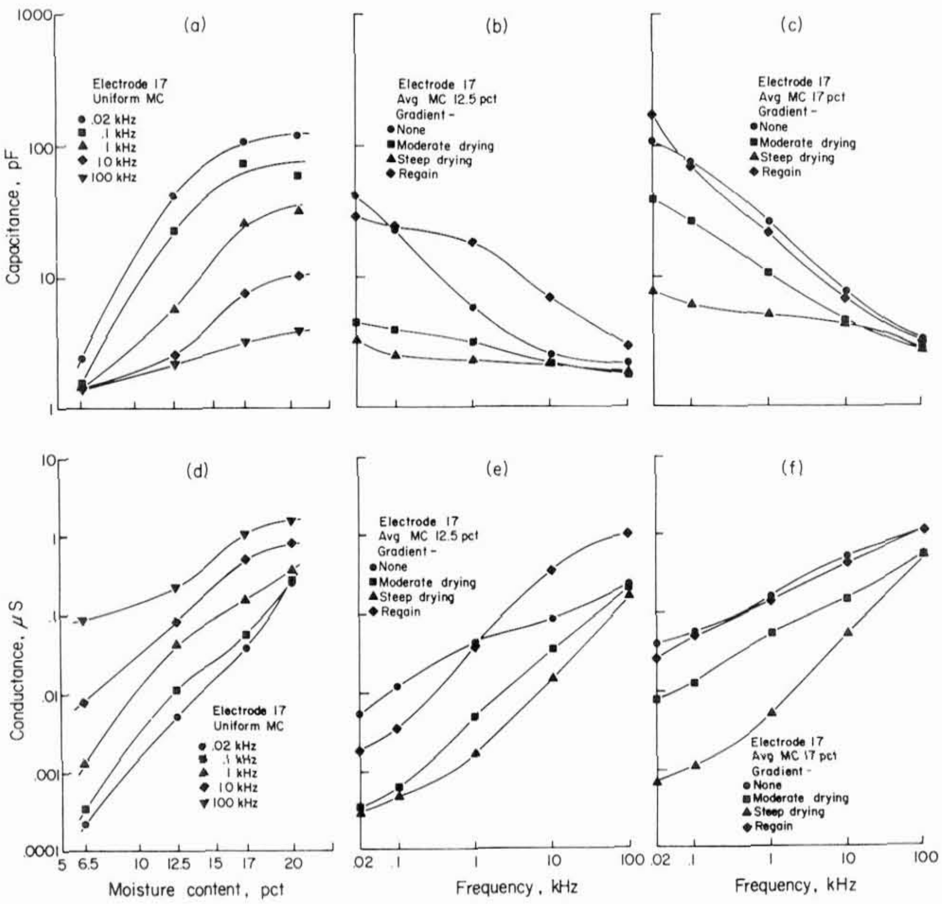

FIG. 7. Data obtained using electrode 17. a. Capacitance with specimens of various uniform levels of MC at various frequencies. b. Capacitance of specimens with various distributions of MC but all at about 12.5% average MC at various frequencies. c. As (b), except at about 17% average MC. d, e, and f. As (a), (b), and (c), respectively, except for equivalent parallel conductance instead of capacitance.

Electrode 20 was the parallel-plate electrode, except that the plates were insulated with 0.005-inch-thick polyethylene. Data taken with this electrode (Fig. 9) were nearly the same as with the bare plates, except at low frequencies and high MC.

Discussion of results

In comparing the various electrode configurations, none is clearly superior in minimizing the overall effect of moisture gradients. The parallel-plate electrode is affected less by a regain gradient than are electrodes with both poles on one side of the specimen. That was predictable because the high conductance and polarizability of the moist surface would logically tend to shield the specimen interior from the fringe field radiating from an electrode like No. 1. In effect the moist surface short circuits electrodes like No. 1, but in electrodes like No. 19 the moist surface conducts the electric field into the drier interior.

