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Fundamentals of Moisture Measurement in Industrial Applications

Moisture is not only a process variable to be measured in industrial applications, but also a common contaminant which must be controlled.

The Basics of
Moisture
Measurement

p1-2

Moisture
Measurement
Technologies

p3-4

Hygrometer
Applications

p5-10

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Moisture is not only a process variable to be measured in industrial applications, but also a common contaminant which must be controlled. Whether in gas or in liquid form, moisture has the power to dramatically reduce product quality, damage industrial equipment, and significantly increase operating costs. Understanding the basics of moisture measurement is a necessary first step in mitigating moisture's potentially harmful effects.

Moisture is generally considered as just another process variable to be measured like temperature, pressure and flow. However, moisture has two unique characteristics. First, it is extremely difficult to accurately and consistently measure within dynamic industrial processes. Second, moisture as a contaminant is capable of severely damaging industrial processes, equipment and end products.



Table of Contents

The Basics of Moisture Measurement

- Humidity p1
- Dewpoint p1
- Hygrometry p1
- Pressure p1

Why Measure Moisture? p2

Moisture Measurement Technologies

- Measurement Technologies p3
- Measurement Techniques p4
- Sampling Systems p4
- The Importance and Purpose of Calibration p4

Hygrometer Applications

- Industrial Plants p5
- Electric Power-Generation Plants p5
- Electric Power Distribution p6
- Furnaces and Metal Heat-Treating p7
- Pipeline Construction and Maintenance p7
- Semiconductor Manufacturing p8
- Natural Gas Production and Transportation p9
- Air Separation and Industrial Gas Suppliers p9
- Ozone for Purification and Sanitation p10
- Calibration Laboratories p10
- Summary p10



The Basics of Moisture Measurement

Across the breadth of industrial applications, it is necessary and challenging to measure moisture. Before we look at specific technologies and applications, it is important to review moisture measurement fundamentals, including the definitions of humidity, dewpoint, and hygrometry, as well as the role and consequences of pressure in moisture measurement.

Humidity

Humidity is simply the presence of water vapor in air or other gases, expressed as relative humidity (RH) or as absolute humidity. Relative humidity is the most common measurement and is defined as the ratio of the actual vapor pressure to the saturation vapor pressure, expressed as a percentage. Absolute humidity, in comparison, measures the mass of water vapor present in a unit volume of air at a given temperature and pressure. Common measurement units are dewpoint (°F or °C), grams of water per cubic meter of air (g/m³) or pounds of water per million cubic feet (lb/ft³).

Dewpoint

Dewpoint or dewpoint temperature is the temperature in °F or °C at which condensation or dew occurs if a gas is cooled at constant pressure. As a measurement of absolute humidity, it indicates how much moisture is present and its identification enables a gas to be maintained at a temperature level that prevents condensation. Dewpoint is the most commonly used engineering unit for absolute humidity.

Hygrometry

Hygrometry is the measurement of the moisture content of gases. The instrument that measures the humidity has many names, such as hygrometer, moisture analyzer, humidity sensor, dewpoint meter, dewpoint monitor, moisture detector, etc. A Hygrometer senses, measures and outputs or displays the relative or absolute humidity in the air and/or other gases.

Pressure

When considering dewpoint measurement, a change in pressure also changes the dewpoint. The increase in overall pressure also increases water vapor pressure. As a result, since water vapor pressure is directly related to dewpoint, the dewpoint increases (becomes wetter) as the overall pressure increases. Similarly, the dewpoint decreases as the overall pressure declines (becomes drier).

Given a gas mixture that is composed of several pure gas components, the pressure of the gas is the sum of the partial pressures of the component gases. At any given temperature there is an upper limit as to how much water vapor a gas can contain, called the saturation vapor pressure (SVP).

While the measurement of moisture in gas is quite challenging, let's look at why it is so important.



Why Measure Moisture?

