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Near Infrared Sensor for Online Measurement and Control

Key Words

- Near Infrared
- NIR
- Spectra-Quad
- Sensor
- Moisture
- Calibration

Thermo Industrial Solutions Note

Thermo Electron Corporation's near infrared (NIR) sensors are in widespread industrial use for online measurement and control of moisture and other constituents. Measurements with NIR sensors are accurate, reliable, fast, and nondestructive, making them ideal for real-time online measurements. By giving very representative measurements in real time, Thermo Electron sensors can improve quality by preventing or quickly detecting production that is out of specification, and can yield significant savings in waste reduction, faster process startups, and decreased energy and material costs.

Thermo Electron sensors, such as the Spectra-Quad™ can measure water and other constituents in a wide variety of materials and installations. Although water is the most common measurement, NIR sensors can also measure other substances such as oils and fats, coat weights, or protein content. Accuracy and precision depend on the application and the laboratory and sampling techniques, but are frequently better than ±0.3 percent, with response times typically ranging from 3 seconds to 10 seconds.

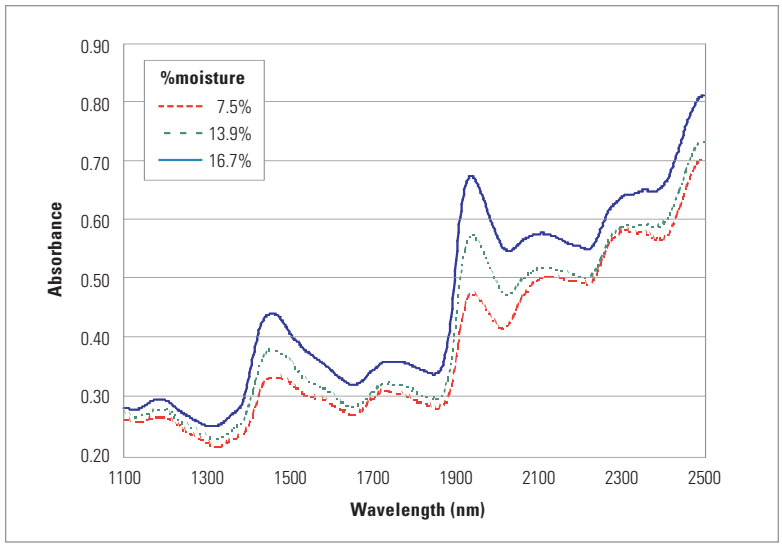

figure 1 – NIR spectra of tobacco at varying moisture levels

Principle of Near Infrared Measurements

NIR sensors measure moisture and other constituents in a typical sample by illuminating the sample with NIR light at a specific wavelength absorbed by water or constituent of interest, and measuring the amount of reflected NIR light. The more water in the sample, the more light will be absorbed, and the less will be reflected. Thus, the amount of reflected light is inversely related to the moisture and can be used to measure it. *Figure 1* shows spectra of tobacco at varying moisture levels. The absorbance at 1940 nm (the wavelength absorbed by water) increases with the moisture content. Thermo Electron sensors typically use this peak for water measurements.

The NIR region of the spectrum falls between visible and infrared light, with wavelengths from 1100-2500 nanometers (nm). Most materials absorb NIR light at specific wavelengths depending on the composition of the material, as shown in *table 1* and the spectra in *figure 2*. This allows NIR to selectively measure different materials by using NIR light at the appropriate wavelengths.

NIR light striking a sample undergoes absorption and diffuse reflection (backscattering), as shown in *figure 3*. The light penetrates only a short distance into the sample. For very thin or transparent samples, some light will also be transmitted or forward scattered through

