Choosing a method for measuring your material’s moisture content

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Accurately measuring moisture in dry bulk materials is one of the keys to ensuring that a final product will meet your quality requirements. However, choosing the right method from the range of moisture-measurement techniques out there isn’t a simple matter. This article will help you make sense of your options by explaining how moisture-measurement methods are applied, how they work, and how to choose one for your application.

To achieve a high-quality final product with good consistency, correct weight, and long shelf life, you need to analyze the moisture content of the dry ingredients that feed into your process. This can be a challenge because moisture content changes with your ingredients’ hygroscopic tendencies. One way to overcome this problem is to use equipment that accurately measures the moisture content of material in your process.

However, the moisture-measurement methods that are currently available aren’t perfect, so choosing one means you’ll make a compromise in at least one area: performance, quality, durability, or cost. Before discussing the methods and how to select one for your process, let’s take a look at some common applications.

How moisture-measurement methods are applied

The moisture content of dry bulk materials can influence the manufacturing process. Some of the variables moisture can influence are the product’s drying time, process timing (such as in mixing), the final product’s quality and reproducibility, and the efficiency of further processing. Depending on the method, the moisture content is determined by lab analysis of a material sample or by analyzing data from a moisture sensor mounted in or near the process line.

Moisture-measurement methods are applied in several industries, including chemicals, pharmaceuticals, foods, glass, concrete, minerals, ceramics, and wood products, to name a few. Some final products that benefit from moisture analysis during processing are detergents, pharmaceutical tablets, sugar, rice, coffee, chocolate, quartz sand, gravel, iron ore, talc, wood chips, and gypsum board.

Of the many methods available, not all are suitable for measuring moisture in dry bulk materials. The following information concentrates on those best suited for these materials and explains in basic rather than exhaustive terms how each differs from the others. The methods discussed here fall into two categories: lab methods, in which a material sample is analyzed in a lab away from the process line, and inline methods, in which data from a remote moisture sensor (or other measuring device) mounted on a material storage vessel or process equipment in the process line is used to calculate the material’s moisture content.

How lab methods work

Lab methods directly subject the moisture in a representative material sample taken from the process to a reaction or measurement; thus the methods are called direct methods. The methods are time-consuming, and their accuracy depends on taking truly representative samples of the material.
These methods include the analytical method known as Karl-Fischer titration and three methods based on gravimetric analysis: the dry chamber, microwave drying, and infrared drying methods.

**Karl-Fischer titration.** The Karl-Fischer titration method is used to analyze small samples of material with low moisture content, such as minerals, paint pigments, plastic granules, and cloth fibers. This lab method is somewhat time-consuming but provides accurate results and can be done with materials and equipment readily available in most labs.

The method is based on the well-known Karl-Fischer titration chemical reaction:

\[ J_2 + SO_2 + H_2O = H_2SO_4 + 2 HJ \]

For the analysis, the water in a material sample is separated from the solids with methanol and analyzed with the Karl-Fischer solution \((J_2 + SO_2)\). The red-brown iodine compound, \(J_2\), is converted into the transparent hydrogeniodine compound, \(HJ\), and the moisture content of the reaction’s final titration product, \(J_2\), is measured by photometric or electrometric means. The quantity of Karl-Fischer solution absorbed by the sample indicates the sample’s water (that is, moisture) content.

**Dry chamber.** The dry chamber method is based on gravimetric analysis, an extremely time-consuming technique, of a material sample typically weighing about 100 to 150 grams. The method requires gradually drying the sample in a dry chamber (a gas-fired, oil-fired, or microwave oven or climate-controlled room) and, at regular intervals, weighing the sample. The drying and weighing continue until the sample’s weight no longer changes, which indicates that the sample’s moisture has been vaporized and the sample is absolutely dry.

The dry chamber method provides the best, most reproducible results of all moisture-measurement methods and, in fact, is accepted in many product and industry standards.

