

A COMPARISON OF MOISTURE MEASUREMENT TECHNOLOGIES FOR NATURAL GAS

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The measurement of moisture in natural gas is an important parameter for the processing, storage and transportation of natural gas globally. Natural gas is dehydrated prior to introduction into the pipeline and distribution network. For the intercountry and interstate custody transfer of natural gas maximum allowable levels are set by tariff, normally expressed in terms of absolute humidity (mg/m^3 or lbs/mmscfh) or dew point temperature. Several technologies exist for the online measurement and for spot sampling. A review of the most commonly used instruments using the following technologies: chilled mirror, impedance sensors, quartz microbalance, Fabry-Perot and tunable diode laser adsorption will be discussed. An intercomparison of those technologies with consideration to the measurement range, accuracy, long-term drift, response time, maintenance and gas sample conditioning will be provided.

1 BACKGROUND

Prior to transportation water is separated from raw natural gas, however some water still remains present in the gaseous state (water vapor). If the gas cools due to weather conditions or comes in contact with any surface that is colder than the prevailing dew point temperature of the gas, water will condense in the form of liquid or solid (ice). In addition under pressure, water has the unique property to form a lattice structure around hydrocarbons such as methane to form solid hydrates. Water combines with gases such as Hydrogen Sulfide (H_2S) and Carbon Dioxide (CO_2) to form corrosive acids. Since the vast majority of natural gas pipelines are constructed of carbon steel, water therefore becomes a “driver” for corrosion which in turn results in loss of product, increased hazards and increased operating and maintenance costs. Since natural gas is essentially a form of transportable energy that is often distributed over vast networks and as water vapor has no calorific or heating value it also adds to the expense of compression and transportation.

When natural gas is sold there are contractual requirements to limit the concentration of water vapor. In the United States the limit or tariff is expressed in absolute humidity in units of pounds per million standard cubic feet (lbs/mmscf). A standard cubic foot is referenced to 1 atmosphere at sea-level (14.65 psia) and 60°F. The maximum absolute humidity for interstate transfer is set at 7 lbs/mmscf . In Europe, bodies such as EASEE-gas make recommendations on the maximum permissible amount of water vapor in the gas. EASEE-gas was setup in 2002 to promote the simplification of transferring and trading natural gas across Europe. Its membership comprises of gas producers, transporters, service providers and end users. EASEE-gas has approved a limit of -8°C Dew Point, referenced to a gas pressure of 70 Bar(a). This recommended limit is generally being adhered to in the gas industry across Europe.

2 UNITS FOR EXPRESSING WATER VAPOR CONCENTRATION

Water vapor concentration can be expressed in a number of different units. In addition parameters such as the dew point temperature are related to changes in pressure. Each industry and process has particular units quantitative the amount of water vapor. Below are formulas for some of the most widely used parameters (SI System)

Saturation Water Vapor Pressure Over Water

$$P_w = K_w \cdot 6.1121 \exp\left(\frac{17.502 \cdot T}{240.97 + T}\right)$$

$$K_w = 1.0007 + 3.46 \times 10^{-6} \cdot P$$

P_w = Saturation Water Vapor Pressure in millibars

T = Temperature in °C

P = Total pressure in millibars

K_w = Pressure enhancement factor for water

Saturation Water Vapour Pressure Over Ice

$$P_w = K_i \cdot 6.1115 \exp\left(\frac{22.452 \cdot T}{272.55 + T}\right)$$

$$K_i = 1.0003 + 4.18 \times 10^{-6} \cdot P$$

P_w = Saturation Water Vapor Pressure in millibars

T = Temperature in °C

P = Total pressure in millibars

K_i = Pressure enhancement factor for ice

Dew Point Temperature

$$T_{\text{dew}} = \frac{240.97 \cdot \ln\left(\frac{P_w}{6.1121}\right)}{17.502 - \ln\left(\frac{P_w}{6.1121}\right)}$$

Frost Point Temperature

$$T_{\text{frost}} = \frac{272.55 \cdot \ln\left(\frac{P_w}{6.1115}\right)}{22.452 - \ln\left(\frac{P_w}{6.1115}\right)}$$

Absolute Humidity

$$\frac{g}{m^3} = \frac{216.7 \cdot P_w}{T + 273.16}$$

P_w = Partial pressure of water vapor in millibars
 T = Temperature in °C

Volume Ratio in Parts per Million

$$ppm_v = \left(\frac{P_w}{P_t}\right) \cdot 10^6$$

P_w = Partial pressure of water vapor in mBars
 P_t = Total Pressure in mBars

Mass Ratio in Parts per Million

$$ppm_w = \left(\frac{P_w}{P}\right) \cdot 10^6 \cdot \frac{18}{MW_{cg}}$$

ppm_w = Volume Ratio in Parts Per Million
 P_w = Partial pressure of water vapor in millibars
 P = Total Pressure in millibars
 MW_{cg} = Molecular Weight of the Carrier Gas

