CHILLED MIRROR HYGROMETERS

BULLETIN CMHYG1

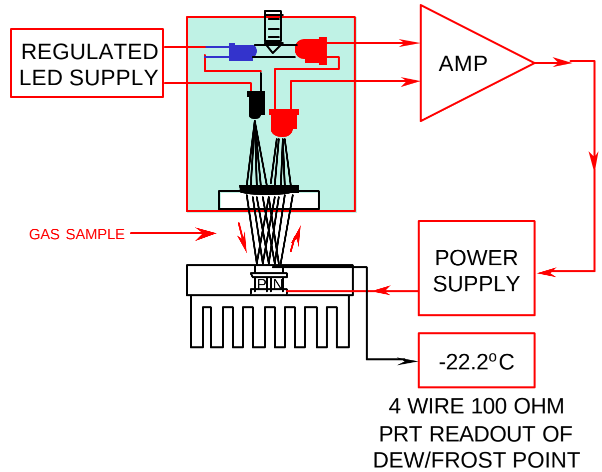
Principle of Operation

The measurement of the water vapor content of a gas by the dew-point technique involves chilling a surface, usually a metallic mirror, to the temperature at which water on the mirror surface is in equilibrium with the water vapor pressure in the gas sample above the surface. At this temperature, the mass of water on the surface is neither increasing (too cold a surface) nor decreasing (too warm a surface).

In the chilled-mirror technique, a mirror is constructed from a material with good thermal conductivity such as silver or copper, and properly plated with an inert metal such as iridium, rubidium, nickel, or gold to prevent tarnishing and oxidation. The mirror is chilled using a thermoelectric cooler until dew just begins to form. A beam of light, typically from a solid-state broadband light emitting diode, is aimed at the mirror surface and a photodetector monitors reflected light.

As the gas sample flows over the chilled mirror, dew droplets form on the mirror surface, and the reflected light is scattered. As the amount of reflected light decreases, the photodetector output also decreases. This in turn controls the thermoelectric heat pump via an analog or digital control system that maintains the mirror temperature at the dew point. A precision miniature platinum resistance thermometer (PRT) properly embedded in the mirror monitors the mirror temperature at the established dew point.

If the mirror is controlled to an equilibrium condition above the ice point, i.e., 0°C, the sensor is measuring the *dew point*. Below 0°C, the deposit cannot long persist as liquid water, and it is assumed that the deposit is frost, and that the sensor is measuring the *frost point*. However, if the mirror is kept extremely clean, it is possible for dew to exist below 0°C, and the only true way to verify that the sensor is controlling on the frost point is to visually inspect the mirror via a microscope. However, especially outdoors, it is typically impractical to maintain a perfectly clean mirror, as contaminants such as spores and other particulates serve as motes on which frost deposits can nucleate. Consequently, errors due to dew/frost point confusion at 0°C are seldom encountered.



CMH Block Diagram

Why select a Chilled Mirror Hygrometer?

The chilled mirror hygrometer (CMH) dew point has several distinct advantages over other water vapor sensing technologies:

- A CMH provides one of the few truly direct physical measurements of humidity. It is recognized as the most precise method of determining the water vapor content of a gas above 5% RH. Use it *when you need maximum precision of measurement.*
- The CMH's optical sensor is a totally inert device. The sample gas contacts glass and non-reactive metals. Thus, it can be easily cleaned and can last indefinitely. Use it *when the gas sample contains contaminants and particulates, which would damage other types of humidity sensors.*
- Unlike polymer RH sensors, lithium chloride dew cells, and other chemically-based sensors, a CM sensor does not lose its calibration. Use it *when you need long-term calibration stability*.

The dew/frost point temperature defines the saturation point for the water vapor in the gas. From this unique equilibrium temperature, all other reporting formats of gas humidity can be derived. With measurements of gas temperature and pressure, other reporting forms for humidity can be derived.