For example, one construction industry standard lists the following mandatory steps for the dry chamber method:

1. Take a representative sample of material.

2. Separate a quantity of the sample for drying. (In general, the larger the sample’s average particle size, the larger the quantity required for drying.)

3. Dry the sample at 110°C ±5°C for 24 hours in the dry chamber, then weigh the sample.

4. Dry the sample for another 24 hours and weigh it again. If the weight loss is less than 1 percent, regard the sample as dry (or continue drying until the weight loss is less than 1 percent).

5. Let the sample cool down to approximately 30°C.

6. Weigh the sample again.

7. Calculate the sample’s moisture content (based on formulas for your material and test requirements).

**Microwave drying.** The microwave drying method is another form of gravimetric analysis that involves drying and weighing the sample (typically one handful or cupful of material, depending on the material) in either several passes or one pass. In this method, microwaves dry the sample in a very short time — typically a few minutes. Because the sample is heated to extremely high temperatures (140°C to 750°C), this method is suited only to materials that can withstand high heat. The method can’t be used with materials that can be destroyed at these temperatures or whose physical composition can be changed by high heat, such as sugar, gypsum, and aluminum hydrate. The sample’s destruction or composition changes can lead to the sample’s loss of mass, which will cause moisture-measurement errors.

**Infrared drying.** In this gravimetric method, infrared heat is used to dry a very small (0.1- to 120-gram) sample in one pass. As with the microwave drying method, the sample dries in a short time (from 2 minutes up to 3 hours, depending on the material) but is heated to extremely high temperatures, making the method suitable only for materials that can withstand these temperatures. In some cases this method is combined with the use of a high-precision scale with software that calculates the sample’s moisture content. The software analyzes the moisture content after the scale indicates the sample is no longer losing weight due to moisture loss. This speeds up the moisture measurement, but unless the method is correctly applied, the measurement can be subject to large errors because of the method’s small sample size.

**How inline methods work**

Inline methods require converting data about the behavior of moisture or other physical structures in the material to indirectly calculate the material’s moisture content; thus they are also called indirect methods. One or more remote moisture sensor (or other measuring device) is required for collecting the data, and a controller, which can be of various types, uses the data to calculate the material’s moisture content. Because the moisture measurement is instant, you can use these methods to continuously monitor the moisture content of material in your process.
Each of these methods is based on one of several technologies: capacitive, infrared, microwave, neutron ray and gamma ray, and conductive.

**Capacitive.** This is the least expensive and easiest-to-handle moisture-measurement method, and it provides accurate, repeatable results for a variety of materials at high frequencies. The capacitive (also called **high-frequency dielectric shift**) sensor measures moisture based on the difference between the dielectric constants of water and the material located between the sensor's capacitor electrodes. Typical process locations for the sensor are shown in Figure 1.

Any solid, liquid, or suspension has its own specific dielectric constant ($\epsilon_r$). There’s a big difference in the dielectric constants of solids and liquids: Most solids have a dielectric constant from about 4 to 13 — for example, sand is from 4 to 5. Water has a dielectric constant of about 80. The sensor measures this difference to determine the material’s percentage of moisture content by weight. When the capacitive sensor measures an increase in the material’s capacitance toward that of water’s dielectric constant, the increase indicates the material has more moisture.

The capacitive sensor provides a real-time measurement and can be used as either a contact or noncontact method. That is, the sensor can contact the material directly or — if the material is sticky, subject to contamination, or likely to wear the sensor’s surface — the sensor can measure the moisture indirectly through a single pane of nonconductive material, such as glass or plastic, as the material flows over it. In either case, the sensor detects the material’s average moisture content — including surface moisture and core moisture — about 6 inches into the material, depending on the material type.

As with most indirect moisture-measurement methods, variations in the material’s bulk density can cause measuring errors, but these can be avoided by correctly locating the sensor in the process line.

**Infrared.** An infrared sensor directs an infrared beam into the material and then measures the material’s moisture content based on the ratio of absorbed and reflected wavelengths. The free water molecules in the material absorb much of the near-infrared wavelength, which, when measured by the sensor, indicates what percentage of moisture the material contains. A typical process location for the infrared sensor is shown in Figure 2.