Notes:

1. The equations above are based on standard air and nitrogen. Gases such as natural gas and CO₂ are super-compressible. Compensation factors for higher-pressure gases are applied to correct for the non-ideality.
2. Below 0°C/32°F water condenses as ice and the equilibrium saturation temperature is known as the “frost point temperature”. Above 0°C/32°F water condenses in the liquid phase and the equilibrium

saturation temperature is known as the “dew point temperature” It is however very common to refer to all readings as the “dew point”. It should be noted however that the saturation water vapor pressure over ice is different to that of liquid water.

3. The conversion from the partial pressure of water to absolute humidity has been traditionally defined in the natural gas industry by reference to the American Society for Testing and Materials standard ASTM-1142, *Standard Test Method for Water Vapor Content of Gaseous Fuels by Measurement of Dew Point Temperature*. The ASTM standard was derived from the Institute of Gas Technology (IGT) Research Bulletin-8, *Equilibrium Moisture Content of Natural Gases*. In recent years ISO-18453 *Natural Gas – Correlation between Water Content and Water Dew Point* has provided a more updated standard. The formulas contained within the standard have been derived from empirical data from GERG.

Table 1: USA Tariff Limit for Moisture in Natural Gas

Absolute Humidity (lbs/mmscf)	7.0
Absolute Humidity (mg/m ³)	112.1
Dew Point at 1 Bar (T _d °C)	-38.7
Dew Point at 1 Bar (T _d °F)	-37.7
Dew Point at 70 Bar (T _d °C)	6.7
Dew Point at 70 Bar (T _d °F)	44.1
Volume Ratio (ppm _v)	147.5

Table 2: EASEE Limit for Moisture in Natural Gas

Absolute Humidity (lbs/mmscf)	2.7
Absolute Humidity (mg/m ³)	43.3
Dew Point at 1 Bar (T _d °C)	-46.9
Dew Point at 1 Bar (T _d °F)	-52.4
Dew Point at 70 Bar (T _d °C)	-8.0
Dew Point at 70 Bar (T _d °F)	17.6
Volume Ratio (ppm _v)	57.0

3 INSTRUMENT TECHNOLOGIES FOR MEASURING WATER VAPOR IN NATURAL GAS

Various viable technologies exist for measuring the amount of water vapor in natural gas. In most cases it is not advisable to install a sensor directly in a natural gas pipeline as it can contain both physical contaminants (rust, scale, etc.), additives (such as odorizers, antifreeze agents such as methanol) and liquid hydrocarbons. By installing a sample conditioning system the gas sample can be extracted, filtered, the pressures regulated and flow controlled. Another benefit of a sampling system is that the can be isolated from the main pipeline. The sample system must also not alter the moisture concentration of the sample via leaks or desorption/adsorption from the wetted components.

While a number of technologies exist for moisture measurement in natural gas, chilled mirror, impedance sensors, quartz microbalance, Fabry-Perot interferometer and tuneable diode lasers are the most widely used technologies. Each type of technology has its advantages and disadvantages.

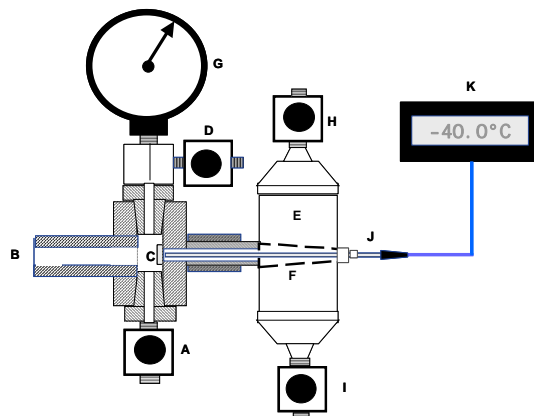
3.1 Chilled Mirrors

Chilled mirror hygrometers can be classified into two basic categories, manually operated and automated. Automated chilled mirrors are further categorized into cycling chilled mirrors and equilibrium chilled mirrors. Chilled mirrors measure the dew/frost point temperature directly by using a coolant or thermoelectric heat pump to cool a plane surface until condensation forms. When the mass of condensate on the mirror is in equilibrium with the surrounding gas sample, the temperature of the mirror is by definition equal to the dew or frost point temperature.

Chilled mirrors can also be used to determine the hydrocarbon dew point. In gas mixtures containing heavier hydrocarbons the partial pressure of hydrocarbons are sufficiently high enough that cooling the gas will result in a phase change from gas to liquid. In a similar principle the temperature at which hydrocarbon condensate is in equilibrium with the sample gas is the "hydrocarbon dew point".