Moisture is an unwanted contaminant that exists in industrial gases and the atmosphere, and is able to penetrate virtually any surface including such metals as copper, bronze and carbon steel. Therefore, it is important to first accurately measure the moisture content in order to subsequently control or remove the unwanted moisture. By understanding when and how to measure and manage moisture, we are able to improve product quality, minimize equipment damage, save energy, reduce costs, and meet contractual obligations. The downside of humidity includes condensation, corrosion and contamination.

Moisture can:

- Penetrate virtually any surface
- Render test results useless
- Result in poor product quality
- Cause corrosion in tubing
- Lead to ice formation at low temperature
- Cause premature wear and equipment failure
- React with other chemicals and gases

Clearly moisture has the capacity to cause expensive problems and potentially catastrophic failures. Before we review the numerous industries that require moisture measurement and control, let's look at select moisture measurement.

The Basics of Moisture Measurement

Moisture Measurement Technologies

There are two primary technologies employed in industrial moisture measurement: capacitive (ceramic or aluminum oxide) sensor technology and optical (chilled mirror) sensor technology.

Capacitive sensors respond to small changes in water vapor pressure, feature a fast response and broad calibrated range, and are economical to purchase and operate. They are widely used in industrial, commercial, and laboratory applications. The sensors measure the capacitive or resistive output of the sensing element. The sensor generally features a ceramic substrate with an oxide coating and a top layer of vapor deposited gold. Water vapor molecules pass through the gold film and are attracted to the oxide layer. Changes in water vapor pressure result in changes in output from the capacitive device. This signal is then conditioned and output as a digital signal to a local display or a distributed control system (DCS).

Capacitive Ceramic Dewpoint Sensor

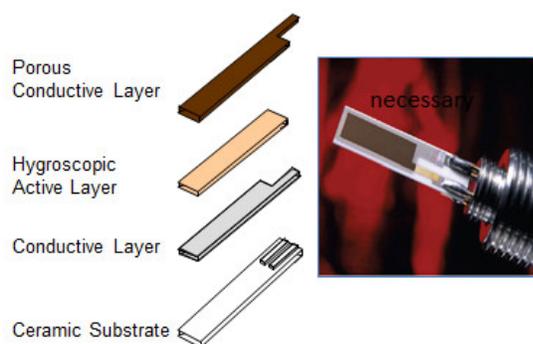


Figure 1

Capacitive measurement challenges include long-term drift and temperature effects. Drift is mitigated by re-calibration with frequency determined by the harshness of the environment. The temperature output for the sensor's on-board thermistor is used in a temperature-compensation algorithm.

In comparison, optical (chilled mirror) hygrometers cool the gas under test to the point where dew or frost forms on a metallic mirror (usually gold, platinum or other metal with excellent thermal conductive) and a platinum resistance thermometer (PRT) embedded in the mirror measures this dewpoint - the temperature at which dew or frost occurs. Operationally, the mirror is chilled via a thermo-electric cooler (TEC; Peltier Heat Pump) until dew or frost initially begins to form. A beam of light (LED) is aimed at the mirror surface and a photo-detector monitors the reflected and/or scattered light from the mirror. Through a proportional-integral-derivative (PID) controller, the mirror temperature is held at precisely the dew or frost point.

This method is more precise than capacitive technology offering accuracy to $\pm 0.1^{\circ}\text{C}$ versus $\pm 2.0^{\circ}\text{C}$ for capacitive. Optical (chilled mirror) technology is considered a fundamental technology and provides long-term calibration stability for such applications as metrology and standards laboratories, continuous industrial process control, critical environment monitoring such as in clean rooms, and the measurement of water vapor in extreme operating environments (e.g. steel mills).