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Working Range of Dew/Frost Point Chilled Mirror Hygrometers

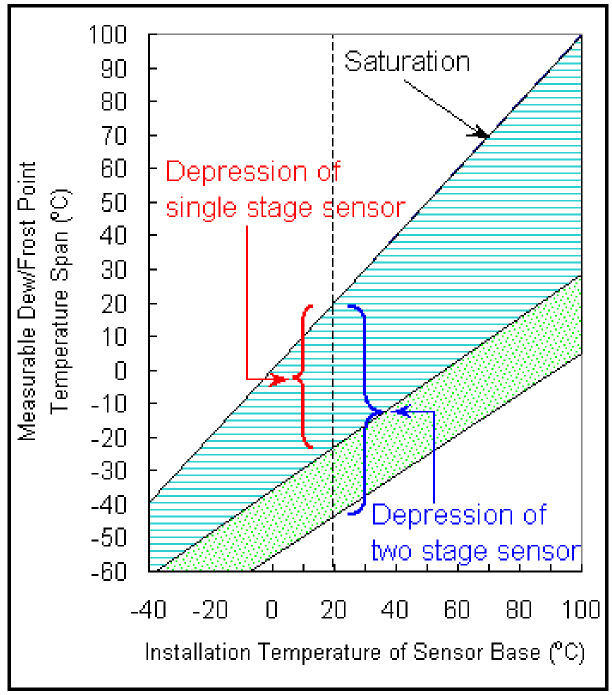
A CMH works by detecting the scattered light from a condensation layer that forms on a cooled mirror from a gas sample. To function properly, a chilled mirror hygrometer must be able to cool its mirror to the dew or frost point of the sample. The range of dew point temperatures that a chilled mirror hygrometer can measure is dictated primarily by the heat pumping capability of the solid state thermoelectric mirror cooler.

The graph shows the typical useful working span of hygrometers with single- and two-stage coolers. In a single-stage hygrometer such as the *YES 2010 series*, if the sensor is installed in an ambient temperature environment of +20°C, dew points (frost point below 0°C) can be measured down to about -25°C. Thus, the mirror can "depress" 45°C. Systems with two stage coolers, such as the *YES 2020 series*, offer greater dew point depression. A two-stage unit running at +20°C can measure frost points down to -45°C. Thus, the mirror can "depress" 65°C. Lower frost points can be measured by reducing the temperature of the hot side of the cooler, or by using 3, 4, or 5 stage coolers or via a customer-supplied mechanical chiller.

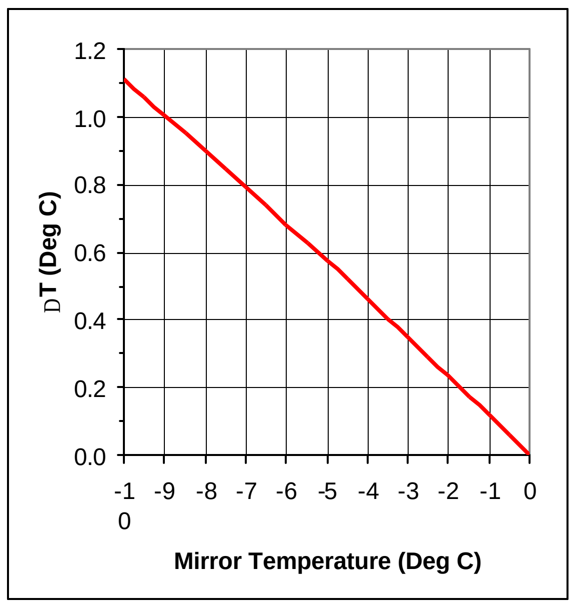
Interpretation of Uncertainty

When measuring dew point or frost point temperatures that are below the freezing point, it is desirable to know the phase (liquid or solid) of the condensate. When the temperature of the mirror surface is slightly below zero degrees Celsius the condensate may be super cooled liquid water or it may be in the form of solid ice. Generally, if the dew point has been dropping, the condensate will initially be in the form of super cooled water. In time, it will usually change to the ice phase because that has a lower energy state. At very low temperatures, the change to ice is more rapid and at –40°C it generally exists only in the ice form. It is desirable to know the state of the condensate because for a given mirror temperature, the vapor pressure in equilibrium with the condensate is higher for water and lower for ice.

For a given vapor pressure over the mirror, if the condensate is ice then the mirror temperature at equilibrium is slightly higher than it would be if the condensate were liquid.



Measurement span of one-and two-stages



Difference in mirror temperatures for a given vapor pressure in the sample

The above chart shows the difference in CMH mirror temperatures for a given vapor pressure in the gas sample. The ordinate is the equilibrium temperature over ice minus the equilibrium temperature over water as a function of the mirror temperature.

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In some industrial and metrology applications, the hygrometer has a microscope providing direct observation so the user can accurately discern the phase state on the mirror surface. In lieu of a microscope, users must assume instruments operating for long periods of time without interruption have an ice layer at temperatures below 0°C and are measuring *frost point*. The relationship in the above chart is very nearly a straight line with a slope magnitude of 0.1127 $\Delta T/T$ mirror.