However, this noncontact method detects only the material’s surface moisture, so influences such as the material’s particle size, particle shape, particle surface characteristics, and color can cause moisture-measurement errors. For this reason, the infrared sensor is typically limited to measuring the moisture content of thin films or layers of material, paper, and other thin materials.
Microwave. A microwave sensor directs microwaves at a material and then measures the energy losses of microwaves emitted from the material and the change in the speed at which the microwaves spread out from the material. Microwaves have a frequency of 0.3 to 30 gigahertz, and selecting the right frequency for the sensor in a given application is important because the sensor must adapt to the material type to give an accurate moisture measurement. The material's particle size, electrolyte content, and other variables should be considered when choosing the sensor's microwave frequency.

For dry bulk material applications, the microwave sensor operates based on the physical principle that microwaves can excite the water molecules in the material. If the microwaves are strong enough, this movement can warm up the molecules, as in a microwave oven. However, the microwaves from a microwave sensor are too small to heat the molecules, and because of this some energy from the microwaves going into the material is lost when the microwaves return or are reflected back to the sensor.

The microwave sensor can operate on one of three principles — transmission, reflection, or resonance. When the sensor is based on transmission, an emitter and a receiver are mounted opposite each other in the process so they can “shine” through the material. The sensor’s application is limited because this mounting method requires so much space and the emitter and receiver can’t shine through a conductive material. With a sensor based on reflection (Figure 3), the emitter and receiver are both in one housing so they can measure the energy losses of microwaves reflected from the material. This eliminates the effect of material influences and gives the sensor flexibility similar to that of a capacitive sensor. However, the sensor can’t be installed on steel equipment in a very narrow location because the sensor can confuse reflections from the steel with those from the bulk material.

A microwave sensor based on resonance is the most advanced microwave method but is also very expensive. The sensor, which is set up like the reflection sensor, builds up a tuned resonance field above the sensor with microwaves of known phases and frequencies. When material enters this field, the field becomes out of tune, and the sensor measures this change to calculate the material’s exact moisture content. The method almost makes it possible to compensate for materials’ different bulk densities, which have the most negative influence on all moisture-measurement methods.

Microwave sensors provide accurate results, especially for very fine, homogeneous materials. However, compared with using most other inline methods, using the microwave method requires more training and experience and more electronic equipment to process the results, which can be costly.
**Neutron ray and gamma ray.** Neutron ray and gamma ray sensors measure the material’s moisture content by sending extremely small doses of neutron or radioactive gamma beams into the material. To measure the moisture content, these noncontact sensors measure the speed losses of the beams after they pass through the material’s water molecules.

The sensors are extremely expensive and not as frequently applied to dry bulk materials as the other inline methods. However, because the sensors measure the reaction of only the water molecules to the beams, they do provide accurate moisture measurements for thicker materials such as large coke chunks used in steel production, nonhomogeneous materials such as asphalt mixtures, and large quantities of material such as tons of mineral chunks traveling on a belt conveyor.

Unlike capacitive, infrared, microwave, and conductive sensors, the neutron ray and gamma ray sensors don’t require calibration to the specific material being analyzed. However, the sensors’ beams require using these sensors with caution, as dictated by regulations for handling radioactive materials. This increases the cost and inconvenience of using the sensors. However, the small radioactive doses of the sensors don’t contaminate the material.

**Conductive.** A conductive sensor uses two electrodes inserted directly into the material to measure its conductivity. The sensor can determine the material’s moisture content from this measurement because each material has a specific conductivity that changes based on its moisture content.

This contact method is inexpensive but has some limitations. One is that electrolytes, such as salt and minerals, and some material characteristics increase conductivity and thus affect the moisture content measured by the sensor, allowing the sensor to make only a vague moisture determination in some cases. Other problems are that the sensor measures only the material’s surface moisture, not core moisture, and is limited to measuring only the moisture near the electrodes.