Manual chilled mirrors typically use the expansion high-pressure gas as the coolant. The manual chilled mirror apparatus (also referred to as the Bureau of Mines type), is described in ASTM-1142. When high-pressure gases such as methane or CO₂ are decompressed, cooling occurs due to the Joule-Thomson effect. The user observes the onset of condensation via a view port while the mirror surface is cooling. The rate of cooling is important. If the cooling rate is too rapid condensation occurs prior to thermal stability. ASTM-1142 provides a procedure consisting of repeating the test several times and successively slowing the cooling rate at the observed onset of condensation. The user also has to learn to identify the difference between water and hydrocarbon condensate. Water appears either as fine droplets/fog (water) or opaque crystals (ice) while hydrocarbon liquids appear as shiny film. In some designs a matte black or ablated surface is used for hydrocarbons while a polished metal surface is used for water. The dew/frost reading is subjective, as each operator must make an observation as to both instance when condensation occurs and the identity of the condensate. Manual chilled mirrors are typically used for spot-checks and do not lend themselves to providing online continuous readings or telemetry.

Figure 1. Manual Chilled Mirror



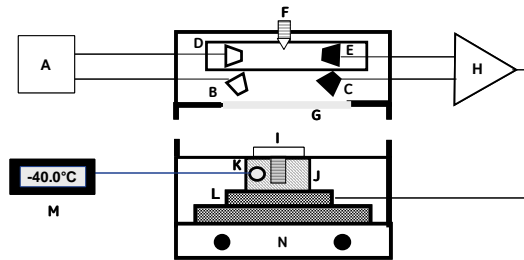
A	Test Gas Inlet
B	View Port
C	Mirror (Stainless Steel)
D	Test Gas Outlet
E	Refrigerant Expansion Chamber
F	Cooling Rod (Copper)
G	Mirror (Polished Stainless Steel)
H	Refrigerant Inlet Valve
I	Refrigerant Vent
J	Temperature Sensor
K	Temperature Indicator

Automatic chilled mirrors utilize a thermoelectric cooling module coupled to a mirror. The cooling module consists of a multistage stack of arrays of P-N junctions arranged in a back-to-back orientation. When direct current is applied to the P/N junctions electrons flow from the "P" junctions leaving holes. The energy holes are filled with heat energy that flows from the mirror. The P-N junctions are additionally thermally coupled to a metal heat sink. If the polarity of the current is reversed the mirror is heated. Visible or infrared light is emitted and aligned to reflect off the mirror. The reflected light is received by a photodetector. When the mirror is cooled sufficiently, water vapor condenses on the mirror. When condensation occurs the light received by the photodetector decreases due to both absorption and scattering of the incident light. The signal from the photodetector is utilized in a feedback control loop to maintain a constant mass. A precision PRTD (Platinum Resistance Temperature Detector) measures the temperature of the mirror. The heat pump can also be augmented by refrigeration (evaporator core) or a liquid coolant block.

The overall measurement capability of typical chilled mirror is -80 to +85°C. The number of thermoelectric cooling stages, auxiliary, governs the full range. This system offers excellent precision and is widely used as laboratory reference standards for calibration and metrology applications.

The instrumentation packages for these instruments occupy a significantly sized footprint and many designs are applied only to laboratory applications. The wetted components are inherently inert and these instruments are characterized by minimal long-term drift.

Figure 2. Automatic Chilled Mirror



A	IR Emitter Regulator
B	IR Emitter
C	IR Detector
D	IR Emitter Reference
E	IR Detector Reference
F	Iris Adjustment
G	Optical Window
H	Operational Amplifier
I	Mirror
J	Mirror Block
K	PRT (Temperature Sensor)
L	Multistage Thermoelectric Cooler
M	Temperature Indicator
N	Heat Sink/Heat Exchanger (Liquid Cooled)

A variation of the automatic chilled mirror is a cycling chilled mirror. Rather than maintaining a constant condensed mass of condensate on the mirror, the mirror temperature is ramped up and down. The cooling ramp is sufficiently slowed around the predicted condensation temperature by an iterative technique. Cycling chilled mirrors are generally not as precise as constant mass units however it is claimed that since for the majority of time the mirror is "dry" the system is less susceptible to contamination.

For high precision the surface of the chilled mirror must remain clean. Inert contaminants will change the reflective properties of the light. Soluble contaminants (salts) elevate the dew/frost point temperature based on Raoult's Law. Soluble salts increase the vapour pressure of a liquid in the same manner as adding table salt increases the boiling point of water.