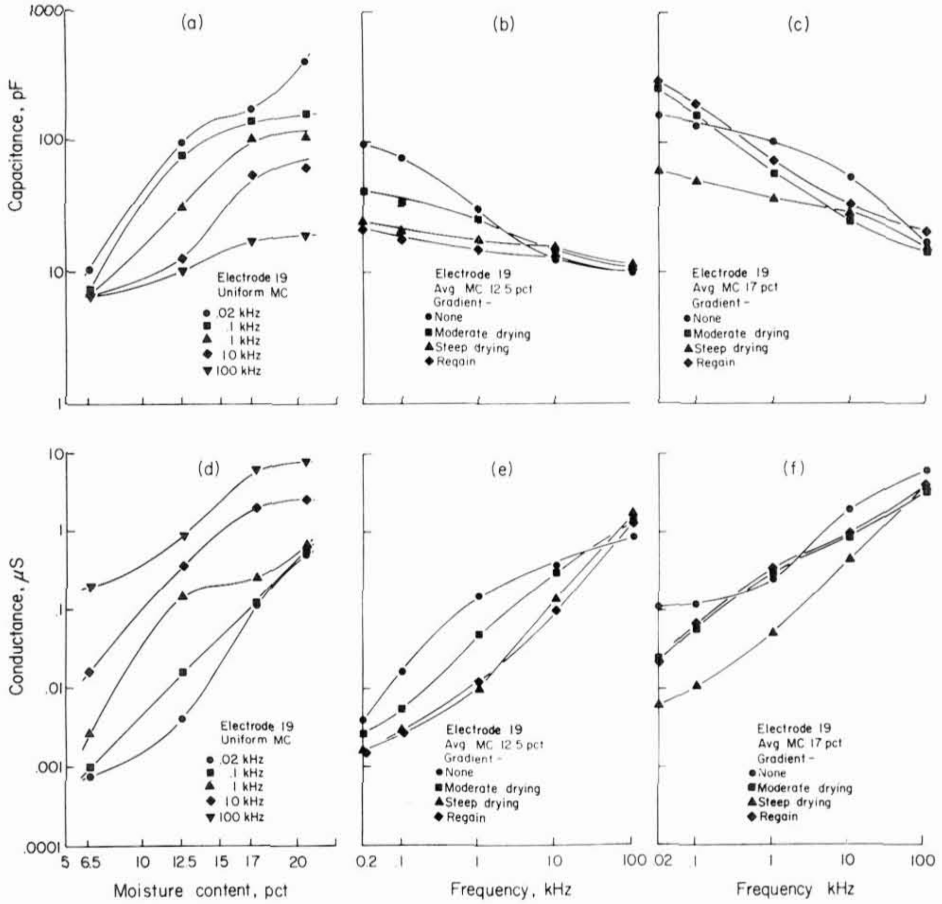

FIG. 8. Data obtained using electrode 19. a. Capacitance with specimens of various uniform levels of MC at various frequencies. b. Capacitance of specimens with various distributions of MC but all at about 12.5% average MC at various frequencies. c. As (b), except at about 17% average MC. d, e, and f. As (a), (b), and (c), respectively, except for equivalent parallel conductance instead of capacitance.

Other general patterns in the data are more obscure, as are the explanations for the observed responses. For example, the persistence of the gradient effect in the response of electrodes 19 and 20 may seem surprising, especially when the observed response to a regain gradient with these electrodes is very close to the response to one or the other of the drying gradients (Fig. 8b, c, e, f). If the response to these two widely different moisture distributions is nearly the same, why is the response to the uniform MC and to the other drying gradient so different? The answer to this question is given partly in the theoretical comments in the "Background" section, and is seen partly in the data in Fig. 8a and d; the (logarithmic) response of the dielectric property to MC is not linear, so simple averages of MC will not result generally in corresponding simple averages in properties. The moisture distributions that gave similar dielectric responses were composed of nearly the same material (veneers), but in different order. This confirms that in a nearly parallel electric field the location of a given element of material is not important.