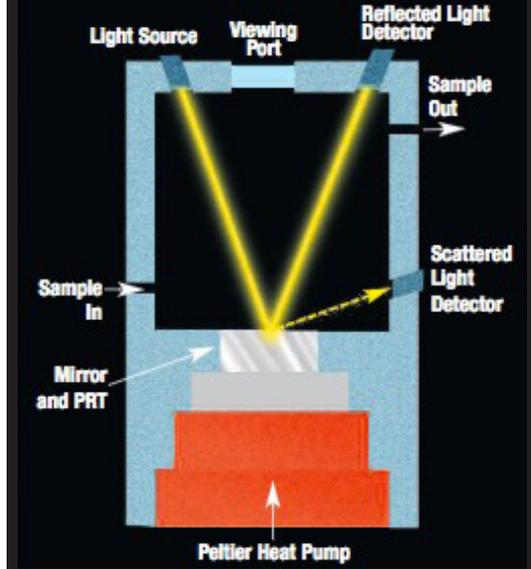


Figure 2 - Optical (chilled mirror) sensor. A chemically resistant, polished metal mirror is thermally bonded to a multi-stage thermo-electric cooler (TEC). Direct current delivered to the TEC allows the mirror to cool until condensation begins



Measurement Techniques

Measurement techniques include direct insertion in the gas and sample bypass methods. Direct insertion measurement is simple and provides the lowest initial cost. However, its downside is that it compromises maintenance and exposes the sensor, leaving it unprotected against damage by contaminants. Gas temperature, pressure, or velocity may also be outside recommended operating ranges with this method.

A sample bypass system diverts a sample of the gas to the sensor, which facilitates maintenance, minimizes contamination when used with appropriate filtration thereby prolonging sensor life, and reduces the need for cleaning. It does, however, require that filters be inspected and replaced, and there is a higher initial cost for the sample bypass equipment.

Sampling Systems

Correct sampling insures that the measurements taken are representative of the condition to be measured. The basic system:

- Inlet/outlet valves
- Filter(s)
- Sample block to direct the gas sample across the sensor
- Tubing, fittings and means for venting the gas
- Anti-diffusion coil to prevent ambient moisture from migrating into the system from the outlet
- Optional gauges, pressure regulator, enclosure, heater, ample pump, etc.

Sampling systems are critical to insure accurate and reliable moisture measurements. Materials of construction, length of flow path, diameter of tubing and myriad other factors are critical in the design of a properly functioning system. Kahn Instruments offers numerous sample system designs, as well as purpose-built designs to accommodate any sampling system requirement.

The importance and purpose of calibration

As with virtually all sensor-based measurements, bias and long-term drift may occur. Calibration, the comparison of an instrument against a reference value, is critical for accurate humidity measurements, but it is not the same as adjustment. Calibration against reference hygrometers using humidity generators is performed in accredited calibration labs, insuring that calibrations are traceable to national standards (e.g. NIST) and competently performed. Typically, humidity instruments should be calibrated every 6 to 12 months or more frequently in harsh environments, while a reference hygrometer in a lab might be calibrated every one to two years. Kahn offers both calibration systems for customer purchase as well as complete calibration services for dewpoint measurements from -120°C to +130°C.

Hygrometer Applications

There are numerous industries that must manage the effects of moisture for a variety of reasons.

There are numerous industries that must manage the effects of moisture for a variety of reasons, including industrial plants, semiconductor manufacturing, water purification and many more. There are both unique as well as common requirements and measurement challenges within each of these markets and applications.

Industrial Plants

Most industrial plants such as refineries, general manufacturing, or paper mills use dry compressed air to power pneumatic tools and equipment, control valves, conveying systems, and other instrumentation. The moisture removal process can be seen in Figure 3.

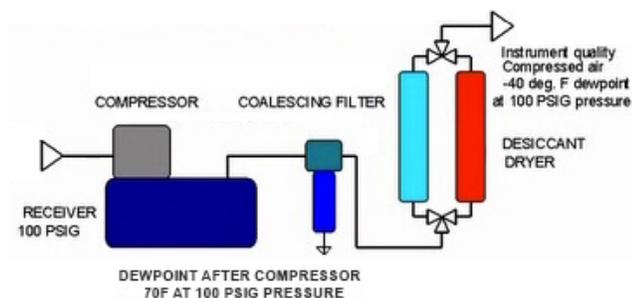


Figure 3 - From the left, ambient air is drawn into a compressor, compressed and piped to a coalescing filter and to the dryer. Moisture is removed in one of the dryer's desiccant towers resulting in instrument-quality outlet air (dewpoint of -40F/C)

In this application, a hygrometer can be permanently installed at the outlet of the desiccant air dryer, in downstream piping or at a remote location if the plant is large enough. Alternatively, spot-check measurements can verify dryer performance or the accuracy of a permanently installed instrument. Handheld, portable hygrometers can be used to measure dewpoint at any of these locations.