Figure 3. Response of Automatic Chilled Mirror – Step Change from +10 to -65°C T_d

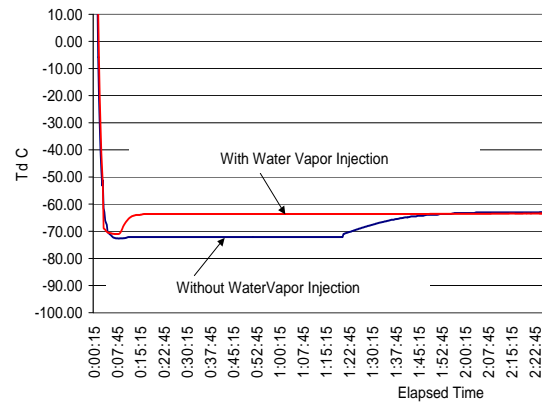


Table 3. Pros & Cons of Chilled Mirror Hygrometers

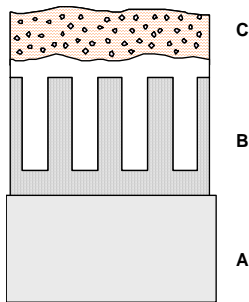
Pros	Cons
Precise: typical accuracy of ± 0.1 to $\pm 0.5^\circ\text{C Td}$	Limited by cooling capacity Not a compact system
Direct fundamental measurement of dew/frost point	Requires containment or installation in a purged enclosure for hazardous area use
Inert wetted components. Long-term stability. 5-20 years of service without any drift.	Not specific to water. Other gases may condense prior to water such as heavy hydrocarbons
Some models can measure at process pressure	Loses the ability to measure low frost points as the temperature and pressure increases
	Manual chilled mirror is subjective and requires operator expertise

3.2 Impedance Sensors

The most widely used impedance based moisture sensor technology for natural gas is the metal-oxide sensor. Specifically the aluminium oxide sensor is used in the vast majority of natural gas installations. Polymer sensors have also been developed for this application. While there are variations on design the most widely used sensors consist of a aluminium base that has a thin layer of aluminum oxide deposited or grown on the surface via an anodization process. A thin layer of porous gold is deposited over the oxide. On a microscopic level the aluminium oxide appears as matrix with

many parallel pores. When exposed to even small amounts of water vapour the superstructure enables water molecules to permeate into the matrix where micro-condensation occurs. Since the dielectric constant of dry gases are significantly lower than gases containing moisture (about an 80:1 ratio for nitrogen or standard air) each pore acts as a micro-capacitor. As the micro capacitors are in a parallel arrangement the total capacitance is additive. In essence the sensor acts as a water molecule counter.

Figure 3. Aluminum Oxide Sensor



A	Aluminum Base
B	Aluminium Oxide
C	Porous Gold

The sensor is excited with a low voltage alternating current at a fixed frequency. The impedance of the sensor relates to the water vapour pressure by the following relationship

$$Z^{-1} = Ae^{BP_w} + C$$

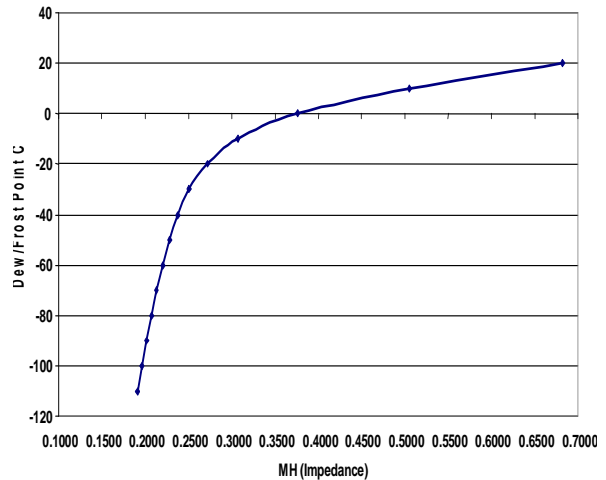
Z = Impedance

P_w = Partial pressure of water

A, B, and C are constants

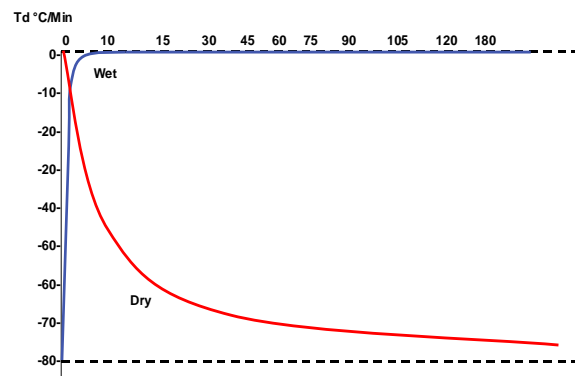
Each sensor is calibrated at multiple dew/frost points (recall that the partial pressure of water is a function of the dew/frost point temperature). The impedance at each dew/frost point is recorded and entered into a digital look up table either imbedded in the memory of the sensor module or programmed into an analyzer. The analyzer utilizes a polynomial expansion equation to convert the measured impedance by reference to the look up table to produce direct readout in dew/frost point temperature. Typical accuracy is ±2°C Td from +60 to -65°C Td and ±3°C Td from -66 to -110°C Td.