**How to select a method**

As you can see from the array of moisture-measurement methods discussed here, choosing one for your needs can be complicated. There is no “best” method: Each has specific capabilities and limitations. However, some of them, such as the capacitive inline method, are more commonly used because they handle more applications and provide more accurate results. See the information in Table I, which compares methods discussed in this article in terms of accuracy, cost, and several process variables.
The most effective way to select a method is to carefully evaluate your needs. How you use the moisture measurement should be a major factor in choosing a method. If you just need to record moisture data for your material, a lab method may be adequate. But if you need continuous moisture measurement, either to trigger an alarm based on a specific moisture level or to transmit moisture data to a batch control system or plantwide process control system, you’ll need an inline method.

By answering the following questions, you can further narrow your choices to those methods most suitable for your application:

1. Is my material electrically conductive (that is, does it have conductivity above 20 ohm/cm as measured by an ohm-meter)? If your answer is no, your only choices are the indirect infrared or neutron ray or gamma ray methods because they’re the only ones not influenced by electrical conductivity at or below 20 ohm/cm.

2. How much moisture does my material contain? If the moisture content is less than or equal to 0.1 percent, only a lab method can measure it. If the moisture content is greater than 0.1 percent but not more than 20 percent, you can use the indirect capacitive, microwave, neutron ray, or gamma ray method. If your material’s moisture content is greater than 20 percent, you can use the indirect capacitive method or the neutron ray or gamma ray method. The latter two methods work at this moisture level because they can measure the beam’s speed loss regardless of the material’s moisture content.

3. Do I need a stand-alone moisture sensor that can connect to my existing control system (such as a PC or PLC), or do I need a complete system that includes the sensor and integrated controls? If you need a stand-alone sensor, select a modular capacitive system that can be upgraded. If you need a complete system, select a microwave sensor that comes complete with batch controls or a complete control circuit with software. The cost for the latter type of system will be much greater, so you also need to weigh this factor.

Table 1

Comparison of moisture-measurement methods: Accuracy, Cost, and the influence of process variables

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
<th>Cost</th>
<th>Integrated Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab methods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analytical</td>
<td>Good</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Gravimetric</td>
<td>High</td>
<td>Medium</td>
<td>No</td>
</tr>
<tr>
<td>Capacitive</td>
<td>Medium</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Infrared</td>
<td>Low</td>
<td>Very Low</td>
<td>No</td>
</tr>
<tr>
<td>Microwaves</td>
<td>Medium</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Neutron ray</td>
<td>Good</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Gamma ray</td>
<td>High</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Conductive</td>
<td>Poor</td>
<td>Expensive</td>
<td>No</td>
</tr>
</tbody>
</table>

(For more detailed information, refer to the original document.)
If the method's cost is the most important factor in your decision, calculate how long it will take to get a return on your investment for the method. Also seek advice from moisture-measurement equipment manufacturers to help you weigh the relative costs for methods that are equally suitable for your application. For instance, you can achieve accurate moisture measurements of large chunks of material by spending $30,000 to install a neutron ray or gamma ray system in your process. Or, for less than half the price, you can install a capacitive sensor on a bypass in the same process. A material sample is periodically diverted to the bypass, where it's ground into homogeneous granules. The material's moisture content can now be accurately measured by the less expensive capacitive sensor. The manufacturers can offer other suggestions for using various moisture-measurement methods to meet your accuracy and budget requirements.

Most manufacturers have years of experience in installing the equipment in various applications. Regardless of which moisture-measurement method you choose, rely on the manufacturer's experience to ensure that you use the equipment properly and get accurate results. For instance, with an inline method, where you install the sensor (or sensors) will determine whether or not the method provides accurate results in your application, so make sure the manufacturer explains which locations are best.

Reference

1. More information is available from the author.

For further reading

Find more information on moisture-measurement methods in articles listed under "Moisture analysis" in Powder and Bulk Engineering's comprehensive "Index to articles" (in the December 1999 issue and at www.powderbulk.com).

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