Kahn solutions for this application include the permanently installed [Cerment II Hygrometer](#) with local display, 4-20mA output and dual alarms, or the simple and economical [Easidew Dewpoint Transmitter](#) with a 4-20mA output. In the handheld category, the [HygroPort Portable Hygrometer](#) and [Easidew Plus Portable Hygrometer](#) are recommended for spot-checking moisture.

Electric Power-Generation Plants

Within coal, natural gas, oil or nuclear electric power-generation plants, several moisture measurement requirements exist, including the measurement of dry compressed air for pneumatic control and instrumentation. In this environment, instrument air can be monitored using permanently installed hygrometers or portables for spot-checks.

Another important application in power plants is the measurement of the moisture content of hydrogen used to cool an electric-power generator. Within the hydrogen-cooled steam turbine generator, recirculating hydrogen coolant is kept dry with a hydrogen gas dryer. A dewpoint sensor installed on the gas dryer monitors the dryer's performance. Because hydrogen can be explosive when mixed with air, the dewpoint sensor must be intrinsically safe or explosion proof. As a result, the [Easidew I.S. Dewpoint Transmitter](#), featuring an approved safety barrier is used for hydrogen moisture measurement in hazardous environments.

The [Easidew PRO I.S. Hygrometer](#) consists of a digital display with integral signal conditioning board, [Easidew PRO I.S. Transmitter](#)/sensor, galvanic isolation interface and a 25-foot interconnecting cable.

In addition, for heavier duty applications, the intrinsically safe [Easidew Pro I.S. Dewpoint Transmitter](#) and [Explosion Proof Easidew PRO XP Moisture Transmitter](#) are also available in a process-type housing with provisions for conduit-type entry.

Electric Power Distribution

Electric power distribution systems with high-voltage substations utilize circuit breakers that operate from 100,000 to 400,000 volts. These circuit breaker vessels are filled with sulfur hexafluoride (known as SF₆), a nonflammable gas serving as an insulating and arc extinguishing substance. It is extremely important that low moisture levels (generally -60°F and below dewpoint) be maintained in the SF₆ gas to prevent condensation formation and corrosive, acidic, damage-causing byproducts in the circuit breaker.

The circuit breaker includes a sample port to spot check SF₆ gas moisture levels with a portable hygrometer, the [HygroPort Portable Hygrometer](#), the same device used for compressed air applications. There is also a Kahn sampling system subassembly that attaches to the [HygroPort Portable Hygrometer](#) to speed measurement setup and to protect the instrument's sensor from contaminants.

Permanent dewpoint transmitters can also be installed allowing for immediate readings by the use of a multimeter (local measurement) or by connecting the transmitter to a DCS network (remote measurement). An [Easidew Dewpoint Transmitter](#) is recommended for this application. If a local display is desired, the [Cermet II Hygrometer](#) is offered.