Figure 4. Calibration Curve of Typical Aluminum Oxide Sensor



In general impedance sensors provide excellent response to moisture changes in the dry to wet direction. They however have significant response times in the wet to dry direction. Figure 5. Illustrates a typical step change.

Figure 5. Response of Aluminum Oxide Sensor



Aluminium Oxide sensors are subject to drift over time. The typical drift as compiled by thousands of sensors returned for recalibration service is 2°C per year. The drift can be managed by applying a regime of recalibration. Since Aluminium Oxide sensors are economical, very often users maintain additional sensors that are rotated in and out of service, thus always maintaining the in-service sensors within their recommended recalibration interval (typically one year).

Aluminium Oxide sensors have the capability to be installed at high pressure (up to 5000psig) and the sensor footprint is quite compact. The sensors however are seldom installed directly in the pipeline. An extraction type sampling system is utilized. By using a sampling system the gas can be filtered, the

pressure regulated and the flow rate controlled. In many natural gas pipelines and processing plants Triethylene glycol is used for dehydration. The gas may contain “glycol carryover” as well as other additives such as methanol and odorants.

Table 4. Pros & Cons of Impedance Sensors

Pros	Cons
Available with hazardous area certification (XP & IS)	Sensors have significant wet to dry response time particularly after process upsets
The sensor has a small footprint and may be installed long distances from the analyzer	Other polar gases such as alcohols or amines also change the sensor impedance
Sensor may be installed at line pressure- No adjustment required for variation in natural gas composition.	Yearly recalibration is required
Large dynamic measurement range (-110°C to +60°C)	May be attacked by some Sulphur compounds
Sensors are economically priced	
Sensors are easy to replace in the field	

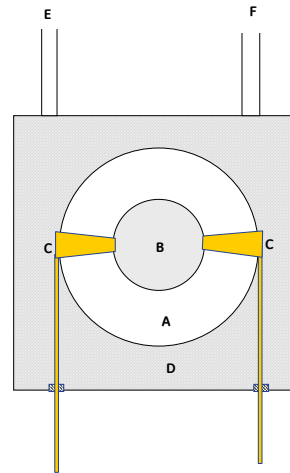
3.3 Quartz Microbalance Hygrometers

Quartz microbalance hygrometers consist of a quartz substrate that is coated with a hygroscopic polymer film. When a voltage is applied, the quartz oscillates at a resonant frequency. When the sensor is exposed to gas with water vapour, water is adsorbed by the hygroscopic coating and the resonant frequency changes in relationship to the increased mass of the sensor. The adsorption of water into the sensor’s substrate is proportional to the partial pressure of the surrounding water vapour. Quartz microbalance sensors have a certain degree of hysteresis and must be “re-zeroed” periodically. The measurement system therefore requires a “zero gas”. While no gas supply can have an absolute value of zero, the zero gas may be defined as a gas that is closer to zero than any significant amount of water. Typically accuracy is ±10% of reading from 1-2,500 ppmv (parts per million by volume).

Some measurement modes employ a non-equilibrium technique where the sensor alternates from being exposed to the zero gas and the process gas. The offline time spent on the zero gas should be factored into response time requirements.

The sensing surface is also susceptible to contamination and must remain clean. A suitable sampling system must be employed. Quartz Microbalance analyzers are characterized by having relatively fast response times.

Figure 7. Quartz Microbalance Sensor



A	Quartz Substrate (Oscillator)
B	Hygroscopic Coating
C	Electrodes
E	Gas Inlet
F	Gas Outlet
G	Stainless Steel Flow Cell

Table 5. Pros & Cons of Quartz Microbalance

Pros	Cons
Wide range ability to measure to sub 1 ppmv levels	Relatively expensive
Moderately fast response time	Supply of zero and span gases needed
	Readings are step changes above zero baseline not absolute values
	Flow rate, temperature and pressure must be precisely controlled