Chemical Structure	Typical Materials	Absorbance Wavelengths (nm)
O-H (water)	Water	1450, 1940
O-H (alcohols)	Alcohols, Glycols, Carbohydrates	2100
C-H (aliphatic)	Coatings, Plastics, Solvents	1720, 2300
C-H (aromatic)	Coatings, Plastics, Solvents	2150

table 1 – Typical NIR absorbance wavelengths

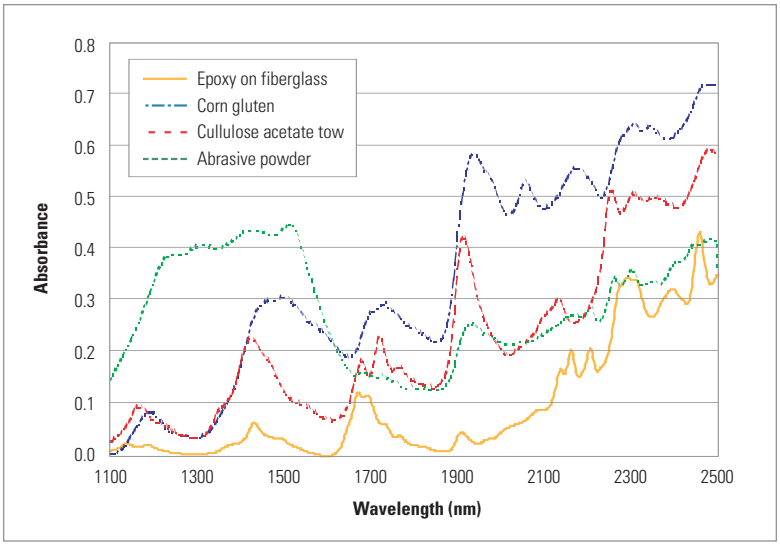

figure 2 – NIR spectra of selected solid materials

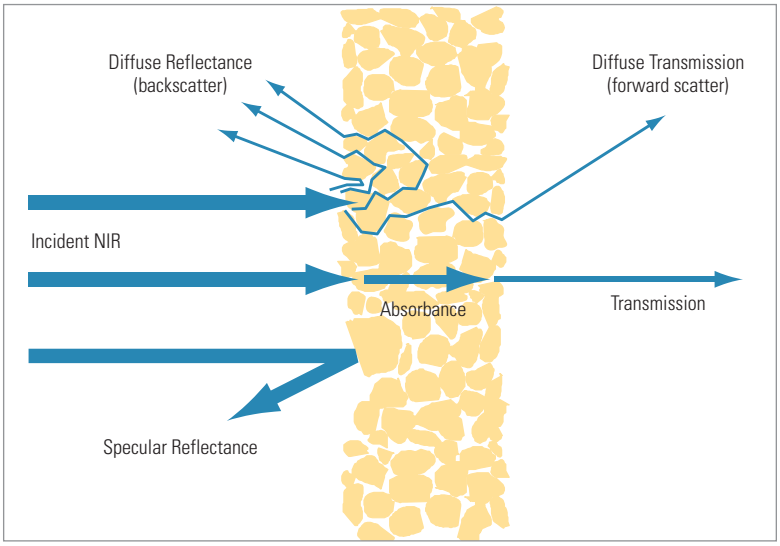

figure 3 – Interactions of NIR light with a typical sample

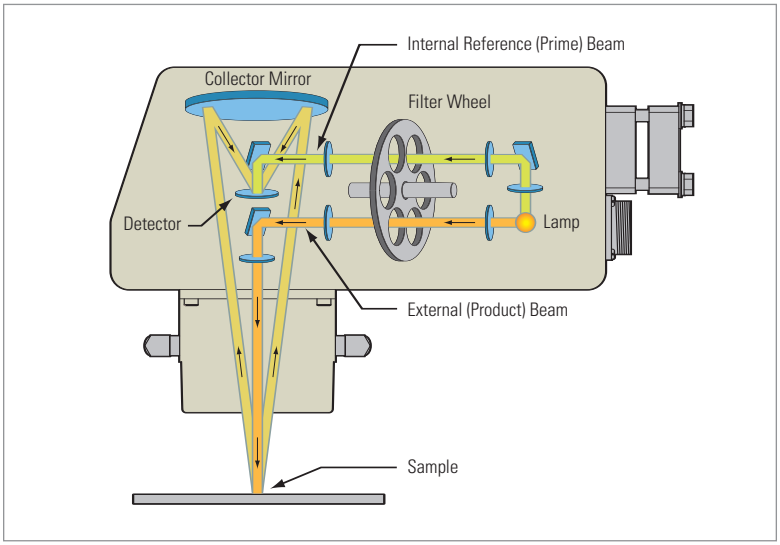

figure 4 – Thermo Spectra-Quad sensor for near infrared measurements

the sample. For most applications, with the sample in a pile on a conveyor belt, NIR sensors measure only the top surface of the sample.