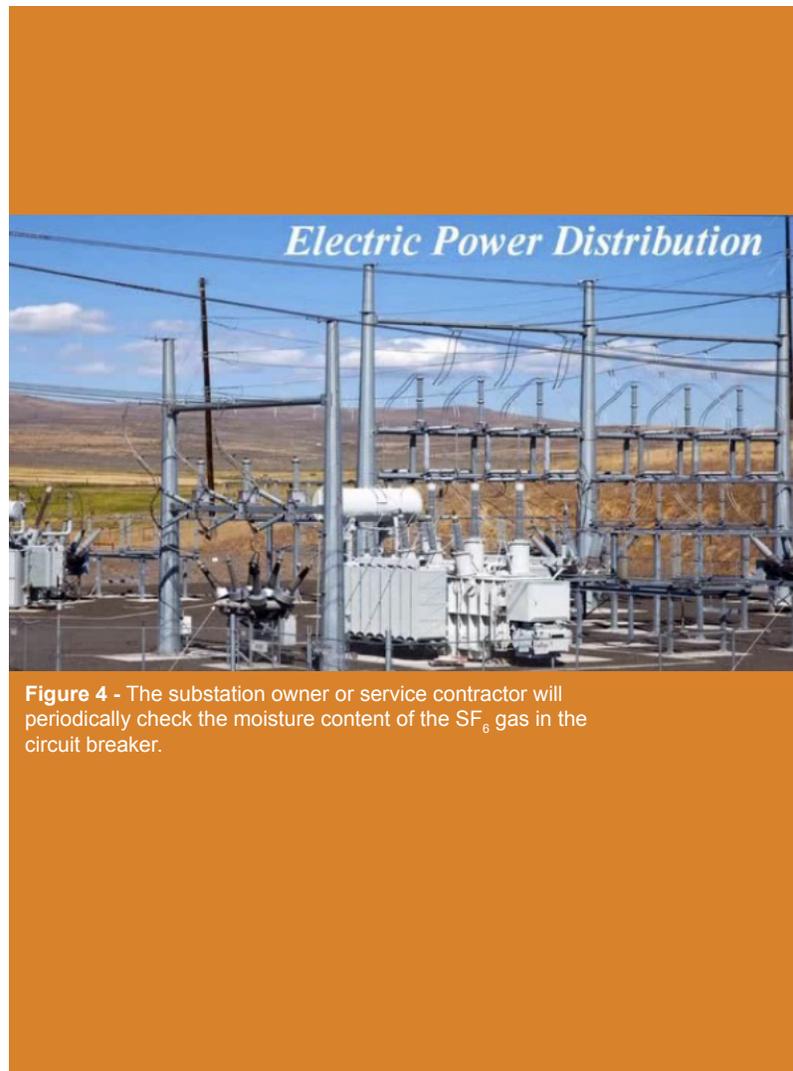


Figure 4 - The substation owner or service contractor will periodically check the moisture content of the SF₆ gas in the circuit breaker.



Figure 5

Furnaces and Metal Heat-Training

Vacuum or annealing furnaces are used to heat-treat metal parts at high temperatures, typically 2,000°F, to improve metallurgic properties. In this application, high gas temperatures and the presence of metallic particulates and combustion byproducts require the use of a sampling system to protect the dewpoint sensor. When a furnace is not pressurized and there is no natural flow of gas samples to the dewpoint sensor, a vacuum pump draws a sample from the furnace to the dewpoint sensor. The [Cermet II Hygrometer](#) is appropriate for the measurement of the dewpoint inside of a furnace or to measure such gases as nitrogen, argon, and hydrogen, used to purge a furnace. The sampling system, also available from Kahn, is enclosed and features a see-through cover so that flowmeter operation and filter cartridge condition can be observed.

Figure 5 - The [Easidew Dewpoint Transmitter](#) is shown with a sampling system including a vacuum pump. The solution provides an analog output to the customer's Distributed Control System (DCS).



Figure 6

Pipeline Construction and Maintenance

Pipelines transfer oil and natural gas and are pressure tested using liquid water during construction as well as periodically throughout their lifetime. After testing, the water is drained and the pipeline is dried. There are several methods used to dry and verify the drying process. One of these is hot air drying and moisture measurement whereby compressed air is fed into one end of the pipeline. Heat evaporates the residual water into water vapor and the water vapor is transported by flowing air out of an exit port located at the pipe's opposite end.

For this method, two hygrometers are used to verify the pipe's dryness. One [Cermet II Hygrometer](#) is installed in a sample block located at the inlet of the pipe and another is installed at the outlet of the pipe. When the difference measured by the two hygrometers is less than 5°C, the pipe is considered sufficiently dry for the flow of gas. Portable, hand-held hygrometers such as the [Easidew Plus Portable Hygrometer](#) or [HygroPort Portable Hygrometer](#) can also be used.