Applications

- Metrology and standards laboratories
- Continuous industrial process control
- Meteorological monitoring
- Automated QC of manufacturing processes, e.g. pharmaceuticals, steel production and photography film
- Critical environment monitoring, e.g. clean rooms, museums, storage vaults
- Measurement of water vapor in extreme operating environments, e.g. curing ovens, heat treating, automotive exhaust testing, plant air, or gas analysis
- Environmental test chambers and R&D

Features

- Solid-state, no-moving-part design assures long, trouble free life
- Proprietary control loop algorithms extend operating range of system
- Unique mirror design provides superior unit-to-unit response
- Freedom from contamination provides long term calibration stability

The YES Chilled Mirror Hygrometer Family

YES manufactures both one- and two-stage chilled mirror hygrometers in its Model 2000 series. Models ending in 10 are single-stage sensors while those ending in 20 are dual stage (3, 4, or 5 stage sensors are available on customer order). Although packaged for different applications, models share the same sensor technology to leverage proven designs.

Selecting the Right Chilled Mirror Hygrometer for Your Application

First, you must answer three questions:

1. What range of dew/frost temperatures of the sample do you intend to measure? This determines the amount of mirror cooling, i.e., "depression" required to reach the dew point. It defines whether you need single or multiple stage thermoelectric cooling.
2. What is the span of ambient temperatures of the gas sample? Keep in mind that the temperature of the sampling lines, if used, must be higher than the highest dew point anticipated. High dew point temperatures must be handled in heat-traced sample lines in order to prevent dew from condensing on the sample line walls, thus giving a lower and incorrect measurement. The highest temperature at which a standard thermoelectrically cooled dew point sensor can operate is limited by the characteristics of the solid state optical dew detectors, usually 85°C.
3. What will be the ambient temperature of the environment where you will install the dew/frost point sensor? This determines the temperature to which the heat from the hot side of the thermoelectric heat pump will be dumped. This can be the prevailing room temperature or water coolant to obtain additional depression.

The answers to these three questions define whether you require a single stage or multiple stage dew/frost point sensor, as well as the type of heat sink required for the sensor, thus determining the feasibility of the measurement and the cost of the solution.

Next, consult the Range Chart above for single and two stage sensors; all manufacturer's range charts are essentially the same, as the "depression" (the amount of cooling the mirror can achieve) of a single or two stage sensor is determined solely by the physics of thermoelectric heat pumping mechanics.

Other factors to consider:

- Is the gas corrosive? For example, does it contain chlorine or other active gasses? If so, the active component will often react with the dew deposit, causing erroneous "acid" dew point readings. We recommend you avoid chilled mirror dew point sensors for this application (regardless of the manufacturer's claims!).
- Is the gas a mixture of gasses such as natural gas, containing methane as well as water vapor? Keep in mind that the chilled mirror will tend to control on the first dew point it encounters as it cools. In such instances, the methane dew/frost point temperature can be above the water dew point, causing an erroneous reading

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- Is the gas radioactive, such as UF6? (Users handling radioactive gasses must know how to handle contaminated instrumentation).
- How dirty is the gas sample and how often can you clean the mirror? Most importantly, how difficult is it for you to clean the mirror? Do you have to remove screws and plumbing? How long will the threads last?

Finally, before making a decision, take a good look at the "guts" of what you're buying. More that any other factor the chilled mirror sensor design and construction defines how well the chilled mirror technique will solve your problem.

Single-stage sensors

Many of the more routine dew point measurements can be made with a single stage sensor; for a typical ambient temperature span of +10°C to +70°C, a dew point span of –45°C to a room temperature of +25°C can be made with an absolute dew point accuracy of ± 0.1°C. To reach lower dew points, a two stage thermoelectric heat pump will attain frost points down to –65°C. Let's see what's available! *(Note: All chilled mirror hygrometers offer pretty much the same dew point depression as a function of the number of stages used in the thermoelectric heat pump; this is a matter of physics of the Peltier cooling function. But that's where the similarities end).*

Mfr Model No	YES DPT-2011	Competitor #1	Competitor #2
Accuracy	± 0.1°C	± 0.2°C	± 0.2°C
Digital I/O	YES	Option	Not available
Mirror cleaning	Remove one hand-tightened O-ring sealed mirror access plug	Remove three screws with a screwdriver	Remove three screws with a screwdriver
Integral water cooling	Standard, no extra cost	Not available w/o special options, and additional cost.	Not available w/o special options, and additional cost.

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