Grain Moisture Measurement with Capacitance Type Devices

Introduction

Since the 1965 publication of a research summary demonstrating capacitance to be a reliable and easily used indirect grain moisture measurement (1), the method has grown to become a workhorse of the grain processing industry. While widely used, this method and equipment often appear to be not well understood. Uses are attempted in which a capacitance type moisture sensor cannot provide the information sought.

Description of a Simple Plate Capacitor

In its most simple form, a capacitor is comprised of two oppositely charged, conductive plates separated by an insulator called a dielectric. The region between the plates occupied by the dielectric contains an electric field. A simple parallel plate capacitor is schematically represented in Figure 1 with an alternating current power supply. Other capacitor geometries, such as concentric cylinders, are valid and frequently used. However, for this discussion of fundamentals, the most simple parallel plate model with an alternating current power supply is used.

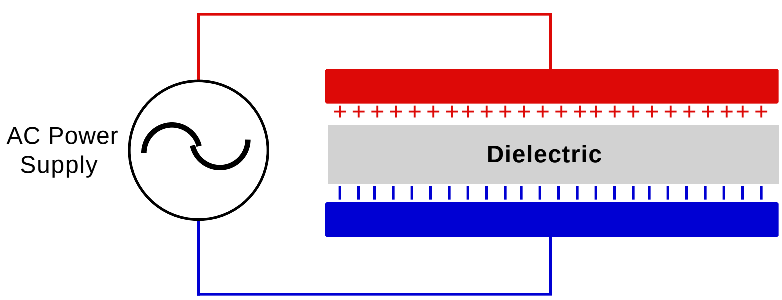

Figure 1: Schematic of a Simple Plate Capacitor

The alternating current used in capacitance moisture measurement is quite different from the familiar household alternating current which has a frequency of sixty cycles per second (1 cycle per second = 1 hertz (Hz)). The frequencies used in capacitance moisture measurement are generally between 1 megahertz (MHz) and 50 MHz (1 MHz = 1,000,000 Hz). When a particular moisture sensor is described as having a "radio frequency", or being an "RF" sensor, it is a capacitance type moisture sensor operating with alternating current having a frequency in the same range as radio transmissions. Radio frequencies are generally considered to fall between 0.1 MHz and 100 MHz. Virtually all capacitance type moisture sensors on the market operate in this range.

Except for this simple schematic, the concepts of capacitance and capacitors are not easily represented by pictures or intuitively. They are primarily mathematical models of observed phenomena. However a few important concepts are central to capacitance as a tool for estimating grain moisture content that can be presented without complicated mathematics.

A capacitor is a device that can hold or store an electrical charge, which is its "capacitance". For a simple plate capacitor, capacitance is defined by the equation: (2)

$$C = \frac{KA}{4\pi d}$$

Where: C = Capacitance; A = Surface area of the plates

K = Dielectric constant; d = Distance between the plates

Since a capacitor is a physical device, a particular capacitor will have a constant plate surface area (A) and distance between the plates (d). Changes in its capacitance are then dependent only on the dielectric properties of the dielectric, as represented by the experimentally determined constant, K. By definition, a vacuum has a K = 1. Water, on the other hand, has a K = 88 at 0 ^{o}C. (3) As the dielectric in a capacitor is changed from one having a small K to one with a larger constant, more energy is required from the power supply to charge the capacitor plates.

A Capacitor as a Moisture Monitor

Converting a capacitor into a grain moisture sensor is theoretically quite simple, the grain to be tested is placed between the capacitor plates as the dielectric, illustrated schematically in Figure 2. Converting theory into practice is another matter. Selections must be made for sensor geometry and power supply frequency, plus precise calibration is absolutely essential. Even the way a sample cell is filled in grain moisture testers has been found to affect the instrument response. These topics are only mentioned here since this discussion assumes a device is being used, rather than being designed.