Figure 6 - Pipelines require the use of water to leak test during and after construction. However, it is important that the added moisture be completely removed prior to flowing gas through the repaired or newly constructed pipeline.

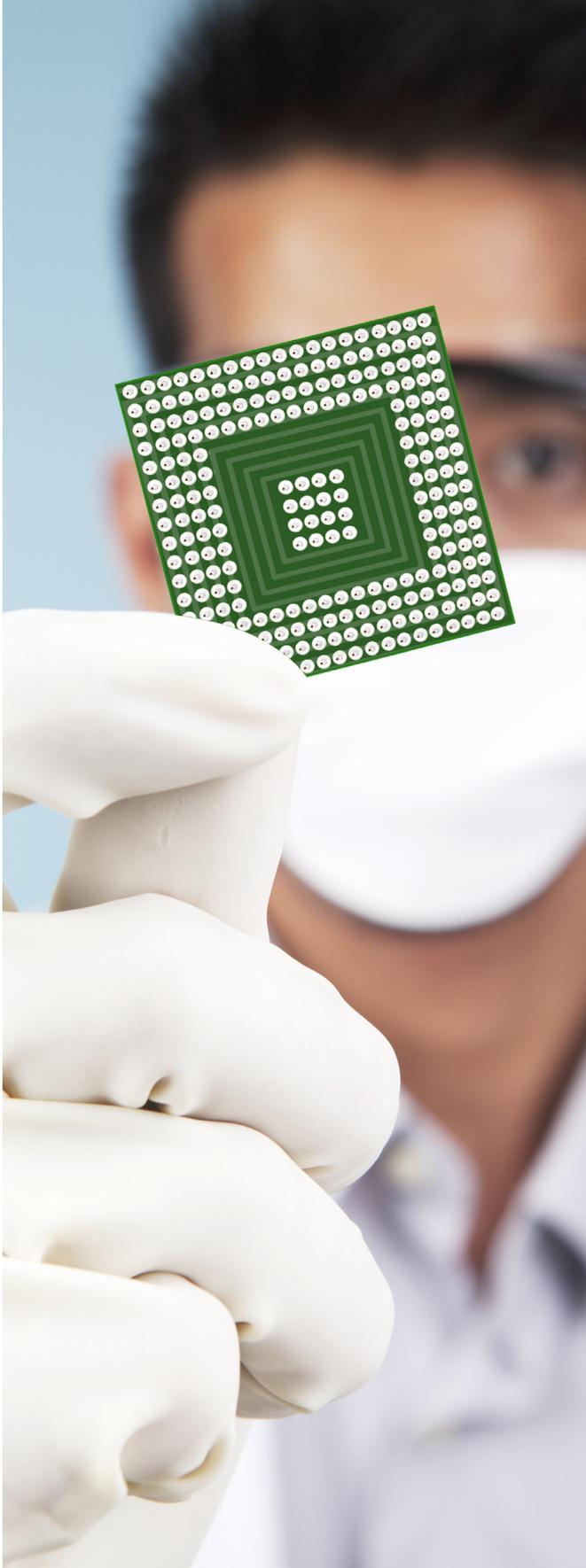


Figure 7

Semiconductor Manufacturing

There are two areas within semiconductor manufacturing where moisture measurements are critical: cleanrooms where semiconductor wafers are produced and stored, and with ultra-high purity gases used in semiconductor manufacturing processes.

In cleanrooms, moisture is measured and controlled to prevent contamination of materials and to eliminate static electricity. In this case, the Kahn [Optidew Hygrometer](#) (see figure 7) uses chilled mirror optical technology to measure the dewpoint temperature and relative humidity. The Optidew features typical relative humidity accuracy of better than 0.5% with rapid response speed to changing moisture conditions.

To measure the dewpoint of ultra-high purity gases, Kahn offers the [Pura High-Purity Gas Dewpoint Transmitter](#). The Pura features accuracy to $\pm 1^{\circ}\text{C}$ and measurements as dry as -120°C or 200 parts-per-trillion (ppt).