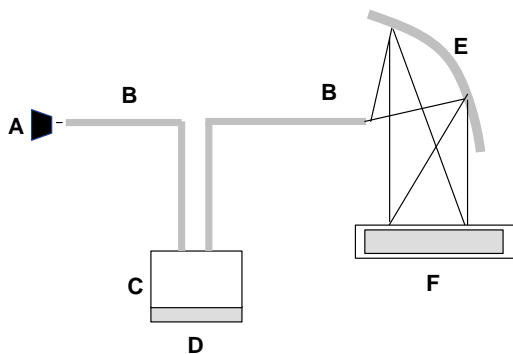
3.4 Fabry-Perot Hygrometer

The sensor head in Fabry-Perot type hygrometers consists of a multi-layered structure comprising materials with high and low refractive indexes. Typical materials used are SiO₂ and ZrO₂. The sensor head is coated with a glass substrate with a maximum surface pore size no bigger than 0.4 nm, making the structure specific to water

molecules (pore size 0.28 nm). A light beam is transmitted through the sensor via fibre optic cable. The light source is generally a light-emitting diode (LED). As water molecules penetrate the sensor surface, they change the refractive index of the light beam (refractive index of Air 1: Water 1.33) causing a change in wavelength. The wavelength change is proportional to the amount of water molecules equilibrated on the sensor. The refracted light is detected by a Polychromator and the reading is calibrated in terms of dew point temperature vs. wavelength shift.

The sensor itself is mounted on the end of a stainless steel probe and connected via fibre optic cable to the control unit. The unit requires temperature compensation and pressure compensation if a ppmv readout is required.

Figure 8. Fabry-Perot Hygrometer Schematic



A	IR Emitter
B	Fibre Optic Beam Waveguide
C	Glass Carrier (Quartz)
D	Multi-Layered Structure (SiO ₂ ZrO ₂)
E	Diffraction Grid
F	CCD Array

Figure 9. Calibration Curve for Fabry-Perot Hygrometer

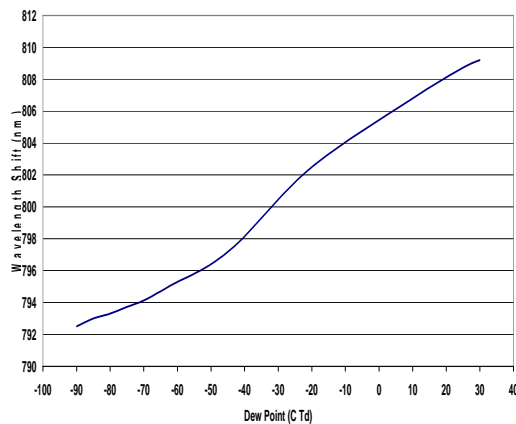


Table 6. Pros & Cons of Fabry-Perot Hygrometer

Pros	Cons
Intrinsically safe – light signal	Expensive fiber optic cable needed to connect probe to analyzer
Sensor may be installed at line pressure	Slow response
	Hygroscopic coating may degrade after prolonged exposure to natural gas

3.5 TDLAS Hygrometers

Tunable diode laser absorption spectrometers (TDLAS) offer a fully non-contact method of continuous moisture measurement in natural gas. The measuring principle is based on the Beer-Lambert Law.

$$A = \ln\left(\frac{I_0}{I}\right) = S \cdot L \cdot N$$

A = Absorption

I = The measurement of beam intensity when tuned to the absorbing wavelength of moisture

I₀ = The reference measurement or beam intensity when tuned away from the moisture absorbing wavelength

S is the fundamental absorption line strength and is a fixed constant

L = the path length of the beam through the sample and is a fixed constant

N = the number of water molecules contained in the beam path passing through the sample

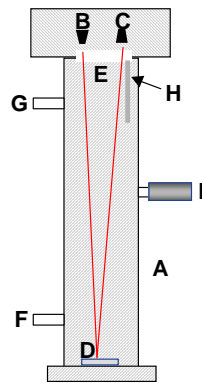
ln is the natural log

The fundamental line strength (S) is a complex term that is dependent on the gas composition, pressure and temperature. The term can only be solved for a given set of conditions using quantum mechanics. In practice however temperature and pressure compensation algorithms can be applied and the system calibrated against a high precision standard such as chilled mirror or two-pressure/two temperature generator.

The laser diode is housed in a hermetically sealed housing devoid of moisture. The laser is mounted on a thermoelectric cooling/heating module and the base temperature is held constant. If the injection current to the laser is ramped the net result is the laser light will be ramped through a narrow band of light frequency in the near infrared spectrum. The frequency scan is repeated continuously. The injection current and thus the frequency is also modulated at high frequency. At certain frequencies light energy (photons) are

absorbed by the water molecules they encounter. Water molecules have an O-H bond that stretches and twists and the unique bond absorbs light energy. The energy is not destroyed but converted to kinetic energy. The light is transmitted through a stainless steel tube where it bounces off a mirror and a certain fraction is returned to a photodetector. Since the path length is constant the natural logarithm of the ratio of the incident light and the returning light is inversely proportional to the mole fraction and thus the partial pressure of water in the path.