Thermo Electron Near Infrared Sensor Technology

Thermo Electron NIR sensors use the mechanically simple fixed filter design. This design gives robust, reliable and maintainable sensors. *Figure 4* shows a Thermo Spectra-Quad for moisture and constituent analysis. It uses up to six wavelengths, which are chosen to optimize the measurement accuracy. Within the sensor, NIR light from a quartz halogen bulb shines on the optical filters. The filters allow only the specific wavelengths of NIR light chosen for the measurement to pass through to the sample. Light returning from the sample is captured by the collector mirror, which focuses it onto the lead sulfide detector. The sensor electronics capture the signal from the detector, perform the necessary calculations, and display the result.

The Spectra-Quad uses the QuadraBeam principle. In any sensor using the QuadraBeam principle, internal reference beams (known as prime beams) are used to improve the sensor stability. The intensity of the external (product) beam light reflected by the product is ratioed with the light intensity passing through the internal reference (prime) beam for the same filter. Since the internal and external beams share the same light source, filters, and detector, this ratio cancels out virtually all sources of instability.

The sensor makes the measurement by calculating the ratio of the reflectances at the reference and measure wavelengths. Because water absorbs light at the measure wavelength but not at the reference(s), the reflectance at the measure wavelength

decreases when the moisture level increases, and the Reference/Measure reflectance ratio is proportional to the moisture. Use of a ratio largely cancels out instabilities due to changes in the environment and in the sensor.

A Spectra-Quad filter wheel spins approximately 20 times per second, making a measurement on each spin. It measures the light intensity from the internal and external reference beams for each filter on every wheel spin, and plugs the intensities into the predefined moisture measurement algorithm, which calculates the percent moisture from the light intensities. The percent moisture can be displayed on the data box, and is also available on current (4-20 mA), serial communication (RS-232 and RS485), DeviceNet and Profibus outputs. The response time can be set from the data box, and ranges upward from a few tenths of a second. Typical response times are between 3 and 10 seconds. The Spectra-Quad 5400's six filters and internal reference beam gives Thermo sensors great versatility and power to make accurate measurements in difficult applications.

To maintain stability with changing sample presentations and environments, process NIR sensors typically use the ratio of two or more wavelengths to make a measurement. The basic measurement of water in most materials uses three wavelengths. The measure wavelength is on the water absorption peak at 1940 nm. The other two reference wavelengths are at 1820 nm and 2200 nm. These wavelengths were chosen on the basis of Thermo's experience in a wide variety of moisture measurement applications.

Calibration

NIR sensors are a secondary measurement. Instead of measuring moisture directly, they measure NIR reflectance properties of the sample, and use these to determine the moisture. As a result, NIR sensors must be calibrated by comparison with a primary reference method to give accurate measurements. NIR sensors are calibrated by determining the correct Span and Zero. When the Span and Zero are correct, the moisture as measured by the sensor agrees with the moisture as measured by the reference laboratory. The Span controls the sensor sensitivity, and the Zero controls the sensor offset. For a Spectra-Quad, the correct values are found by measuring the moisture of a range of samples using both the sensor and a laboratory reference method such as oven drying, using linear regression to determine the relationship between the sensor and laboratory moisture measurements, and using the regression results to calculate the new Span and Zero. The regression calculations can be performed by the Spectra-Quad's calibration mode.

NIR calibration accuracies can be no better than the sampling and reference methods used. The quality of sampling techniques, the laboratory reference methods used, and the range of samples available are critical to gaining the best possible accuracy in an NIR application. Laboratory measurement errors should be minimized. The sampling technique must ensure that the laboratory sample is representative of the sample measured by the NIR sensor. The calibration samples used should cover the entire range of variation ever produced by the process.

A well-calibrated NIR sensor measuring water will give very precise and accurate measurements. The NIR measurement is frequently more precise than the reference measurement. However, because NIR is a secondary measurement, it cannot be proven to be better than the reference measurement accuracy. Errors in the reference and sampling methods are frequently the limiting factor on the NIR measurement accuracy.