Natural Gas Production and Transportation

Wet natural gas is extracted from below the earth's surface and is dried using a glycol dehydration process in production plants. A permanently installed moisture analyzer monitors the dehydration process. For permanent installation applications, the intrinsically safe [Easidew PRO IS Hygrometer](#) is used, as well as the explosion-proof [Easidew PRO XP Moisture Transmitter](#). For spot-check moisture measurement, the intrinsically safe [HygroPort IS Portable Hygrometer](#) can be used.

Natural gas contains several potential contaminants that affect the performance of moisture analyzers requiring the sample gas to be properly conditioned before contact with this dewpoint sensor. Kahn offers several sampling systems designed specifically for this application.

Natural gas sources are often dirty, corrosive, laden with moisture, and operate at high pressure. This moisture can corrode pipelines, affect pipeline flow capacity, and lead to pipeline blockage and filter, valve and compressor damage. Hence, there is a need for careful monitoring of the natural gas using a well-designed sampling system.

Air Separation and Industrial Gas Suppliers

A typical air-separation plant separates atmospheric air into such primary components as nitrogen, argon, oxygen, hydrogen, carbon dioxide and helium. Bottled separately, the gases are used in a variety of industrial processes. Permanently installed as well as spot-check hygrometers are used to measure moisture content. Kahn products appropriate for this use include the [Cermet II Hygrometer](#), [Easidew Dewpoint Transmitter](#), and for portable spot-check measurements, the [Easidew Plus Portable](#) or [HygroPort Portable](#) solutions.

When high accuracy ($\pm 0.2^{\circ}\text{C}$ or better) is required, a chilled mirror hygrometer such as the [Optidew Dewpoint and RH Hygrometer](#) or the [Optisure Hygrometer](#) is recommended.



Ozone for Purification and Sanitation

Ozone generators are commonly used in purification and sanitation processes. Applications include purification of beverage and sanitation of industrial wastewater at treatment plants, cleaning of fruits and vegetables in agricultural processes, and in the bleaching of pulp for papermaking.

The ozone generator uses air or oxygen as a feed gas to the generator, which converts the oxygen to ozone. This feed gas must be dry to prevent arcing in generator electrodes and corrosion of system components. A hygrometer is used to monitor and control the dewpoint of the feed gas, so that the feed gas is sufficiently dry to maintain generator efficiency and extend the life of the ozone generator.

The appropriate Kahn product for this application is a [Cermet II Hygrometer](#) in a NEMA 4 enclosure.

Calibration Laboratories

In addition to industrial applications, hygrometers serve as reference standards for dewpoint and relative humidity sensor calibration.

Calibrating dewpoint and relative humidity sensors requires a very accurate and stable instrument with a wide dewpoint measurement range. Generally, the reference hygrometer should be four times as accurate as the instrument under test. To meet this level of accuracy, Kahn's [Optisure Hygrometer](#) product family of chilled

mirror optical hygrometers provide fundamental direct measurement of dewpoint, are inherently drift-free and offer accuracy of $\pm 0.1^\circ\text{C}$ dewpoint. Importantly, all Kahn hygrometer calibrations, both capacitive and chilled mirror (optical) are traceable to the National Institute of Standards and Technology (U.S.) and all calibrated hygrometers are provided with a calibration certificate.

Summary

There are numerous other industries and applications that utilize hygrometers ranging from pulp and paper to petrochemical to aerospace and defense. Each has its own requirements and challenges, which can be addressed with Kahn's extensive product range.

Within these varied and often harsh and challenging environments, Kahn delivers the broadest product line and the best possible solutions to meet the challenges of a moisture-filled world.

Kahn Instruments manufactures a full line of humidity instrumentation for measuring dew point or moisture content in air and compressed gases. Kahn hygrometers measure moisture in a broad variety of gases at dewpoints from -120°C to +130°C (-184°F to +266°F) and at pressures from vacuum to 6000 PSIG using the most accepted, proven technologies.

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