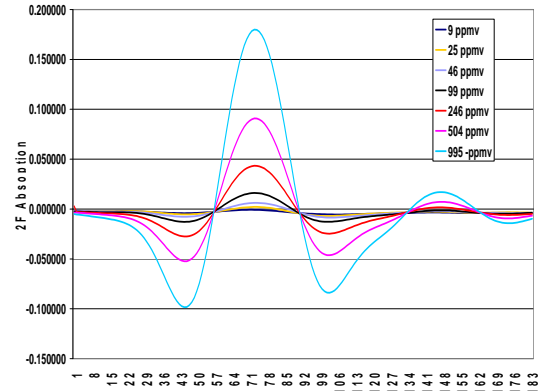
Figure 10. TDLAS Hygrometer



A	Stainless Steel Absorption Cell
B	Tunable Diode Laser
C	Photodetector
D	Mirror
E	Window
F	Gas Inlet
G	Gas Outlet
H	Temperature Sensor
I	Pressure Sensor

The graph below is a scan of the second harmonic (2F) signal at various moisture concentrations. The peak height is directly proportional to the mole fraction of water.

Figure 10. 2nd Harmonic Scan at Various Moisture Concentrations



The typical accuracy of a TDLAS hygrometer for natural gas is 2% of reading in terms of the mole fraction or ppmv. By simultaneously measuring the temperature and pressure, the absolute humidity and dew/frost point temperature is measured with high precision by the use of psychrometric equations. Measurement of the process line pressure also enables these units to calculate the pressure dew point.

TDLAS hygrometers are characterized by having very fast response times. The optical response is in <2 seconds, however it takes time to purge the absorption cell and sampling systems. Typical system response times are less than 5 minutes for a 90% step change. Figures 11 and 12 illustrate the response time in wet to dry and dry to wet directions respectively.

Figure 11. Wet to Dry Response of TDLAS Moisture Analyzer System

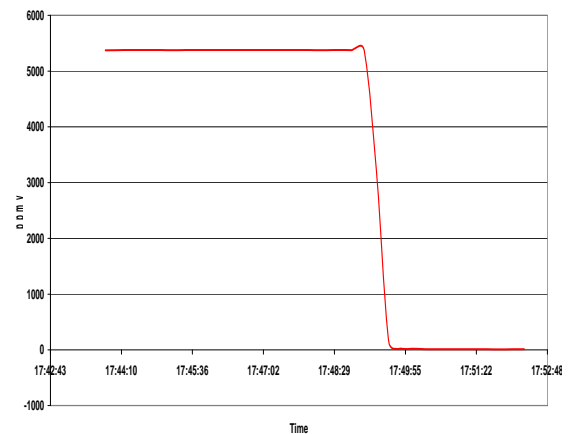


Figure 12. Dry to Wet Response of TDLAS Moisture Analyzer System

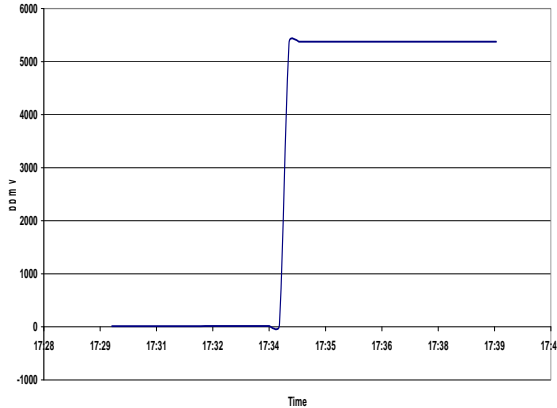


Table 7. Pros & Cons of TDLAS Hygrometers

Pros	Cons
Very fast response in both directions. Dry to wet & wet to dry	Relatively expensive
Non-contact. No sensing surface to degrade due to exposure	Must be calibrated using a test gas with the same basic major components of the process gas
High long-term stability	Measurement is made a close to atmospheric pressure.
No zero or span gases needed	
Based on fundamental measurement	
Immune to glycol, H ₂ S, methanol and other contaminants found in natural gas.	

4 CONCLUSIONS

The technology with the widest measurement range is typically the impedance type sensor, which can measure from -110°C to +60°C. The narrowest measurement range is confined to the automatic chilled mirror, which is constrained by the number of stages (cooling capacity) of the sensor installed with the device. Fabry-Perot type analyzers have range capability similar to impedance type sensors. The TDLAS technology range of measurement is determined by the type of measurement cell used in the device. A standard measurement cell has a typical lower detectable limit of 5ppmv; a special measurement cell (Herriot type) typically has a lower detectable limit of 0.1ppm. Upper ranges can

be from 2000 to 5000ppm. Quartz microbalance ranges down to 0.1/1ppm with upper ranges of 1000 to 2000ppm_v.