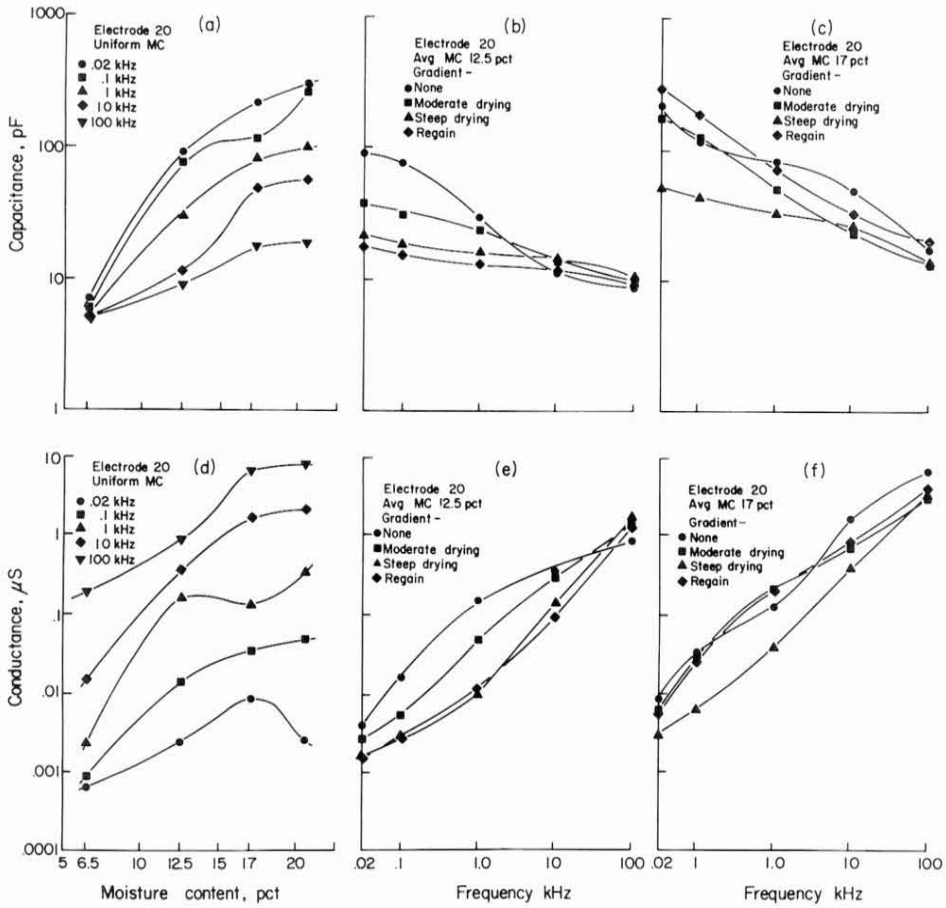

FIG. 9. Data obtained using electrode 20. a. Capacitance with specimens of various uniform levels of MC at various frequencies. b. Capacitance of specimens with various distributions of MC but all at about 12.5% average MC at various frequencies. c. As (b), except at about 17% average MC. d, e, and f. As (a), (b), and (c), respectively, except for equivalent parallel conductance instead of capacitance.

In the nonparallel fields generated by other electrodes, however, position is an important factor because the field strength varies significantly with position.

CONCLUSIONS

The results of this study indicate that no electrode design is clearly superior in reducing the effect of moisture gradients on dielectric measurements on wood.

The parallel-plate electrode, and other electrodes that locate poles of the electrode or other conductors on opposite faces of the specimen, do not have advantages sufficient to warrant the comparative inconvenience of their use in moisture measurement.

As the frequency is decreased, the sensitivity of the dielectric properties to changes in MC increases, but also the sensitivity to moisture gradients increases. The present data suggest that a weak optimum is obtained at about 10 kHz when using a simple two-pole electrode on one face of the specimen (Fig. 3). It appears also that capacitance is a somewhat better measure of MC than equivalent parallel conductance. Present commercial dielectric moisture meters use either a combination of capacitance and conductance (capacitive admittance), or predominantly conductance (power loss) and operate at higher frequencies.

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