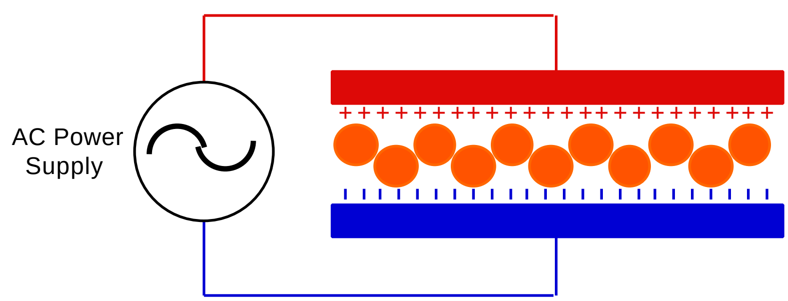

Figure 2: "Grain Kernels" as the Dielectric

Dielectric constants of many materials, including most feed grains, have been experimentally determined. The constant for air is essentially that of a vacuum. Dry feed grains, such as corn, wheat, barley, etc. have dielectric constants in a range between 2 and 3. Dielectric constants of agricultural materials, such as grain, increase with increasing moisture content. (1)

Sample Uniformity

In addition to moisture content, which has the major effect on the dielectric constants of grains, two other variables can have a significant impact on the dielectric constant, and hence the accuracy of any moisture measurement made using a capacitance type device; density (structure), and temperature. Temperature can be measured and compensation made in the signal generated. Variations in density can be a significant problem to accuracy if precautions are not carefully taken to control them.

If the dielectric is a vacuum, it is perfectly uniform. The electric field is also essentially uniform and behaves basically as the mathematical model predicts. If the dielectric is a particulate material, it is a mixture of the solids and its surroundings. In the case of a grain "dielectric", the mixture is grain and air. If the moisture content has recently changed, either through drying or moisture addition for process conditioning, a third variable component is introduced. Predicting the dielectric properties of mixtures is nearly impossible, unless the mixture composition is known precisely. In practice, with normal quality grain, the random variations due to kernel size differences, broken kernels, dirt, etc., tend to "average out" and are thus not a problem for practical accuracy. There are, however, "mixtures" routinely encountered in grain handling that do cause significant problems: (4)

Problem	Potential solution
1. A variety of grains monitored	Calibrate sensor for each grain
2. Variations in kernel size and/or bushel weight	Calibrate for size & density ranges
3. Wide range of moisture content	Calibrate for specific moisture ranges
4. Unusually large quantity of debris, dirt, broken kernels, etc.	Clean grain, or erroneous detector response unavoidable with errors of several percent
5. Grain with surface moisture or moisture gradients from drying	None. No moisture sensor can produce a valid signal before equilibration*

*Capacitance, microwave and NIR moisture sensors commonly used in the grain processing industries require that there be no moisture gradients in the grain. (5)

Summary

Capacitance has been demonstrated to be a safe, simple, economical, and reliable method for routine grain moisture monitoring, both "on-line" and on "the bench", provided:

1. The sensor is calibrated properly for grain variety, moisture content range, and particle size.

2. The sensor is carefully used within its calibrated ranges.

3. Grain moisture is uniformly distributed throughout the kernel, without surface moisture or having moisture gradients from drying. (6)

Bibliography

1. Nelson, S. O., "Dielectric Properties of Grain and Seed in the 1 to 50 mc Range", Trans. ASAE, vol. 8:1, pp 38 - 48, 1965

2. Handbook of Chemistry and Physics, 44th ed., p 3211, Chemical Rubber Co., Cleveland, OH, 1963

3. ibid., p 2623

4. Nelson, S. O., "Measurement and Applications of Dielectric Properties of Agricultural Products", ISEEE Transactions on Instrumentation and Measurement, vol. 41:1, pp 116 - 122, February, 1992

5. Wilson, Michael A., "Comparison of Alternate Approaches to Measurement of Moisture in Grains and Oil Seeds", Cereal Foods World, 31:6, pp 406 - 408, June, 1986

6. Christensen, C. M., et. al., "U. S. Standards - Storage of Cereal Grains and their Products", p 49, Am. Assoc. of Cereal Chemists, St. Paul, MN, 1982

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