In terms of accuracy, the automatic chilled mirror technology is the most precise offering a typical accuracy of 0.1°C to 0.5°C dew point. The TDLAS unit is the next most precise instrument with a typical accuracy of +/-2% of reading (accuracy will vary in terms of dew point due to the non-linear relationship).

The most stable or drift free technologies can be considered to be TDLAS and Chilled Mirror. Lasers, by their nature are inherently stable and the remaining components in the device can essentially be considered drift free. The non-contact nature of the measurement ensures that there is no process related degradation of the measurement circuitry, laser light source or detectors. At the other extreme, the measurement layer in impedance type sensors is in a continual state of drift, which needs to be continually corrected by regular calibrations.

In terms of response time, TDLAS comes out on top; essentially being a light based non-contact measurement. The technologies that require equilibrium of moisture in the gas sample with a sensing surface/layer suffer in this category due to the polar nature of the water molecule and its tendency to stick to surfaces. A significant contact time with the gas to be measured is required, more specifically in going from a wet sample gas to a dry sample gas.

Maintenance is a big consideration when evaluating the lifetime costs of the different measurement technologies. As more customers outsource the maintenance function within their plants, they continually look to install low maintenance equipment. Contact based sensors will always require more in terms of maintenance than non-contact based measurements as their successful operation is much more dependent on a clean sample gas reaching the sensor. Corrosive components in the natural gas stream, like Mercaptan or Sulphur compounds will also add to the maintenance requirements for contact based sensors. Maintenance requirements range from periodic inspection/replacement of sample system filters to annual or bi-annual recalibration of the sensors themselves. The TDLAS technology does not have an annual recalibration requirement and is typically sold as a maintenance free technology, with the exception of any associated sample system filter maintenance. A planned factory calibration check every three to five years is typical with TDLAS technology.

All technologies require a clean gaseous phase sample to reach the sensor, hence a sample handling system is recommended in all cases, although some vendors tout direct inline

measurement as an advantage. Mixed phase sample, condensate or liquid glycol carryover, can coat contact based sensors, causing them to become unresponsive or read erroneously, or in extreme cases, can require sensor replacement. Liquid contaminant can also deposit in the TDLAS measuring cell, causing dispersal of the light signal, resulting in an erroneous measurement. The TDLAS technology has the capability to alert the user if contamination occurs, by comparing the measuring photo-detector tuned to a non-absorbing wavelength with a reference photo-detector, to determine if a shift has occurred (within some specified limits). Contact based sensors may be partially contaminated and continue reading, although experienced users may be able to determine contamination has taken place by observing sensor behavior in terms of response to step changes in moisture or an actual step change in process readings after the contamination event. In most cases, if sensors become contaminated they can be cleaned, purged with a dry gas, and returned to service.

Table 8. Scorecard of Moisture Measurement Technologies for Natural Gas

	A	B	C	D	E
Range	1	5	3	4	3
Precision	5	2	3	3	4
Stability	5	2	4	4	5
Speed of response	3	2	3	2	5
Maintenance	3	3	2	3	5
Price	1	5	1	2	1
TOTAL	18	19	16	18	23

5 = Most Desirable, 1= Least Desirable

A = Chilled Mirror

B = Impedance

C = Quartz Microbalance

D = Fabry=Perot

E = Tuneable Diode Laser

4 REFERENCES

[1] Buck, A.L., "New Equations for Computing Vapor Pressure and Enhancement Factor", Journal of Applied Metrology, Vol. 12, Issue 20, 1527-1532, 1981

[2] ASTM-1142 (1995, Reapproved 2006). "Standard Test Method for Water Vapor Content of Gaseous Fuels by Measurement of Dew Point Temperature." American Society for Testing and Materials Standards, West Conshohocken Pennsylvania.

[3] ISO-18453 (2004) Standard. "Natural Gas – Correlation between Water Content and Water Dew Point." ISO Publishing Switzerland 2004.

[4] Willsch, Reinhardt, Ecke Wolfgang, and Schwotzer, Günter "Spectrally Encoded Optical Fibre Sensor Systems and their Application in Process Control, Environmental and Structural Monitoring". Proceedings of SPIE 2005.

[5] Soleyn, Ken "The Theory and Operation of Optical Chilled Mirror Hygrometers for Humidity Calibration". Cal Lab, The International Journal of Metrology, July 2002

[6] Sparges, Narages and Soleyn, Ken "The Development of an Automated Calibration System for Tunable Laser Based Moisture Analyzers". Proceedings from the ISA 55th Analysis Division Symposium New Orleans, LA USA April 2010

[7] Blakemore, C.B. and Baker, W.B. "Piezoelectric Moisture Analysis". Moisture Symposium, National Physical Laboratory, (UK) September 1996.