Installation

Typical online NIR sensors consist of a sensor and a data box. *Figure 5* shows a typical installation, with NIR sensors measuring water at the inlet and exit of a dryer. The data box is mounted at line or in a control room. It calculates and displays the moisture values, and sends the moisture signals to the dryer controls. Sensors have also been successfully installed on screw conveyors, shaker conveyors, gravity feed lines, fluidized beds, spray dryer discharges, through windows into pipes, and in other situations. Thermo sensors can be configured with accessories for specific measurement situations, such as optical photo eyes to detect a loss of product.

Important considerations for mounting a NIR sensor include:
Sample Presentation: The sensor must consistently see the product. The product passing under the sensor should be representative of the entire product stream. For calibrations, it is helpful if grab samples can be pulled from the same product viewed by the sensor. The distance between the sensor window and the top of the sample bed should be from 12.7 cm to 30.5 cm (5 in to 12 in).
Reference Laboratory and Sampling Methods: Grab samples for calibration must be representative of the sample seen by the sensor. Sampling and reference methods must be accurate and repeatable.

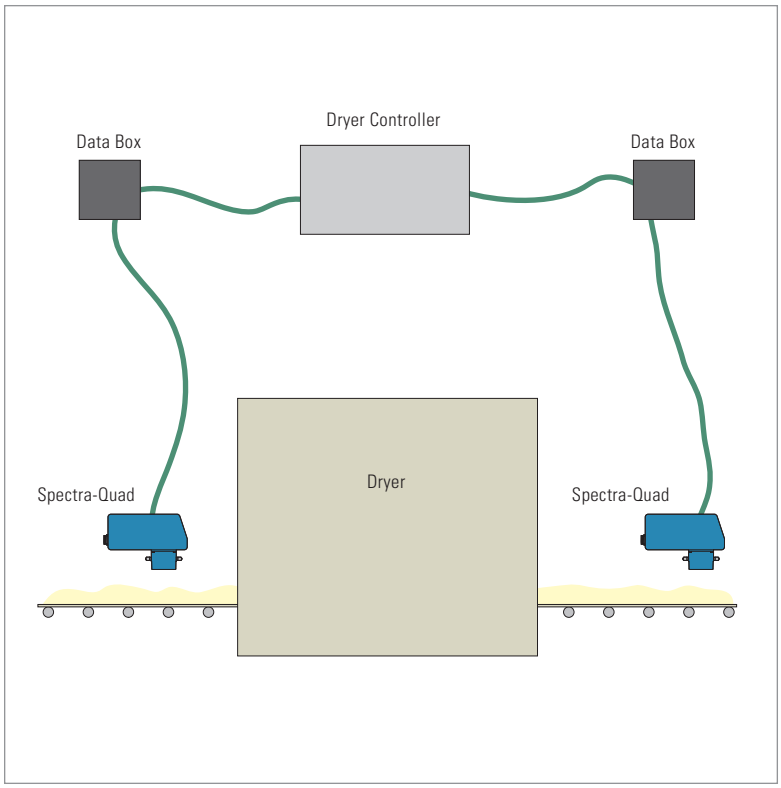

figure 5 – Typical Spectra-Quad installation for feed forward and feedback control of a dryer

Temperature: Typical NIR sensors will not operate in temperatures greater than 50°C without additional cooling.
The absorbance characteristics of water in liquids are affected by the sample temperature, which should be held constant.
Ambient Light: Light from strong NIR sources, such as direct sun, infrared dryers, and bright incandescent lamps, should be avoided or blocked.

Conclusion

The speed, accuracy, and reliability of Thermo NIR sensor technology makes it ideally suited for use in closed loop process and quality control. Use of NIR sensors in closed loop control can improve quality by maintaining the moisture tightly within specification, and can also yield savings in decreased waste, lower material costs, and lower energy costs by allowing moisture to be more tightly controlled to the target value. Used for quality control, NIR sensors monitor the entire production, rather than the small grab samples typically used for lab tests. This makes the NIR measurement more representative of the actual product, and allows it to catch short-term process fluctuations. The Spectra-Quad online moisture and constituent analyzers are a fast, accurate, precise, and reliable method for online moisture analysis and other measurements.

For More Information

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